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Experimental study on use of lightweight foam concrete as subgrade bed filler of ballastless track

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HIGHLIGHTS

- According to the compressive strength and dynamic triaxial test results, it is found that the strength of lightweight foam concrete with target density of 500–800 kg/m^3 can meet the requirements of both the static and dynamic conditions of ballastless track subgrade. The lightweight foam concrete with target density of 650 kg/m^3 are proposed to cast the bottom layer of subgrade bed after considering safety factor.
- A large-scale model of a subgrade filled by lightweight foam concrete with target density of 650 kg/m^3 is established. It is found that the ballastless track subgrade has a long-term dynamic stability under cyclic loads.
- The research results of this paper show that lightweight foam concrete with target density of not less than 650 kg/m^3 can be used as filler of the bottom layer of subgrade bed.

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ABSTRACT

Controlling settlement of ballastless track subgrade in special soil areas is an ongoing scientific problem in the construction and operation of high-speed railways—primarily because of the consolidation settlement of the ground soil, which is caused by additional stress from large loads. To reduce the subgrade weight and additional stress, the authors propose the use of lightweight foam concrete as subgrade filler, thereby controlling subgrade settlement in special soil areas. However, it remains unknown whether the ballastless track subgrade filled with lightweight foam concrete has a long-term dynamic stability under cyclic loads. To solve this problem, compressive strength and dynamic triaxial tests are conducted to analyse the static and dynamic strength of lightweight foam concrete. Then a large-scale model of a subgrade filled with lightweight foam concrete with target density of 650 kg/m^3 is established to determine its long-term performance under cyclic dynamic loads. The esults show that the strength of lightweight foam concrete with target density of 500–800 kg/m^3 can meet the requirements of both the static and dynamic conditions of ballastless track subgrade, and the ballastless track subgrade filled by lightweight foam concrete with target density of 650 kg/m^3 has a good long-term dynamic stability under cyclic dynamic loads when a dynamic buffer layer with thickness of 0.5 m is set between lightweight foam concrete layer and foundation slab.

1. Introduction

With the development of high-speed railways, mixing piles, pre-tensioned high-strength concrete pipe piles, bored piles and cement–fly ash–gravel piles have been widely used to reinforce special soil foundations to control the settlement of ballastless track subgrade. This is known as "pile-supported subgrade" (Fig. 1). A ballastless track subgrade structure is composed of a ballastless track structure layer, top and bottom layers of the subgrade bed and embankment fillings below the subgrade bed [1]. The subgrade below the ballastless track structure layer is a layered geotechnical structure mainly filled with granular earth–rock materials with densities of 1700–2000 kg/m^3. Although high design standards are used to construct the ballastless track subgrade, the subgrade still settles under the weight load of both the subgrade filler and trains. The primary cause of this settlement is the added stress put on the special soil ground by these weight

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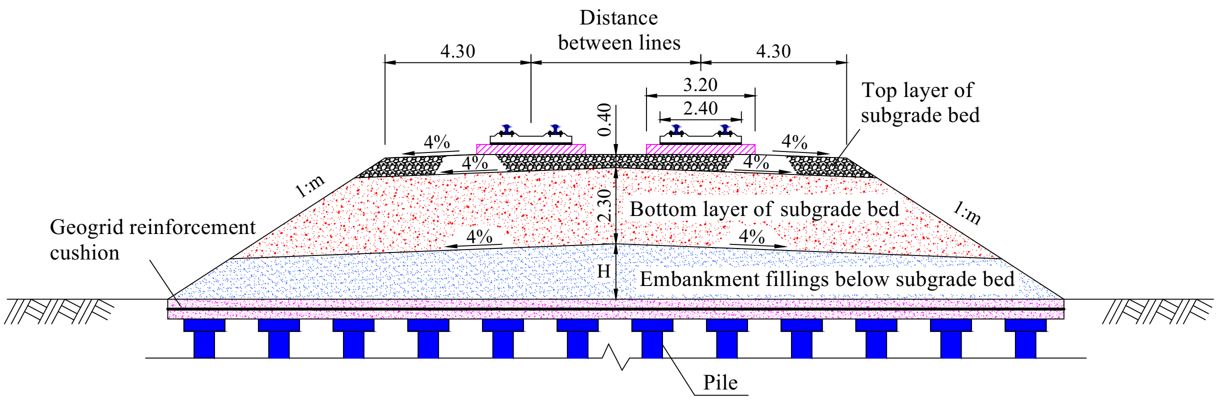

Fig. 1. Pile-supported subgrade of ballastless track.

loads: soil consolidation is caused by the long-term effect of large additional stress, resulting in subgrade settlement. Therefore, reducing the additional stress on the ground after reinforcement is an important approach to control subgrade settlement. Lightweight foam concrete (LFC) is advantageous in that it is easily constructed, lightweight and provides good heat insulation [2,3]. So if it is introduced to fill the subgrade of ballastless track, the subgrade weight will be reduced greatly, as will the additional stress on the ground. Thus, lightweight foam concrete provides a new method to control subgrade settlement in special soil areas.

In 1923, Valore [4] first applied for a patent on foam concrete. Since then, foam concrete has been widely used as a lightweight non- and semi-structural material. As foam concrete developed further, more attention was paid to its potential applications. Valore [5], Rudnai [6], Taylor [7] and Short and Kinniburgh [8] studied its constitution, physical characteristics and engineering applications. Tan [9] investigated its degradation characteristics with lightweight aggregate and polypropylene fibre under freeze–thaw cycles. Wee [10] studied the effect of the water–cement ratio on foam concrete air–void systems as well as the mechanical properties of such systems. In addition, Jones and McCarthy [2,3] studied the construction applications, fire resistance, thermal conductivity and acoustic properties of foam concrete. Mydin and Wang [11–13] further investigated the thermodynamic properties of foam concrete with different densities under high-temperature conditions and established a fire-resistance prediction model.

Kearsley and Wainwright [14–16] conducted a series of tests to study the relationship between porosity and permeability and the effect of porosity on the compressive strength of foam concrete; they then constructed a mathematical model of the relationship between compressive strength and the age and porosity of the foam concrete. Nambiar and Ramamurthy [17] analysed the influence of the pore size distribution of mixed cement–mortar and cement–fly ash foam concrete on its strength and durability and found that the pore parameter is a key factor influencing material properties. Just and Middendorf [18] improved the strength of foam concrete by adding aluminium powder and chemicals and investigated the microstructure characteristics of high-strength foam concrete and their effect on the foam concrete. Yang and Lee [19] used the ground granulated blast-furnace slag activated by different types of alkali activators to produce foam concrete with no aggregate or filler; they then investigated the compressive strength and thermal conductivity of the formed concrete. Their test results show that the compressive strength of their foam concrete is higher than that of ordinary Portland cement (OPC) foam concrete under the same densities.

According to these studies, the compressive strength of foam concrete without hybrid materials or chemical additives is between 0.5 and 40 MPa and that with hybrid materials and/or chemicals can be up to 120 MPa. Both types of foam concrete have good integral structures.

Therefore, given that foam concrete is widely used for thermal insulation, soundproof and fireproof materials, it is now also used as highway and airport subgrade filler, pipeline backfill and ground replacement filler [20,21]. For example, foam concrete has been applied in the construction of highway subgrades in special soil areas in China, as shown in Fig. 2. These applications demonstrate that foam concrete used to fill subgrades in special soil areas can effectively control subgrade settlement. The research results listed above and practical experiences provide a basis for introducing foam concrete filler to ballastless track subgrades in high-speed railways. However, the loading amplitude and frequency of high-

(a) Transition section between bridge abutment and embankment

(b) Road subgrade widening

Fig. 2. Use of lightweight foam concrete in highway subgrade construction.