JOINT TRANSPORTATION RESEARCH PROGRAM

Principal Investigator: Monica Prezzi, Purdue University, mprezzi@purdue.edu, 765.494.5034

Program Office: jtrp@purdue.edu, 765.494.6508, www.purdue.edu/jtrp

Sponsor: Indiana Department of Transportation, 765.463.1521

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Use of Soil-Steel Slag-Class-C Fly Ash Mixtures in Subgrade Applications

Introduction

In Indiana, large quantities of recyclable materials—such as steel slag, blast furnace slag and fly ash—are generated each year as by-products of various industries. Instead of disposing these by-products into landfills, we can recycle them into beneficial civil engineering applications by replacing traditional construction materials with these industrial by-products. Replacing traditional materials with these industrial by-products may be a cost-effective alternative that can help save natural resources and reduce the costs associated with landfilling.

In this research study, the suitability of using mixtures of steel slag and Class-C fly ash and mixtures of steel and blast furnace slags to replace lime in subgrade stabilization applications was evaluated. Initially, mixtures of steel slag and Class-C fly ash were explored as a replacement for lime. *In situ* soil collected from a proposed implementation project was mixed with 10% (by weight of soil) of steel slag and Class-C fly ash mixtures. The following mixtures of steel slag and Class-C fly ash were considered in this study: 5% steel slag-5% Class-C fly ash, 7% steel slag-3% Class-C fly ash and 8% steel slag-2% Class-C fly ash by weight of soil. Since the Class-C fly ash used in this study is expensive, a 7% steel slag-3% blast furnace slag mixture by weight of soil was also investigated for use as an alternative mixture that could also be used for soil stabilization.

In order to determine the properties of the soils prior to stabilization, initial tests were performed on the clayey soil collected from the proposed implementation site. The clayey subgrade soil was characterized through a series of tests that included specific gravity, Atterberg limits, grain size analysis, compaction, swelling and unconfined compression tests.

The mechanical properties of the mixtures of soil, steel slag and Class-C fly ash and soil, steel slag and blast furnace slag were determined through compaction and unconfined compression tests. In order to assess the swell-

ing potential of the *in situ* soil and mixtures, CBR swelling tests were also performed.

Findings

The present report includes the following findings:

1. The soil collected from the implementation site was classified as lean clay (CL) according to the USCS classification and as A-6, with a group index of 7, according to the AASHTO classification system. In general, materials in this group show high volume change behavior when the moisture content changes and therefore, they are not considered suitable as subgrade materials. The general rating of A-6 soils according to AASHTO is fair to poor as subgrade material.
2. The optimum moisture content and maximum dry unit weight of the clayey soil were 13% and 18.56 kN/m³ (118.2 pcf), respectively.
3. The unconfined compressive strength of the soil samples compacted to 95 to 101% relative compaction ranged between 214 and 329 kPa. The average unconfined compressive strength of the samples was 282.9 kPa (41 psi). Since INDOT typically requires a minimum unconfined compressive strength of about 552 kPa (80 psi) for subgrade soils, the clayey soil at the implementation site required stabilization to support the loads from the pavement without causing excessive settlements.
4. Long-term CBR swelling tests were performed on the compacted soil samples. After approximately 13 days of soaking, the compacted soil samples reached a maximum swelling strain of approximately 0.41% and then started shrinking. Eventually, the soil samples reached equilibrium at a swelling strain of approximately 0.24% after 35 days of soaking.
5. No significant change was observed in the Plasticity Index (PI) of the soil-7% steel slag-3% Class-C fly ash and soil-7% steel slag-3% blast furnace slag mixtures when compared to that of the *in situ* clayey soil.

6. The optimum moisture content and maximum dry unit weight of the soil-7% steel slag-3% Class-C fly ash mixture were 15% and 18.04 kN/m³ (114.8 pcf), respectively. The optimum moisture content and maximum dry unit weight of the soil-7% steel slag-3% blast furnace slag mixture were 16% and 16.94 kN/m³ (107.7 pcf), respectively.
7. The compaction curves for both the soil-steel slag-Class-C fly ash and soil-steel slag-blast furnace slag mixtures indicated higher water content and lower maximum dry unit weight than those obtained from the compaction curve of the *in situ* clayey soil. This trend is similar to that observed in lime treated soils.
8. The two-day unconfined compressive strength of the soil-7% steel slag-3% Class-C fly ash and soil-7% steel slag-3% blast furnace slag mixtures were 820 kPa (119 psi) and 602 kPa (87 psi), respectively.
9. Based on the unconfined compressive strength test results, the strength gain rate of the compacted soil-7% steel slag-3% Class-C fly ash mixture was higher than that of the compacted soil-7% steel slag-3% blast furnace slag mixture. These results indicate the occurrence of stronger cementitious reactions in the mixture of *in situ* soil, steel slag and Class-C fly ash.
10. The maximum swelling strains of the compacted soil-7% steel slag-3% Class-C fly ash and soil-7% steel slag-3% blast furnace slag mixtures were 0.13% and 0.052% based on the results of the long-term CBR swelling tests. These results showed that both the steel slag-Class-C fly ash and steel slag-blast furnace slag mixtures were effective in reducing the swelling potential of the *in situ* clayey soil.
11. The mixture of soil-7% steel slag-3% Class-C fly ash was selected as the most suitable and cost-effective subgrade material for the implementation project.

Implementation

The mixture of *in situ* soil, steel slag, and Class-C fly ash selected based on the laboratory test results was implemented as a subgrade material in an INDOT project.

The implementation project for the mixture of soil, steel slag and Class-C fly ash selected was carried out at the intersection of 109th Avenue and I-65, near Crown Point, Indiana. The 7% steel slag-3% Class-C fly ash mixture was used to stabilize the *in situ* subgrade soils of some sec-

tions of the I-65 ramps located in the SW and NW quadrants of the intersection of 109th Avenue and I-65.

The main construction steps followed for the stabilization of the *in situ* soils with the pre-mixed 7% steel slag-3% Class-C fly ash mixture were: (1) spreading; (2) mixing and water spraying; and (3) compaction. Field compaction quality control was done by performing Dynamic Cone Penetration Tests (DCPT) and nuclear gauge tests.

NDCPT values recorded for 0 to 6 inch and 6 to 16 inch penetration at various stations in the SW ramp were in the ranges of 11–24 and 12–32 96 hours after subgrade compaction, respectively. The NDCPT values recorded for 0 to 6 inch and 6 to 16 inch penetration at various stations in the NW ramp were in the ranges of 5–15 and 6–15 approximately 1 hour after subgrade compaction, respectively. The ranges of values recorded in the NW ramp were lower than those recorded in the SW ramp. This was attributed to the fact that the testing in the NW ramp was done only 1 hour after compaction of the subgrade, and a period of 1 hour is not sufficient to allow for the cementitious reactions to take place.

NDCPT values recorded at all stations in the NW and SW ramps fall in the range specified by criteria developed by U.S. DOTs and hence, the compaction of the subgrade was deemed satisfactory.

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