

Model experiment of uneven frost heave of airport pavement structure on coarse-grained soils foundation

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HIGHLIGHTS

- An original laboratory experiment model of UFHAPS is designed and established.
- The reliability of laboratory experiment model is verified by field experiment.
- The influence of external water infiltration on moisture field of APS is obtained.
- The cause and mechanism of UFHAPS on coarse-grained soils foundation are revealed.
- The effects of temperature, moisture, and their coupling on UFHAPS are obtained.

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ABSTRACT

Sample soil was prepared with natural gravel soil and surface silt from Guoluo Airport in China in this study. An original laboratory experiment model of uneven frost heave of airport pavement structure (UFHAPS) was designed and established, whose experimental apparatus' accuracy and precision were demonstrated by calibration. A test of external water infiltration, an indoor model experiment and a field monitoring experiment of the UFHAPS were conducted, then, the laboratory experiment model's reliability and applicability were verified by the results of the field monitoring experiment of UFHAPS. Experimental results showed that the model experiment intuitively simulated the phenomenon of faulting of slab ends between runway and its shoulder, clarifying the causes and mechanism. The effect of external water infiltration on UFHAPS was obtained, especially moisture field redistribution suffered the most impact of external water infiltration. The phenomenon of UFHAPS was a result of the coupling of temperature field and moisture field inside airport pavement structure. Moisture migration and accumulation were affected by the cooling rate and temperature gradient, in turn, the moisture field redistribution also affected the delivery of temperature. In summary, the basic laws of temperature field, moisture field and displacement field, especially the laws of moisture-heat coupling were systematically revealed.

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1. Introduction

Coarse-grained soils are widely used as foundation materials in engineering construction due to the widespread distributions, abundant reserves and the excellent engineering properties. However, the frost heave of foundation has been a frequent occurrence in engineering construction of Seasonal Frozen Soil Region. Coarse-grained soils are usually identified as frost heave insensitive materials because of large grain size, small grain surface energy, weak hydrophilic performance, little film water, large porosity,

unapparent capillarity, weak water migration and water is easy to freeze into ice in situ [1]. In fact, based on the frost heave monitoring of coarse-grained filling of Harbin-Dalian high-speed railway subgrade [2] and the indoor frost-heaving ratio experiment of gravel soil of Guoluo Airport [3], it is found that there will be obvious frost heave deformation in coarse-grained soils with under the joint action of silt content, moisture content and temperature. Particularly, the deformation will be more obvious because of these factors' uneven distribution. According to the feedback of the actual projects, the service safety of some airports, highways and railways in Seasonal Frozen Soil Region has been affected by uneven frost heave deformation. The damage of uneven frost heave deformation of airport pavement structure (APS), with strict deformation requirements, especially can't be ignored. The brush-fire

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deformation, which is caused by uneven frost heave, has been a great threat to the safety of aircraft for the great influence on the flatness of the runway. Therefore, it is necessary to study the causes and mechanisms of the uneven frost heave of airport pavement structure (UFHAPS) for providing a theoretical basis for preventing and curing the uneven frost heave deformation.

Although the problem of coarse-grained soils frost heave has caught many researchers' attention [4–11], the research of uneven frost heave is still less. Ogino and Matsuoka [12] were the first to put forward the repetition of differential heave and soft-loam settlement promotes decimetre-scale involutions in near-saturated soils subject to deep seasonal frost penetration. Saarenketo, et al. [13] had undertaken the research timely and systematically on the location of uneven frost heave area and associated the formation of longitudinal crack and differential frost heave. Besides, Zheng, et al. [14] evaluated uneven frost heave in three-dimensional space. Wan, et al. [15] summarized that the salt expansion and frost heave would cause uneven swelling and cracking of roads, channels and airport runways through experiment. After that, in 2016, the role of differential frost heaving was examined by the creation of depressed margins and raised centres by Roy-Léveillé and Burn [16]. In recent year, Wang, et al. [17] advanced a new opinion that the foundations of photovoltaic stents in seasonally frozen regions suffered from uneven frost heave in winter. Above all researches reflect that more and more attentions have been paid to the uneven frost heave problem, and provide a theoretical basis for the future study of this problem.

As noted above, the research status of the frost heave of coarse-grained soils and uneven frost heave show that much more attention have been paid to railway subgrade than airport foundation. Most researches tend to pay more attention to the holistic frost heave not the uneven frost heave. Therefore, this study intends to thoroughly study the problem of the UFHAPS on coarse-grained soils foundation so as to provide constructive suggestions for the prevention and cure of the UFHAPS. Measurements of frost heave in granular soils and aggregates under laboratory conditions have been the subject of research in recent years [18–23]. In addition, considering the inconveniences and imprecision of field monitoring experiment [24], the indoor model experiment was adopted in this paper. Afterwards, the scheme of APS was taken as the prototype against the actual project background of Guoluo Airport. Next, the model sample box of APS was designed originally, and the model experiment of the UFHAPS on coarse-grained soils foundation was conducted. After summing up to the experimenting model and experimental results, the basic law of external water infiltration, temperature field, moisture field and displacement field, especially the laws of moisture-heat coupling, as well as the cause and mechanism of the UFHAPS were obtained. We hope that the results presented below will provide a practical theoretical basis and technical support for the prevention and cure of the UFHAPS in Seasonal Frozen Soil Region.

2. Materials and methods

2.1. Engineering background

Guoluo Airport, which is located in Qinghai-Tibetan Plateau Seasonal Frozen Soil Region, was chosen as the research background and prototype in this paper. The climate of Guoluo Airport is characterized by low air temperature, long negative temperature period, small cooling rate and large frozen depth. Accordingly, this kind of regional climatic condition is apt to intensify moisture migration and frost heave. Furthermore, the uneven frost heave is increased due to the non-homogeneity of the soil which is consisted of natural gravel soil and surface silt. Need to add that, the influence of underground water on frost heave can be ignored owing to the low-down underground water level.

Considering that the faulting of slab ends is generally not easy to occur in the runway between panels, this study only discussed the faulting of slab ends between runway and its shoulder, which is closely related to the kind of pavement and construction methods. In traditional APS, the runway shoulder layer is thinner than the runway surface layer. Moreover the runway shoulder is the last part of the concrete pavement construction, through which most rainwater and curing water for construction flows in. As the soil area is higher than the runway shoulder base, the flowing water is difficult to discharge, thus most of the water will accumulate in runway shoulder and infiltrate into the soil base. This phenomenon leads to the greater moisture content and frost heave amount of soil base under runway shoulder than that under runway. This ultimately leads to the faulting of slab ends between runway and its shoulder. The process diagram is shown in Fig. 1.

2.2. Soil analysis

According to the sampling survey, the actual silt content (the mass fraction of the particle with a diameter less than 0.075 mm) and moisture content of the foundation of Guoluo Airport are shown in Table 1. According to Table 1, the uneven distribution

Table 1
Actual measurement of silt and moisture content.

Measure number	H = 20 cm		H = 60 cm	
	Silt content/%	Moisture content/%	Silt content/%	Moisture content/%
1	14.4	8.4	8.4	5.9
2	7.9	6.5	6.8	5.7
3	8.8	7.7	9.5	6.3
4	6.1	6.0	15.9	8.9
5	10.4	8.6	12.7	7.9
6	8.0	6.2	4.6	5.5
Average value	9.3	7.2	9.7	6.7

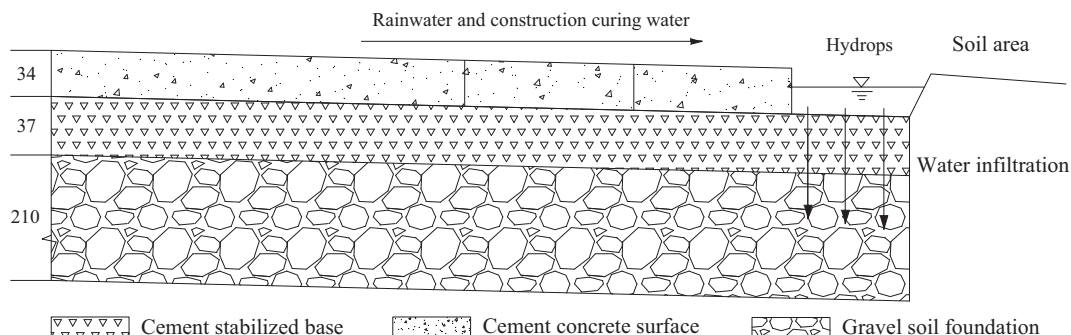


Fig. 1. Diagram of external water infiltration (cm).

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