FREEZE-THAW EFFECTS ON ROADWAYS

Approach to Pavement Design with Special Reference to Roads in Mongolia
by

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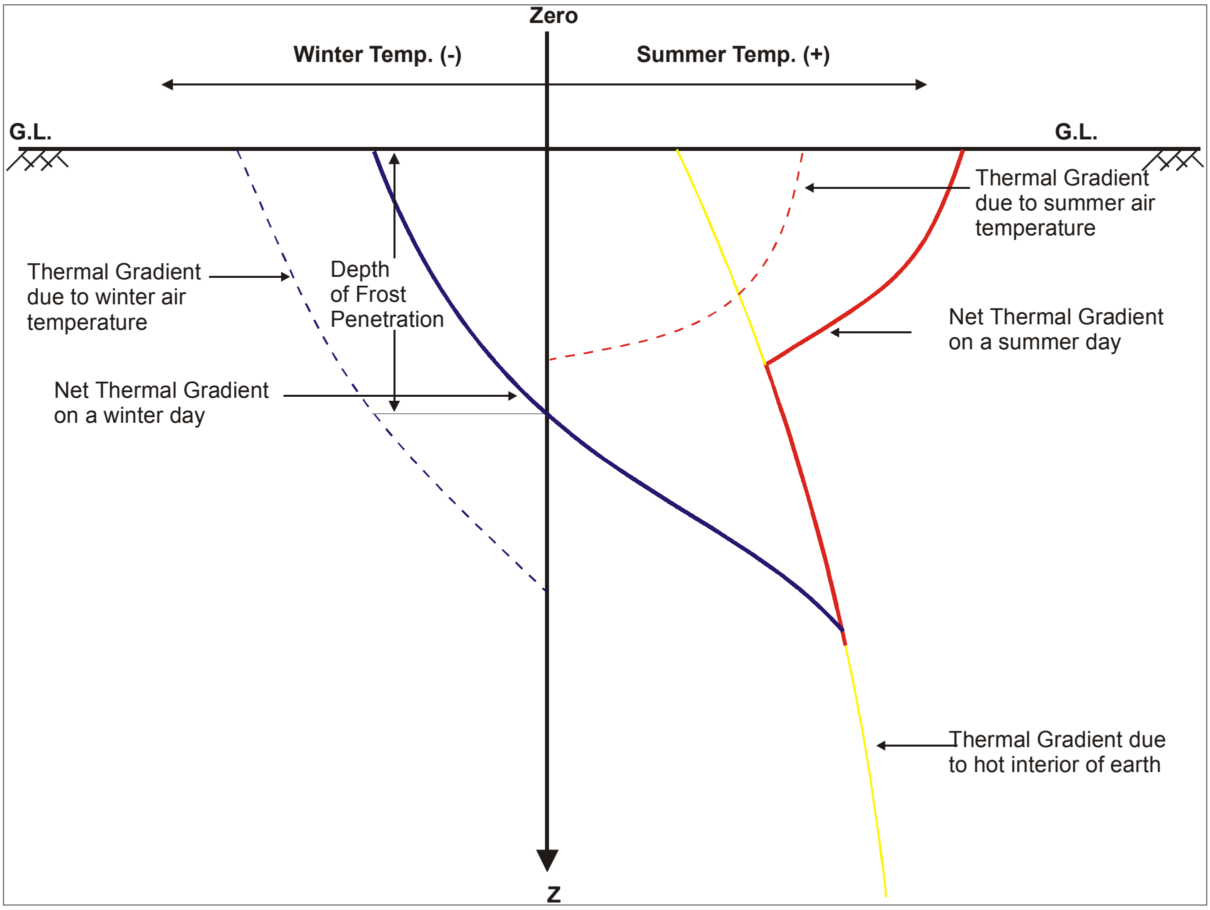
SYNOPSIS

More than traffic, it is the changing thermal regime of the ground that affects the performance of road pavements in cold regions like Mongolia. **Figure 1** gives a schematic description of seasonally changing thermal regimes of ground in cold regions.



Three types of thermal regimes, which generally prevail during different seasons in Mongolia, can be recognized.

i. Sustained Winter Thermal Regime during months of November to February
ii. Fluctuating Thermal Regime during months of March to April and October to November
iii. Sustained Summer Thermal Regime during months of May to September

Under sustained sub-zero temperatures during winter months, the ground up to a certain depth below pavement will freeze and increase in volume. The pavement will be consequently subjected to the swelling pressures. And, if the sub-grade soil happens to be clayey silt and water table is near, the pavement will be subjected to the phenomenon of **'Frost Heave'**. Further, the pavement may even crack due to the excessive tensile stresses produced under the effects of extremely low sub-zero temperatures in winter.

Under the Fluctuating Thermal Regime during months of March to April and October to November, the temperatures are likely to change diurnally – with plus and minus temperatures prevailing during day and night respectively. Such temperature reversals, repeated daily over a couple of months, could produce pavement distress, particularly in its top layers, due to the effect of **'Thermal Fatigue'**.

Under the Sustained Summer Thermal Regime with the onset of summer from May onwards, the frozen ground will start **Thawing**. This thawing of the ground accompanied by increased activity of summer traffic on roads can cause considerable damage to the pavement.

Therefore, for the relatively low volume of vehicular traffic on the roads in Mongolia, the performance of pavements will essentially be affected more by the changing thermal regime of the ground than by the axle loads. This calls for a paradigm shift in the approach generally followed for designing pavements, rather than the road pavements based on axle loads. Therefore, the road pavements in Mongolia should be designed primarily on the consideration of extremely varying climatic and geotechnical conditions of the ground. Such designs will also be found adequate for the vehicle axle loads, which the pavement is expected to carry during its design life.

1. INTRODUCTION

The effects of the changing thermal regimes of the ground are recognized as the major contributors to the deterioration of structures including road pavements constructed in the cold regions. Depending on the climatic conditions of the cold region, the ground on which the structures are to be founded could be either in a permanently frozen state (Permafrost) or seasonally freezing and thawing. Whereas the permafrost can provide a thermally stable and strong foundation, it is the seasonally freezing and thawing ground which, if not fully factored into the design process, can severely affect the performance of road pavements and other structures founded on such grounds.

Under the climatic conditions generally prevailing in Mongolia, the ground on which roads are built can be classed as **'Seasonally Freezing and Thawing Ground.'**

During winter freezing, the pavement will be subjected to the swelling pressures and to the possible phenomenon of '**Frost Heave'**. Further, the pavement may even crack due to the excessive tensile stresses produced under the effect of extremely low sub-zero temperatures in winter.

With the onset of summer from May onwards, the frozen ground will start thawing. This **Spring Thaw** of the ground accompanied by increased activity of traffic on roads can cause considerable damage to the pavement.

In between extremes of summer and winter, during months of March to April and October to November, the temperatures are likely to fluctuate between plus temperatures during day and minus temperatures during night. The pavement is thus subjected to **'Thermal Fatigue'** under such daily temperature reversals, which could lead to pavement distress, particularly in its top layers.

Keeping in view the aforesaid climatic condition and the fact that these are low volumes of vehicular traffic in Mongolia. The road pavements should be designed primarily on the consideration of extremely varying climatic and soil conditions of the ground.

2. CLIMATIC CONDITIONS IN MONGOLIA

Mongolia experiences extreme climatic conditions – ranging from severe winters between November and March to nearly sub-tropical summer conditions between May to September. The annual temperatures could range from the low of –35 ^{0} C in some places in the north during winter, to as high as + 35 ^{0} C in south during summer. On an average, the temperatures within a region may vary from –25 ^{0} C to + 20 ^{0} C. **Figure 2** shows the average temperature variations recorded at a few places in Mongolia.

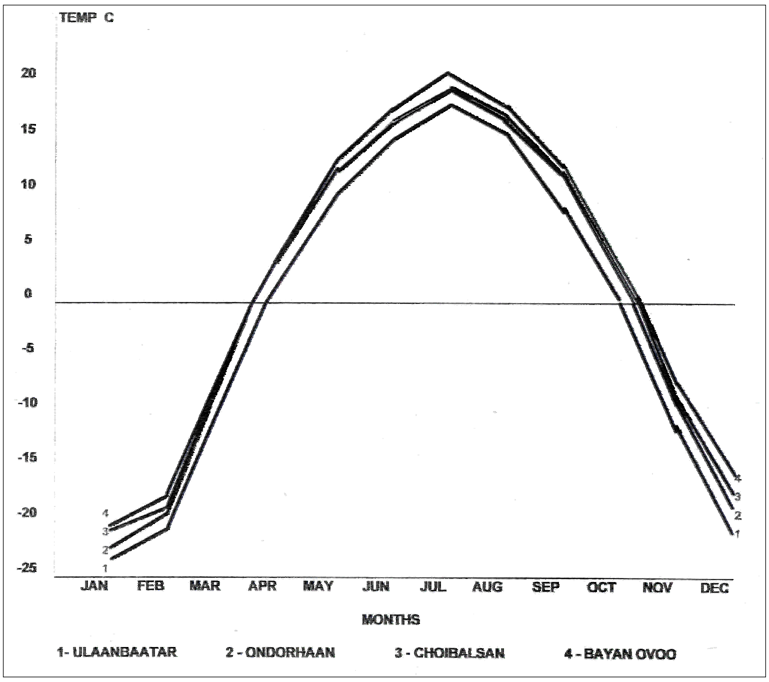


Fig. 2 : Typical Average Monthly Temperature Record

Snowfalls in winter, though not very heavy, are common. The grounds as also the less trafficked roads, therefore, remain under snow cover for long periods during winter.

The rainfall varies from region to region. It is generally concentrated during the summer months of July and August. **Figure 3** shows a typical record of monthly rainfall variation in Ulaanbaatar.

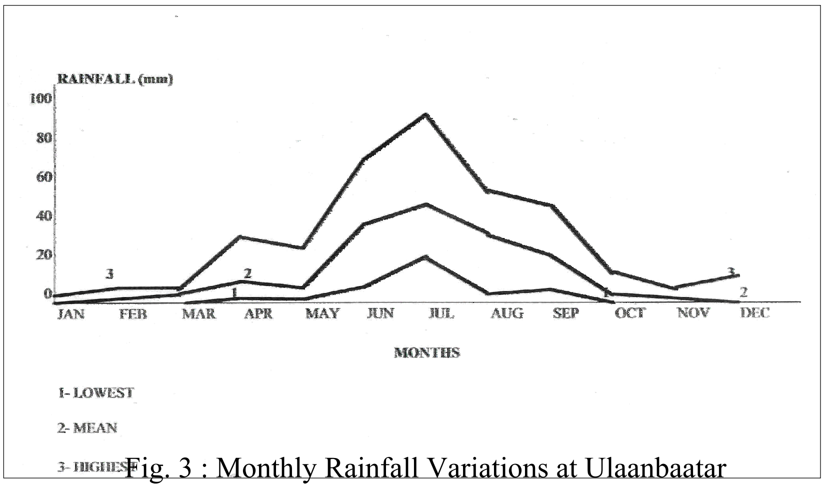


Fig. 3 : Monthly Rainfall Variations at Ulaanbaatar

The distress potential of climate is essentially due to its extreme variations – from acute winter temperature of about –25 ^{0} C to moderate summer temperature of + 20^0 C -, which significantly alters the thermal regime within the pavement and the ground below it. These alterations in the thermal regime bring about changes in the particle state of the ground, resulting in deformations and excessive thermal stresses, which may cause pavement failure.

3. THERMAL REGIMES

Considering the climatic variations in Mongolia, the following three types of thermal regimes of the ground, can affect the pavement in various ways :

i. Sustained Winter Thermal Regime during months of November to February
ii. Fluctuating Thermal Regime during months of March to April and October to November
iii. Sustained Summer Thermal Regime during months of May to September

The effect of these thermal regimes on behavior of ground and consequently on the performance of the pavement is explained below.

4. FREEZING OF GROUND UNDER WINTER THERMAL REGIME

Figure 4 shows a typical record of ground thermal regime at some locations in Mongolia during winter months of November to February. During these months, the ground remains permanently frozen upto varying depths.

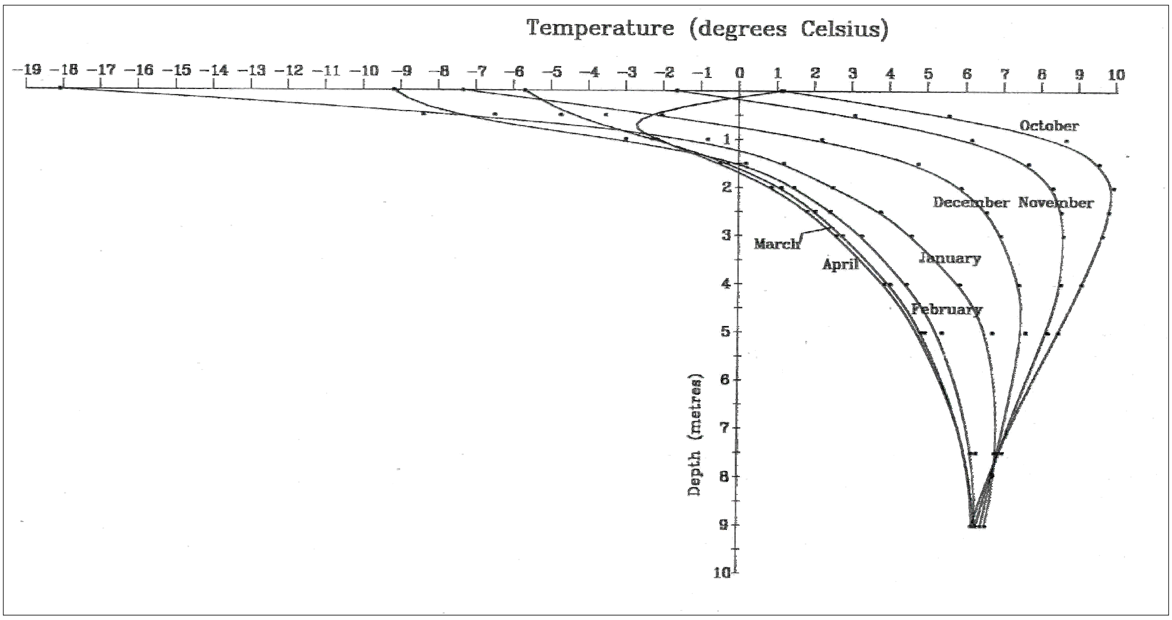


Fig. 4 : Sustained Winter Thermal Regime of Ground (A Typical Record)

4.1 Frost Penetration

The depth 'Z' upto which frost (sub-zero temperatures) penetrates will depend on

i. Thermal Properties 'TP' (Thermal Conductivity, Latent Heat of Fusion and Specific Heat) of the ground.
ii. Freezing Index 'F' representing the combined effect of sub-zero temperatures and their duration, expressed in degree-days.

Z = f (TP, F)

Figure 5 shows a typical record of the depth of frost penetration during winter months.

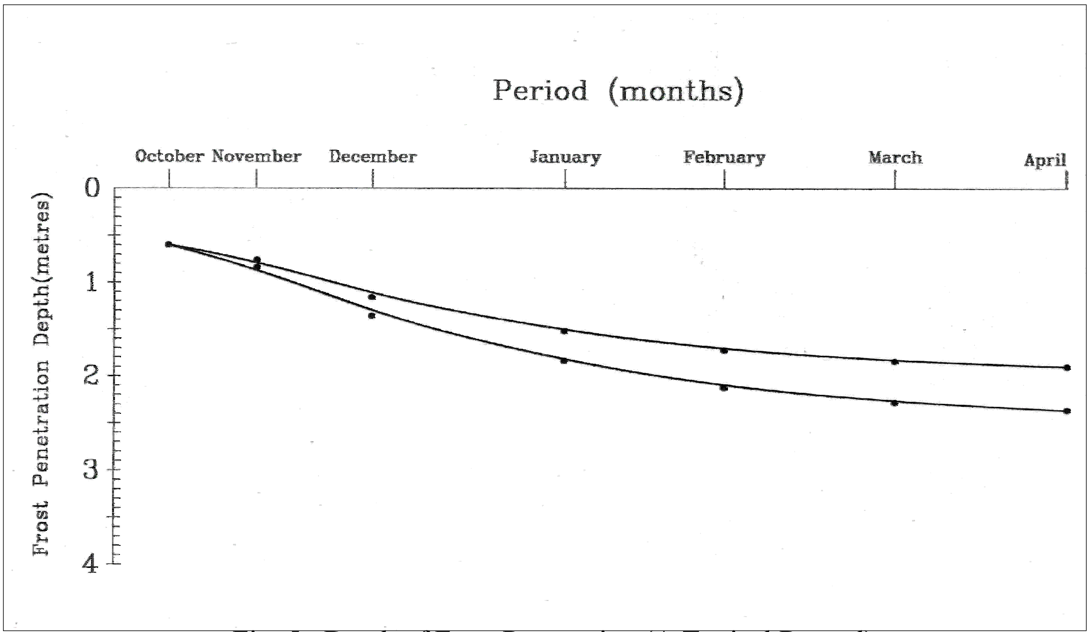


Fig. 5 : Depth of Frost Penetration (A Typical Record)

Two things can happen as a result of the freezing of ground during winter months, namely:

i. Volume changes in the frozen ground leading to 'Frost Heave'
ii. Thermal Stresses

4.2 Frost Heave

In the frozen state, the ground volume will increase and the pavement will be subjected to swelling pressures. The ground volume may continue to increase leading to the frost heave of the pavement, if the following three conditions necessary for ice segregation and frost heave are existing.

i. Sustained freezing temperatures
ii. Frost susceptible soils, like silts and
iii. clayey silts
iv. Supply of water

The frost heaving can displace roads, buildings, pipelines, drainage systems and other structures.

4.3 Thermal Stresses

Under the effect of sustained minus temperatures in winter, the pavement will be subjected to excessive tensile stresses resulting in the formation of cracks.

5. THERMAL FATIGUE UNDER FLUCTUATING THERMAL REGIME

During the months of March to April and October to November, the temperatures are likely to change diurnally – with plus temperatures prevailing during day and minus temperatures during night. **Figure 6** shows the diurnal temperature changes that may occur. This type of thermal change will result in a daily fluctuating thermal regime occurring essentially in the top layers of the road pavement. These top layers of the pavement will therefore be subjected to repeated cycles of daily temperature reversals over a period of about two months and may fail under the effects of 'Thermal Fatigue'.

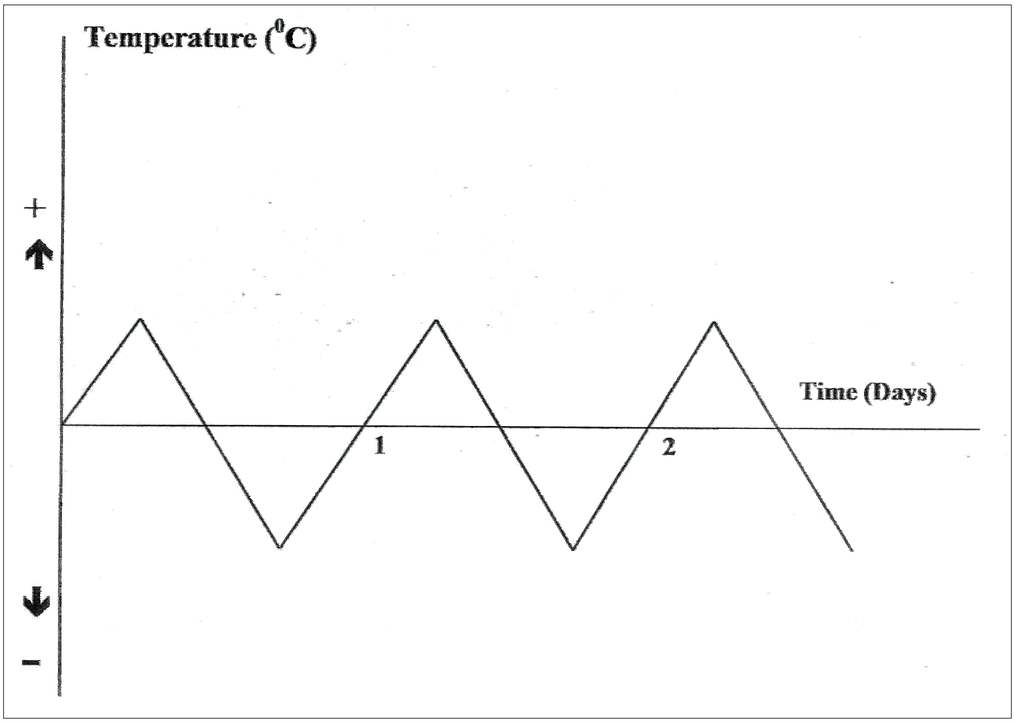


Fig. 6 : Diurnal Changes in Temperatures

6. THAWING OF GROUND UNDER SUMMER THERMAL REGIME

With the onset of summer from May onwards, the frozen ground will start thawing in spring. A great deal of water in the upper layers of soil melts first. With the bottom layers still in a frozen state at this point, the melt water cannot drain. The soil becomes saturated and looses most of its strength. This weakening of the sub-grade soils due to Spring Thawing of the ground, accompanied by increased activity of summer traffic on roads, can cause considerable damage to the pavement. The pavements supported on such soils will develop cracks and potholes. Other structures like fence posts, etc can often become skewed. Thawing of sloping ground can also lead to landslides.

7. PAVEMENT DESIGN AND MATERIAL SPECIFICATIONS

7.1 Pavement Design

Keeping in view the distress potential of climate as also the relatively low volume of vehicular traffic on the roads in Mongolia, the performance of pavements will essentially be affected more by the changing thermal regime of the ground than by the axle loads. This calls for a paradigm shift in the approach generally followed for designing pavements. Instead of designing for axle loads, the road pavements in Mongolia should be designed primarily on the consideration of extremely varying climatic and geotechnical conditions of the ground. Such designs will invariably be found adequate for the vehicle axle loads, which the pavement is expected to carry during its design life.

The traffic volume and its characteristics will, however, be the determining factor for designing the road capacity and its geometry.

7.2 Pavement Materials

While locally available soils, gavel, stone aggregates can be appropriately used for the construction of sub-base and base courses, special attention needs to be given to the type of bituminous material and the bituminous concrete mix used in the top layers of the pavement. This layer is subjected to the severe effects of excessive tensile stresses during winter and to thermal fatigue during the periods immediately preceding and following the winter. In order to ensure the right quality of the top bituminous layer, which can resist well the above thermal effects, it is suggested that, in addition to the routine tests, following special tests should be carried out for the bitumen and the bituminous concrete materials.

- *Bitumen*

  i. FRAAS Breaking Point
  ii. Rolling Thin Film Oven Test
  iii. Ductility

- *Bituminous Concrete*

The design of bituminous concrete mix should essentially be based on the results of **Freeze – Thaw tests**. Appropriate freeze – thaw cycle tests should be developed to simulate the effects of:

i. Rapidly (diurnally) Fluctuating Thermal Regimes
ii. Sustained Thermal Regimes changing from Winter to Summer

The trial design mix for the above tests can be based on the results of stability tests.

The approach to the pavement design and the specifications for the pavement materials, as suggested above, calls for appropriate modifications in the standards and specifications which are currently used for the pavement design and construction of roads in Mongolia.

8. CONCLUSION

This Paper is based on experience of ICT in implementation of a number of road projects in Mongolia. As brought out in the Paper, in view of extreme cold climate conditions prevailing in this country, the design of road pavement should be based on consideration of extreme varying cold climatic and soil conditions rather than based on low volume of traffic. However, this subject needs further in-depth study and the experience gained from other international participants in execution of road projects by them in their own country and other countries under severe cold climatic conditions will help us to formulate a more rational design of road pavement for adoption for future projects in Mongolia.