Properties of Cementitiously Stabilized Materials

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Abstract: Our country has built highways in more than 90% for the semi-rigid base asphalt pavement structure, the structure bearing capacity is strong, rut depth is small, good water stability, and has become the main structural type of high grade highway in China. But the practice has proved that there are some inevitable semi-rigid base asphalt pavement of technical problems, in a number of highways open to traffic soon after the pavement early damage phenomenon more serious, such as rutting, and vertical and horizontal cracks, cracks and potholes, local loose aging, seriously affected the normal traffic, but also violates the highway within the use fixed number of year is not for the purpose of the large maintenance. This paper analysis the properties of cementitiously stabilized materials linked to pavement performance, summing up the experiences of domestic and foreign research, from the shrinkage of CSL and related pavement distresses and the fatigue of CSL and related pavement distresses, stiffness of CSL and related pavement performance and erudibility, to do researches for the development of the improvement of the pavement.

Keywords: CSL; Durability of CSL and related pavement performance; Fatigue of CSL and related pavement distresses

1. Introduction

Our country began to use in road construction since the 50's, calcareous soil as pavement base and in subsequent decades of lime stable kind of semi-rigid material has always been grade highway main types at the grass-roots level in China. From the mid 70's, our country began to use the cement stabilized material as base. With the continuous development of national economy in the 80's, due to the awareness of highway traffic on important role in promoting the development of national economy, our country began to development of highway traffic on a large scale. 90 s, highway construction is still in the phase of the peak, every year there are tens of thousands of kilometers of roads have been built, including thousands of kilometers of high grade highway. During this period by the cement stabilized material and lime and fly-ash stabilized material of semi-rigid material accounted for all levels of consumption of the highway pavement base materials more than 95%.

From the road performance inorganic binder, which is mainly composed of cement, lime stabilized soil has its unique advantages, such as compared with flexible base material with high intensity, large bearing capacity, good water stability, strong plate body; Inorganic binder stabilized soil materials accessible, can fully use of local sand materials; Also in use for many years accumulated a lot of design, the construction unit built using inorganic binder stabilized soil base construction experience. Therefore, semi-rigid base materials at present even a long period of time will still dominate in road base materials in our country.

Semi-rigid base materials have prominent advantages at the same time there are also some disadvantages, the semi-rigid material in the process of using the main problems are: when selecting raw materials or not at that time, the mixture ratio design semi-rigid base is easy to appear insufficient crack resistance and erosion resistance, frost resistance is bad still exist and poor surface bonding defects. Therefore, the understanding of the semi rigid base materials remained deeply, in order to reduce the error of actual use. The application practice and research show that by adjusting the ratio of mixture of various materials, can effectively change the strength and modulus of semi-rigid material, including the crack resistance, erosion resistance performance, and allow them to have a more extensive applicability.

2. Fatigue of CSL and Related Pavement Distresses

2.1. Bottom-up tensile-fatigue of CSL

Bottom-up tensile-fatigue of CSL, as shown in Figure 1, occurs as a result of tensile strain at the bottom of the CSL due to repeated traffic loads. Otte (1978) studied the fatigue cracking of CSL and reported that when the tensile stress exceeds 35% of the strength or a tensile strain level of more than 25% of the break strain in a flexural beam test, microcracking starts and the stress-strain relationship becomes nonlinear. Microcracks initiate at the bottom of the CSL and propagate upwards. According to

Theyse (1996), bottom tension fatigue consists of three phases. De Beer (1990) reports that bottom-up cracking typically occurs in relatively thin CSL in which tensile strain could cause fatigue damage[4]. The fatigue life in the laboratory is multiplied by a shift factor to account for traffic that occurs between the time of crack initiation and visible cracks. The bottom-up fatigue consists of three phases: (1) a pre-cracking phase (including shrinkage cracking) prior to fatigue initiation, (2) fatigue initiation and propagation, and (3) a post-cracking phase. The duration of the pre-cracking phase consumes about 20% of the life of the CSL. During fatigue propagation, the modulus of the CSL decreases due to fatigue damage. Permeability of the CSL increases as the number of loads increases due to cracks. The rate of degradation of the effective modulus is 52 ksi per 1 million loads for the wet state. In Phase 3, the CSL degrade into small pieces. The size of the degraded CSL depends on the strength of the CSM. After Phase 3, the disintegrated pieces could intrude into the underlying subgrade. During the post-cracking phase, the effective modulus value of the CSL is equivalent to that of the granular materials in terms of CSL thickness. When CSL is dry, the size of the equivalent granular materials is about 1.5 times of the CSL thickness and, after it is wet, the size is 0.3 times that of the CSL thickness. During the post-cracking phase, compressive strength and erodibility govern the rut depth.

Figure 1. Fatigue Cracking in CSL (Yeo et al. 2002)

According to Little et al. (1995), heavily stabilized base layers often fail in fatigue due to tension if the CSL are thin. A minimum thickness of 8 inches is recommended to limit the stress ratio, i.e., the tensile stress at the bottom of the CSL divided by the modulus of rupture (MOR), to 0.5. The crack propagation in the CSL follows the laws of fracture mechanics. The modulus value of the CSL is reduced as a result of fatigue. Yeo (2008) reports that a reduction in the backcalculated modulus is an indication of fatigue. Increasing the modulus improves fatigue resistance[5].

The fatigue of CSL is related directly to the strength of the CSM. For concrete pavement with CSL, Nussbaum and Childs (1975) found that higher MOR (also called flexural strength) values of CSM correspond to a longer fatigue life of the CSL. Hadley et al. (1972) investigated the indirect tensile (IDT) strength of CSM and found that increasing the IDT strength increases fatigue resistance. Theyse et al. (1996) report that an increase in the break strain of CSM

2.2. Crushing Fatigue of CSL

Crushing fatigue occurs due to the repeated compressive strain at the top of CSL (De Beer 1990). Crushing fatigue of CSL could cause rutting in asphalt pavements with CSL. Crushing typically happens in relatively thick, lightly stabilized CSL and is related to the compressive stress ratio. Freeman and Little (2002) report that the failure of CSL is due to debonding between the CSL, fatigue on top of the CSL, and pumping of fines.

3. Durability of CSL and Related Pavement Performance

Stabilized material deteriorates as a result of environmental conditions such as freeze thaw cycles, wet-dry cycles, and erosion. Under freeze-thaw and wet-dry cycles, the strength and stiffness values of the CSL are reduced. As a result, resistance to fatigue cracking might be compromised. As shown in Figure 2, freeze-thaw cycles can cause significant damage to CSM.

Laboratory studies indicate that freeze-thaw cycles significantly reduce the UCS and MOR of CSL (Wen and Ramme 2008, Naji and Zaman 2005, Dempsey and Thompson 1973). A field study by the research team for a previous project shows that, after seven years of service, the UCS in the middle of the traffic lane of CSL is less than 10% of the original strength (Wen and Ramme 2008). The loss of strength in the middle of the traffic lane indicates that the deterioration of CSL strength comes primarily from climatic conditions instead of traffic loads. In addition, the reduction of stiffness and strength causes high deflections and high stress levels in the surface layer, which results in bottom-up fatigue cracking in the surface layer.

Dempsey et al. (1984) studied the effects of freeze-thaw cycles on the properties of CSM and found that cooling and heating rates are important to freeze-thaw durability. In Illinois, most freeze-thaw cycles occur between December and February, with January having the most cycles. The average number of cycles is four per year in Illinois. The cooling rate is 0.15°F/hr and the heating rate is 0.30°F/hr. According to Bonnot (1991), durability can be evaluated in terms of expansion, loss of mass, residual strength or change of strength, or swelling.

4. Strength of Cementitiously Stabilized Materials and Related Pavement Performance

The strength of CSL directly controls their performance and thus affects overall pavement performance. Various strength measures of CSM are used to quantify their specific engineering behavior. The MOR is the key parameter in the fatigue failure of CSL. Tensile strength affects the development of shrinkage cracking in CSL. UCS is a key parameter for the top compression fatigue model. In addition, UCS tests often are used for the purpose of mix design.

Figure 2. Material Degradation after Freeze-Thaw Cycles (Khoury 2005)

Otte (1978) reports that the linear portion of the stress-strain curve in a flexural beam test reflects up to 35% strength of 25% break strain. The ratio between direct tensile strength and IDT strength is close to one. The Otte study also evaluates compressive strength, tensile strength, IDT strength, and bending strength. The bending test is recommended by Otte (1978) for fatigue study. Bonnot (1991) reports that in Europe, Spain uses the MOR, Italy uses IDT strength, and France uses tensile strength.
According to Theyse (1996), increasing the UCS reduces compression fatigue, and increasing the breaking strain decreases tension fatigue. The yield strength of damaged CSL is negatively related to the plastic strain of CSL. Thompson (1986) reports that an increase the MOR mitigates fatigue cracking. George (2001) reports that a low strength or low modulus/strength ratio is beneficial in mitigating shrinkage cracking. Pretorius et al. (1972) report that flexural testing simulates field conditions better than direct tension testing. High confinement leads to high strength of the CSM but low failure strain. A sustained load that is larger than the critical stress (75% strength) can cause microcracks and eventual failure. Pretorius et al. also found that tensile strength is about one-tenth of UCS and one-fifth of MOR.

5. Stiffness of CSL and Related Pavement Performance

The stiffness (or modulus) of CSL is critical to the analysis of pavement and performance prediction. Low stiffness of CSL may create high stress levels in the surface layer and, subsequently, fatigue cracking. However, HMA pavements with a very stiff base are prone to top-down cracking (ARA 2004). In general, high stiffness stems from high additive content, which also may cause high shrinkage rates. Therefore, the impact of stiffness (or modulus) must be studied to develop an appropriate stiffness range for pavement application. For stabilized subbase, high stiffness is generally not a concern. Stiffness of CSM refers to the resilient modulus, modulus of elasticity, flexural modulus, or IDT modulus, depending on the test mode.

6. Interface Bond

Romanoschi and Metcalf (2001) report that the loss of a bond between HMA and CSL significantly increases the tensile strain at the bottom of the HMA layer. The bond between CSL and HMA is often lost due to the presence of water and erosion/crushing of the CSL surface. Shear failure occurs within the top of the CSL instead of at the interface of the CSL and HMA. The loss of the bond between the asphalt and CSL causes a shift in critical tension from the top of the subgrade to the bottom of the asphalt layer.
Wimsatt et al. (1987) report that increasing the interface bond strength between Portland concrete cement (PCC) and the base results in narrow crack spacing. The failure plane happens in CSL. The IDT strength of the CSL is correlated with the friction forces. Grogan et al. (1999) report that for concrete on top of CSL, asphalt emulsion does not work well as a bond breaker. Slippage and horizontal cracks are located below the interface of the concrete and CSL.
Wesevich et al. (1987) also report that for concrete pavement with CSL, friction at the interface results from adhesion, shearing and bearing. The soil cement base has the highest level of friction with a concrete surface, followed by the granular base, and asphalt and lime clay bases.

7. Conclusion

Practice shows that there are some inevitable semi-rigid base asphalt pavement technical problems, such as due to shrinkage properties of semi-rigid base material of asphalt pavement early cracking of semi-rigid base materials in water action of vehicle load and temperature gradient under the combination of the phenomenon of pumping mud at the grass-roots level, under the condition of heavy traffic phenomenon of early fatigue damage and so on. In this paper, from the characteristics of semi-rigid base, typical structure and the main diseases and prevention measures of semi rigid base asphalt pavement is introduced in detail, and the structure optimization and overloading condition half rigid base asphalt roadbed development were discussed. Through a lot of investigation and study, analyze the properties of cementitiously stabilized materials linked to pavement performance, mainly the shrinkage of CSL and related pavement distresses and the fatigue of CSL and related pavement distresses, stiffness of CSL and related pavement performance and erudibility, to do researches for the development of the improvement of the pavement.

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