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Pavement mechanic response of sulfate saline soil subgrade section based on fluid–structure interaction model

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Abstract

It is a consensus that salt heaving and frost heaving are urgent and typical distress in the sulfate saline soil area. To further investigate the microscopic performance of pavement structure in this special area, Jinan-Dongying Freeway in Shandong Province is selected as a case study engineering and the mechanic responses under salt heaving, frost heaving and traffic loads were analyzed through the finite element (FE) Program (ANSYS). In this paper, the process of salt heaving and frost heaving was divided into 3 stages and FE models were established based on fluid–structure interaction (FSI) model. It is shown that under both effects of salt heaving and frost heaving, the tensile stress of asphalt surface course could be up to 96.75% of its tensile strength, which means its tensile strength was seriously inadequate; however, traffic loads could help to dramatically counteract effects of salt heaving and frost heaving, which could decrease 40–80% of the tensile stress in asphalt surface course. It is also shown that in Jinan-Dongying Freeway effects of salt heaving had slightly larger effects on pavement compared with that of frost heaving, probably because salt heaving occurred from the top to the bottom of subgrade. However, as a whole, in sulfate saline soil area, compared with general area, crack resistance of asphalt courses and foundation treatment should always be strengthened.

Keywords: Sulfate saline soil subgrade; Asphalt pavement; Pavement mechanic; FEM; FSI; Cracks and bulging

1. Introduction

Saline soil is widespread in China, mainly in costal area, alluvial plain and inland basin etc. According to the 2nd National Soil Survey [1], the area of saline soil nationwide was nearly 190,800 km^2, accounting for 2% of the national land area. At present, about one fifth of arable land in China was characteristic of salinization and secondary salinization in different degrees. Besides, about 173,333 km^2 was under potential threat of salinization.

In geotechnical engineering, saline soil has seriously adverse impact due to its particular characteristics [2]. The constitution of solid, liquid and gas phases is special: the liquid phase contained soluble salt solution; and the solid phase contained soluble salt crystal. Under the influence of temperature and humidity, soluble salt would easily precipitate from or dissolve into liquid phase, which would lead to collapsibility and salt expandability. Therefore, most of mechanical and physical parameters would be influenced, especially the strength, which would be effected by the content and characteristic of soluble salt, the type and original structure of saline soil, time and volume of immersion, infiltration mode and the permeability of soil, etc [3]. Besides, saline soil is corrosive and would lead to material corrosion of underground facilities and buildings.

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Sulfate saline soil is one kind of typical saline soil that destroys engineering projects. It contains large amount of soluble sulfate, such as Na_2SO_4 and $NaHSO_4$, etc. Among them, Na_2SO_4 was the leading role that dominated the salt expandability, because of the largely varying solubility of Na_2SO_4 in the process of temperature descending. In this way, Na_2SO_4 would crystallize and become $Na_2SO_4{\cdot}10H_2O$. Hence, the salt volume would increase about 2.1 times, which would result in serious superstructural deformation failure.

For highway engineering, sulfate saline soil would cause subgrade swell, cracks on pavement, and slope loosing, etc [4]. Due to the soluble sulfate in solid phase, when subgrade was immersed, collapsibility deformation would occur. Hence, the strength and stability would drop dramatically. Besides, in winter and spring, due to temperature variation, Na_2SO_4 precipitated and dissolved repeatedly, which would exacerbate frost heaving and boiling. In addition, the salt in sulfate saline soil was also corrosive to cement, asphalt, and steel, etc. Thus, it was significant to properly conduct highway design and construction in sulfate saline soil area, because distress was usually irreversible.

At present, researches on highway engineering in sulfate saline soil area could be approximately divided into 3 categories: subgrade deformation under salt heaving and frost heaving [5–8], reinforcement and treatment for sulfate saline soil subgrade [9–11] and mechanical properties of sulfate saline soil [12–14]. However, they were mainly about sulfate saline soil subgrade.

As for researches on the asphalt pavement in this area, they primarily concentrated on pavement distress [15–18]. Due to effects of sulfate on pavement, an abundance of longitudinal cracks developed on the surface. With the variation of seasons and air temperature, cracks would develop cumulatively and their scales would also change subsequently. Moreover, under effects of capillary water and salt migration, water content in subgrade would increase and liquid limit would decrease. Therefore, soil in subgrade would be in saturated and halfsaturated state, which would result in differential settlement of subgrade and eventually destruct the evenness of pavement. In this way, pavement surface would become undulate and rutting around wheelpath would be caused, heavily influencing driving comfort and surface quality. In addition, in late winter and early spring, due to the retention and increase of water content in subgrade, the upper part of subgrade would alternately freeze and thaw repeatedly. Under effects of dynamic loads, this part of subgrade would fluctuate like liquid and corrugated ridge would be formed in the middle of a lane. Even worse, pavement would be in utter devastation.

In spite of researches on pavement distress in sulfate saline soil area, there were few on the pavement mechanic response under such special soil condition. At present, researches on pavement distress as mentioned above mainly focused on the macro performance of asphalt pavement. However, it was indispensable to make clear the mechanical response on asphalt pavement, because it was very significant to find out essential pavement behaviors and understand the microscopic performance of asphalt pavement distress in the sulfate saline soil area.

Shandong Province, located along the lower, Yellow River has extensively distributed saline soil, mainly in the strand plain, inland plain and costal area. Primarily, saline soil in Shandong Province could be divided into 4 types: coastal saline soil, salined flavo-aquic soil, alkaline soil and inland saline soil. Sulfate saline soil was very typical in Shandong Province. Therefore, it was unavoidable that hundreds of highway would pass such special soil area and it was burdensome to conduct highway design, construction and maintenance in this area.

Jinan-Dongying Freeway is a typical example of freeway containing sulfate saline soil subgrade section, which passes the area of calcareous fluvo-aquic soil and salined flavo-aquic soil. In this paper, based on this engineering, through FE Program (ANSYS), the asphalt pavement mechanic response under coupling effects of salt heaving, frost heaving and traffic loads was simulated and analyzed.

This paper is organized as follows:

(1) Introduction of the deformation relationship among volume increase, salt heaving and frost heaving, in the process of temperature declining in sulfate saline soil area;
(2) Pavement FSI model established and other parameters;
(3) Simulation results of pavement mechanical response under 5 conditions: a) pavement under salt heaving and frost heaving in sulfate saline soil area; b) pavement responses in Period A (mentioned in the following) in this area; c) pavement responses in Period B (mentioned in the following) in this area; d) pavement under coupling effects of traffic loads, salt heaving and frost heaving in sulfate saline soil area; e) pavement under traffic loads in general area.
(4) Conclusions and suggestions for pavement design and construction in sulfate saline soil area.

2. Deformation relation in sulfate saline soil subgrade

In sulfate saline soil area, subgrade deformation was composed of two parts: salt heaving and frost heaving. It was due to this particular characteristic that it is difficult to describe the deformation relationship among the volume increase of soil, salt heaving and frost heaving in sulfate saline soil. Thus, in this paper the deformation of salt heaving and frost heaving were considered separately. The deformation of salt heaving was because of the precipitation of Na_2SO_4 and the consequent generation of $Na_2SO_4{\cdot}10H_2O$. The deformation of frost heaving was due to the generation of ice.