

CRITICAL AND DESIGN HEIGHTS OF FILL MATERIAL IN PERMAFROST REGIONS ON NATIONAL ROAD 214, EASTERN QINGHAI-XIZANG PLATEAU, CHINA

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Abstract

The artificial change of the permafrost table under fill materials in permafrost regions has been reported for forty years. Changes along national road 214 are reported in this paper. The conclusions of the research indicate that the critical height of the fill material is about 0.80 m, i.e., when the height of fill materials is more than the critical height of fill, the new permafrost table rises, when less, the new permafrost table descends. This is one of the important reasons causing frost heave in roads. Because of the influence of climatic warming, permafrost in the region is degrading and the natural permafrost table has dropped by 0.3 m during the last thirty years. Because of the rapid development of the economy and the increasing use of road transportation, the increase in the amount of frost heave in the road is greater than the above would indicate. Thus, the new permafrost tables must be raised in fill. The design height of the fill on national road 214 has been determined to be 1.6 m for gravel-paved road surfaces, and about 2.0 m for concrete road surfaces.

Introduction

National Road 214 is the highway with the second highest standard from Qinghai Province to the Xizang Autonomous District. It was constructed in 1953 and opened to traffic in 1954. At the time of construction, the height of the applied fill material was about 10-30 cm above the natural ground surface. Later, the height of the fill material was increased annually, up to 20-70 cm by the beginning of the 1980's, in order to control the frost heave caused by thermokarst. In the districts where serious road frost heave occurred, the height of the fill material was increased to 80 cm or more, and, in some local sections, increased to 150 cm. The road is maintained every year, but the frost heave has not been completely controlled.

Along National Road 214, the permafrost zone extends about 330 km, starting on the northern slope of Ela Mountain and continuing to the southern slopes of the Bayan Har Mountains. The highest and lowest elevations are respectively 4824 and 3907 m; the mean elevation is above 4300 m. In the region, the mean annual temperatures range from -2.5 to -5.0°C; the annual precipitation is about 300 mm. There are significant diffe-

rences in the permafrost distribution along the road. In areas where the ground temperature is warmer, the permafrost thickness is thinner; where the loose soil contains more gravel, the percentage of the ice-rich soil is smaller and the permafrost table is deeper. The permafrost in this areas is degrading.

Key factors influencing the permafrost table beneath the road

The permafrost table is affected by changes in natural conditions, such as surface vegetation, moisture content of the active layer, solar radiation, and fluctuations of the air temperature. Where the ground surface is disturbed or changed, the permafrost table will be affected. The heat and moisture conditions of the near-surface ground layers are inevitably altered during road building; consequently, the permafrost table often is greatly changed.

THE HEIGHT OF ROAD FILL MATERIAL

Data from three hundred drill holes on the Tibetan Plateau indicate that the permafrost table under a roadbed will not change when the height of the fill

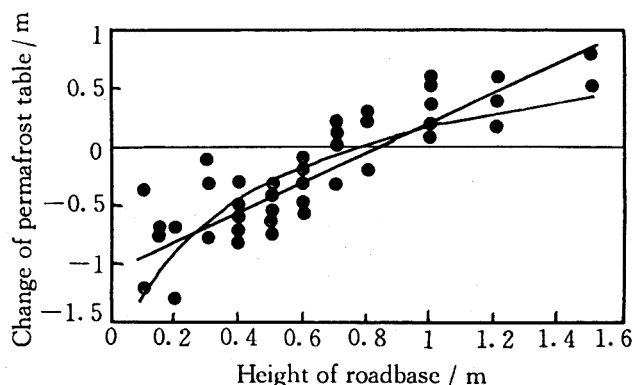


Figure 1. Relationship between the changes of the permafrost table under the roadbed and the height of the fill material.

material is equal to the critical height (H_0). The permafrost table will rise when the height of the fill is more than the critical height (H_0), and conversely, the permafrost table will fall when the height of the fill is less than the critical height (H_0). When the height of the fill is between 10 and 160 cm, the relationship between the height of the fill and change in the permafrost table position is linear (Figure 1).

THE NATURAL PERMAFROST TABLE

The natural permafrost table is an important parameter for the environment of permafrost, and is influenced by soil type, moisture content, soil density, and the vegetation at the ground surface. Therefore, there is a close relationship between the height of the fill and changes in the natural permafrost table. For gravel surface roads, the relationship between the depth to the permafrost table beneath the fill (H_r) and the depth to the natural permafrost table (H_a) is close and linear (Figure 2), i.e., $H_r = H_a + 0.73$. It is clear that this relationship is controlled by the depth to the natural permafrost table.

RELATIONSHIP WITH AIR TEMPERATURE AND THE ACTIVE LAYER

The north to south permafrost distribution along the highway can be divided into three large sections

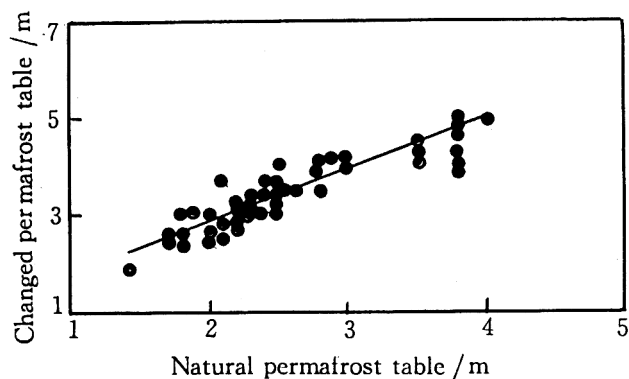


Figure 2. Relationship between the changed position of the permafrost table beneath the roadway and the natural permafrost table position.

(Table 1). From Table 1, it can be seen that the properties of the active layer, the particle-size distribution, the moisture content and the vegetation cover, are important factors influencing the depth to the permafrost table. The air temperature also influences the permafrost table position, but in the same section, the fluctuating influence of the air temperature is secondary. In the section where the Bayan Har Mountains are located, the air temperatures are lower, but the critical height of the fill is greater than that at Ela Mountain because of the controlling influence of the particle-size distribution in the active layer. In the Ela Mountain section the depth to the natural permafrost table is low, because of the icy and fine-grained soil in the active layer, and the abundant vegetation. There is a close relationship between these three factors.

Critical height of fill material

With changes in the depth of the permafrost table and topographic conditions, the critical height (H_0) of the fill material (in meters) changes. For example, in the Ela Mountain section, the natural permafrost table is found at depths between about 1.4 and 3.5 m; in the Changshi Tou Mountain section, it is between 1.8 and 4.0 m deep; and in the Bayan Har Mountains section it is between 1.8 and 3.8 m deep. Because of the large changes in the depth to the natural permafrost table within the same section, it is difficult to design for construction of the road. Observations and investigations over many years show that, for sections with icy and fine-grained soils, and particularly, for the sections across ridges, the critical height of the fill is small. At the same time, most of these sections have poor stability. Where water collects, frost heave in the road continuously results, making it difficult to provide a stable permafrost table beneath the roadbed.

Based on long-term observations and investigations, frost heave has been a problem for thirty years after construction. Therefore, we believe that the critical height of the fill should be determined in terms of the regional temperature conditions along the road for practical applications.

The critical height of the fill can be determined by two methods given below.

USING THE RELATIONSHIP BETWEEN THE CHANGED PERMAFROST TABLE BENEATH THE ROADWAY AND THE NATURAL PERMAFROST TABLE

From Figure 2, we obtain the regression equation:

$$H_r = 1.07H_a + 0.73 \quad [1]$$

where the correlation coefficient $R = 0.865$, the mean square deviation $\sigma = 0.27$, H_r is the depth to the per-

Table 1. Relationship with the atmospheric temperature and the active layer

Section	Ela Mountain	Hong Tu Slope - Changshi Tou Mountain	Yeniu Gou - Bayan Har Mountains
Elevation (m)	4283-4487	4142-4506	4276-4823
Relative Air temperature	Middle	High	Lower
Properties of the active layer	Icy and fine-grained soil, thinner active layer	Ice-poor and coarse-grained soil with dry gravel, and thicker active layer	Properties of active layer is between above two
Critical height of fill material for gravel-paved surface	0.69	0.89	0.81

mafrost table beneath the fill, and H_a is the natural permafrost table under the roadbed. When the natural permafrost table is to be controlled and not changed, the height of the fill required is regarded as the critical height H_0 , i.e.,

$$H_0 = H_r - H_a \quad [2]$$

By introducing equation (1) into (2), we obtain:

$$H_0 = 0.07H_a + 0.73 \quad [3]$$

In order to apply equation (3), the depth to the natural permafrost table must be determined.

USING THE RELATIONSHIP BETWEEN THE HEIGHT OF THE FILL AND THE CHANGE OF THE PERMAFROST TABLE UNDER THE ROADBED

From Figure 1, using a linear and logarithmic equation, we obtain the two following regression equations; the linear equation is:

$$\Delta H = 1.27H - 1.06 \quad [4]$$

where ΔH is the change of the permafrost table under the roadbed, $R = 0.781$ and $\sigma = 0.233$, and H is the height of the fill.

Letting $\Delta H = 0$, i.e., the permafrost table under the roadbed is stable and not changing,

$$H_0 = 0.835 \quad [5]$$

The result of the regression using the logarithmic equation is

$$\Delta H = 1.48 \ln H + 0.147 \quad [6]$$

$$R = 0.675, \sigma = 0.28$$

Letting $\Delta H = 0$

$$H_0 = 0.80 \quad [7]$$

Discussion about the design height for fill in permafrost regions

Based on the critical height of the fill, the design height can be determined in permafrost regions. The values obtained by the three regression methods are different, but for practical applications they are regarded as in agreement. From the point of view of design security, for equations (4) and (5), using 1.5 times the mean square deviation, the critical design height [H_0] of the fill is:

$$[H_0] = 1.18 \quad [8]$$

Since the atmospheric temperature is rising, it is obvious that the permafrost will degrade along National Road 214. Supposing the atmospheric temperature is rising at an average rate of 0.04°C per year, the permafrost table would be lowered by 34 cm after thirty years, or 10 to 11 cm every ten years (Li Dongqing, 1996).

Because traffic on the road has increased over time, a new standard for highway design is required during rebuilding, i.e., the gravel-paved road surface would be gradually replaced by a high-standard highway. To keep the road surface flat and stable, first of all, the stability of fill must be maintained. On the one hand, to prevent thaw settlement, the permafrost table under the roadbed must be maintained and not lowered, on the other hand, frost deformation of the active layer above the permafrost must be controlled to a given value for a flat road surface. That value is about 1%.

Application of engineering

Using road grade standards, the design height (H_d) of fill for the main-line highway is proposed as follows: $H_d = [H_0] + H_t + H_i$, where H_d is the design height of the fill, H_t is the lowered depth of the permafrost table with the permafrost degrading and the temperature rising, H_i is the height of the frozen core in the soil profile to keep the bottom of the roadbed dry and $[H_0]$ is the critical design height of the fill adding 1.5 times the mean square deviation. For the gravel-paved road surface, H_t and H_i are both regarded as minima, i.e., $H_d = 1.58$ m. Conversely, for a concrete road surface H_t , H_i and are the maximum, i.e., $H_d = 2.02$ m. For the gravel-paved branch road surfaces $H_d = [H_0] = 1.18$ m.

An experimental road section was constructed on National Highway 214. For the concrete road surfaces, the height of the fill was 2.0 m and the natural permafrost table was 1.4 m beneath the fill. One year after being opened for traffic, the new permafrost table was at a depth of 2.8 m the permafrost table under the roadbed surface having risen by about 0.6 m. For the gravel-paved road surfaces, the height of the fill was 2.0 m, the natural permafrost table 2.2 m beneath the fill and the new permafrost table was at a depth of 3.4 m beneath the road surface, having risen by about 0.8 m. The permafrost table had not risen into the base of the fill materials in either case.

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