

Cement Stabilization with Fiber Reinforcement of Subbase

RESEARCH PROJECT TITLE

Central Iowa Expo Pavement Test Sections: Phase I – Foundation Construction (InTrans Project 12-433)

SPONSORS

Iowa Department of Transportation
Federal Highway Administration

RESEARCH TEAM

David J. White, PhD, PE
Director, Center for Earthworks
Engineering Research
Associate Professor
515-294-1463, djwhite@iastate.edu

Pavana K. R. Vennapusa, PhD, PE
Assistant Director, Center for Earthworks
Engineering Research
Research Assistant Professor
515-294-2395, pavanv@iastate.edu

Peter Becker
Research Assistant

Christianna White, PhD
Technical Editor

RESEARCH PARTNERS

Iowa Department of Transportation
Central Iowa Expo
Boone County, Iowa Engineer
Foth Engineering Alliance
JB Holland Construction, Inc.
Center for Earthworks Engineering Research

IOWA DOT CONTACT

Mark Dunn, PE
Operations Research Engineer
Office of Research & Analytics
Iowa Department of Transportation
515-239-1447, mark.dunn@dot.iowa.gov

MORE INFORMATION

<http://www.ceer.iastate.edu>

The sponsors of this research are not responsible for the accuracy of the information presented herein. The conclusions expressed in this publication are not necessarily those of the sponsors.

CENTER FOR

CEER

EARTHWORKS ENGINEERING
RESEARCH

IOWA STATE UNIVERSITY
Institute for Transportation

The Iowa Department of Transportation (DOT) worked with its research partners to design comparative pavement foundation test sections at the Central Iowa Expo Site in Boone, Iowa. The project was constructed from May through July 2012. Sixteen 700 ft long test sections were constructed on 4.8 miles of roadway with the following goals:

- Construct a test area that will allow long-term performance monitoring
- Develop local experience with new stiffness measurement technologies to assist with near-term implementation
- Increase the range of stabilization technologies to be considered for future pavement foundation design to optimize the pavement system

This tech brief provides an overview of in situ test results and key findings from two test sections constructed using portland cement (PC) stabilization with fiber reinforcement in the subbase layer using two types of fibers.

Background

Previous research studies on discrete fiber-reinforced natural and chemically-stabilized soils have generally shown improvements in soil shear strength, bearing capacity, ductility, toughness, and resistance to rutting (Gray and Ohashi 1983, Consoli et al. 1998, Santoni and Webster 2001, Kaniraj and Havanagi 2001, Consoli et al. 2003, Newman and White 2008).

Gray and Ohashi (1983) reported that the failure mechanism of a fiber-reinforced soil depends on the acting average effective stress. Failure occurs through slippage of fibers up to a critical stress and, as the stresses increase, failure is governed by the tensile strength of the fiber element (Consoli et al. 2011).

Santoni and Webster (2001) reported that in unconfined compressive strength tests, the fiber-reinforced soil yielded higher shear strengths due to development of tension in the fibers with increasing

strains. Consoli et al. (2003) indicated that the fiber content, orientation of fibers with respect to the shear surface, and the elastic modulus of the fibers influence the contribution of the reinforcement to the shear strength. In Iowa loess, Hoover et al. (1982) found that inclusion of fibers decreased freeze-thaw volumetric changes on the order of 40% compared to soil with no fibers.

In this study, test sections were built to evaluate the long-term performance of PC stabilization with fiber reinforcement in subbase layers by measuring in situ engineering properties (i.e., strength and stiffness) over time with special focus on freeze/thaw performance.

Description of Test Sections and In Situ Testing

The test sections originally consisted of a thin chipseal coat and an 8 in. recycled asphalt subbase at the surface. The subbase material was excavated down to the subgrade level. The existing subgrade material is classified as CL or A-6(5).

PC stabilization with fiber reinforcement in recycled subbase material (reclaimed from the original test sections) was conducted on the 6th St. North and South test sections. Two different fibers—polypropylene (PP) black fiber and monofilament-polypropylene (MF-PP) white micro-fiber (Figure 1)—were used for reinforcement. MF-PP white fibers were used on 6th St. South and PP black fibers on 6th St. North. About 60 ft on the south end of 6th St. South and about 80 ft on the north end of 6th St. North included only fiber reinforcement without PC stabilization in the subbase layer.

The black PP fibers are discrete fibrillated strands that are 1 in. long and have a specific gravity of 0.91. The white MF-PP micro-fibers are monofilament strands with a specific gravity of 0.91, but are 3/4 in. long.

The construction process involved: (1) placing the recycled subbase material (classified as SM or A-1-a with 14% fines content) over the subgrade; (2) distributing a target 0.4% fibers on the subbase layer using a straw blower (Figure 2); (3) mixing the subbase material with fibers using a soil reclaimer (Figure 3); (4) distributing a target 5% cement on the subbase-fiber mixture (Figure 4); (5) mixing and moisture conditioning the mixture by injecting water into the mixing drum (Figure 5); and (f) compacting the stabilized layer with a vibratory padfoot roller immediately behind the reclaimer (Figure 5). Note that the PC and fiber content are based on dry weight of the soil. Close-up views of the subbase material after mixing with PC and fibers are shown in Figure 6. An image of a Proctor sample of subbase material stabilized with PC and PP fibers is shown in Figure 7.

Within one to three days of curing, a 6 in. crushed limestone-modified subbase layer was placed over the stabilized layers and compacted using a vibratory smooth drum roller.

Data from six contractor bidder unit prices indicated a median price of \$12.87/yd² with a range of \$9.63/yd² to \$14.51/yd² for 5% PC + 0.4% fiber stabilization of subbase. The median price for 0.4% fiber stabilization (with no PC) was \$9.66/yd² with a range of \$7.22/yd² to \$10.28/yd². This cost includes only the stabilization cost for the subbase layer and not the cost of placing the modified subbase layer on the surface.

In situ testing involved testing the foundation layers prior to construction (May 2012) and 1, 3, 7, and 84 days after stabilization (July to October 2012) and after 266 days (April 2013), which was immediately after the spring thaw. In situ testing methods used included light weight deflectometer (LWD), dynamic cone penetrometer (DCP), falling weight deflectometer

(FWD), and roller-integrated compaction monitoring (RICM). Results from only the DCP and FWD tests are presented here. (All test results are presented in the Phase I final report.)

The temperature profiles in the pavement foundation layers are being monitored at a nearby site on US Highway 30 near Ames,



Figure 3. Mixing of fibers with subbase material using a soil reclaimer



Figure 4. Distribution of cement on the subbase layer mixed with fibers



Figure 5. Mixing, moisture conditioning, and compacting the PC + fiber-stabilized subbase mixture



Figure 1. Polypropylene (PP) black (left) and monofilament-polypropylene (MF-PP) white fibers (right)



Figure 2. Distribution of fibers using a straw blower



Figure 6. PC + PP black fiber-stabilized subbase (left) and PC + MF-PP white fiber-stabilized subbase (right)

Iowa. The maximum and minimum temperatures recorded up to a depth of about 64 in. below the surface and the number of freeze-thaw (F/T) cycles observed at various depths are shown in Figure 8a. Figure 8b shows a 2010-2011 winter F/T cycle profile for a roadway in Plainfield, Iowa from Johnson (2012), which indicates that the number of F/T cycles can be on the order of 40 to 50 at the top of the subbase/subgrade foundation layers.

Various laboratory tests to characterize the compressive strength and freeze-thaw durability of the PC-stabilized subbase with the two fibers are also underway and will be reported separately.

In Situ Test Results

The field-determined PC and fiber contents were calculated by dividing the delivered weight of PC and fibers over the roadway area and assuming a uniform reclamation depth of 6 in. The calculated PC contents were about 5.6% and 5.5% in the North and South sections, respectively. The calculated fiber contents were about 0.5% in both sections.

DCP-California bearing ratio (CBR) and cumulative blow profiles with depths before stabilization and after several days of curing up to about three months after construction and after spring-thaw in April 2013 for the PC + PP and PC + MF-PP stabilized subbase sections are shown in Figures 9 and 10, respectively. For comparison, DCP profiles from 7th St. constructed with only PC stabilization in the subbase (without fibers) is presented in Figure 11.

A summary of changes in the average CBRs of the subbase, the PC + PP or PC + MF-PP fiber stabilized subbase, and the subgrade layers are shown in Figure 12. The average values were calculated based on three to five tests per section. Bar charts of average FWD subbase modulus values of the two test sections are shown in Figure 13. The average values were calculated based on nine to ten tests per section. Figure 13 also shows the FWD modulus of a portion of the 6th St. North section that was reinforced with PP fibers without PC. (Note that only one test was performed in this section during each testing time.)

CBR and FWD modulus of the subbase layers and CBR of the stabilized layers achieved peak values about three months after construction. On average, CBR values in the PC + PP fiber and



Figure 7. Proctor sample (4 in. diameter) of PC + PP black fiber-stabilized subbase material

PC + MF-PP fiber stabilized subbase layers were similar. FWD modulus of the subbase layer stabilized with fibers (without PC) showed lower values at all three times of testing compared to sections stabilized with PC + fibers.

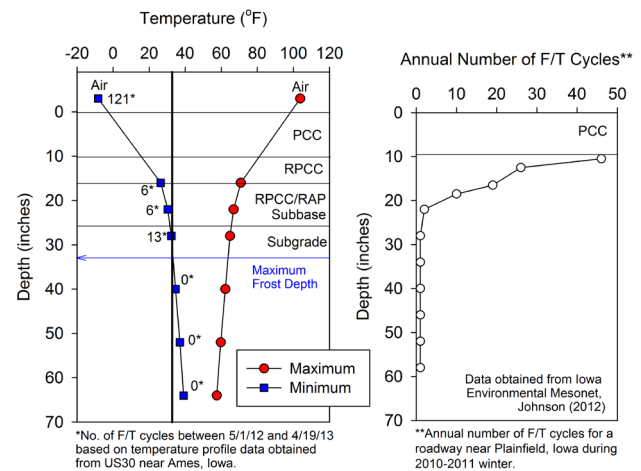


Figure 8. Maximum and minimum temperatures and number of F/T cycles recorded at various depths in pavement foundation layers from US Highway 30 near Ames, Iowa (left) and Annual number of F/T cycles recorded on a roadway near Plainfield, Iowa during winter 2010-2011 (right)

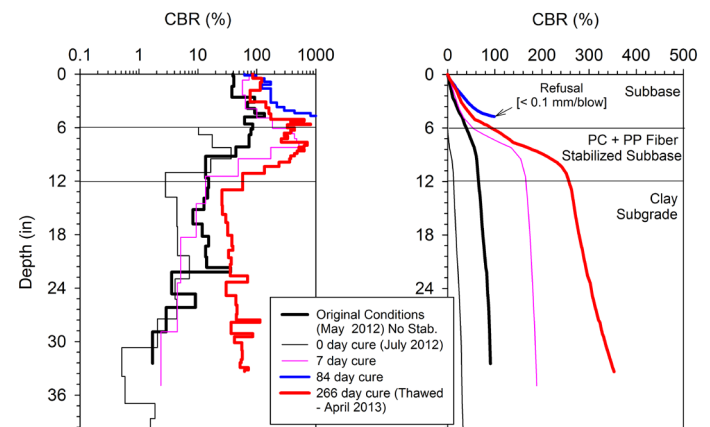


Figure 9. DCP-CBR and cumulative DCP blows with depth profiles from tests conducted on PC + PP fiber-stabilized subbase section before stabilization and at four different times after stabilization

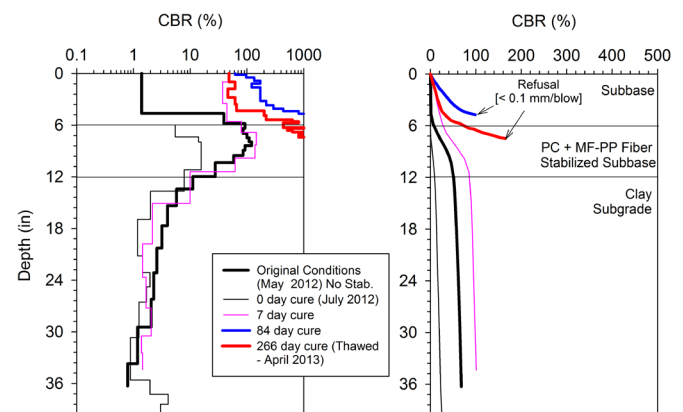


Figure 10. DCP-CBR and cumulative DCP blows with depth profiles from tests conducted on PC + MF-PP fiber-stabilized subbase section before stabilization and at four different times after stabilization

Testing during the thawing period yielded the lowest CBR and FWD modulus values. These results show weakening of the overlying unstabilized subbase during the spring thaw. The subbase layers were visibly wet during testing. The PC + fiber stabilized subbase layers were also weaker, but the CBR values were still high (> 100) and were comparable to the 7th St. PC-stabilized (with no fibers) subbase layer CBR. Additional monitoring is warranted to investigate the changes in strength and stiffness with time.

References

- Consoli, N. C., P. D. Prietto, and L. A. Ulbrich. 1998. "Influence of fiber and cement addition on behavior of sandy soil." *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 124, No. 12, 1211–1214.
- Consoli, N. C., M. D. T. Casagrande, P. D. M. Prietto, and A. Thome. 2003. "Plate load test on fiber-reinforced soil." *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 129, No. 10, 951–955.
- Consoli, N. C., F. Zortea, M. de Souza, and L. Festugato. 2011. "Studies on the dosage of fiber-reinforced cemented soils." *Journal of Materials in Civil Engineering*, Vol. 23, No. 12, 1624–1632.
- Gray, D. H., and H. Ohashi. 1983. "Mechanics of fiber reinforcement in sand." *Journal of Geotechnical Engineering*, Vol. 109, No. 3, 335–353.
- Hoover, J., D. Moeller, J. Pitt, S. Smith, and N. Wainaina. 1982. *Performance of Randomly Oriented Fiber-Reinforced Roadway Soils: A Laboratory and Field Investigation*. Iowa DOT Project HR-211, Iowa State University, Department of Civil Engineering, Ames, Iowa.
- Johnson, Alex. 2012. *Freeze-Thaw Performance of Pavement Foundation Materials*, MS thesis, Iowa State University, Ames, Iowa.
- Kaniraj, S.R., and V.G. Havanagi. 2001. "Behavior of cement-stabilized fiber-reinforced fly ash-soil mixtures." *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 127, No. 7, 574–584.

Newman, J. K. and D. J. White. 2008. "Rapid assessment of cement and fiber-stabilized soil using roller-integrated compaction monitoring." *Transportation Research Record: Journal of the Transportation Research Board*, No. 2059, 95–102.

Santoni, R. L., and S. L. Webster. 2001. "Airfields and road construction using fiber stabilization of sands." *Journal of Transportation Engineering*, Vol. 127, No. 2, 96–104.

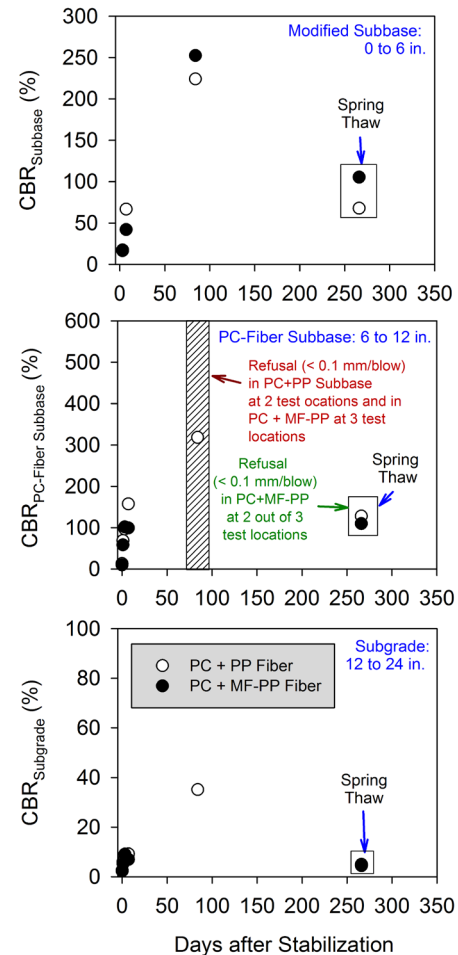


Figure 12. Average CBR (three to five tests) of subbase, PC + PP fiber or PC + MF-PP fiber-stabilized subbase, and subgrade with curing time

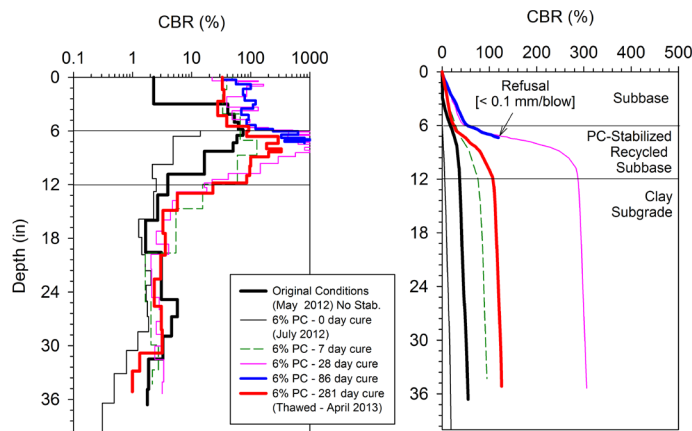


Figure 11. DCP-CBR and cumulative DCP blows with depth profiles from tests conducted on 7th St. South before stabilization and at five different times after stabilization with 6% PC in recycled subbase

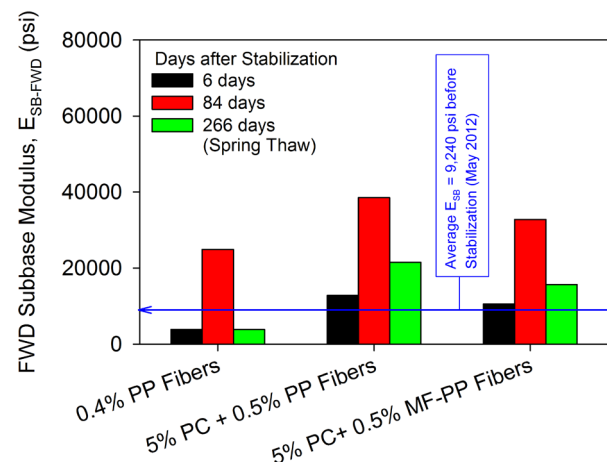


Figure 13. Average FWD subbase modulus (nine to ten tests) from PP fiber, PC + PP fiber, and PC + MF-PP fiber-stabilized subbase sections