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Scientific concept and application of frozen soil engineering system

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ABSTRACT

Frozen soil is “cryalfs” in soil classification and belongs to a “special” soil type category in engineering geology and geotechnical engineering. Based on the system theory of engineering geology, we used scientific philosophy to describe frozen soil engineering as a whole research system. The frozen soil engineering system is such a complex synthesis that it is difficult to define the complete physical process in this system. According to the dynamic change between atmosphere, engineering construction and frozen soil, this study breaks up the frozen soil engineering system into two circles: the atmospheric engineering circle and the engineering frozen soil circle. Moreover, the mutual connection, interdependence, interaction and mutual restrict of many elements involved in the frozen soil system were expound. Frozen soil engineering system is a functional collection of interactions between natural and artificial objects in permafrost regions, which as a scientific logic methodology is established in order to solve frozen soil engineering problem. It has high effectiveness, more economy, more application, and low maintenance when applied in engineering construction in permafrost regions, and it will be more realistic and safer.

1. Introduction

Frozen soil regions occupy nearly a quarter of Earth's terrestrial surface (Brown J.et al.), including extensive areas of the Arctic and Antarctic, high-elevation terrain in mid-latitude mountain ranges, and even mountain tops in the subtropics. Frozen soil is one of the five layers of the earth system and an important component of the cryosphere (Cheng, 2005; Li et al., 2002). The establishment of geocryology dates back more than 80 years. Like other branches of knowledge, geocryology is the result of practical needs, and its development as a field has reflected the economic development of huge frozen soil tracts (Yershov, 1995). Its establishment and further development has a close relationship with human production and life (Cheng and Zhou, 1988). At the initial stages, geocryology was divided into two branches: general geocryology and engineering geocryology. Demands for energy development and subsequent cold region building structures that require a great deal of project planning resulted in additions to the research field of engineering geocryology (ASCE et al., 2003).

The biggest difference between frozen soil engineering and conventional geotechnical engineering is considerations of climatic condition changes, and heat-moisture transfer that it poses. Other than some special engineering considerations to measure the influences of rain, the effects of conventional geotechnical engineering on the climate is not considered. In the permafrost regions, however, engineering construction is located on and in the frozen soil, and is easily affected by external environment (Ma et al., 2012; Wu et al., 2016). This closer relationship of frozen soil with the environment therefore determines the variability, sensitivity, instability and complexity of frozen soil engineering (Zhang et al., 2016a, 2016b; Luo et al., 2017).

To sum up, the research method of conventional geotechnical engineering cannot be completely suitable for frozen soil engineering where there is a greater need to consider the impact of climate change. These climatic changes will lead to further heat-moisture exchange between the engineering construction and the frozen soil foundation, which will cause changes of frozen soil composition, structure, physical-mechanical properties and so on (Kurylyk and Hayashi, 2016). It will response from the frozen soil onto the engineering construction, and could threaten the safe and stability of engineering construction. One can begin to imagine the complexity and difficulty of frozen soil engineering research. This article provides a methodology for frozen soil engineering research. By looking at the interactions between the climate, engineering construction (artificial structures) and frozen soil, a system of frozen soil engineering is built and the dynamic change processes in the system are analyzed.

2. Concept of frozen soil engineering system (FSES)

2.1. Definition

As frozen soil engineering system is defined by the network of

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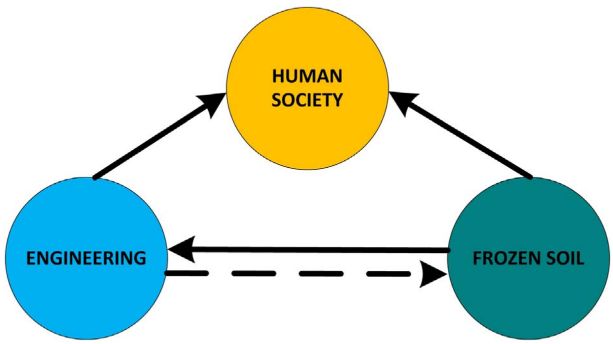

Fig. 1. Relationships among frozen soil, engineering and human society.

interactions between engineering construction and their permafrost regions environment. FSES is a functional collection of interactions between natural and artificial objects in permafrost regions. Natural objects are permafrost regions environment, such as climate and geological conditions. Artificial object, i.e. frozen soil engineering is engineering construction in permafrost regions, together with its associated construction and exploitation of engineering and other facilities, technical means and engineering measure. So, especially as is pointed, there is a fundamental difference between frozen soil engineering and frozen soil engineering system.

2.2. Aims and objectives

The ultimate goal of frozen soil engineering research is service for development of human society. With continued economic and social progress, highway, mineral engineering, and energy engineering construction has been conducted in frozen soil regions (Lai et al., 2013). These human activities affect the frozen soil. Meanwhile, the changes occurring in the frozen soil and its surrounding atmosphere can also affect engineering stability (Fig. 1). Ultimately, these dynamic changes will impact human society, but there could be significant negative impact.

Many reports of thaw-induced damage to buildings, roads, airfields, and other infrastructure have appeared in the past decade (Nelson et al., 2002a, 2002b). Human infrastructure in areas of ice-rich permafrost is subject to thaw-induced settlement or collapse if inadequate engineering techniques are used. If thermal design standards are exceeded by climatic warming, serious damage to engineered works can be the result, even when these structures are designed for permafrost conditions (Nelson, 2003). This sort of damage is the results of not enough research on system change.

Therefore, the principal aim of the FSES is to solve negative impact of human society, which was associated with dynamic changes between engineering and frozen soil. FSES is a scientific and systematic study approach dealing with the science and engineering-technical problems of cold environments in the Cold and Polar Regions.

2.3. Structure

FSES research is a process that combines engineering construction with geological environment. On the one hand, engineering design and project construction should be optimized, and manpower and resources should be used reasonably. On the other hand, the stability of both the project construction and the geological environment needs to be ensured in a finite time period. Therefore, it is important to systematically research the relationships between atmosphere, engineering construction and frozen soil.

FSES is a research system made up of three elements: atmosphere, engineering construction and frozen soil. Dynamic change among these three elements is quite complex; however, it can be better organized as two systems: (1) the dynamic change of atmosphere in relation to engineering and (2) the dynamic change of frozen soil in relation to engineering. Therefore, it can be seen that these three interrelated elements constitute two sets, which have specific functions of two whole, organic systems, i.e. the atmospheric engineering circle and the engineering frozen soil circle (Fig. 2).

In the FSES, interdependence, interaction and mutual restriction of each element contact each other in a certain way. The dynamic change has integrity, relevance, grade structure, dynamic balance and timing characteristics, which make up the basic characteristics of system. Accordingly, the basic premises of the system theory method was used to study frozen soil engineering. Taking all research objects as a system, we analyzed the structure and system function and studied the interaction and change rule of each element in the system. This study approaches the subject from the viewpoint of system optimization in order to discover, analyze and solve scientific problems (Li, 1995).

3. Engineering geology system method in support of frozen soil engineering system

The system can be viewed as an organic whole, which is composed of a number of elements and holds a certain function. System research in engineering geology specifically is divided into three types by Professor V. T. Trofimov et al. (2005): (1) the real natural-geological system, (2) the ideal natural-engineering-geological system, and (3) the real natural-engineering-geological system (Fig. 3).

The real natural-geological system is the exploration stage of geological engineering, which serves as a preliminary study on the construction site. During this stage, morphology (composition, structure and properties), genesis (formation) of soil and engineering geological conditions of construction area should be mastered.

The ideal natural-engineering-geological system is the design stage of the engineering process. Base on the results of the exploration stage, a foundation and building types are selected. During this stage, interaction between engineering construction and geological environment is analyzed, simulated and predicted.

The real natural-engineering-geological system occurs after project construction. Interaction between engineering construction and geological environment needs to be monitored long-term using the results from previously monitored rock and soil masses to determine the

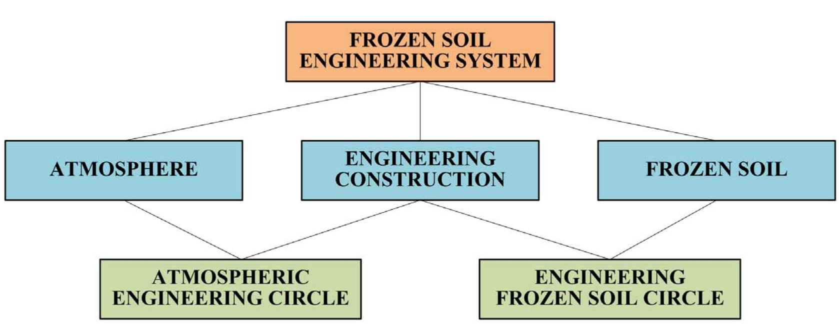

Fig. 2. Frozen soil engineering system.