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Properties of Cementitiously Stabilized Materials Linked to Pavement Performance

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Abstract: At present, 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; Shrinkage of CSL and related pavement distresses; 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. Shrinkage of CSL and Related Pavement Distresses

Shrinkage cracking of CSL as base layers, as shown in Figure 1, can cause the cracking of the surface layer due to the bond between the surface layer and the CSL. Shrinkage of CSL includes autogenous shrinkage due to hydration, drying shrinkage due to loss of moisture and thermal shrinkage due to low temperature contraction

(ACI 2008). Shrinkage of CSL, when restrained (e.g., bonding from underlying layer), causes the development of tensile stress in the CSL. When the tensile stress exceeds the tensile strength of the stabilized materials, shrinkage cracking occurs (George 1990)[1]. Shrinkage cracking could occur within a few days or over a couple of years, depending on the curing, shrinkage strain, and other factors. Shrinkage of CSL is affected by many factors, such as moisture, additive content, raw material characteristics, and curing after compaction.

Figure 1. Shrinkage Cracking of CSL (George 2001)

2.1. Moisture

Kodikara and Chakrabarti (2001) report that shrinkage results from moisture loss, which leads to matric suction (capillary forces), osmotic suction, and thermal cooling. George (1990, 2001) reports that moisture content that is higher than the optimum moisture content (OMC) causes excessive shrinkage cracking[2]. George (1990) also reports that shrinkage can be reduced by reducing molding moisture, increasing compaction density, avoiding montorillonite clay, and limiting the degree of saturation to 70 percent.

The moisture content in CSL is affected by the curing method. Sebesta (2005) reports that bituminous curing is minimally effective in reducing cracking problems. Bituminous curing and dry curing provide little difference in shrinkage cracking for 4% cement sections. Shrinkage cracking occurs within the first two days. However, moist curing works better in mitigating shrinkage cracking than dry curing and prime curing for 8% cement sections.

Pretorius et al. (1971) use the theory of viscoelasticity to analyze shrinkage cracking. Increasing the RH reduces the creep and shrinkage strain but increases the relaxation modulus. With an increase in curing time, the tensile strength continues to increase at 100% RH during curing. However, for other RH values, the strength value reaches a peak and then starts to decrease. Increasing the RH reduces shrinkage stress.

2.2. Binder Content

Sebesta (2005) reports that increasing the cement content increases the amount of shrinkage cracking. Matthew et al. found that low strength ensures narrow and closely spaced shrinkage cracks that do not reflect through the wearing course. This finding is in line with that of Van Blerk and Scullion (1995) who conclude that high-strength CSL have wide cracks at large spacing and low strength CSL have fine cracks at close spacing. Little et al. (1995) report that shrinkage cracking spacing depends on tensile strength and the friction between the CSL and underlying layer. The width of the cracks depends on the tensile stiffness of the CSL. A maximum shrinkage strain of 250 microstrain is recommended[3].

2.3. Soil Properties

The characteristics of soils directly affect the shrinkage behavior of CSL. Norling (1973) found that increasing the clay content increases the occurrence of shrinkage. Van Blerk and Scullion (1995) also indicate that an increase in the plasticity index (PI) value increases the shrinkage potential. Smectite clay causes the most shrinkage, when compared to other types of clay. The linear shrinkage of the fine fraction of the aggregate is a good indicator of the ultimate drying shrinkage of the CSL. It is recommended that linear shrinkage of 1.5%, PI value of 4.0, passing #200 sieve of 7%, and shrinkage after 21 days of 250 microstrain are the maximum allowed.

Kodikara and Chakrabarti (2001) report that a clay size that is smaller than 0.08 mil is responsible for shrinking and swelling. Autogenous shrinkage accounts for only 5% of the total shrinkage. The shrinkage potential of cementiously stabilized materials (CSM) is between that of clay and cement paste. Adding cement to clay reduces shrinkage due to the reduction in matric suction. However, after reaching a low point, adding more cement will induce higher shrinkage strain due to more gel particles. The restrained shrinkage cracks were examined with a microscope in the Kodikara and Chakrabarti study.

2.4. Thermal Cooling

Bonnot (1991) reports that factors that affect shrinkage include water content, thermal shrinkage, and the strength of the materials. Shrinkage cracking can result from thermal contraction. Cooling by 9 □F to 18□F cause thermal cracking in the laboratory.

3. Fatigue of CSL and Related Pavement Distresses

3.1. Bottom-Up Tensile-Fatigue of CSL

Bottom-up tensile-fatigue of CSL, as shown in Figure 2, 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, as shown in Figure 3. 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 2. Fatigue Cracking in CSL (Yeo et al. 2002)

Figure 3. Fatigue Cracking in CSL Trenching (Moisture in Cracks) (Yeo 2008)

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.

3.2. 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.

4. 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.

5. Erodibility

Erosion can cause several issues in pavements with CSL, such as pumping of fines, creating a loose layer between the surface layer and CSL, and accelerating the degradation of the CSL. Water can infiltrate the pavement structure through the shoulder and surface cracks or from underground. High dynamic pore pressure builds up with traffic loading, which loosens fine particles, reduces densities, and creates voids (De Beer 1990).

Wjvdm et al. (2001) report that the introduction of water accelerates permanent deformation and erosion. Vorobieff (1997) reports that, in order to prevent erosion, a minimum of 4% binder content is needed. Jung et al. (2009) report that concrete pavement on top of weak CSL does not perform well due to pumping. High-strength CSL have better pumping resistance than low-strengh CSL. Jung et al. introduced and developed erosion models and tests.

The damage to CSL by weathering and traffic also tends to accelerate erosion and pumping issues (Li et al. 1999, Meng et al. 2004). Thus, the durability of CSL is an essential property that affects pavement performance.

6. Conclusion

More than 90% in our country has built highways 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 structure of high grade highway in China. But 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 grassroots 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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