LOUISIANA TRANSPORTATION RESEARCH CENTER

Technical Summary

LTRC Report 701

SIO No. DOTLT1000424
LTRC Project No. 22-2C

Optimizing Aggregate Gradation to Reduce Concrete's Permeability

Introduction

Concrete durability has become an increasingly important design parameter as state highway agencies look to increase the service life of concrete infrastructure. While there are several approaches to produce durable concrete (i.e., by reducing its permeability), one factor that often gets overlooked in a mixture design is the aggregate gradation. In practice, most concrete producers tend to use the grading limits specified in ASTM C33 for aggregates. However, the use of these limits may not necessarily produce durable concrete mixtures because the grading limits are too broad to guarantee optimum packing density. By maximizing the aggregate's packing density, the concrete's cement demand can be reduced, resulting in a less permeable concrete since cement paste is the most porous material in concrete. A high cement paste should also be avoided to minimize shrinkage and lower the environmental footprint of Portland cement.

For these reasons, there is a need to optimize aggregate gradations for concrete mixture designs to maximize durability. This study focused on preparing concrete mixtures with optimal gradations based on five different aggregate gradation techniques in order to minimize permeability and cement demand without sacrificing workability. Durability tests through surface resistivity (AASHTO T 358) and formation factor (AASHTO 119-15 [Option A]) were conducted to test how different gradations perform versus the typical gap graded mixtures (per ASTM C33) that are prevalent in concrete field practice.

Objective

The objectives of this study were to:

1. Measure the influence of aggregate gradation on concrete's permeability.
2. Optimize concrete mixture designs that meet the strength, permeability, and workability criteria for construction.

Scope

To fulfill the objectives of this study, five different aggregate gradation techniques were used to prepare concrete mixtures. Durability tests through surface resistivity and formation factor were conducted to determine the optimal gradation for concrete mixture design.

Methodology

Five different aggregate gradation techniques (Shilstone coarseness factor chart, Power curve, 5-20 band [specified in Louisiana Standard Specifications for Roads and Bridges], Tarantula curve, and a gap gradation [60/40 coarse-to-fine aggregate ratio]) were employed in this study. For each technique, four different gradations were tried to study the packing density based on the aggregate's void contents (per ASTM C29). Generally, the gradations that produced the highest and lowest packing density for each gradation technique were then used to prepare concrete mixtures. Surface resistivity (AASHTO T 358) and formation factor (AASHTO TP 119-15 Option A and AASHTO PP 84-18) tests were conducted to investigate the influence of different gradations on concrete's permeability. Table 1 (see reverse side) summarizes the concrete mixture design variables for this study.

Principal Investigator
Zhen Liu, Ph.D., P.E.
225-767-9138

LTRC Contact
Samuel Cooper, III, Ph.D., P.E.
225-767-9164

Funding
SPR: TT-Fed/TT-Reg - 6

Read final report online:
www.ltrc.lsu.edu/publications.html

Variable	Levels	Description
Aggregate gradation techniques	5 x 2	Shilstone chart; Power curve; 5-20 band; Tarantula curve; Gap gradation
w/cm ratio	1	0.45
Coarse aggregate type	1	Gravel
Cementitious material systems	3	100% Portland cement (100TI); 70% Portland cement and 30% class C fly ash (70TI/30C); 50% Portland cement and 50% slag cement (50TI/50S)
Cementitious material content	2	650 lbs./yd.^{3} (baseline); and a reduced amount based on a 1.5 paste-to-voids volume ratio
Total mixtures: 60		

Table 1. Concrete mixture design variables

Conclusions

In this study, five different aggregate gradation techniques were used to prepare concrete mixtures. Through a comparison of the test results, it is found that for gravel aggregates:

- Tarantula gradation T-4 with cementitious system 50TI/50S and the minimum amount of cementitious materials produced the highest formation factor (i.e., more than 2,000 after 56-day curing) and the second highest surface resistivity among all 20 mixes.
- Power gradation P-3 with cementitious system 50TI/50S and the minimum amount of cementitious materials produced the second highest formation factor (i.e., more than 1,800 after 56-day curing) and the highest surface resistivity among all 20 mixtures.
- Tarantula gradation T-3 with the minimum amount of cementitious materials produced a slump value of zero, a very low 28-d compressive strength (i.e., less than 3,000 psi), and a very low formation factor for all three cementitious systems.
- Among all three cementitious systems, 50TI/50S produced the highest surface resistivity and formation factor for the majority of the gradations at all four different curing times (i.e., 14 days, 28 days, 56 days, and 90 days).

Based on the findings, it can be concluded that Tarantula gradation T-4 and Power gradation P-3 would be good gradations for high durability concrete mix design when mixed with cementitious system 50TI/50S and the minimum amount of cementitious materials.

Recommendations

To improve concrete's durability, it is recommended to:

- Use the Tarantula or Power gradation technique to select the aggregate with the lowest aggregate void ratio during concrete mix design.
- Use cementitious system 50TI/50S.
- Minimize the amount of cementitious materials, if possible.