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REPORT

RESILIENT AND PERMANENT DEFORMATION BEHAVIOR OF UNBOUND AGGREGATES UNDER REPEATED LOADING

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ABSTRACT

During recent decades, growing interest in the development of so-called analytical or mechanistic road pavement design methods has resulted in substantial research into the mechanical behavior of the materials involved. In flexible pavements, especially when unsurfaced or thinly surfaced, overall structural performance is largely dependent on the behavior of the unbound granular base and subbase layers. A proper understanding of the mechanical properties of granular materials is, therefore, a prerequisite for the success of analytical design procedures for flexible road pavements. The present doctoral thesis is based on a five-year research project on the structural characterization of unbound granular materials and consists of six papers on different aspects of the research topic.

Papers I and II present the findings from an extensive literature survey and summarize the current state of knowledge in regard to resilient and permanent strain behavior of granular materials. The review of previous research shows that the structural response of these materials is affected, to varying degrees, by several factors such as stress level, moisture content, stress history, density, fines content, aggregate type and number of load applications. Different views on the significance and the extent of the impact of each individual factor are presented and discussed. A great number of mathematical models have been developed over the years for prediction of stiffness properties and long-term performance of granular materials. The models found in the literature are listed and their advantages and shortcomings are reviewed.

The focus of Papers III and IV is on the issue of mathematical modeling of permanent strain development in unbound granular materials. The results of a series of repeated load laboratory tests are used to assess the relationship between permanent strain and both number of load repetitions and stresses. The experimental data are used to compare the predictive capabilities of some of the existing models found in the literature, including the so-called Paute model which is part of a newly proposed European standard for road material characterization. Through further analysis of the test results, a new model is introduced expressing the accumulated permanent axial strain, after any given number of load cycles, as a function of the maximum shear to normal stress ratio and the length of the stress path applied. Based on the application of this model, it is suggested that a shakedown approach, similar to that proposed by others for pavement analysis, would be a useful means for relating permanent strain development and long-term performance of granular materials to stress condition. Further, it is shown that permanent strain development under repeated loading cannot be sensibly related to monotonic shear strength data, a common surrogate performance measure referred to in the literature.

Paper V presents, in detail, the design work for a large-scale triaxial testing apparatus developed as part of this research project. This triaxial apparatus uses a specimen size of 500x1000 mm and enables testing of granular materials with up to 100 mm maximum particle size at cyclic deviatoric and confining stresses of up to about 1300 kPa and 600 kPa, respectively. The new triaxial equipment was employed in a series of tests on different granular materials, the results of which are also presented and discussed. The materials tested were crushed limestone, granite and concrete, and natural sand and gravel. The structural response of crushed concrete proved to be the best, showing the highest stiffness and resistance to permanent deformation. The suitability of crushed limestone was rather doubtful, as it exhibited high stiffness but low resistance to

permanent deformation. The performance of granite was moderate, whereas sand and gravel behaved poorly.

Finally, Paper VI presents the findings of an investigation into the effects of grading scale, or changes in the maximum particle size of graded aggregates, on triaxial testing results. Since most triaxial testing facilities available to date do not satisfy the specimen size requirements for coarse-grained aggregates, these materials are commonly tested in so-called scaled-down gradings. This paper attempts to explore the importance of grading scale on the basis of a series of repeated load triaxial tests on crushed limestone and concrete, and natural sand and gravel at gradings of 0/90, 0/63, 0/32 and 0/16. The test results showed clearly that both resilient and permanent strain responses are affected by the grading scale of the triaxial specimen. The reduction of grading scale resulted in lower resilient moduli and higher Poisson's ratios, but the extent of the impact was dependent on aggregate type. The susceptibility to permanent strain was also influenced markedly, but the nature of the response proved to be highly inconsistent. On the basis of the experimental analyses presented in this paper, it is found necessary for triaxial tests on granular materials to be conducted at their natural gradings.

KEYWORDS:

Granular materials, unbound aggregates, mechanical behavior, resilient response, permanent strain, mathematical modeling, shakedown, triaxial apparatus, large-scale triaxial testing, grading scale, maximum particle size

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