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Effect of plasticity index and dust ratio on moisture-density and strength characteristics of aggregates

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ABSTRACT

Unbound aggregate base and subbase layers distribute wheel load induced stresses to protect subgrade. Standards such as AASHTO and individual states specifications have set several quality control limits for a variety of properties of aggregates used in the pavement base and subbase courses. Most standards and DOT specifications suggest that the ratio of percent passing No. 200 sieve to percent passing No. 40 sieve should not be greater than two thirds, and plasticity index of the material passing No. 40 sieve should be less than 6%. The ratio of percent passing No. 200 to percent passing No. 40 sieves is called the dust ratio (DR). There are many states that have either waived the standard limits or adopted their own quality control method. In this study the effect of dust ratio, percent passing No. 200 sieve and plasticity index (PI) affecting moisture-density and strength characteristics of crushed limestone aggregates are investigated. The prepared samples represented one of the most commonly utilized dense-graded standard aggregate gradation in Illinois, i.e. CA6. Standard Proctor compaction and soaked California Bearing Ratio (CBR) tests were conducted on specimens to determine the moisture-density and strength characteristics of the material with moisture content, respectively. In addition, two staged triaxial tests using three confining pressures were performed to study the effect of confining pressure and fine quantity on strength of aggregates. According to the results, the effect of percent passing No. 200 sieve on strength variation is significant in unbound aggregates. The sensitivity of aggregate strength to moisture content variation is also discussed.

Introduction

Pavement subbase and base are the layers placed immediately above the prepared subgrade to act as an intermediate medium between the surface course and subgrade layer. Proper and effective distribution of the wheel load from the surface to the subgrade layers will result in a longer lasting road. Composition of aggregate materials used in base and subbase layers is dictated by particle size and shape distributions, moisture content of fines, aggregate layer assembly, aggregate interlock, compactability, and shear strength properties of the aggregate (Yoder and Witczak, 1975). Compaction level, moisture content, texture and type of aggregate, gradation, percentage of fine content, and plasticity index are contributing factors in defining aggregate qualities.

Increased compaction and density will typically result in higher strength (Seyhan, 2001; Elliot and Thornton, 1988; Lekarp et al., 2000). Sufficient compaction decreases probability of failure due to swelling or shrinkage of

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material (Holtz, 1990). High compaction achieved in base/-subbase would increase the resilient modulus and strength properties and decrease the tendency for accumulating permanent deformation (Elliot and Thornton, 1988; Lekarp et al., 2000). For example, a dramatic increase in permanent deformation due to reduction in degree of compaction was observed by Barksdale (1972).

The type of aggregate will impact the strength properties (Tutumluer et al., 2000). Crushed limestone has less potential for permanent deformation when compared to other granular materials, both compacted and prepared at the same level of compaction (Allen, 1973). In a study by Yoder (1959), higher CBR values, as a strength indictor, were achieved for crushed limestone compared to gravel, when the same compaction level and fine content were used.

Gradation and percentage of fines content (i.e. passing No. 200 sieve) have significant impacts on the ability of aggregates to bear stresses. Kamal et al. (1993) and Dawson et al. (1996) showed gradation has noticeable influence on unbound aggregate strength compared to compaction level. Gray (1962) studied aggregates using various fine contents of 1–20% and concluded that 8% fines content provides the optimum strength when maxium particle size is 25.4 mm. This optimum fine content decreased as the maximum size of aggregate increased. About 60 percent loss in resilient modulus was shown by Barksdale and Itani (1989), when fines content was increased from 0% to 10%.

Both quality and quantity of fines affect the properties of coarse aggregates. For example, a considerable decrease in bearing ratio and shear strength was reported, due to an increase in the amount of plastic fines (A & H Engineering & Testing Corp., 1969). Tutumluer demonstrated that the variation in strength due to change in moisture content is more intense and abrupt in materials having large percentages of plastic fines. Furthermore, it was concluded that base and subbase layers containing an excessive amount of plastic fines cannot adequately withstand high levels of stress regardless of their thickness (Tutumluer et al., 2000). Dekoltz (1940) and Faiz (1971) identified detrimental effects of the plasticity and the amount of fine grains on aggregate behavior.

Strength characteristics can be identified with various lab and insitu methods. California Bearing Ratio have been used by many agencies and institutes due to its easiness, reliability and affordability compared to other conventional tests such as triaxial test, resilient modulus, and Dynamic Cone Penetration (DCP) test. Accordingly, many design manuals use CBR value in order to determine the required thickness of layers such as base and subbase.

Current practice

American Association of State Highway and Transportation Officials (AASHTO), American Society for Testing and Materials (ASTM), and various states have set specifications for allowable fines content and plasticity index values for aggregates used in highway construction (2008; 2000). A summary of these limits is provided in Table 1.

The fines content is commonly controlled by specifying a certain limit on material passing No. 200 sieve. Dust Ratio (DR) is defined as the ratio of material weight passing No. 200 sieve to the one passing No. 40 sieve. According to Table 1, the maximum allowable passing No. 200 sieve varies from 12% to 20%. Dust ratio is not commonly considered as a criterion; however, 0.6 or 0.66 is the recommended upper limit of dust ratio in some standards or specifications.

As far as plasticity index requirement, Hogentogler and Willis (1936) were the pioneers who determined upper allowable limits for the Plasticity Index (PI) and Liquid Limit (LL) of the material utilized in base layers. Their suggestion has been the basis for many standards and state specifications. Many states limit the PI to about 6% and ASTM sets an upper limit of 4%. McDowell (1966) reported that the limits recommended by AASHTO may be capped at higher values, as no valid relation between consistency limits and operational lifetime of roads in Texas was observed.

In this study, the effect of PI and dust ratio on strength of aggregates is investigated using laboratory experiments. A systematic test matrix plan is developed to identify each factors contribution on strength. The moisture sensitivity of aggregate matrix is also addressed.

Test plan and matrix

Soaked CBR

To investigate the effect of PI, dust ratio, as well as percent passing No. 200 sieve on moisture-density and strength characteristics of aggregates, a test matrix was developed. The aggregate used in this study is a crushed limestone material with dense graded coarse aggregate garadation, which is commonly used in Illinois as base and subbase. This aggregate is referred to as CA6 and is discussed in more detail in Section "Engineering gradation and index properties". The strengths were determined by conducting soaked CBR, and staged triaxial tests on compacted specimens using Standard Proctor procedure (AASHTO T 99-10). To develop the compaction curves, four to five samples were prepared each with different moisture contents. The compacted samples were placed in a water bath and soaked for four days. Then, soaked CBR tests were conducted per AASHTO T 193-99.

The allowable percent passing No. 200 sieve for CA6 aggregate ranged from 4% to 12%. Therefore, in order to cover the range allowed, percent passing No. 200 sieve values of 5%, 8%, and 12% were targeted in the test matrix plan. Furthermore, many state specifications have used 0.66 as the maximum allowable dust ratio. Consequently, the dust ratio (DR) of 0.6 and 1.0 were selected as target dust ratios to study. In terms of the PI requirement, most states have limited the plasticity index of the unbound aggregate base course to 6%. There are also some states, such as Illinois, that the aggregates with up to 9% are allowed for use in base and subbase courses. Accordingly, two PI values of 5% and 9% were targeted in preparing samples in this study.