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MUST

Soil distension originated by seasonal freezing and its influence to the road construction

INTRODUCTION

The Mongolian continental climate brings number of unpleasant engineer- geological conditions all over country and this specific condition has to be accounted for the road project and completely planned. Otherwise, it is impossible to provide reliably functioning roads for the long term .

For example, all over Mongolia due to the widely spread out unstable base soil caused by permafrost, soil distension from seasonal deep freezing, and soil that sets while get moisturized , soil that gets swelled while wet occurs.

During use of the roads in Mongolia, construction of road beds have been changed to an abnormal, uneven shape , because of soil distention and setting during times of freezing and thawing ,causing expensive pavement damage.

In this paper I will discuss about the phenomenon of soil distension from freezing.

1. Contributing factors to base soil distension from freezing

In the end of the 19th century , Russian engineer V. Shtukenberg for the first time studied the Phenomenon of soil distension from freezing. After that, engineers S.G. Voislov, N.N. Lubimov, N.S.Bogdanov studied soil distension in area of permafrost soil.

Soil distension from freezing originates when water in soil porosity has frozen, its volume increases about 9%, also increasing the total amount of moisture causing water absorbed from the surround area. During the seasonal freezing, the top layer of base soil freezes abruptly. At that moment, the light freezing occurs on a middle layer between frozen and unfrozen layers and the intensive liquid phase transition goes in the freezing layer. Figure 1 shows the development and results of this phenomenon .

Figure1 Steps of soil freezing and water phase transition regime in the layers

Figure2 Base soil distension originates during seasonal freezing (a), Moisture changes (b), straight line is indicated before freezing

curved line is shown after freezing

Intensity of soil distension is determined by comparison of soil surface distension –hf to the depth of freezing -Df and if indicate as of soil distension (dh) originates in frame of elementary layer of base soil (dz),so the intensity of soil distension can be determined by (f) =dh/dz.

During soil distension , unfreezing layer is pressed by upper layer distension and creates number "S" pressure .

So that, amount of distension is equal to difference between amount of soil distension from freezing and soil setting from thawing.

Figure3 intensity of volume changing from soil freezing

Amount of moisture that moving from unfreezing layer of soil does have a main function to the base soil distension and glaciating.

During the freezing, soil minerals shrink but the soil moisture water create glaciating that makes an expansion of soil volume. Besides that, the expansion of soil volume is increasing much more because freezing of additional moisture which moves from lower layers.

It is also confirmed again by our study results. Soil distention originates from glaciation during the soil freezing , occurs not only in freezing layer, it also happens in surround layers. Soil distension of these layers causes to raise soil surface.

In first half of the 20th century, N.A. Tsytovich, N.E. Ivanov, E.E. Bykov, N.Sungin, M.N. Goldshtein studied the phenomenon of soil

distension because of building railroad in Russia. In the results of many years studies of scientists determined that base soil distension has been influenced by many factors such as, structure of soil particles, moisture, ground water level , density, mineral content of clay , freezing regime , state of tension. Professor E. D. Ershov from Moscow University identified that the distension from freezing is complex of deformation of shape and tension which occurs a rock volume change. Let me explain factors that influence to base soil distension.

Particle formation of base soil

While decreasing particle's diameter or increasing crushing level, soil distension happens very strong. According to a notes of above mentioned scientists , distention capacity of soil depends on activities of soil minerals to contact with water. While decreasing diameter of solid portion of clay, increases volume of solid bonded water because of that happens less movement of moisture during the freezing. But, clay and sand soil with much more dusty parts have weak bonded water because of that happens strong movement of moisture and glaciation. In the result of research studies of Russian scientist M. N. Goldshtein, Sweden scientist Beskov, Teber determined that the mechanism of moisture movement in the part of soil with diameter 0.1-0.07 mm has strong effect. B.O. Orlov considered that dusty parts with diameter 0.05-0.005mm create intensive soil distension. Reason of that is when dusty parts leads in the soil, it creates a good condition for moisture movement.

While soil particles diameter decreases up to 0.005- 0.002 mm , moisture movement is decreased. Especially , while raise surface energy of mineral parts of dense clay soil, then soil doesn't participate to moisture movement process and volume of solid bonded water is increased.

Density. Ya. A. Kronik, V.S.Lastochkin, V.D.Karlov, N.Ya.Harhutai, V.O. Orlov, B.N.Melinikov, B.Bathuyag studied the influence of density of soil to the origination of soil distention.

When three content soil density increases , soil distention intensifies and it continues until certain degree of loosening of soil system. The certain degree of soil density makes good condition for water movement that covers soil mineral. Therefore, degree of density that can be originated maximum soil distention , and it was determined by B.N.Melinikov, and V.B.Shvets by following formula :

P'd = Popt(0.8-0.9)

P'd – density that makes maximum soil skeleton distension

Popt- density that makes optimal moisture

Mineral contents :

Mineral parts that makes soil distention are containing more in clay . Intensity of originating soil distension in clay with one type of minerals can be revealed as follows :

Kaolinite > ellit > montmorillonit

Additional multi valiant kation (Ca+2,Fe+2, Ae+3) will increase intensity of soil distension , but one valiant kation (Na+) will decrease intensity of soil distention. This principle confirmed by Z.A.Nersesova's

research study. But very rare that base soil contains only one type of clay mineral.

Regime of freezing and temperature:

Regime of freezing has much influence to base soil distension from freezing.

As noted by N.A. Tsytovich soil that freezes slowly makes more soil distension. Reason of that is , during slowly freezing water molecules get possibility to transfer to the freezing frontline. During a fast freezing, a moisture freezes without a time to move.

If N.A. Puzakov noted that temperature for continues process of originating soil distention from freezing and movement of moisture is 3-5C , then Orlov's laboratory study determined that critic temperature of continues moisture movement in sand soil is –1.5 – 2.0C, in clay soil –2-3C, in clay –4C accordingly.

Pressure :

M.E.Goliddshtain, V.B. Shvets, Bukos, N.A.Puzakov, D.Dashjamts were noted in their papers about influence of pressure to base soil distention from freezing. According to their study, while increasing outside pressure , decreases soil distention because of reducing moisture movement process to the frontline of freezing . This shows that volume of unfreezing water in soil get less in connection with outside pressure. 2-3 kg/m3 pressure can be much reduce moisture movement process in the soil. But, If dusty soil has more bond density Yd then it makes more soil distension.

Moisture :

One of the main factors to influence soil distension from freezing is moisture.

If soil has more primary moisture that makes more soil distention from freezing. The volume of moisture that get over certain volume of soil moisture (w) and starts originating soil bump of freezing is named "Critical moisture" (Wcr).

At first ,N.A.Tsytovich had an idea to determine maximum moisture volume that doesn't make soil distention from freezing and proposed a simple formula. Similiarly to this V.A.Kudryatsev proposed an idea and simple formula to determine volume of moisture in powder content soil at the moment of starting soil distention from freezing.

According to a studies of scientists M.N.Golidshtain , M .F. Kiselev, V.O.Orlov, B.N.Melinikov, the volume of moisture that is starting origination of soil distention is in most soil close to stale limiting moisture (Wp). For example : volume of moisture to soil bump of freezing for clay and clay soil is Wcr >Wp +0.25Jp, for dusty sand soil is Wcr>Wp-0.5Jp.

If calculated volume of moisture in seasonal freezing soil is over critical moisture (W>Wcr) then happens soil distention from freezing.

Maximum soil distention is originating in dusty clay soil which has water saturation degree Sr>0.9, and ground water level close to seasonal freezing deep. In view of scientists , soil with big scrap that contains dusty clay soil with water saturation degree Sr>0.6, powder particles size D>1 , and also sand soil carry out soil distention from freezing.

2. Estimation of soil distention from freezing

Classification of degree of soil distention from freezing which worked out by scientists V.O.Orlov , and M.F.Kiselev has been used in Standard and regulations to prepare project for construction foundation in Mongolia. The location of ground water level and consistence are taking into consideration to make classification with degree of soil distention from freezing. If ground water level is located less than 2 meters from depth of frozen soil, scientists consider that moisture movement influence to the soil distention .

State of soil distention is estimated by following indexes :

- **Quantity of surface deformation during the freezing of base soil – hf**
- **Deformation of soil distention – f**
- **Thickness of frozen layer – df**
- **Comparative index of soil distention = f= hf/df**

Soil that originates the distention is divided to 5 groups depending on particle contents of soil and water saturation degree.

- **extreme distention - f>0.12**
- **strong distention – 0.07<f <0.12**
- **medium distention - 0.035< f < 0.07**
- **weak distention - 0.01< f <0.035**
- **none distention - f<0.01**

3. **The Phenomenon of moisture movement and formation of seasonal soil.**

The Phenomenon of moisture movement which happens in frozen soil is main reason to make soil distention during the base soil freezing.

At first, scientists G.Buykos(1917), A.F.Lebedev (1930), M.N.Golidshtain(1940) published about phenomenon of moisture movement that happens during the soil freezing, especially in temperature –0C –5C soil moisture is redistributed and moisture moves to the freezing frontline.

"Theory of cover water " about moisture movement in fine particles soil (A.F.Lebedev 1919, G.Beskov 1935) is the best theory of the 20th century.

This theory can be used to explain the phenomenon of moisture movement in frozen and unfrozen soil.

Between years of 1923 and 1929 G.Buykos, and Teber worked out theory of crystallization force. This theory improved Theory of cover water , but it was possible to use for only freezing soil.

In result of scientists' many years persistent work , the following conclusions were made about moisture movement in freezing soil.

- **Moisture movement happens in freezing soil at any minus temperature (in frozen soil up to -70C) (N.A.Tsytovich, Z.A.Nersesova)**
- **During soil freezing, if water has pressed out from front line of frozen sand soil with big particles, then in clay soil water moves to freezing frontline and increases a glaciation .(V.V.Orlov)**
- **Soil distention and glaciation happens with rhythm to repeat itself in the laboratory and in the field.(R.Martin, A.M.Pchelintsev)**
- **Unfrozen water moves in both freezing and frozen soil (M.A.Tutunov, N.A.Tsytovich, A.A.Anayan) and moisture movement of freezing soil happens mostly in liquid phase as a cover water (A.P.Bejenova)**

- **Maximum glaciation carry out in soil that is rich with multi valiant kation , and one valiant kation soil makes less glaciation.(Z.A.Nersesova)**

Depending on freezing regime , side condition (freezing from 2-3 sides etc.), level of water supply, formation of frozen soil are different and their quality is dissimilar.

If aged frozen soil is located under seasonal freezing soil then moisture collects more in places close to surface of earth and border of permafrost. However , if unfrozen soil is located under seasonal freezing soil then moisture moves and located upwards.

4.Temperature regime of seasonal freezing soil and moisture distribution

Layer that has thawing during summer time on area with spreaded permafrost is called seasonal thawing , and layer that has freezing during winter time on area without permafrost is called seasonal freezing. Seasonal freezing and thawing layer has different temperature and freezing and thawing regime is not identical. (Figure 4)

These differences are depending on that permafrost is located under seasonal thawing layer , and permanent unfrozen soil is located under seasonal freezing soil.

Figure 4. Temperature distribution in layer of soil with seasonal thawing (a), and freezing(b)

Summer temperature of seasonal thawing soil is less by several points than seasonal freezing soil and it can be explained by influence of under located permafrost . Therefore seasonal thawing soil is freezing more quick (shortly) and seasonal freezing soil is thawing faster during the summer time. Results of studies carried out in East Siberia, Transbaikal territory, and Mongolia (V.O.Orlov, Elgin, Jeleznyak, A.Anand) showed that layers of seasonal freezing soil can be divided into following type of layers by state of freezing condition.

- **first 1.0-1.5m thick layer is staying in solid frozen state with temperature up to minus 2.5C, and under it completed layer in elastic frozen state with thickness 1.0-1.5meter and temperature from 0C to –2.5C. These state of layers observed during months of December and January of the year while freezing deep get up to 3 meters. If get more cold , then layer temperature decreases and in March most of layers will transferred to solid frozen state.**

For the seasonal thawing soil , during November and January soil temperature decreases up to –3C in 1-6 meter depth of soil.

In the Spring , layers of solid frozen soil in Winter to be settled into 3 layers different by physical state.

Top side 1 meter thick elastic frozen layer, in the middle solid frozen layer, and in below 2 meter thick elastic frozen layer.

According to above mentioned states seasonal freezing soil is thawing in Spring and Summer not only from topside and also from bellowed, but seasonal thawing soil is thawing only from the topside. Soil freezing regime, and speed happens differently in layers. For example : In seasonal thawing soil (permafrost) , the topside 1 meter thick layer's freezing speed is 4-5cm/day , below it 0.5meter thick

layer's freezing speed is 6-8 cm /day . On the other hand soil freezing goes intensively from both side. But middle layer's freezing speed not more than 2.5 cm/day . At this moment could have high probability of glaciation.

During soil freezing , moisture volume is changing and redistributing into soil layers depending on temperature regime. The moisture regime of seasonal thawing is much different than the moisture regime of seasonal freezing. The feature distinction is related to mass transition and heat exchange between some part of the soil and atmosphere, and among other parts of soil and basic permafrost layers.

In most case , 3 layers with different moisture from up to down completed during the freezing of seasonal thawing soil . The moisture in up and down layers increases and the moisture in middle layer decreases. This is related to soil moisture moves to both sides front lines of freezing. But, moisture in seasonal freezing soil moves to only front line of freezing. Moisture distribution during soil freezing is influenced in to structure of glaciation of layers in frozen soil. An according to the study by V.O. Orlov seasonal freezing soil surface area (0.3m) layered glacier soil, below of this completed solid structure from intensive freezing and next layer made of honey-layer structure soil from decreasing speed of freezing and last layer which contact with unfrozen soil made also layered glacier layer. But solid structure is originated in seasonal thawing soil's up and down parts and layered structure is originated in the middle part. On the other hand, solid structure is originated because of comparative quick freezing of both end layers.

In engineering practice, seasonal freezing ground classifies depth and not depth freezing ,causing amount of depth of freezing. If normal depth of freezing does have until 2.5 m, it is called not depth freezing. If depth of freezing is more than 2.5 m, it is related to depth freezing. The normal depth in seasonal freezing and thawing is determined by the result of long-term observations and measures, but accounting method is developing. Scientist identifies that amount of depth of freezing in base soil depend on several factors such as cold temperature, its continued term, thickness of snow cover, type of base soil. In the direction of construction standard , depth of seasonal freezing is determined by following formula.

Dfn=do Mt

If Mt=1 , do' takes into account of freezing depth. Ph.D. A. Anand determined that depth of freezing is 28sm for clay and soil, 34sm for dusty sand soil and 40 cm for sand with large and medium sizes and big fragment soil in Mongolian seasonal deep freezing condition.

5. Main phases(cycle) of moisture and heat regime in seasonal freezing and thawing :

Annual water –heat regime cycle of road dam In seasonal freezing region consists of interrelated 4 steps of water moisture changes.

1. **First moisture collecting period**

2. **Intensive moisture movement period during freezing of road dam**
3. **Maximum moisture supply period during soil thawing**
4. **Soil drying up period**

All these steps act as a complex cycle of soil moisturizing in result of natural influence from surroundings of road dam. Starting time of the period of this cycle depends on weather conditions in present region.

Water and heat regime of road dam is different from surroundings' regime. It is essentially different in areas depending on road dam , and pavement structure, and weather condition of region.

In Mongolia , duration time of cold season is decreasing from North to South, because of that time for intensive movement and collection of moisture is also reduced accordingly. (Table 1)

Duration time for freezing and thawing of base soil in some Aimag and city

N	Name of city and aimag	Freezing : start	Freezing : finish	Thawing : start	Thawing : finish
1.	Meren				
2.	Ulaangom				
3.	Ulaanbaaatar				
4.	Arvaikheer				
5.	Sainshand				
6.	Dalanzadgad				

Table 1 shows that time of soil freezing is continues in Arvaikheer 6 months 15 days, in Ulaanbaatar 6 months 12 days, in Ulaangom 6 months 5 days,in Meren 6 months, in Sainshand 4 months 10 days, and in Dalanzadgad 4 months accordingly and in proportion to it , time of moisture movement in frozen soil is prolonged and because of it increases probability of originating soil bump .

Our study results confirmed that soil bump happens more intensive in Steppe region than Mountain and Gobi regions in Mongolia.

1th cycle or period of collection of Fall moisture in road dam.

This period starts after Summer dry up with average temperature of day +3 to+5 C. At this time heat flow of soil is directing from up to down. Although in the Fall volume of precipitation at the same time is reduced , and time for precipitation is prolonged , because of these air moisture is reducing and that causes to increase of steam of soil moisture.

In this period main source of collecting moisture are air precipitation and water steam. In the Fall unorganized removal of surface water causes to be accumulated water on foot of road dam and this is an additional sourse of moisture collecting in road dam.

The end of moisture collecting period is determined by time of constant freezing of soil or air temperature is get less than –5C.

2nd cycle or period of accumulation of winter moisture in road dam.

The heat of base soil is directed from the depth to surface and moisture movement goes intensively if ground water level is located close to surface. In the Winter hydraulic bond occurs in result of moisture movement between ground deep water and frozen dam and accumulation of moisture is increasing while deepening of freezing.

Because of accumulation of moisture , glaciation of base foundation is added to be originated soil bump and in result of it base soil is loosen.

Speed of moisture movement in frozen soil depends on type of soil , degree of density, and location of ground water. Dusty soil has more surface energy and it accumulates more moisture . For this reason it accounts as a dangerous of the soil bump.

Speed of freezing of base soil is various on territory of Mongolia and it depends on thickness of snow cover, direction of surface slope, and vegetation layer. Coefficient of base soil bump is determined by comparison of size of surface bump to depth of freezing, and sometime it reaches up to 15 % as a noted on books and papers, but our study showed that this coefficient is 7-8% on Ulaanbaatar city territory.

Studies determined that moisture accumulation and origination of intensive soil bump are happening in the layer which is located on 0.5 to 1.5 meter from the surface of road dam.

3d cycle or period of thawing of freezing soil and saturation of moisture.

This period is continue from constant plus temperature on soil surface to complete thawing of frozen layer.

Duration time of thawing of base soil in some aimag and cities showed in the table 1.

Temperature of frozen soil is increased before its thawing and change direction of heat flow and at this time a water which was freed from thawing of soil is moisturizing the soil that loosened from originating of soil bump and reducing soil stability .

Moisture of melting snow and water is added to moisture that accumulated during the Winter.

A Water, which is freed from thawing frozen soil, is supplying just thawed soil by water that is to weaken carrying capacity of road dam.

Therefore, thickness of layer with weakened carrying capacity of water saturated road dam and duration time of this situation on present dam are main index to determine its stability.

^{4th} cycle of heat or dry up period starts hence road dam is to get warm in the sun

At this period renew density and carrying capacity of soil. Dry up is accelerated by surface drainage.

Even in Summer get more high intensity of air precipitation but air dry up is high, because of this moisture cannot be accumulated in

upper part of road dam. In this time deformation of road dam module is increased.

Seasonal freezing and thawing are happening in all region of Mongolia and implement a measures to protect from originating bump in road dam structure (construction) and base soil. In case of building road on places with base soil bump need to be implement measures such as remove and drain a water from surrounding area, put up high dam, build a water unpenetrateable layer etc.

There is need to prohibit of using soil that would originates soil distension in road bed with purpose to prolong lifetime of road, reduce expenses to repair and maintain of roads in Mongolia. Our study confirmed that dusty sand and clay soil originate much more distension than any other type of soil. (Figure 6)

Figure 6. Dependence of tension volume and deformation size from content of clay in soil during the origination of soil distension from freezing.

The road construction uses soil that is composed of clay , dusty and large and gravel . To determine portions of these compositions in the soil can be considered weather condition , especially, ability of these compositions can protect from soil freezing distention. Road dam uses gravel which has an ability not occur to soil freezing distention. It is important condition to provide reliable road dam.

When the soil moisture is to close to precise measure then the capacity coefficient is high. The consolidated soil dam in winter or

spring the density id not decreasing less than 0.95. In spring thawing of dam was E=60-200kg/sm. From the researchers, the moisture in some cases 0.75 to 0.8-0.85 of road dam in dry climate area. So, in moisturized soil a module of shape damage is decreased in result in breakup in road dam.

The expenses for densitying the road soil, protecting from moisture and drying are decreases the expenses of restoring the road pavement.

movement.