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## Observation Scheme for Temperature and Deformation of Permafrost Subgrade in Yichun-Bei'an Highway

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# Observation Scheme for Temperature and Deformation of Permafrost Subgrade in Yichun-Bei'an Highway

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**Abstract.** The permafrost in the region of Yichun-Bei'an highway is characterized by thin thickness, high ground temperature and high local ice content, and is in the process of degradation, resulting in highway thaw subsidence and longitudinal cracking, which has a very serious impact on traffic. In order to design the observation scheme reasonably and master the variation law of temperature and deformation of permafrost subgrade, based on determining the observation scheme for temperature and deformation of permafrost subgrade, we established a monitoring system of temperature, humidity change and subsidence deformation of permafrost subgrade after construction by selecting typical permafrost observation sections along the highway, which can provide basic data for the design, construction and maintenance of highway subgrade in permafrost regions.

## 1. Research background

The total mileage of highways in Heilongjiang Province has reached 166,000 km, of which the sections through permafrost regions account for a considerable proportion. During the operation, there have been some subgrade diseases such as thaw subsidence, longitudinal cracking and slope freeze-thaw loosening in some sections of highway (Figure 1).

Through the analysis of temperature field and subsidence deformation characteristics of subgrade in permafrost regions at home and abroad, it is found that the subsidence deformation is closely related to the distribution of temperature field. Due to the influence of local atmospheric hydrology, landform, permafrost type and soil texture, the subsidence deformation of subgrade in different permafrost regions is slightly different and has its own characteristics. The subsidence deformation of subgrade in permafrost region will greatly affect the stability of subgrade, causing subsidence, cracking and other typical permafrost subgrade diseases. Therefore, it is necessary to improve the monitoring accuracy of subgrade subsidence deformation and obtain more comprehensive and accurate observation data. In addition, it is essential to strengthen the construction and stability control of filling subgrade in permafrost regions.





Figure 1. Highway diseases in Permafrost Regions

Through the analysis of temperature field and subsidence deformation characteristics of subgrade in permafrost regions at home and abroad, it is found that the subsidence deformation of subgrade in permafrost region is closely related to the distribution of subgrade temperature field. Due to the influence of local atmospheric hydrology, landform, permafrost type and soil texture, the subsidence deformation of subgrade in different permafrost regions is slightly different and has its own characteristics. The subsidence deformation of subgrade in permafrost region will greatly affect the stability of subgrade, causing subsidence, cracking and other typical permafrost subgrade diseases. Therefore, it is necessary to improve the monitoring accuracy of subgrade subsidence deformation, obtain more comprehensive and accurate observation data, and strengthen the construction and stability control of filling subgrade in permafrost regions.

Yichun-Bei'an highway is located between longitude  $128^{\circ}54'\sim 126^{\circ}30'E$  and latitude  $47^{\circ}43'\sim 48^{\circ}14'N$ . The climatic zoning of the highway is  $I_2$ . The geological conditions along the highway are complicated, and it passes through many permafrost areas. The engineering geological exploration report shows that the permafrost in this area has the characteristics of thin thickness, high ground temperature and high local ice content. The permafrost is rich in ice and frozen soil, and there are some ice layers in the local area. Most of their thaw subsidence grades are in level III and IV, and they are in the process of degradation.

Yichun-Bei'an Highway is a newly built expressway with a total length of 163.02 km. It was opened to traffic in October 2012. In August 2013, some sections were repaired. The total length of the repaired section was 2,278 m, and the depth ranged from 3 cm to 6 cm, with one section reaching 13.3 cm. Some sections were repaired from June to August 2014. The total length of repaired sections was 4,369m, and the depth ranged from 3cm to 11cm. Some sections were repaired from June to July in 2014. The total length of repaired sections was 3,655 m, and the depth ranged from 3 cm to 25 cm. Due to the degradation of permafrost, the thawing subsidence and longitudinal cracking of highway subgrade are not only difficult to maintain, but also costly, which has a serious impact on normal traffic. Therefore, it is necessary to design reasonable observation scheme so as to grasp the change rules of temperature and deformation of permafrost subgrade more accurately.

## 2. Observation items

The typical permafrost section along the highway is selected to establish the monitoring system of the temperature change and subsidence deformation of the subgrade after construction. The monitoring and testing contents are as follows:

### 2.1 Physico-mechanical properties of permafrost

The basic properties of permafrost have been mainly studied in laboratory experiments. Testing items: Non-frozen water content and thermal conductivity.

### 2.2 Subgrade filling material test

Testing items: moisture content, porosity and density.

### 2.3 Subgrade subsidence deformation monitoring of permafrost regions

DS18B20 temperature sensor and the Subgrade Deformation Monitoring System are used to monitor the temperature change and subsidence deformation of subgrade in permafrost region.

## 3. Observation scheme

According to the statistics table and engineering geological investigation report of permafrost area, taking the subgrade filling height and permafrost type as the classification standard, we selected 14 observation sections which are typical and suitable for the scheme implementation.

### 3.1 The formation and layout of the subgrade temperature field monitoring system

The permafrost subgrade temperature collecting system consists of five parts: temperature collecting cell, core controller, GPRS communication module, power supply and user end. Working principle: the power supply ensures the normal operation of the whole system. The temperature collecting cell collects the temperature data of the subgrade and converts the format through the core controller. The temperature data are transmitted to the user in the form of wireless signal through the GPRS communication module. Figure 2 shows the overall constitution of the system. In order to ensure that the temperature collecting system can work round the clock, the solar power supply equipment is added, as shown in Figure 3 and Figure 4.

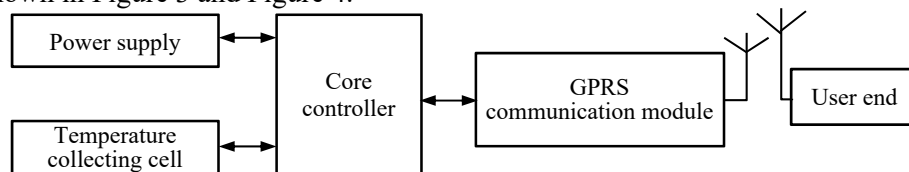


Figure 2. Overall constitution diagram of temperature collecting system

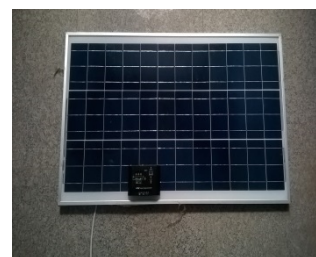
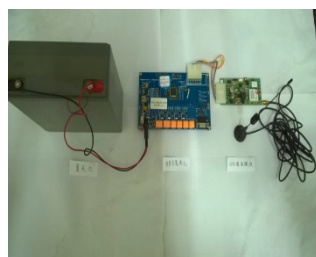


Figure 3. Temperature collecting system      Figure 4. Solar power supply system

The subgrade temperature collecting cell uses DS18B20 temperature sensor (Figure 5), which whose test temperature range is ranging from  $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$ , and the precision can be accurate to  $\pm 0.1^{\circ}\text{C}$ . Because the temperature sensors need to be located at different depths in a temperature measuring hole, temperature sensors can be connected in multiple on a shielded line (Figure 6), and the connection circuit diagram is shown in Figure 8. The DS18B20 temperature sensors are numbered and calibrated indoors in advance, and then several temperature sensors are connected with a shield wire in parallel. The connected temperature sensing line is connected to the core controller, and the observation data is transmitted to the base station through the GPRS wireless transmission module. The observation data is transmitted to the base station through the GPRS wireless transmission module.



Figure 5. Temperature sensor



Figure 6. Temperature measurement sense lines after connection

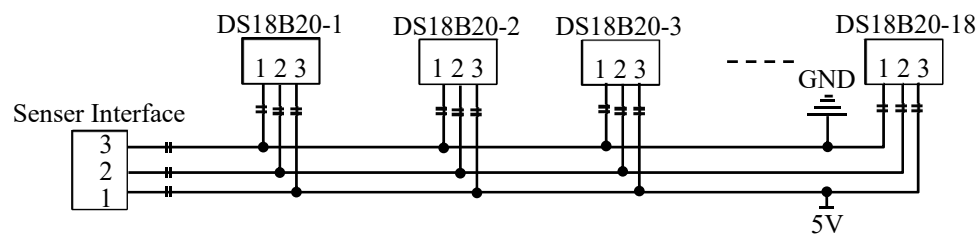


Figure 7. Circuit diagram of temperature sensor

The influence of the atmospheric temperature on the subgrade temperature field decreases gradually with the increase of the depth. When it reaches a certain depth, the temperature in the subgrade is almost not affected by the outside atmospheric temperature, and the influence range is 3 to 10 meters below the subgrade surface. In the depth of about 3m below the top of the natural surface, there is a region with frequent temperature changes which freezes in winter and melts in summer under the influence of the external atmospheric temperature, and the water is in frequent phase change recycle in the freeze-thaw process. Therefore, from the subgrade surface to the natural surface, a temperature sensor is laid every 0.5m depth, and the temperature measurement points are densified within 0.5m above and below the permafrost upper limit, and the distance between the temperature measurement points in the densification area is 0.2m. The lowest end of the temperature observation system is 3m below the permafrost upper limit. The plane position of the thermometer holes is at the shoulder of the earth road 5m to the left and right of the middle line of the road, and at the natural ground 10m from the slope foot. Figure 8 is the layout of the temperature observation system.

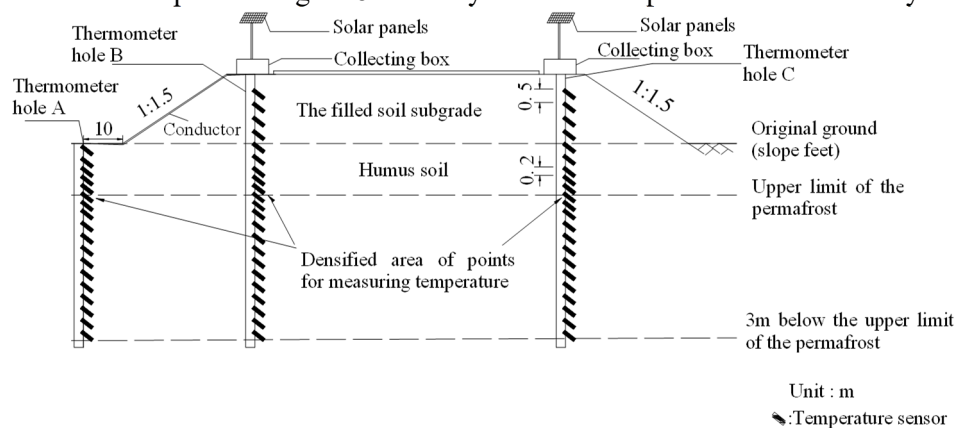


Figure 8. Layout of the temperature observation system

### 3.2 Monitoring system composition and layout of subgrade deformation

#### 3.2.1 Layout of subsidence system

The subgrade subsidence monitoring system determines the subsidence deformation by changing the position of the magnetic ring on the subsidence pipe, and the location of the magnetic ring is

determined by the actual distribution of permafrost in the field. A cross section is selected for each segment of the highway and the layout of the devices for each section is shown in Figure 9. The layout of subsidence points and magnetic rings is based on three principles: (1) laying magnetic ring at the stratum transmission of soil textures; (2) laying magnetic ring at different height in the same soil layer; (3) laying magnetic ring at the same height in different fracture surfaces. According to the position of magnetic rings in different soil layers from top to bottom of subgrade, they will be mainly laid as follows: one is set 1m below the natural ground in the subgrade, one is set at the natural ground, one is set at the permafrost upper limit and one is set 0.5m below the upper limit of permafrost inside the permafrost. The bottom of the subsidence observation system is set 3m below the permafrost upper limit. Observation benchmarks are set on the subgrade surface, and the subsidence change is monitored by a leveling instrument. The plane position of the subsidence observation point is at the shoulder of the earth road 5m to the left and right of the middle line of the road, and 1m away from the temperature observation point.

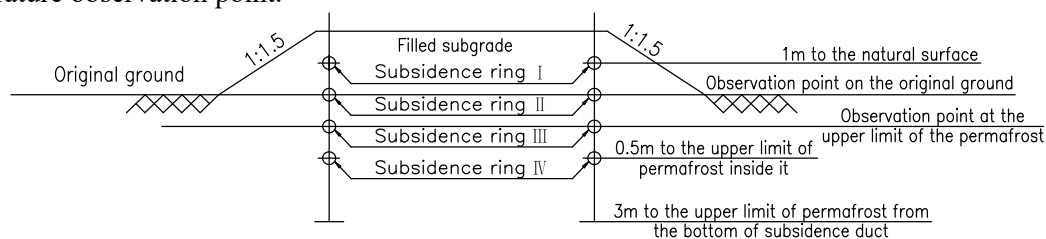


Figure 9. Layout of subsidence monitoring system

### 3.2.2 Lay of inclinometer system

The subgrade lateral horizontal displacement is not only one of the important indexes to reflect the stability of fill subgrade, but also one of the important means to guide its construction and stability control. At present, inclinometer is generally used to measure the horizontal displacement and sliding direction of soil mass. Inclinometer is composed of probe, cable and data acquisition instrument (data reader). Currently, the most widely used is servo-type inclinometer. As shown in Figure 10, the probe is composed of sensor, shell, guide wheel, base, cable clamp and so on. Its working principle is to measure the changes of the intersection angle between the axis of the inclinometer tube and the plumb line, so as to calculate the horizontal displacement of the soil mass at different elevations. The working principle of the inclinometer is shown in Figure 11.

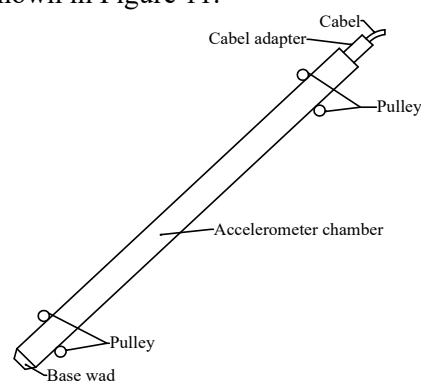


Figure 10. Structural map of inclinometer



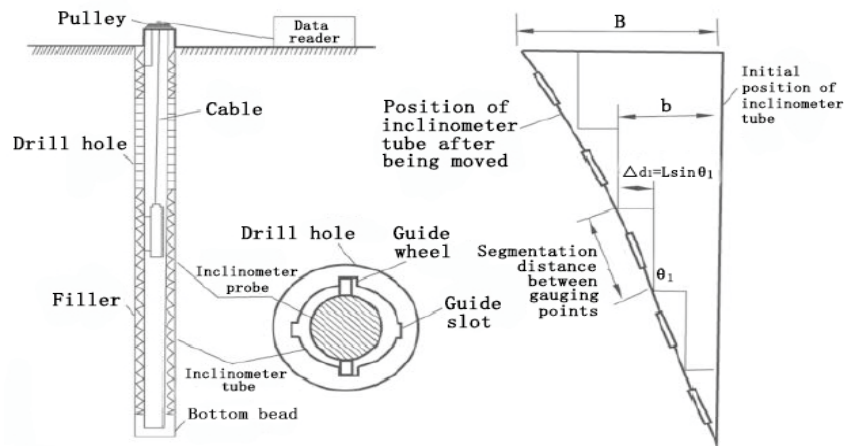


Figure 11. Working principle diagram of the inclinometer

The inclinometer is embedded about 1.0 m to the slope foot of the embankment or the outer edge of the upper opening of the side ditch. When the bidirectional sliding inclinometer is used, the displacement variation in both directions can be obtained only by observing a pair of guide slots. During observation, the sensor is placed at the bottom of the hole along the main leading slot. After being stable for 5 to 10min (to eliminate the influence caused by temperature), the sensor begins to read the data. In general, the reading of Direction A or Direction B is measured every 0.5m (Direction A is the direction towards the leading guide slot and B direction is perpendicular to Direction A). After it reaches the orifice, rotate the sensor 180° and observe again. The observation results should be compared with the previous one and recorded in the observation process which ends at the orifice.

### 3.2.3 Observation scheme of moisture content

TDR-3 type soil moisture sensor is used in humidity acquisition unit, which is characterized by high measurement accuracy, fast response speed, minor soil impact, wide application area, nice sealing and long period of being embedded under the soil. The main parameters are shown in Table 1. One humidity sensor corresponds to one humidity acquisition interface in the core controller. The number of humidity sensors used depends on the situation. The humidity acquisition unit is made precisely waterproof. The humidity sensor is laid 0.5m below the upper limit of the permafrost.

Table 1. Main parameters of TDR-3

Item	Name	Parameters
1	Measurement parameter	Volumetric water content of soil $\theta_v$
2	Unit	% ( $\text{m}^3/\text{m}^3$ )
3	Measuring range	0~100%
4	Precision	$\pm 2\%$ ( $\text{m}^3/\text{m}^3$ ) in the scope of 0~50% ( $\text{m}^3/\text{m}^3$ ) 90% of the influence being kept inside a cylinder with a
5	Measuring area	diameter of 3cm and a length of 6cm centered by a central probe.
6	Stabilization time	Around 10s after being powered on
7	Response time	Entering the steady state process within one second
8	Working voltage	DC-5V
9	Working current	50-70mA; typical value of 60mA
10	Output signal	0~2.5v
11	Cable length	Standard length of 12m

The layout of Temperature and humidity monitoring system & deformation monitoring system is shown in Figure 12.

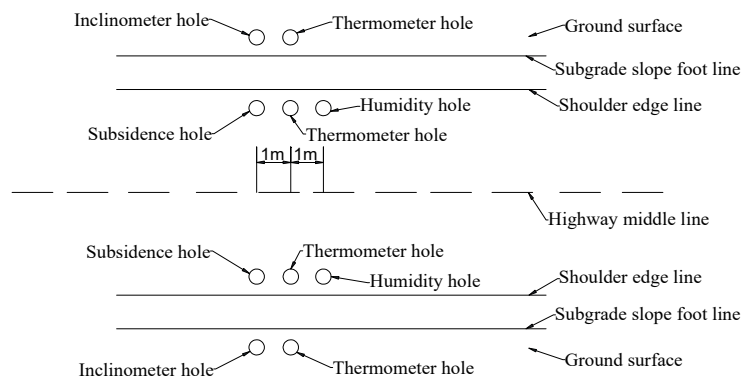


Figure 12. Layout of the monitoring system

### 3.2.4 Design for GPRS communication module and power supply

The system uses DATA-6106 GPRS data transmission module, which has in-built watchdog for software and hardware, and supports transparent data transmission and user self-development software system. Ordinary mobile phone card is used in the module, which supports GPRS and SMS dual channel data transmission, and is able to communicate with multi-center. It is suitable for harsh outdoor environment, with working temperature scope ranging from  $-40$  to  $+85^{\circ}\text{C}$  and humidity being less than or equal to 95%. The GPRS communication module transmits the collected data to the Internet through the mobile base station, and the user end communicates with the acquisition system by sending instructions or receiving the transmitted information through the Internet. The mode of communication is shown in Figure 13.

The power supply of the system adopts high-power anti-low temperature storage battery, which can ensure the acquisition system to work consecutively for more than three months. The GPRS communication module and power supply must be made precisely waterproof.

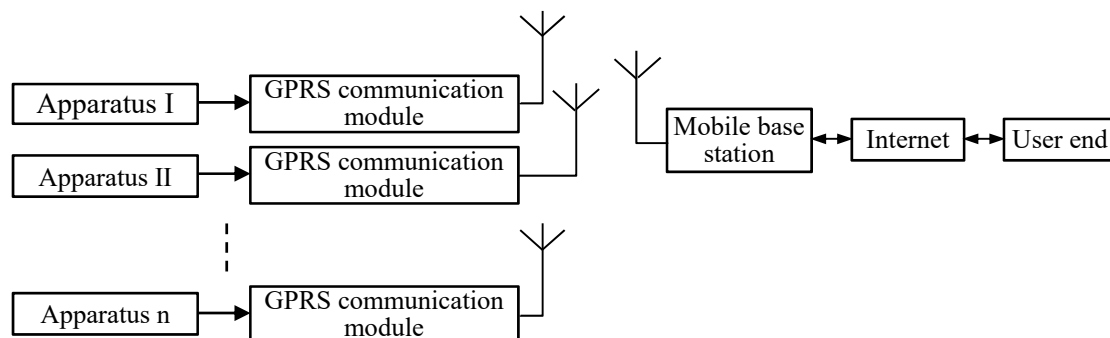


Figure 13. Schematic diagram of communication mode

## 4. Data Acquisition and Processing Scheme

The subgrade temperature acquisition unit is connected to a three-core shielding wire in parallel. There are many temperature acquisition units in each temperature measuring hole. Because of the limited power supply, it is impossible to install multiple temperature acquisition lines on one system, otherwise the far-end temperature acquisition unit will not work properly due to the insufficient power supply. Therefore, each temperature acquisition system is set up on the left and right shoulders of a spare section. A total of 14 sections are selected, that is, 28 sets of temperature and humidity acquisition system are needed.

Deformation observations are made once a month in the first year. If the deformation changes little in the next year, it can be observed once every two or three months. Automatic observation and data acquisition can be performed in temperature observation. It is necessary to replace batteries at the



embedded sites periodically and check if the apparatus is damaged. If the interruption of data transmission is found, it should be repaired in time.

Temperature and humidity monitor system adopts intelligent transmission monitoring, which can achieve uninterrupted and consecutive observation, and is helpful to grasp the variation law of moisture content of permafrost subgrade and upper limit of permafrost.

The subsidence deformation of permafrost subgrade are mainly caused by the increase of permafrost temperature, the thawing of permafrost and the decrease of permafrost upper limit. Therefore, it is necessary to monitor the temperature change of permafrost subgrade. The speed of temperature conduction is related to the moisture content, void ratio, density of existing subgrade, as well as the unfrozen moisture content and unfrozen thermal conductivity coefficient of permafrost. By measuring the above indexes, we can analyze the temperature variation law of the permafrost subgrade further, which provides a basis for analyzing the subsidence of the permafrost subgrade. As the above test indicators vary with the seasons, the layout of 14 spare sections of subgrade subsidence and temperature monitoring system will be completed in four seasons including spring, summer, autumn and winter, in order to measure the above test indicators correspondingly.

## 5. Conclusion

The main causes of subgrade subsidence deformation in permafrost areas can be concluded by monitoring the physical and mechanical properties of permafrost, subgrade filling materials, subgrade temperature and subgrade subsidence deformation. Meanwhile, the subsidence deformation of subgrade can be prevented and improved by subgrade treatment in permafrost area, which provides basic data for construction plan in permafrost area. The proposal of monitoring scheme design for temperature and deformation of permafrost subgrade provides a complete set of ideas for design, construction and maintenance of permafrost areas in China, and also plays a certain role in promoting subgrade stability in permafrost areas in China.

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