California Bearing Ratio Improvement of Remolded Soils by the Addition of Polypropylene Fiber Reinforcement

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The California bearing ratio (CBR) of a micaceous silt, common to the Piedmont in the southeastern United States, was significantly enhanced by the addition of discrete polypropylene fiber reinforcement. Dosages of fiber ranging from 0.09 to 1.5 percent of the soil's dry unit weight were used in soil compacted to 100 percent of its standard Proctor maximum dry density. Fiber configurations consisted of monofilament fiber of 0.38- and 0.76-mm diameter as well as an equivalent fibrillated fiber of 0.38-mm diameter, a lattice-work comprising smaller-diameter webs and stems. Fiberlengths were 19 and 25 mm. The addition of fiber increased the CBR values 65 to 133 percent over unreinforced specimens, depending on fiber configuration and dosage. CBR values using 25-mm-long, 0.76-mm monofilament fiber reinforcement increased significantly up to a dosage of 1 percent, then began to decrease. The test results indicated that there is an optimum fiber dosage as well as an optimum configuration for improving a compacted soil's CBR value.

Limited data and research are available concerning improvement of the engineering properties of soils caused by the addition of random discrete fibers. Far more research has been performed on oriented soil-geosynthetic systems, including fabrics, geogrids, and fibers oriented perpendicular to a direct-shear failure plane. Of the research performed using random fibers, granular soils were typically used. Fibers used included fiberglass, polypropylene, steel, and cellulose (wood byproducts, reeds, etc.).

Compacted granular materials generally have excellent strength, incompressibility, and bearing ratios, and are not typically thought of as needing improvement. Thus, one of the primary objectives of this research was to identify if the addition of discrete, commercially available fibers could enhance the California bearing ratio (CBR) of soils with a significant cohesion strength component. Cohesive soils typically exhibit CBR values inferior to those of granular soils. The fibers themselves should be readily available, durable, and capable of being easily integrated into fill placement and compaction. Ease of placement implies that the fiber should be resistant to curling, bulking, clumping, etc. Furthermore, the testing associated with this approach should be routinely performed by the practicing geotechnical engineering community because the applicability and design values obtained from this technique must be verified in local practice.

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LITERATURE REVIEW

Virtually no published research is available concerning the effect on California bearing ratio from the addition of discrete fibers to compacted soil. Several papers have been published that discuss the effects of fiber reinforcement on compacted soil-cement. Craig et al. (*1*) performed testing on fiber-reinforced soil-cement test specimens. Fibers tested included straight steel, hooked steel, polypropylene, and fiberglass. Two fiber dosages were used (either 0.75 and 1.5 percent, or 1.0 and 2.0 percent), presumably added on the basis of percent dry weight. The soils tested consisted of a clean sand and a clayey sand. The tests performed included compressive strength, split tensile strength, direct shear strength, freeze-thaw, and wet-dry tests. Test results were variable, indicating that various fibers either enhanced or detracted from properties compared with unreinforced specimens, on the basis of fiber type, material tested, and the test performed.

Satyanarayana et al. (*2*) performed split tensile and compression tests of fiber-reinforced, soil-cement specimens where the tested soil consisted of a clay with a plasticity index (PI) of 33. Fibers tested consisted of asbestos and fiberglass, with dosages ranging from 1 to 3 percent by weight. Cement content values were 6, 8, and 10 percent. Both the tensile and compressive tests indicated a significant enhancement of strength at all cement content values and with all fiber dosages.

LeFlaive (*3*) and LeFlaive and Liausu (*4*) presented a patented process by which continuous strands of monofilament fiber were integrated into the subgrade. Triaxial strength testing of granular specimens reinforced in this manner indicate enhanced strength and modulus. Polypropylene fibers were typically used at dosages of 0.14 and 0.2 percent.

Gray and Ohashi (*5*) performed direct shear tests of beach sand reinforced with a variety of materials, including reeds, PVC plastic, or copper wire. The reinforcing was placed at varying angles to the shear plane both in dense and loose sand. Gray and Al-Refeai (*6*) performed triaxial tests using beach sand with reeds or fiberglass filament reinforcement oriented randomly throughout the specimens. This testing indicated that the shear strength typically increased with the addition of more fiber, and increased with an increase in fiber length. Their research also indicated that there was a critical confining stress above which failure envelopes for the fiber-reinforced material paralleled the failure envelope for the unreinforced material. Below a critical confining stress, the failure envelopes for the fiber-reinforced soils were steeper than the failure envelope for the unreinforced material, indicating a higher apparent angle of internal friction. The addition of fiber tended to increase the compression modulus over unreinforced sand.

Gray and Al-Refeai (*6*) also studied the effects of fiber dosage. For a given length-to-diameter ratio (aspect ratio), there seemed to be an asymptotic relationship between dosage and shear strength increase. Gray and Al-Refeai (*6*) also suggested that the critical confining stress could vary significantly with fiber smoothness, i.e., smoother fibers could exhibit a higher critical confining stress. Data also indicated that progressively higher aspect ratios decrease the critical confining stress.

Freitag (*7*) performed unconfined compressive strength testing on both reinforced and unreinforced sandy clay with a plasticity index of 22. Several polymer-based fibers were used, and the reinforced soil exhibited higher unconfined compressive strength values than the unreinforced soils. The percent strength gain was most apparent in specimens remolded at moisture contents wetter than optimum. Modulus values of all reinforced specimens were comparable to slightly inferior to the unreinforced specimens.

Noorany and Uzdavines (*8*) and Maher and Woods (*9*) have performed dynamic testing on randomly oriented fibers within sand. In both instances, there was a significant increase in the reinforced sand's shear modulus. Polypropylene fiber of various configurations was used. Dosages were 0.38 percent by weight (*8*) and from 1 to 5 percent by weight (*9*). Maher and Woods (*9*) also indicate that shear modulus is a function of aspect ratio, i.e., a higher aspect ratio yields a higher reinforced shear modulus. Furthermore, this research indicates an asymptotic relationship between fiber content and improvement in soil properties.

Setty and Chandrashekar (*10*) performed laboratory plate load tests on a clayey sand (PI = 10) reinforced with polypropylene fiber at dosages of 1, 2, and 3 percent, by weight. The 1 and 2 percent dosages showed an increase in ultimate bearing capacity over the unreinforced specimens, with the 2 percent dosage showing the most improvement. The 3 percent dosage had a decrease in ultimate bearing capacity compared to the unreinforced specimens. For a given load, the 1 and 2 percent reinforced specimens demonstrated less settlement than the unreinforced specimens. The 3 percent reinforced specimens had greater settlement than the unreinforced specimen.

Shewbridge and Sitar (*11*) describe a model for quantifying the effects of fiber reinforcement on the basis of shear zone width, fiber length, stiffness, and concentration. Their work was performed using large direct shear apparatus and a layered reinforcement-sand system. Reinforcement consisted of parachute cords, bungee cords, wood, aluminum, and steel rods.

A recent article published in the *Texas Contractor* (*12*) indicated the commercial feasibility of blending polypropylene fiber into soil for subgrade stabilization. Fibrillated polypropylene 25 mm long was blended into the soil at a rate of 109 g/m^2. A 7 percent cement stabilizer was also added. Fibers were spread with a specially modified former manure spreader and blended into the soil with a Bomag MPH100R. The fiber added an immediate load-carrying capacity to the processed subgrade, allowing quicker access by heavy construction equipment.

INITIAL TESTING

Purpose and Scope

The initial testing phase was conducted in 1985 and designed more as a qualitative "what will happen" to the CBR value of a cohesive material if discrete polypropylene fibers were blended. The soil selected was a residual silt derived from the in-place weathering of rock. The fiber selected was 0.76-mm monofilament polypropylene cut to 25-mm length (aspect ratio = 33). The fiber dosages were ½, 1, and 1½ percent, by weight, of the dry soil sample. These dosages were selected on the basis of perceived economics, as the greater cost of fiber at higher dosages was assumed to negate an increase in benefit. Polypropylene was chosen because of its availability, resistance to ultraviolet degradation, chemical stability, and reasonably high strength characteristics. The 25-mm length was deemed compatible with the sample size (152.5-mm diameter) and piston diameter (49.5 mm) and exhibited excellent resistance to bulking and curling. Bulking and curling were perceived as the primary impediments to easily blending the fiber during commercial placement. Table 1 presents the pertinent material properties and configuration of the initial test fiber.

The soil selected was a residual reddish brown fine sandy silt derived from the in-place weathering of metamorphic bedrock. The sample location was Simpson, South Carolina. Overstreet and Bell (*13*) found that the sample location is within the Southern Piedmont physiographic province. Likely parent material of the soil is a Precambrian granitoid gneiss within the Charlotte Group of rocks. The reason this soil was selected is that the Piedmont-derived silts typically exhibit poorer CBR characteristics than Coastal Plain material found within the same general area of practice. Table 2 presents the index properties of this material.

Test Procedures

All testing was performed in general accordance with the then current edition of the American Society for Testing and Ma-

TABLE 1 INITIAL STUDY FIBER PROPERTIES

Fiber	Diameter, mm	Length, mm	Specific Gravity	Tensile Strength, kPa x 10^5	Tensile Modulus, kPa x 10^5
Monofilament Polypropylene	0.76	25	0.91	9.9	7.5

TABLE 2 TEST SOIL INDEX PROPERTIES

Property	Test Results
Specific Gravity	2.79
Gravel, % (>4.75 mm)	0
Sand, % (>0.075 mm; <4.75 mm)	13
Silt, % (>0.005 mm; <0.075 mm)	30
Clay, % (<.005 mm)	57
Liquid Limit, %	52
Plasticity Index, %	17
Natural Moisture Content, %	24
Unified Soil Classification	MH

terials (ASTM), Volume 4.08 (*14*). Three standard Proctor compaction tests (ASTM D698) were performed on each of the soil-fiber mixtures as well as a control (nonfiber) specimen. All tests were performed by technicians working in the geotechnical laboratory of a geotechnical consulting firm, with the testing integrated into the everyday routine of the firm. The Proctor samples were first oven-dried, and each Proctor soil specimen was weighed to the nearest gram. The dosage of fiber was calculated, and the fiber was weighed on an electronic balance to ±0.01 g. The fiber was then added to the sample and blended by hand until a uniform mix was visually obtained. Water, measured to the nearest milliliter, was then added and the mixture again hand blended to achieve a uniform consistency. The samples were then allowed to cure for a period of at least 24 hr before molding. This blending procedure was used in all subsequent phases of testing.

The maximum dry density and optimum moisture content for each soil and soil-fiber group were taken as arithmetic averages of the three tests, and this information was used to mold the CBR specimens. The CBR tests were performed in general accordance with ASTM D1883 (*14*). The CBR specimens were molded to a density equal to approximately 100 percent of the soil's or soil-fiber's standard Proctor maximum dry density, approximately at its optimum moisture content. The samples were molded in six lifts using a manual tamp 50 mm in diameter with machined graduations to obtain approximately equal lift densities. Three specimens per dosage (including control specimens) were molded in this manner.

The CBR specimens were then placed in a water bath in a controlled temperature environment, and allowed to soak for a period of 96 hr. A surcharge stress of about 3.64 kPa was applied using steel weights. Volume change measurements were taken with a dial gage accurate to the nearest 0.03 mm (0.001 in.).

After the 96-hr soaking period, CBR tests were then performed. Deflection readings were taken with a dial gage accurate to 0.03 mm (0.001 in.) and load was obtained from an 8.9-kN proving ring. CBR was calculated according to ASTM D1883 (*14*), and the arithmetic average of the three tests was calculated per dosage.

Initial Test Results

Table 3 presents the average Proctor test results. As can be identified from this table, the addition of increasing volume of fiber generally caused a modest increase in maximum dry density as well as a slight decrease in optimum moisture content. Note that the moisture content was calculated as the weight of water divided by the weight of solids, including soil and fiber. This approach was deemed the most practical, as it was difficult to separate and remove the individual fibers from the soil. Although the maximum dry density at 1 percent fiber was the same as for the ½ percent fiber dosage, the maximum dry density generally increased with a higher fiber content. The no net change in maximum dry density from ½ to 1 percent dosage would tend to substantiate the general premise by Hoare (*15*) that the inclusion of fibers increased the resistance to densification. However, a dosage of fibers at 1½ percent of the soil's dry weight increased the maximum dry density of the soil-fiber mix.

The CBR test results are presented on Table 4. No corrections to CBR values were required because all plots of penetration versus stress were initially linear. The calculated CBR values at 5.08 mm were, in all instances, greater than those at 2.54 mm. Thus, the higher CBR values at 5.08 mm are presented in Table 4. An increase in fiber content actually tended to decrease the CBR value. Recall that the maximum dry density for the soil with 1½ percent fiber by weight was greater than the maximum dry density for both the ½ percent and 1 percent fiber dosage. An increase in density logically should yield a higher CBR value. However, more swell occurred in the 1 and 1½ percent dosages than in the unreinforced specimens. The swell in the ½ percent dosage was

TABLE 3 INITIAL STUDY PROCTOR TEST SUMMARY

Material	Average Maximum Dry Density, kg/m³	Average Optimum Moisture Content, %
Soil	1505.8	28.0
Soil Plus 0.5 % Fiber[1]	1531.5	26.7
Soil Plus 1.0 % Fiber[1]	1531.5	26.1
Soil Plus 1.5 % Fiber[1]	1541.1	25.5

[1]0.76 mm monofilament polypropylene, 25 mm long, weight of fiber based on dry weight of soil, i.e., fiber weight = (percent/100)(dry soil weight)

TABLE 4 INITIAL STUDY CBR TEST RESULTS

Material	Average Swell, %	CBR at 5.08 mm Penetration
Soil	0.14	5.4
Soil Plus 0.5 % Fiber[1]	0.13	11.7
Soil Plus 1.0 % Fiber[1]	0.28	12.6
Soil Plus 1.5 % Fiber[1]	0.17	11.7

[1]0.76 mm monofilament polypropylene, 25 mm long, weight of fiber based on dry weight of soil

comparable to slightly less than the swell obtained for the unreinforced specimens. The greater number of coarse fibers may have created more avenues for water to infiltrate the specimens, contributing to a higher swell. Greater swell could also have occurred because of elastic expansion of the randomly oriented fibers.

The data show a decrease in CBR values for the 1½ percent dosage, indicating there is an optimal fiber dosage beyond which CBR values decrease. It is possible that the larger volume of fibers in the 1½ percent dosage caused many of the fibers to be in contact with one another. The slick finish of the fibers would tend to decrease the punching shear resistance if there were considerable fiber-to-fiber contact.

The results of this initial testing were deemed favorable. These results formed the basis of subsequent laboratory testing performed in 1988.

SUPPLEMENTARY TESTING

Purpose and Scope

Crude calculations of likely in-place costs, even with only a ½ percent inclusion of 0.76-mm monofilament polypropylene fiber, indicated that the process may not warrant widespread use simply because the cost of the fiber was significant compared with the likely benefit obtained in a thinner pavement section. In order to reduce the cost, an equivalent number of 0.38-mm monofilament polypropylene fiber was substituted to determine if the number of fibers was a principal governing criterion rather than its diameter. Also, an equivalent 0.38-mm-diameter fibrillated polypropylene fiber, composed of a lattice-work array of webs and stems that could stretch laterally, was selected to identify if style of fiber could possibly influence the CBR value. The number of fibers for this new phase of testing was based on the previous ½ percent fiber dosage.

In a further attempt to minimize the weight of fiber and subsequent in-place costs, the fiber length was reduced from 25 to 19 mm. For example, the number of 0.76-mm fibers per cubic meter is approximately 744,150, based on a ½ percent by weight fiber dosage. The weight of 25-mm-long fibers in each cubic meter would then be 7.68 kg. If the same number of fibers were used, but the diameter reduced to 0.38 mm and the length reduced to 19 mm, the resulting weight of fiber per cubic meter would be reduced to 1.46 kg. Thus, the calculated dosage of the 0.38-mm fiber that would yield the same number of fibers as the ½ percent dosage of 0.76-mm fibers is 0.09 percent, by weight. The length reduction increased the aspect ratio of the new fibers to 50. Table 5 presents a summary of the fiber properties used for the supplemental testing.

The fibrillated fiber comprises webs and stems, and resembles a lattice-work when stretched. The fiber is also a flat, rectangular tape shape rather than the cylindrical shape of the monofilament fiber. The individual fibers that make up this lattice-work are of much smaller equivalent diameter (0.11-mm stems and 0.08-mm webs) than the composite diameter of 0.38 mm. The lattice-work would likely break apart to various degrees during blending, thus disseminating a larger number of smaller-diameter fibers implied by the previous calculations.

TABLE 5 SUPPLEMENTAL STUDY FIBER PROPERTIES

Fiber	Diameter, mm	Length, mm	Specific Gravity	Tensile Strength, kPa x 10^5	Tensile Modulus, kPa x 10^5
Monofilament Polypropylene	0.38	19	0.91	5.7	7.5
Fibrillated Polypropylene	0.38[1]	19	0.91	6.2	7.1

[1]Composite diameter comprised of 0.11 mm stems and 0.08 mm webs

Supplementary Test Procedures

The test procedures used for this phase of testing were the same as those procedures used for the initial phase of testing. The necessary Proctor tests both for the 0.38-mm monofilament and 0.38-mm fibrillated fibers were performed to identify the maximum dry density and optimum moisture content to which test specimens would be molded.

Supplementary Test Results

Proctor test results are presented in Table 6. The control specimen and ½ percent, 0.76-mm dosage test results are included for comparison. Addition both of the 0.38-mm monofilament and 0.38-mm fibrillated fiber caused an increase in the average maximum dry density beyond that of the control (nonfiber) and ½ percent 0.76-mm monofilament specimens. The optimum moisture contents for the new fiber types were less than the control and ½ percent 0.76-mm monofilament specimens. The 0.38-mm fibrillated fiber specimens exhibited the highest maximum dry density and lowest (or comparably lowest) optimum moisture content of all specimens tested, including the previously tested 1½ percent, 0.76-mm fiber-reinforced specimens.

CBR test results are presented in Table 7. Again, no corrections to CBR values were required because of the linearity of the initial portions of the plots of penetration versus stress. The calculated CBR values at 5.08 mm were again greater than those at 2.54 mm. In all instances, addition of fibers significantly increased the CBR value, compared with those of unreinforced specimens. The sample with the 0.38-mm fibrillated fiber came closest to duplicating results achieved with the larger-diameter, longer, 0.76-mm monofilament fiber. However, neither of the smaller-dosage, smaller-diameter fiber-reinforced specimens matched the CBR values of the previously tested ½ percent, 0.76-mm monofilament, fiber-reinforced specimens.

The smaller-dosage, smaller-diameter, fiber-reinforced specimens swelled approximately twice the magnitude of the control and larger-dosage, larger-diameter specimens. An increase in dry density of the smaller-diameter reinforced specimens is probably responsible for the majority of the swell increase.

CONCLUSIONS

The addition of polypropylene fibers significantly improved the CBR value of the soils tested. The improvement ranged from a 65 percent increase for the 0.09 percent, 19-mm-long, 0.38-mm-diameter monofilament fiber dosage to a 133 percent increase for the 1.0 percent, 25-mm-long, 0.76-mm-diameter, monofilament fiber dosage.

The initial research suggests that there is an optimal fiber dosage for improvement of the CBR value. Table 4 indicates that the dosage that yields the greatest improvement in CBR value is approximately 1 percent. Dosages greater than the optimal dosage decrease the CBR value. With increasing fiber content, there was a decrease in confining soil between the fibers, possibly to the extent that sliding occurred at fiber-to-fiber contact points.

Soil reinforcement with the same number of shorter, 19-mm-long, 0.38-mm-diameter monofilament fiber reinforcement did not produce the same CBR as specimens reinforced with the 25-mm-long, 0.76-mm-diameter monofilament fiber. The longer length and greater cross sectional area of the 0.76-mm-diameter fibers compared to the 0.38-mm monofilament fibers appear to be more important criteria than the number of fibers in enhancing the CBR. Gray and Ohashi (*5*) found that a decrease in fiber length should decrease shear resistance. Conversely, Gray and Al-Refeai (*6*) describe data that indicate there should be a shear strength increase with increasing aspect ratio. The aspect ratio for the 0.38-mm-diameter monofilament fiber was 50 compared with 33 for the 0.76-mm-diameter monofilament fiber. This difference suggests that the concept of increasing the fiber's aspect ratio to achieve a higher strength or CBR is probably only valid for one fiber type where only the length is varied, not comparing several fibers of similar configuration whose lengths and diameters vary.

Specimens reinforced with the same number of 19-mm-long, 0.38-mm equivalent diameter fibrillated fibers yielded a 16 percent higher CBR than the 0.38-mm-diameter mon-

TABLE 6 SUPPLEMENTAL STUDY PROCTOR TEST SUMMARY

Material	Average Maximum Dry Density, kg/m³	Average Optimum Moisture Content, %
Soil	1505.8[1]	28.0[1]
Soil Plus 0.5 % 0.76 mm Monofilament Fiber, 25 mm Long	1531.5[1]	26.7[1]
Soil Plus 0.09 % 0.38 mm Monofilament Fiber, 19 mm Long	1537.9	26.0
Soil Plus 0.09 % 0.38 mm Fibrillated Fiber, 19 mm Long	1558.7	25.6

[1]Test results from initial study

ofilament fiber-reinforced specimens, and came closest to duplicating the CBR values for the 25-mm-long, 0.76-mm-diameter monofilament fiber-reinforced specimens (see Table 7). These results suggest that fiber configuration or shape can significantly affect CBR values. The fibrillated fiber is a relatively flat and rectangular tape shape compared with the cylindrical configuration of the monofilament fiber. A small percentage of the fibrillated fiber did break apart into smaller segments of webs and stems, and thus the total number of discrete fibers disseminated throughout the soil mass was more than that calculated. Thus, the slightly greater number of fibrillated fibers could have contributed slightly to the greater CBR value of the fibrillated fiber-reinforced specimens.

Addition of fiber generally increased the standard Proctor maximum dry density. The increase in Proctor maximum dry density does not substantiate the premise by Hoare (*15*) that the inclusion of fibers increases the resistance to densification.

Table 6 indicates that 0.38-mm, fibrillated, fiber-reinforced specimens exhibited the highest maximum dry density and lowest optimum moisture content of all the specimens tested. A logical expectation would be that these specimens should exhibit the highest CBR value of all specimens tested. However, the highest CBR value was obtained with a specimen reinforced with a 1 percent dosage of 0.76-mm-diameter monofilament fiber 25 mm long that exhibited a dry density approximately 2 percent less and an optimum moisture content approximately 2 percent more than the 0.38-mm, fibrillated, fiber-reinforced specimen. Thus, assessment of traditional nonreinforced soil mechanics indices of maximum dry density and optimum moisture content to postulate the results of CBR tests on fiber-reinforced specimens is probably not valid.

Likewise, use of swell measurements as indicators to predict CBR results of fiber-reinforced soils does not appear to be valid. Table 4 indicates that the swell for the 1 percent dosage of 0.76-mm-diameter fiber is approximately double the swell of both the ½ and 1½ percent dosages. However, the CBR value for the 1 percent dosage is about 8 percent greater.

DISCUSSION OF RESULTS

The addition of polypropylene fiber significantly improved the CBR values of the soils tested. These results, coupled with the dynamic testing results obtained by Noorany and Uzdavines (*8*) and Maher and Woods (*9*), suggest a potentially significant approach to improving soil subgrade support characteristics.

The 1986 *AASHTO Guide for Design of Pavement Structures* (*16*) recommends that the soil's resilient modulus be used in the design of flexible pavements and that the soil's modulus of subgrade reaction be used for the design of rigid pavements. From the literature review, it is apparent that the addition of fiber significantly improves the dynamic shear modulus of the materials tested, and that the bearing capacity and incompressibility of a fiber-reinforced soil can be superior to an unreinforced soil. It is, therefore, likely that the addition of fiber could improve the resilient modulus as well as modulus of subgrade reaction used for these designs. Detailed research should be performed to quantify the degree of improvement, taking into account fiber finish, length, shape, and dosage. The research should focus on commercially available fibers that can easily be blended into the soil.

The subgrade stabilization project in Texas (*12*) demonstrated that discrete fiber can be easily mixed and compacted into subgrade soils by equipment commonly used in subgrade stabilization. The fibrillated fiber used in this application is also commercially available, and is identical to the fibrillated fiber used in the previously discussed research. The testing associated with this research could have been performed by numerous public agencies and commercial firms, not just university environment research facilities. Although continuing research must still be performed to properly quantify the mechanisms of CBR enhancement, there is sufficient evidence in the literature and this current research to indicate that the addition of fiber to improve soil subgrade support is a practical, quantifiable, and biddable process.

The research indicates that there could possibly be "designer fibers" that could have application for different types of soil. Fiber is manufactured in many shapes and finishes, and it is possible that these different manufactured products could provide an optimal CBR increase for different soils. For example, the tape shape may be more beneficial for CBR enhancement in cohesive soils, and the monofilament shape may be more beneficial in granular soils. Further research should be performed to study the effects of fiber finish, length,

TABLE 7 SUPPLEMENTAL STUDY CBR TEST RESULTS

Material	Average Swell, %	CBR at 5.08 mm Penetration
Soil	0.14[1]	5.4[1]
Soil Plus 0.5 % 0.76 mm Monofilament Fiber, 25 mm Long	0.13[1]	11.7[1]
Soil Plus 0.09 % 0.38 mm Monofilament Fiber, 19 mm Long	0.26	8.9
Soil Plus 0.09 % 0.38 mm Fibrillated Fiber, 19 mm Long	0.30	10.3

[1]Test results from initial study

shape, and dosage on CBR values. Again, the research should focus on fibers that are commercially available and can easily be blended into the soil.

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