Lowland Technology International 2016; 18(1): 51-58
International Association of Lowland Technology (IALT): ISSN 1344-9656

Technical Note

Influences of Long-Term Tectonic and Geo-Climatic Effects on Geotechnical Problems of Soft Ground - Ulaanbaatar, Mongolia

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ARTICLE INFORMATION

Article history:

Received: 13 May, 2016
Received in revised form: 21 May, 2016
Accepted: 23 May, 2016
Publish on: June, 2016

Keywords:

Geological/Tectonic setting
Geo-climatology
Geotechnical problems
Freeze-thaw phenomena
Permafrost of soft ground
Physical weathering

ABSTRACT

Ulaanbaatar city situates in Ulaanbaatar Folded System with presence of Mongolo-Baikal seismic zone. The presence of the Tuul River Valley dissected the basin with the formation of soft sediments transported by fluvial and Aeolian environments. The presence of scattered permafrost soil due to geo-climatic condition has led to freeze-thaw phenomena by physical weathering of the ground. This study reveals the influences of long-term tectonic and geo-climatic effects have brought up geotechnical problems in the area. Further it is advised that special attention need to be given in settlement of the area associated with mechanical disintegration of the ground, characterizing similar with lowlands along the valley bottom.

1. Introduction

Mongolia is a landlocked sovereign country in East Asia situated in between China to the south and Russia to the north, lies between latitudes 41° and 52°N, and longitudes 87° and 120°E. On the other hand, Mongolia has not shared its border with Kazakhstan and it is separated from Kazakhstan by only 36.76 kilometers (**Fig. 1**). The capital of Mongolia is Ulaanbaatar which is the largest city and about 45 % of the country's population live there. Swan (1990) mentioned that the Mongolian People's Republic was declared as a Soviet satellite state in 1924. The city is situated at the Tuul River Valley (Selenga River basin). The peaceful democratic revolution in early 1990 had led to a multi-party system with the formation of new constitution in 1992. Jerryson (2007) and Michigan State University (2015) have described that in the Tibetan Buddhism began to spread in Mongolia in the sixteenth century and almost one-third male had been turned into Buddhist monk by the early 1900s.

Mongolia is the 19th largest, world's second-largest landlocked country comprised of one of the most sparsely populated country in the world, with a population of around 3 million people with an area of 1,564,116 square kilometers. Mongolia is belonged as the "Land of the Eternal Blue Sky" or "Country of Blue Sky" because it has 257 average sunny days in a year.

Geo-climatology is highly responsible to form the soft ground in the Mongolian territory due to different types of permafrost. Freeze-thaw phenomena of physical weathering produce soft grounds which are extremely susceptible for any types of settlement in the country. Besides, tectonic upliftment of formation of the Mongolian

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Note: Discussion on this paper is open until September 2016.

Fig. 1. Map of study area (Source: www.mapsofworld.com).

Plateau at an average elevation of 2500 m influences seismic risk and produce several geotechnical problems associated with permafrost activities. The landscape of capital city, Ulaanbaatar is surrounded by the steppe grassy mountainous slopes dissected by the Tuul River Valley and formed soft sediments transported by aeolian and fluvial environment. Such types of ground can also be considered as lowlands as dissected by the river and form similar types of riverine lowlands (Miura et al., 1994). In this paper, basic understanding of geological/tectonic evolution of Mongolia, its long-term influences on settlement area cope with geo-climatic variation are discussed with possibilities of seismic risk and geotechnical problems to bring designing any infrastructures in the future.

2. Geo-climatology

The country is recognized with very little arable land. Most of the area is covered with grassy steppe with cold mountainous area with forested area which is comprised of 11.2 % of the total area to the north and the Gobi Desert to the south (FAO, 2013). Most of the part is hot in summer and extremely cold in winter. As a result, the average temperature in winter drops as low as −30 °C in January. The Siberian Anticyclone influences the entire country through upcoming of a cold, heavy and shallow air which accumulated in river valleys and lower basins, causing very cold temperatures. On the other hand, slopes of mountains remain much warmer due to the effects of temperature inversion. It has long, cold winters and short summers, during which most of its annual precipitation falls .It has occasional harsh climatic condition, also known as zud. The annual average temperature of Ulaanbaatar is −1.3 °C, the world's coldest and windy capital city (Republic of Mongolia, 2004).

The annual average temperature and precipitation of Mongolia (2013) reported that the highest annual precipitation occurred in forests of Bulgan Province near to the border of Russia with 622.297 mm rainfall while the Gobi Desert received the lowest rainfall of 41.77 mm during the period between 1961-1990. On the other hand, and annual average temperature and precipitation of Mongolia (2013) reported that the northern part showed the highest annual precipitation with the average of 200-350 mm and the lowest annual rainfall with the average of 100 to 200 millimeters in the south.

According to Rosenberg, Ulaanbaatar city belongs to the zone of discontinuous permafrost. As a result thawing in summer is precluded more easily if soils are subject to fully thaw. Therefore, suburban residents live in Ger which do not protrude into the soil (Mongolian People's Republic, 1984). Extreme temperatures in the city range from −49 °C to 38.6 °C (Extreme Temperatures Around the World, 2013).

Ger is the traditional Mongolian architecture used for shelter. Lamaseries developed these architecture for dwelling throughout the country in the 16th and 17th centuries, started as ger-temples. The Ger structures were enlarged with 6 and 12 angles with pyramidal roofs approximated to round shape to accommodate large number of worshippers. If requires further enlargement, the structure was led to the quadratic shape of the temples. The roofs were made in the shape of marquees (The Art of Mongolia, 1984). Indiana University (2007) reported descriptions of the Ger. The trellis walls, roof poles and layers of felt were replaced by stone, brick, beams and planks, and became permanent. **Figure 2** represents the present outer architect and interior of the Ger citizens in Ulaanbaatar.

3. Geological/Tectonic setting, seismic and geotechnical influences

3.1 Geological/Tectonic setting and seismic influences

The present scenario of geological setting in terms of tectonic evolution in Asian continent is extending from the Himalayas in the south to the Baikal rift zone in the north, with a number of lateral displacements of rigid lithospheric blocks, formed a large continental domain. Previous studies (Tapponnier and Molnar, 1977, 1979; Molnar and Deng, 1984; Molnar et al., 1987) recognized a limited number of large strike-slip faults straddling Asia. Thrusting and crustal shortening in high topography compressional ranges have accommodated some of the convergence of Indian-Eurasian continent subjected to the formations of the Himalayas, the Pamir-Tien Shan range, the Mongolian Altay, and the Gobi Altay (**Fig. 3a**). As a consequence, the Tibetan and Mongolian plateaus are formed at the higher elevations with an average elevations of 5000 m and 2500 m forming crustal thicknesses up to 70 km and 50 km respectively. Mongolia represents the northern limit of deformation resulted by the collision of India-Eurasia at the rate of 7 mm/yr (Calais et al., 2003).

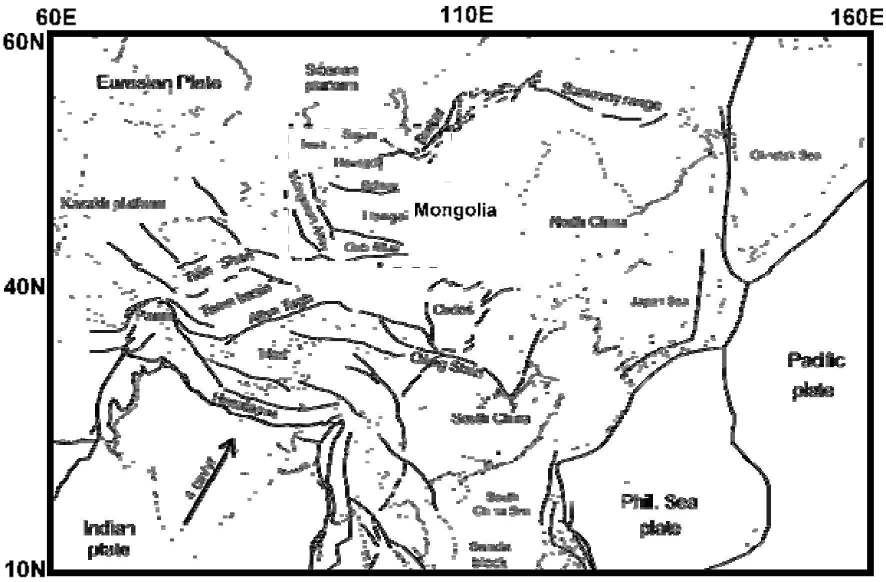
Geologically, Mongolia is sandwiched by the Siberian platform in north and Sino-¬Korean massif in south, and is roughly divided into two large blocks by the Ural-Mongolian Lineament (UML). The northern block is comprised with two folded systems, North Mongolian Folded System and Ulaanbaatar Folded System, occupies the larGer area of the country as shown by **Fig. 3b**. The North Mongolian Folded System belongs to the Caledonian orogeny while the Ulaanbaatar Folded System situates at Variscan orogeny. Ulaanbaatar Folded System is further subdivided into Tsetserleg Folded Belt, Ulaanbaatar Folded Belt and Dochiin gol Depression. The Dochiin gol Depression is subjected to widely distribution of Permian to lower Triassic sediments (Tseden et al., 1992). The study area lies in the Ulaanbaatar Folded System which is the capital of the nation.

Ulaanbaatar is located in the Mongolo-Baikal seismic zone which is one of the most seismically active zone in the world. The city is bordered by the Bogd uul massif on the south. The northern part is steeper than the southern part and is dissected by the deeply entrenched Zaisan, Ikh tenGeriin am, Khurkhree and other creek valleys (Batsaikhan, 2011). The extension of the tectonic structure associated with the Baikal rift system (Woldai and Bayasgalan, 1998; Bayasgalan, 1999) due to collision have produced several new faults near the city, threatening to a serious impacts towards the rapid development. The fluvial sediments of the Tuul River plays a vital role to amplify ground motion at the time of earthquake which will impact the infrastructures of the area which are being built in soft soils with sporadic permafrost characteristics.

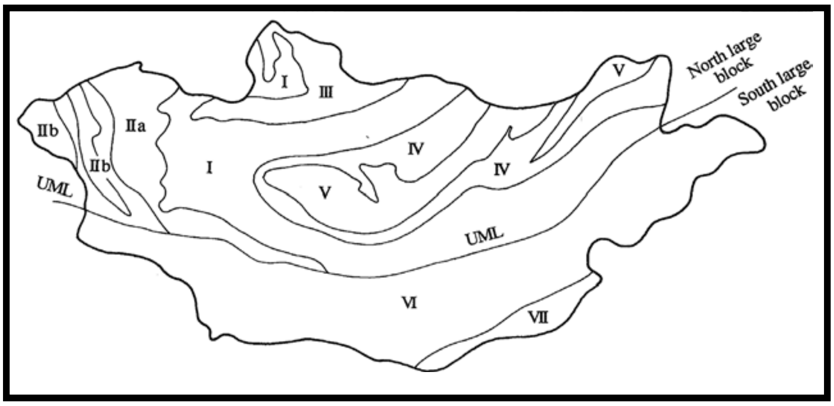
3.2 Geotechnical problems of the soft ground due to physical weathering

Mongolian territory is further amalgamated with permafrost soft ground together with highly fragile tectonic evolution. These climatic factors are highly responsible to form different types of permafrost in the ground. The macro climatic factors are influenced with geographical position, general heat flux and the positions of seas and oceans which are responsible to the continental climate of a specific area. The meso climatic factor incorporates the basic relief of the area and elevation above sea level while the micro climatic factor influences on comparatively low plateaus, surface relief, vegetation cover, minerology of soil and moisture content inclusive of human activities on the ground. In the winter season, when the average annual temperature of the ground approaches below 0 °C, the solar heat does not get penetrate into the ground sufficiently and soil becomes frozen. During summer season, the solar heat penetrates the ground and the upper layer of soil thaws. Since, Mongolia is affected with several climatic variations, the permafrost distribution throughout the Mongolian terrain is accommodated with meso and micro climatic variations (Gravis, 1973). As a result different types of permafrost are distributed as shown in **Fig. 4** and classified into five different types as shown in **Table 1** (Dashjamts et al., 2013). It reveals that about 63 % of the ground with permafrost zone due to different climatic factors associated with typical geographical distribution. Out of 324 districts 244 districts are affected due to permafrost phenomena. **Figure 5a** represents the statistical representation of areal coverage (in hector) of different types of permafrost together with distribution of areal percentage. Similarly, **Fig. 5b** delineates the information of depth of occurrences of permafrost with

Fig. 2. Architect of Ger (a) outer structure and (b) interior of the ger.



(a) Tectonic evolution of Asian continent (Source: Calais et al., 2003).



(b) Tectonics of Mongolia (Source: Tseden et al., 1992):
I : Central Mongolian Median Mass; II a : Nuriin Folded Belt; II b : Altai Folded Belt; III : Shishkhid-Zeddin Megazone; IV : Khangai-Khentiin Megazone; V : Ulaanbaatar Folded System; VI : South Mongolian Folded System; VII : Inner Mongolian Folded System; UML : Ural-Mongolian Lineament

Fig. 3. Geological/Tectonic setting of (a) tectonic evolution of Asian continent and (b) tectonics of Mongolia.

the types of frozen soil. Seasonally frozen soil is subjected to 1.5-5.5 m thick permafrost zone. With the increase in depth of permafrost, types of frozen soils are categorized as sporadic permafrost, scattered permafrost, and continuous and discontinuous permafrost. Dashjamts et al. (2013) identified that the permafrost thickness in Ulaanbaatar area constitutes 10-15 m thick while in the Nailekh district of Ulaanbaatar it encounters up to 6-50 m thick. Analyzing this data, Ulaanbaatar area reflects scattered permafrost type of soil.

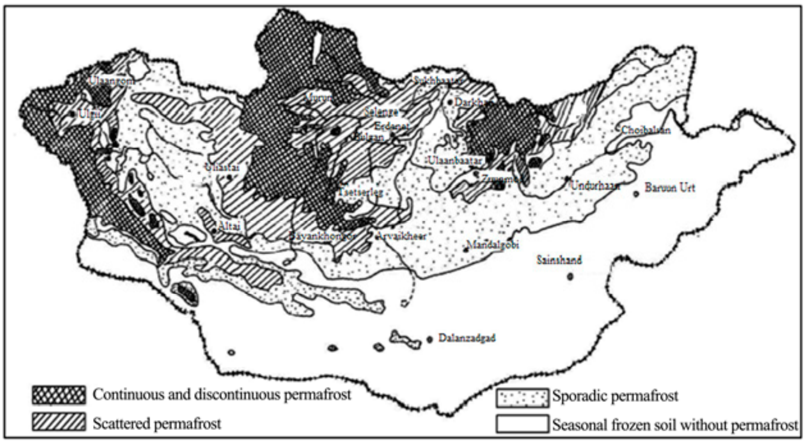


Fig. 4. Distribution of permafrost in Mongolia (Source: Dashjamts et al., 2013).

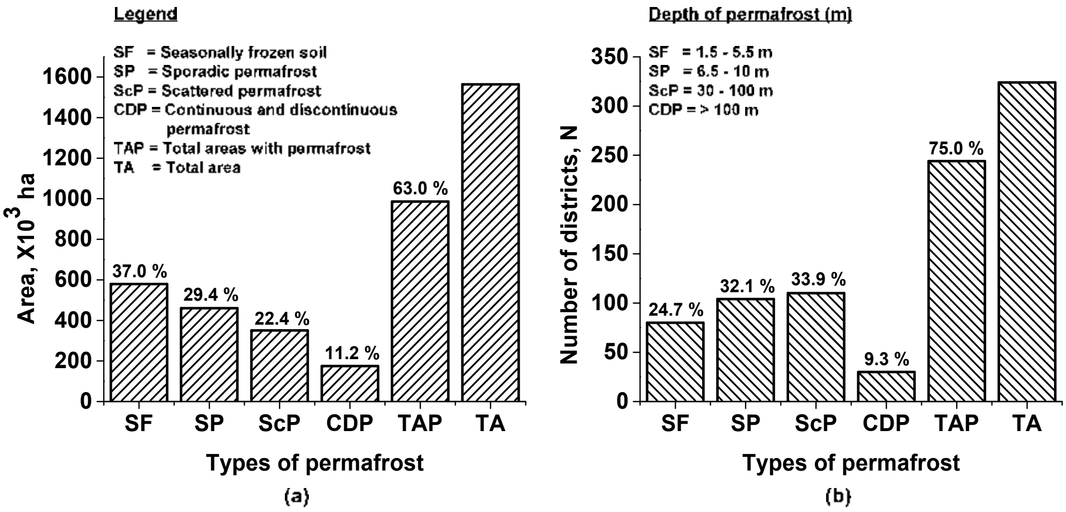


Fig. 5. Types of permafrost in Mongolia (a) areal distribution, and (b) affected districts in Mongolia.

Table 1. Mongolian permafrost classification, after Dashjamts et al., 2013.

S.N.	Types	Thickness (m)		Temperature at 10 m deep (°C)		Temperature at 12 m deep (°C)	
		Average	Max	Average	Max	Average	Max
1	Continuous permafrost	120–250	500	−3.0 to −5.0	−8.0	−2.5 to −4.5	−8.0
2	Discontinuous permafrost	50–120	250	−1.5 to −3.0	−5.5	−1.0 to −2.5	−4.5
3	Scattered permafrost	15–50	120	−0.8 to −1.5	−3.5	−0.1 to −1.0	−2.8
4	Sporadic permafrost	5–15	50	−0.5 to −0.8	−1.8	−0.1 to −0.7	−1.2
5	Seasonally frozen soil	0–5	15	−0.3 to −0.5	−0.8	−0.3 to −0.1	−0.2

In general, when the average annual temperature falls below −2 °C, permafrost thickness is increased from 30 m to greater than 100 m, scattered permafrost and continuous and discontinuous permafrost formed. These zones are represents permanent frozen types of soil. In such conditions, foundation designs should be incorporated as mentioned by Dashjamts (1999). In contrast, when the average annual temperature falls between 0 °C and −2 °C, the thicknesses of permafrost is limited and heat flux can penetrate with seasonal changing. Therefore, these areas are mostly subject to freeze and thaw phenomena according to mechanical disintegration of the ground by physical weathering. As a result foundation design needs to be incorporated with the control of heating phenomena.

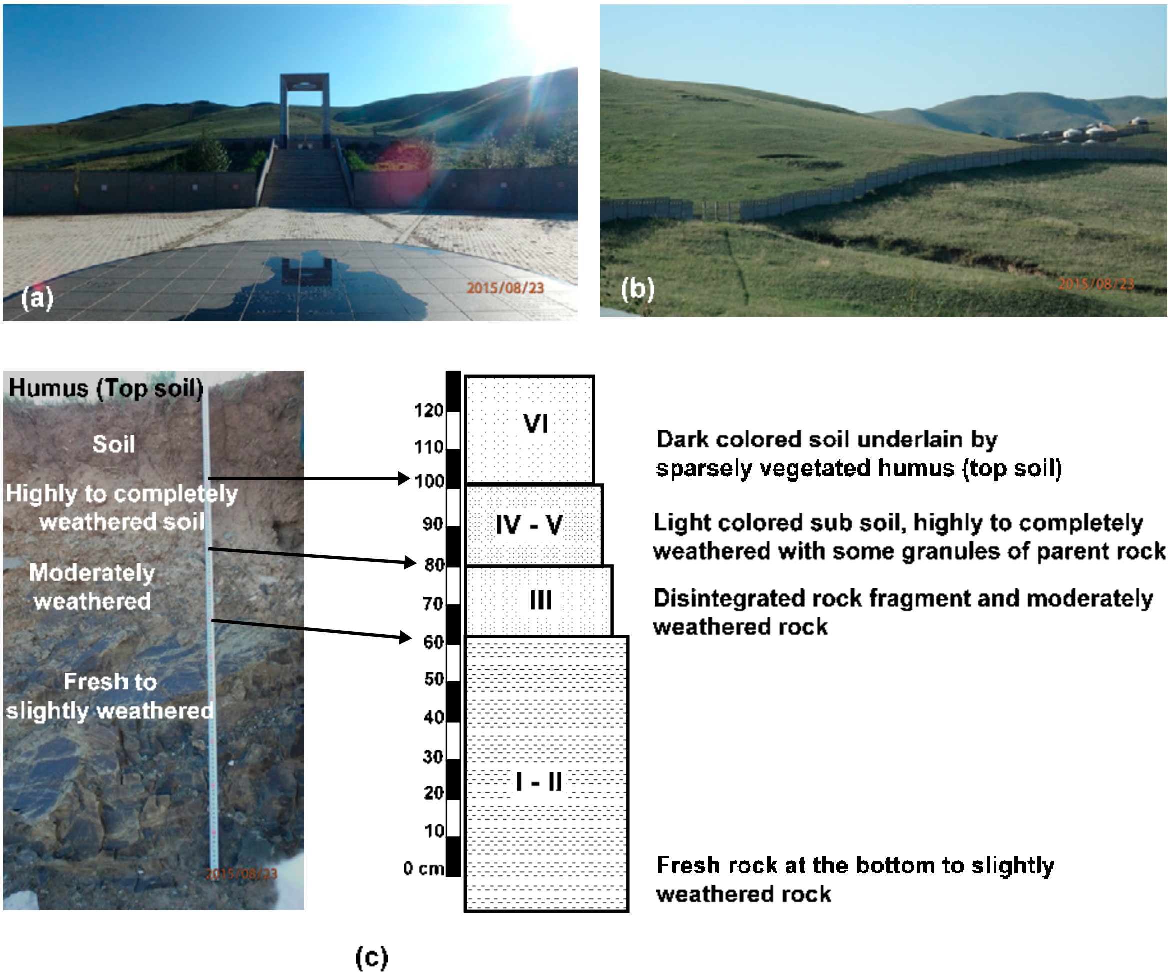


Fig. 6. Site investigation (a) Japanese Cemetery court yard, (b) ger area, north Japanese Cemetery in Ulaanbaatar and (c) weathering profile and weathering grade of the ger area near the northern part of Japanese Cemetery, Ulaanbaatar.

The field investigation has been carried out in Ulaanbaatar area at Japanese Cemetery area and north of Japanese Cemetery area on the foothill of the slope where Ger area has been encroaching towards the uphill (**Figs. 6a and 6b**). A distinct weathering profile has been studied, measured and classified from the outcrop. **Figure 6c** shows one of the weathering profile and its classification in scattered permafrost zone.

About 130 cm deep outcrop was identified near north of Japanese Cemetery of Ulaanbaatar. At the bottom, fresh dark grey colored lustrous mud stone has been outcropped. The outcrop has intact at the bottom and subsequently it is followed by numerous joints at the section and several hair cracks at the surface of the bedding (**Fig. 6**). Less than 10 cm outcrop are intact followed by slightly weathered rock up to the 60 cm from the bottom. The color of the outcrop is changed and fragments are disintegrated with its intact form which can be termed as moderately weathered. The thickness of this section is about 20 cm and lies in the range between 60-80 cm. The color variation is changing towards light colored. From 80 cm to 100 cm depth from the bottom of the outcrop, the outcrop is highly to completely weathered some granules of host rock. Above this section, dark colored soil encountered just below the thin layer of humus from the top soil. Hence, the weathering profile can be classified into four different grades namely I-II, III, IV-V and VI from bottom to top just below the top soil as shown by **Fig. 6**.

The weathering grades lacks the systematic distribution of disintegration of parent rock. The profile in the figure shows fresh rock is immediately encountered with numerous joints and several hair cracks. Since this area represents the scattered permafrost zone, it is prone to continuous freeze and thaw actions. As a result feeding up of snow in cracks and joints led to increase the spacing of joints by the expansion of volume of ice in the filled cracks/joints and rocks are disintegrated easily and quickly.

Figure 7 shows settlement and cracks have occurred at the periphery of Japanese Cemetery region. Numerous cracks and openings can be observed in the pavements

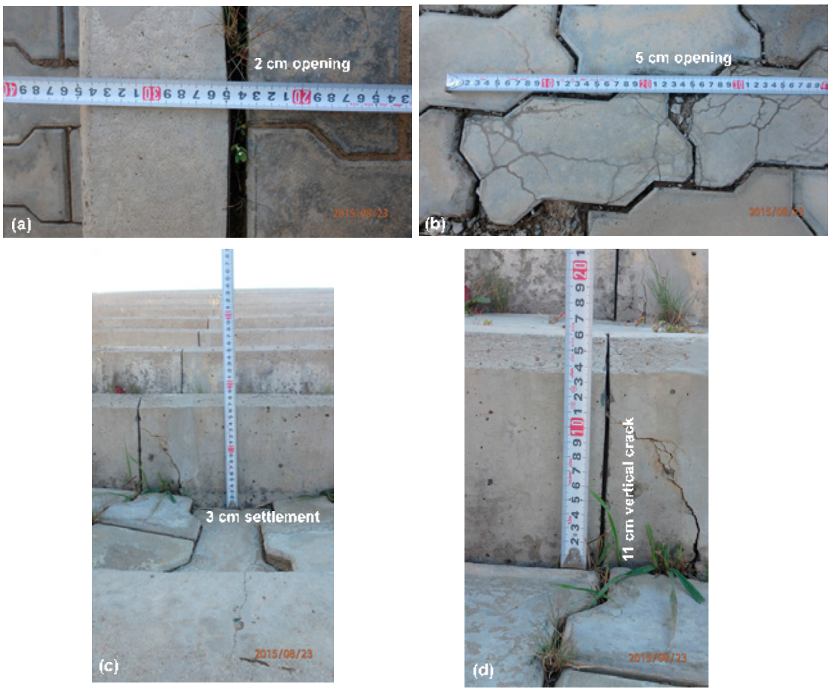


Fig. 7. Settlement problem due to physical weathering of soft ground (a) 2 cm openings on floor pavement, (b) 5 cm openings on floor pavement, (c) 3 cm settlement on floor step and (d) 11 cm vertical crack on step.

on the courtyard and ladder. This indicates the settlement of permafrost due to scattered permafrost ground. The measurement showed that pavements are opened from 2 cm to 5 cm (**Figs. 7a and 7b**). On the steps, 3 cm settlement can be clearly measured and vertical cracks are advanced up to 11 cm (**Figs. 7c and 7d**).

4. Conclusions

Mongolian Plateau is formed at an altitude of 2500 m along the northern limit of deformation due to collision of India-Eurasia. The Ural-Mongolian Lineament (UML) divides Mongolia into the Siberian platform in the north and Sino-Korean massif in the south. The northern block constitutes North Mongolian Folded System and Ulaanbaatar Folded System.

Ulaanbaatar lies in Ulaanbaatar Folded System at Variscan orogeny with presence of Mongolo-Baikal seismic zone. As a result several new active faults have been formed in the vicinity. Besides, the presence of the soft sediments transported by fluvial system of the Tuul River would amplify the soft ground more at the time of seismic phenomena which will be prone to the entire capital city encompassed by the rapid urbanization and expansion of haphazard Ger area.

Furthermore, the average annual temperature falls in between 0 °C and – 2 °C during winter. The depth of permafrost zone is limited to shallow depth ranging from 10-15 m and some other parts up to 50 m which led to formation of sporadic to scattered permafrost soil. Consequently, the ground is prone to freeze-thaw phenomena by physical weathering of the ground and surplus geotechnical problems specifically in settlement and foundation designs.

Site investigation showed that the settlement occurred in Japanese Cemetery courtyard observed with the openings of 2-5 cm on pavement and 3 cm depression on the pavement. Vertical cracks were spread up to the height of 11 cm. Adjacent to the northern side along the Ger area, weathering profile showed the effects of permafrost climatic condition to form fresh to completely weathered grade within 130 cm deep outcrop of mudstone host rock.

Consequently, the influences of long-term tectonic and geo-climatic effects have brought up geotechnical problems in the area focused to settlement problems associated with physical weathering of the ground by permafrost action to form the soft grounds of Ulaanbaatar similar to the effects of lowlands. In order to cope with such foreseeable disaster associated with tectonic and climatic condition, detail and advanced techniques has to be implemented to prevent from soft ground problem as well as seismic hazards.

Acknowledgements

Authors are indebted to Grant-in-Aid for Scientific Research (B) (Overseas Academic Research) for research for investigating the project in Mongolia, collaborated under the Principal Investigator, Prof. Keiko

Kitagawa (Seitoku University); Issue Number: 15H05193. Authors are also delighted for receiving great cooperation of various scholars from National University of Mongolia, Mongolian National University of Medical Sciences, Embassy of Japan and JICA in Ulaanbaatar, Mongolia.

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Symbols and abbreviations

CDP	Continuous and discontinuous permafrost
ha	Hector
ScP	Scattered permafrost
SF	Seasonally frozen soil
SP	Sporadic permafrost
TA	Total area
TAP	Total areas with permafrost
UML	Ural-Mongolian Lineament