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Bonding characteristics of grouting layer in Prefabricated Cement Concrete Pavement

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HIGHLIGHTS

- Selecting three groutings to study their usability in Prefabricated Pavement.
- An orthogonal test consisting four factors at three levels has been designed.
- After fatigue loading, the neutral surface of surface layer has shifted upwards.
- The grouting material kind is a key factor to properties of pavement structure.

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ABSTRACT

In order to select an optimum grouting layer to apply to Prefabricated Cement Concrete Pavement, small rectangular-section beam specimens have been used to simulate the airport pavement surface, and the test sections of stabilized soils have been paved indoor as the base layer. An orthogonal test program consisting of four factors (i.e. grouting type, slab bottom roughness, grouting thickness and base structure) at three levels has been designed, in which the vertical static loading, vertical fatigue loading and lateral loading tests have been carried out. The results show that the ordinary cement mortar (PTC) is the most fluid, and the fast setting and hardening cement mortar (SKC) has the highest strength on Day 1 of curing, but its strength increases slowly thereafter. On the other hand, the strength of PTC is the highest on Day 28 of curing. The effect of slab bottom roughness on the bonding performance between the grouting layer and the surface layer is the most significant, while the grouting type has the greatest effect on the bonding performance between the grouting layer and the base layer, and on the bearing capacity of the pavement structure. After the fatigue loading, the neutral surface of the pavement surface layer has shifted upwards. The results show that there are three phases in the relationship between the deflection, pressure and number of fatigue loading times. The first phase is the large change, the second phase is the linear change and the third phase is the constant phase. Under the lateral loading, the bonding performance between the non-shrink grouting material with high strength (CGM) and the base layer is the best, and there is a quadratic polynomial relationship between the lateral load and the superstructure's displacement. When the grouting material is 2.0 cm thick CGM, the bottom of the slab is smooth, and when the basic structure is 12% cement stabilized soil, the pavement structure has the best properties to carry the fatigue load and the lateral load.

1. Introduction

Prefabricated Cement Concrete Pavement (PCCP) is a type of highway/airport pavement. It can be produced within a controlled environment, in which there are less limitations on the construction time and environmental constraints. Hence, high quality products, either repaired or new pavements can be produced within a short time [1,2]. The advantages of PCCP include better quality repair due to the controlled fabrication process, shorter pavement construction time, and higher potential for long-lasting repairs [3]. The PCCP has been mainly used for repairing highway and airfield pavements repair since the early 1930's [4]. The Soviet Union used PCCP for not only road construction, but also for airfield construction. By the 1980s, the Soviet Union had a sophisticated concrete

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industry for both airfield and road constructions [5]. In recent years, numerous studies on the PCCP have been conducted in the U.S., but the major focus has been on highway pavement repairs [6]. The field testing of the PCCP for airfield pavement repair showed that the PCCP can withstand between 5000 and 10,000 passes of C-17 aircraft traffic [7]. Therefore, the PCCP is an ideal method for rapid laying of high-grade airport pavement as part of an airport pavement repair. It is also of great practical use for delivering post-disaster humanitarian relief supplies, airport construction at a front line during a war and permanent airport construction under harsh conditions, such as islands.

The recent study on the PCCP also confirms the suitability of using PCCP in the rapid repair of airport pavement and the rapid construction of high-grade airport pavement. From 2008 to 2012, the U.S. conducted a research project entitled "SHRP2 Project R05-Modular Pavement Technology". The results of this project showed that if the PCCP was well constructed (including panels, bedding materials and load transfer dowel), the repair had the potential to provide long-term service for 15–20 years for highway applications [8]. The main methods of PCCP repairs in the U.S. are the Fort Miller Super-Slab Method, the Michigan Method, and the Uretek Method or some variation of these three methods. The main differences among these repair methods are the base support, panel size, spacing and load transfer [9,10]. The U.S. Air Force attaches great importance to the studies on the assembling-type concrete pavement slabs, and has developed a quick airport pavement repair method known as the "Air Force Method". This method can complete the airport pavement repair and putting it back into service between 4 and 8 h [11–13].

The PCCP has been used in the areas of highway and airfield constructions, including repair and construction, for 50–80 years. However, the PCCP has not been applied on a large scale like other prefabricated products. One reason is that the process of disposing the bedding materials can be time consuming and requires experienced field crews and heavy or specialized equipment [14]. The used bedding materials include injected polyurethane foam, compacted aggregate, flowable fill (i.e. low cost ordinary cement grout or more costly proprietary or high early strength grouts) and sand [10,15,16]. For the repair of a single panel or small scale panels, the new panels can be effectively connected to the existing panels through dowels. Both the existing and new panels have strong connections with the base layer. However, for the new construction or large scale repair using PCCP, the connections between the new panels and the base layer need to be investigated.

At present, there are many types of grouting materials for engineering applications. Earlier studies on grouting materials mainly focus on the reinforcement of soft soil foundation, repair of dam cracks and road maintenance [17–19]. Further, the bonding characteristics can affect the performance of the panels under traffic [20]. However, in PCCP engineering, only a few studies have been conducted on the bonding properties of the grouting layer [10,15,16]. Furthermore, in these studies, the performance of the grouting materials and the structural response of the grouting layer subjected to loading have often been neglected. Therefore, it is necessary to carry out experimental research to study the bonding characteristics and the structural response of the grouting layer subjected to loading.

2. Objectives and approach

The objectives of this study are to investigate the bonding characteristics and the structural response of the grouting layer subjected to loading, and to research the background information on the large scale applications of the PCCP in repairing or constructing airfield pavements. Based on the results of an indoor test using beam test-pieces to simulate pavement surface, they showed that it is economical and effective to use the beam-simulated pavement to conduct the structural test [21,22]. Therefore, in this study, following the earlier studies [21,22] and based on the specification [23], the surface layer of the PCCP had been simulated using the 150 mm × 150 mm × 550 mm (height × width × length) beam specimens. According to the specification GJB 1278A-2009 [23], the cement used in the concrete was Qinling brand P.O 42.5R. According to the specification GJB 1112A-2004 [24], the mix proportion and tensile strength of the concrete are shown in Table 1, and the concrete beams were made using the standard concrete mould according to the specification JTG E30-2005 [25].

The bottom roughness of the slab can affect the bonding properties between the grouting layer and the other structural layers [10,26,27]. The numerical simulation results also confirmed that the bottom roughness had a significant effect on the performance of panels under loading [28]. In view of this, three types of bottom roughness have been used in this study, i.e. smooth, chipping, and cutting, as shown in Fig. 1. For the cutting roughness, the width of the slot is 10 mm, the depth is 5 mm, and the distance between the slots is 20 mm.

Based on the earlier studies on the bedding materials, which were used in repair and construction of highway and airfield pavements [10,15,16,20], and taking the cost and availability into consideration, three types of grouting material with three different thicknesses have been selected for this study. They are ordinary cement mortar grouting material (PTC), high-strength non-shrink grouting material (CGM), and double fast cement grouting material (SKC). The thicknesses of the three types of grouting materials are 1.5 mm, 2.0 mm, and 3.0 mm, respectively.

Based on our earlier studies [26,27,29], the base layer with 8% cement stabilized soil can meet the operation requirements of an emergency airport. In order to further the investigation, three other types of base layer with 6%, 9% and 12% cement stabilized soil have been selected for this study. The soil is wet collapsible loess, which was taken from a construction site in the eastern suburb of Xi'an, China. The cement is similar with the type used in the concrete beam. The cement stabilized soil base layer was constructed indoor, as shown in Fig. 2.

Based on the four factors (i.e. grouting type, slab bottom roughness, grouting thickness and base structure) that affect the bonding properties between the grouting layer and the other structural layers, an orthogonal test program has been designed. The main loads applied to the pavement are the vertical static load and the vertical fatigue load. In addition, when the aircraft is operating on the pavement, there is a horizontal impact force on the pavement. Therefore, a vertical static loading test, vertical fatigue loading test and lateral loading test have been carried out. The convenience and efficiency of the grouting layer construction, fluidity and strength of the grouting materials have been tested and compared. The structural responses of the PCCP under vertical static loadings, vertical fatigue loadings and lateral loadings have also been analyzed.

3. Overview of test

3.1. Test materials

Ordinary cement mortar grouting material (PTC) is made of ordinary Portland cement of Qinling brand P.O 42.5 produced by Jidong cement mill, with a density of 3100 kg/m^3. PTC is popular because of its low cost and available at many sources. High-strength non-shrink grouting material (CGM) is produced by Shandong Qiandun grouting material factory. It is a self-flowing micro-expanded dry mortar with early high strength (i.e. high strength, self-flowing and micro-expansion). CGM is characterized by mod-