

STATE OF FLORIDA



FULL-SCALE LABORATORY EVALUATION OF POLYPROPYLENE FIBER REINFORCEMENT OF SUBGRADE SOILS

**Research Report
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EXECUTIVE SUMMARY

Full scale laboratory testing was carried out to establish the magnitude of the resilient and strength properties of polypropylene fiber reinforced subgrade soils as compared to those obtained on both the traditional Florida limerock stabilized and non-stabilized (control) soils.

Two soils, from different sources, were used for the purpose of this study. The first, obtained from a St. Augustine source, had 3 percent passing a 75- Φ m (#200) sieve and an LBR value of 19. The second, from the Orlando area, had 10 percent passing a 75- Φ m sieve size and an LBR value of 32. Both sands were classified as A-3 materials based on the AASHTO classification system. A total of six material combinations were considered, namely: (1) St. Augustine sand with fibers, (2) Orlando sand with fibers, (3) St. Augustine sand with limerock, (4) Orlando sand with limerock, (5) control St. Augustine sand, and (6) control Orlando sand. Each test mixture was evaluated using a repeated load testing in the State Materials Office Test Facility for Pavement Support Layers referred to as Test Pit. Both cyclic load-deformation and resilient modulus data were collected. In addition, modified Proctor and Limerock Bearing Ratio (LBR) tests were also performed on each of the test samples.

The findings indicate that the polypropylene fibers, although significantly enhanced the strength behavior of the virgin soils, are neither a practical nor an effective alternative to limerock stabilization for pavement subgrade layers.

INTRODUCTION

The long-term performance of a pavement structure is strongly dependent upon its supporting soil conditions. Therefore, it is imperative to improve poor properties of native soil such as high plasticity, poor workability, potential for high volume changes, and low shear strength in pavement applications. These unsuitable materials characteristics are traditionally altered using stabilizing materials such as lime and cement. When added under the right temperature and moisture conditions, the stabilizing materials induce several reactions that modify some of the soil characteristics (1). The changes would then result in increased strength and stiffness of the compacted soil mixtures, thus improving the structural adequacy of the pavement system. Yet, under certain field conditions, they may also lead to weaker supporting layers due to potential infiltration of sulfate- and carbonate-bearing moisture or strong alkaline ground water conditions (2). Consequently, there has been a continuous search for potential mechanical alternative forms to chemical stabilization methods. Of interest are geosynthetic systems that include fabrics, geogrids, and fibers.

Several studies have been performed to investigate the effects of fiber reinforcements on compacted soil-cement (3, 4). The reported findings were mixed, showing that different fibers either improved or weakened the engineering properties of the test samples, depending on the type of fibers, materials tested, and the tests performed. However, the data concerning the impact due to the addition of random discrete fibers on the characteristics of compacted native or virgin soils are limited (5). Thus, there is a need for information on the effects of fibers on the properties of the pavement supporting soil layers. Ideally, the fibers themselves should be readily available, non-degradable and capable of being easily blended into the soils and compacted. The workability of fiber-reinforced materials implies that the fibers should be resistant to bulking and clumping.

OBJECTIVES

The primary objective of this study was to evaluate the effect of discrete polypropylene fibers on the performance of pavement supporting soils. The inherent goal was to produce a stabilized material with enhanced properties relative to the traditional Florida limerock stabilization. The evaluation process consisted of comparing the resilient and strength characteristics of compacted fiber-reinforced soils to those of limerock-stabilized and control (non-stabilized) virgin soils and establishing the magnitude of inherent variations in these fundamental properties.

EXPERIMENTAL PROGRAM

Test Facility for Pavement Support Layers

The Florida Department of Transportation (FDOT) maintains a full scale test facility for pavement support layers located at the State Materials Office. The schematic drawing of its principal structural components is shown in Figure 1. The test facility is a 7.2-m long by 2.4-m wide by 2.1-m deep (24x8x7 ft) concrete dugout that is commonly referred as the Test Pit. The reinforced walls of the pit confine three support layers over a structural reinforced concrete floor. The bottom layers consist of 300 mm (12 inches) of river gravel and 300 mm of builders sands separated by a fiber fabric. These layers are used to allow water to rise to the overlying materials during the soaked portion of the test series. The third layer is a 900 mm (36 inch) thickness of an A-3 sand serving as a subgrade material for all tests. This sand has 3 percent passing a 75 Φ m (#200) sieve size and a Limerock Bearing Ratio (LBR) of about 23. Note that the LBR is similar to the California Bearing Ratio (CBR), with the primary exception of using the penetration of a crushed Florida limerock as the standard reference (6). The upper part of the pit can be bulkheaded to test three combined base/subgrade sections simultaneously. The pit is also designed so that a material may be tested at different moisture levels. A sump that is filled with

river gravel surrounds the test pit. The water moves from this sump through a series of connecting galleries located at the bottom of the pit walls. Such a design feature allows the water table to be raised and lowered either to saturate or drain the test layers. The major advantage of the test pit is that it provides for testing under controlled conditions related to material properties, quality of construction, loading, and moisture. Thus, the effect of one or a combination of specific variables on the performance of the supporting layers may be isolated and evaluated.

Loading System

A Materials Testing Services (MTS) closed-loop servo-hydraulic system is used for loading application. The system is on a movable track both in lateral and transverse directions. The load is applied through a 300-mm (12-inch) diameter rigid plate. The loading plate is positioned on top of a thin layer of a gypsum cement which is cast to provide for a uniform and leveled contact area during testing. The load levels are measured using a load cell while the resulting deflections are monitored through two linear variable differential transducers (LVDT) placed 180 degrees apart on the rigid plate. It should be noted that the LVDTs are mounted on an aluminum beam which rests on the longitudinal sides of the pit. Thus, the transducers are completely independent of the loading assembly, and, hence, are not affected by the potential deflection of the load supporting beam during testing. Figure 2 shows a schematic illustration of the loading system.

The testing system is linked to a PC computer through an analog-to-digital card that converts the analog voltage signals from the load cell and LVDTs into a digital voltage output. A data acquisition system is also provided for automatic data collection and processing.

Materials

Soils

Two native soils, from different sources, were used in this study. The first was obtained from a St. Augustine source. It was a tan colored sand having 3 percent passing a 75- Φ m (#200) sieve and an LBR value of 19. The second was a darker sand from the Orlando area. It had 10 percent passing a 75- Φ m sieve size and an LBR value of 32. Both sands were classified as A-3 materials based on the AASHTO classification system. The soil descriptions are given in Table 1. These two materials were chosen because of their poor LBR characteristics for subgrade applications. The current Florida specifications require subgrade materials to have a minimum LBR value of 40, as determined using the Florida test method FM 5-515 (6).

Stabilizing Materials

Fibers

As stated previously, two stabilizing materials were considered for the purpose of this investigation, namely synthetic fibers and limerock. The fibers used were 50-mm long discrete fibrillated polypropylene strands that resemble a lattice-work when stretched. Polypropylene was chosen because it is a chemically stable and inert polymer with reasonably high strength characteristics and its availability. Presumably, during the blending process, the fibrillated fibers would open into nets or grids that would mechanically reinforce a soil. Preliminary laboratory test results indicated that a dosage at 0.2 percent of the soil's dry weight is an optimal fiber content beyond which LBR values decrease. It is possible that larger amount of fibers would cause considerable clumping of fibers, thus, decreasing the punching shear resistance of the soil-fiber mixtures (5). Therefore, a fiber content of 0.2 percent based on dry weight of soil was used for all subsequent testing.

Limerock

Florida limerocks consist of different types of grains formed from the calcium carbonate minerals calcite and aragonite. They are formed by chemical precipitation of calcium carbonate from sea water and by accumulation of skeletal remains of marine animals. These deposits are generally known by their formation names. The limerock used in this evaluation was from the Ocala formation. It was a non-plastic material with a fairly uniform gradation and a carbonate content of 94 percent. Preliminary laboratory tests showed that the optimum limerock content for stabilization applications, based on dry weight of soils, was 20 percent when blended with St. Augustine sand and 10 percent when added to the Orlando sand.

Materials Preparation

Six mixture combinations were respectively prepared and evaluated, namely, (1) St. Augustine sand-fibers, (2) Orlando sand-fibers, (3) St. Augustine sand-limerock, (4) Orlando sand-limerock, (5) raw St. Augustine sand, and (6) raw Orlando sand. Raw soils and stabilizing materials were blended using a standard concrete mixer. As mentioned earlier, a fiber content of 0.2 percent was added to both soil types while 10 and 20 percent of limerock were respectively added to Orlando and St. Augustine sands. All these dosages were based on the dry weight of soils as determined during preliminary laboratory tests. Modified Proctor compaction and LBR tests were performed on each of the soil-fiber and soil-limerock mixtures as well as on control (raw) soil specimens in accordance with the Florida test methods FM 5-515 (6) and FM 5-521 (7), respectively.

After the mixing process, the upper part of the pit was bulkheaded into three 2.4 m x 2.4 m sections. The two opposite sections were then used so that two different mixture types could be independently placed and tested at one time. Test materials were placed into the pit sections

in two 150-mm (6-inch) lifts. Each lift was compacted to a minimum of 98 percent of the lab density. Fiber-reinforced mixtures were first placed and evaluated, followed by the limerock blends then the virgin soils. It should be noted that the soil-fiber mixtures were not easily workable because of the fiber webbing during mixing. In addition, though the target density was fairly easy to achieve on the St. Augustine sand-fiber mixture, it took comparatively four times as much compactive effort to obtain that of the Orlando sand-fiber blend. This observation may be due to a combination of factors that include the type of fibers used in this application and the larger amount of fines in Orlando sand. It is possible then to speculate that the inclusion of fibrillated fibers may increase the resistance to densification of cohesive soils. The remaining soil mixtures were placed and compacted to the desired density level without difficulty. All the test mixtures were compacted using a hand-held vibratory compactor and the compaction level was monitored using a nuclear gauge density.

Materials Testing

In order to account for the effect of moisture, the different soil mixtures were tested under three moisture conditions. These conditions were, namely, (1) as compacted at or near optimum moisture, (2) drained and dried, and (3) soaked condition. Repeated loading tests were performed for 30,000 cycles and the corresponding deflections were measured for each condition.

As a conditioning phase, a static load of 8.8 kN (2000 lb) was applied in 2.2-kN (500 lb) increments. The resulting deflections were allowed to stabilize after each load increase. Then, the loading was released and the material was let to recover. This conditioning process was repeated three times to stabilize the resilient deformation.

After the initial conditioning period, the repeated (fatigue) testing phase was initiated. It

was estimated that a stress level of approximately 135 kPa (20 psi) would simulate the effects of a 40 kN (9,000 lb) wheel tire on a subgrade layer surface of a typical flexible pavement section. Thus, using the MTS loading system, a 135 kPa constant stress level was applied for up to 30,000 cycles or until fatigue failure, whichever came first. The adopted criterion for failure was a total deformation of more than 10 mm (0.4 inches). A haversine loading with a duration of 0.1 second and a rest period of 0.9 second was used in this repeated load test. It is generally accepted that a haversine waveform better simulate the actual loading occurring in the field (8). Both total and permanent deformations were recorded at a number of designated cycles. In addition, since the basis for materials characterization in the AASHTO Guide for Pavement Design is the resilient modulus (9), resilient modulus data were also collected. The resilient modulus is the elastic modulus determined based on the recoverable deformation under repeated loads. For the purpose of this investigation, the resilient modulus, M_r , at each designated number of cycles, was determined based on Burmister's theory on rigid plate loading using the following equation:

$$M_r = 1.18pa / \Delta_r \quad (1)$$

Where:

p is the applied stress, Mpa;

a is the radius of the circular loading plate, mm; and

Δ_r is the recoverable deformation at the designated number of cycles, mm.

For each moisture condition, a dynamic loading test was conducted at three different locations on each of the compacted soil mixtures. Therefore, a total of nine tests were performed per mixture type. The locations were randomly chosen, for each moisture condition, within the pattern shown in Figure 3. Each of these locations was not used more than once per soil mixture type.

DATA ANALYSIS

All the data collected during this investigation were analyzed to establish the magnitude of inherent variations in the resilient and fundamental strength properties of compacted fiber-reinforced soils as well as of those of limerock-stabilized and control (non-stabilized) virgin soils.

Maximum Dry Density

Modified Proctor test results are summarized in Table 2. As it can be seen, the inclusion of stabilizers (both fibers and limerock) significantly increased the maximum dry density of the St. Augustine sand but caused, comparatively, only a modest increase to that of Orlando sand. These laboratory results do not seem to substantiate the general premise that the addition of fibers would increase the resistance to densification. During the full scale testing phase, however, even though the target density was fairly easy to obtain on the St. Augustine sand-fiber mixture, four times as much compactive effort was required to achieve that of the Orlando sand-fibers blend. Again, as stated previously, this observation may be due to a combination of factors that include the type of fibers used for the purpose of this investigation and the cohesiveness level of Orlando sand. The material preparation and placement phase of this evaluation showed that the inclusion of fibrillated fibers significantly reduced the soil workability and, depending on the soil types, could increase the soil resistance to densification. Table 2 also shows that the addition of fibers caused a reduction in the optimum moisture content, though more significantly in the St. Augustine sand than in the Orlando sand sample. Note that the moisture content was determined based on the weight of solids, including soil and fibers, since it would not have been practical to remove the fiber strands from the soil samples. The addition of limerock, however, significantly increased the optimum moisture content in St. Augustine sand but decreased it in the Orlando sand.

LBR

Table 2 also includes the results of the LBR test. In all instances, the addition of limerock and fibers significantly improved the LBR values as compared to those of unreinforced soils. In addition, regardless of the soil and reinforcement types, the strength of test samples increased with the increase of the maximum dry density, independently of the optimum moisture content levels. This strength-density relationship is illustrated in Figure 4. Therefore, it appears that the use of the traditional soil mechanics index of maximum dry density alone as an indicator to assess the strength of reinforced soils may be appropriate.

Deformations

The average total and permanent deflections as measured on three different locations for each materials type and moisture condition during the full scale testing are illustrated in Figures 5 through 10. In all instances, as one would expect, the magnitude of the deformations decreased with the decrease of moisture level. In the case of St. Augustine sand, limerock stabilization resulted in significantly better performance at all the three moisture levels as compared to those of virgin and fiber-reinforced soils. Further, in the soaked state, which represents the most critical field condition, virgin and fiber-reinforced St. Augustine Sands failed prematurely at less than 2,000 loading cycles. These observations are also valid for the Orlando sand when drained. However, at both soaked and optimum moistures, the virgin Orlando sand resulted in lower deformation values while those of the fiber-reinforced soil were the highest. In addition, the latter material failed at 10,000 loading cycle when tested in a soaked condition. Permanent deformations as measured during a repeated load test are synonymous of rut depth. Therefore, based on these results, it may be speculated that, overall, the limerock-stabilized soils would have a better rut resistance under actual field conditions.

Resilient Modulus

The resilient modulus values are plotted in Figures 11 through 16. With the exception of the soaked St. Augustine soils (both unreinforced and fiber-reinforced), the effect of increasing the number of load repetitions on the resilient modulus is not clearly evident. For each material type and moisture condition, the modulus of resilience remained essentially constant throughout the cyclic testing. Moreover, in both soaked and drained conditions, the addition of reinforcement did not affect the stiffness of the Orlando sand. The latter was slightly improved with the inclusion of fibers and limerock at the optimum moisture level, with the limerock resulting in relatively higher values. Figure 16 shows that, unlike the fibers, the limerock significantly increase the resilient modulus of the St. Augustine sand when drained.

CONCLUSIONS

Full scale laboratory testing was carried out to assess the effects of random discrete fibers on the resilient and strength properties of compacted subgrade soils. These properties were compared to those obtained using the traditional Florida limerock stabilization and control (non-stabilized) soils. Based on the findings of this investigation, and within the test range, the following conclusions can be drawn:

- ! LBR values of both soil types were significantly enhanced by the respective inclusion of fibers and limerock.
- ! Limerock stabilization resulted in significantly better performance, in terms of deformation, as compared to that of fiber-reinforced soils. Further, in the soaked state, which represents the most critical field condition, both fiber-reinforced soil types failed prematurely.

- ! For each material type and moisture condition, the modulus of resilience remained essentially constant throughout the cyclic testing. When considering the Orlando sand, in both soaked and drained conditions, the addition of reinforcement did not affect its stiffness. In addition, the inclusion of fibers and limerock induced only marginal improvement at the optimum moisture level, with the limerock resulting in relatively higher modulus values. In the case of St. Augustine sand, the limerock, unlike the fibers, significantly increased the soils resilient characteristics while in drained state. In all other cases, the resulting variations were insignificant.
- ! Materials preparation and placement showed that the inclusion of discrete polypropylene fibers could significantly impede the soil workability and could also, depending on the soil types, increase the soil resistance to densification during actual field applications.

RECOMMENDATIONS

The present study does not provide sufficient evidence that the random discrete polypropylene fibers are as effective as the limerock in enhancing soil subgrade support characteristics for pavement applications. In addition, depending on the soil type, the fibrillated fibers may not be as easily blended and compacted into subgrade soils. It is also possible that different fiber shapes, lengths, and finishes than those considered in this investigation may provide for superior performance. However, the present findings indicate that the polypropylene fibers considered in this investigation, although enhanced the strength behavior of the virgin soils, are neither a practical nor an effective alternative to limerock stabilization.

ACKNOWLEDGMENTS

The work reported herein was the result of a team effort. Annette Malpartida provided project oversight and report on the initial data analysis and preliminary findings. Rick Venick and Kelly Hamm performed the full scale tests and collected the deflection data, while Rufus Green and the Soil Lab staff performed the modified Proctor and LBR tests. The authors are grateful for their diligent efforts and contributing knowledge.

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Table 1 Soil Description

Soil Source	AASHTO Class	Sieve Analysis, percent passing			
		Sieve Sizes, mm			
		2.00	0.425	0.250	0.075
Orlando	A-3	100	87	64	10
St. Augustine	A-3	10	87	49	3

Table 2 Results of Modified Proctor and LBR Tests

Material	Max. Dry Density, kg/m ³	Optimum Moisture Content, %	LBR
St. Augustine Sand	1675.5	10.2	19
St. Augustine + 0.2% Fiber	1713.7	7.2	45
St. Augustine + 20% Limerock	1754.4	12.0	49
Orlando Sand	1860.7	9.9	32
Orlando Sand + 0.2% Fiber	1890.2	9.3	62
Orlando Sand + 10% Limerock	1880.9	9.0	53

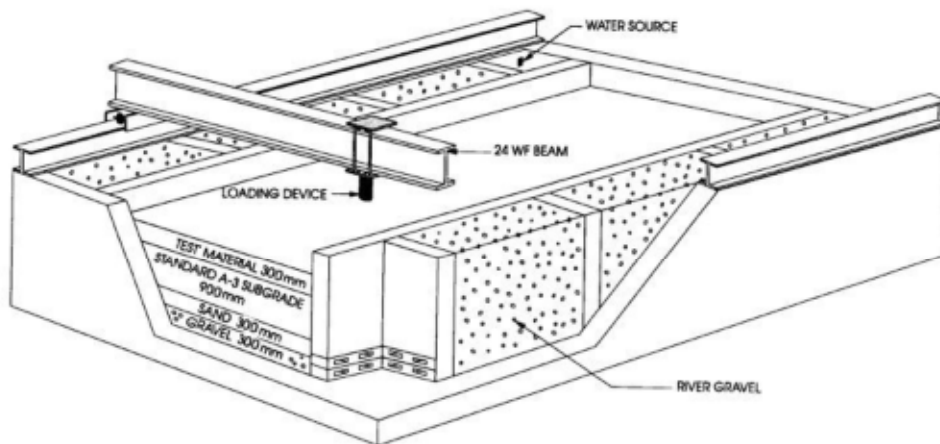


Figure 1 Schematic drawing of a sectional view of the Test Pit

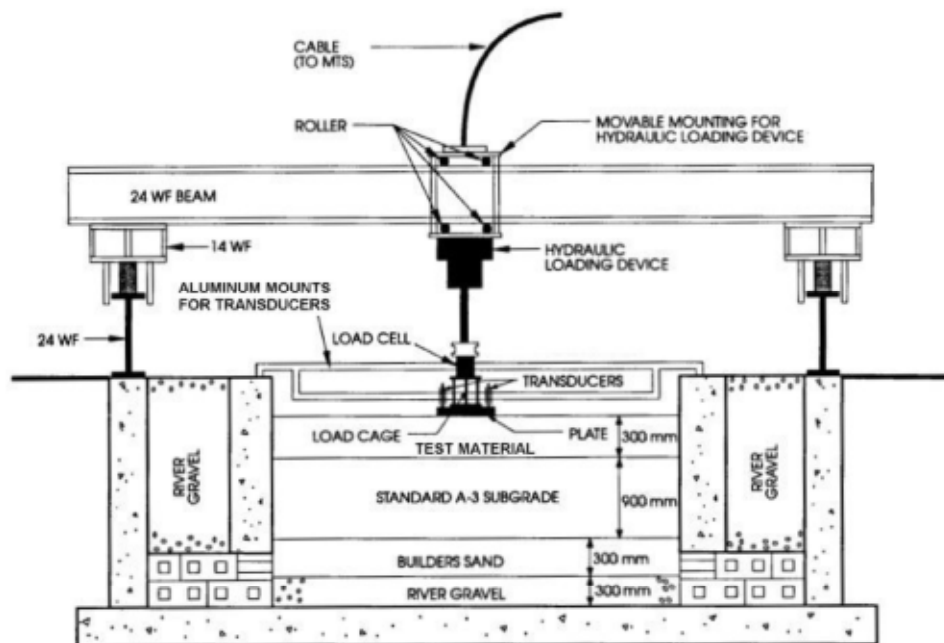


Figure 2 Schematic illustration of the testing set up

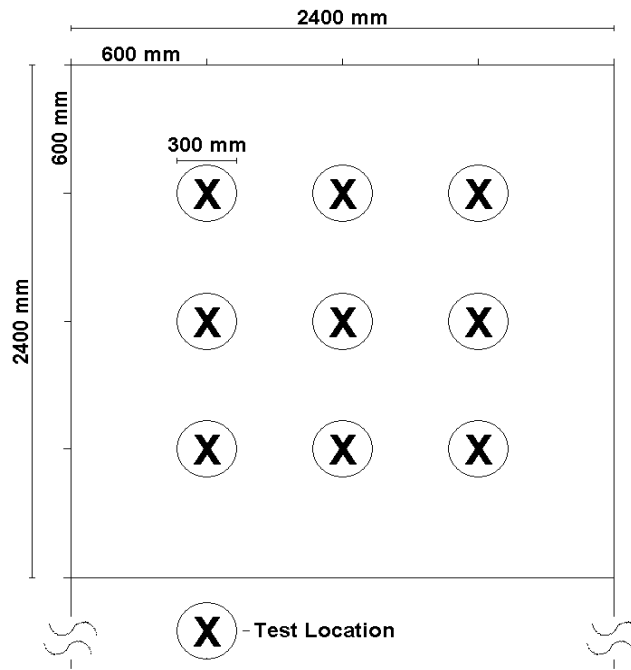


Figure 3 Lay out of loading locations per test section

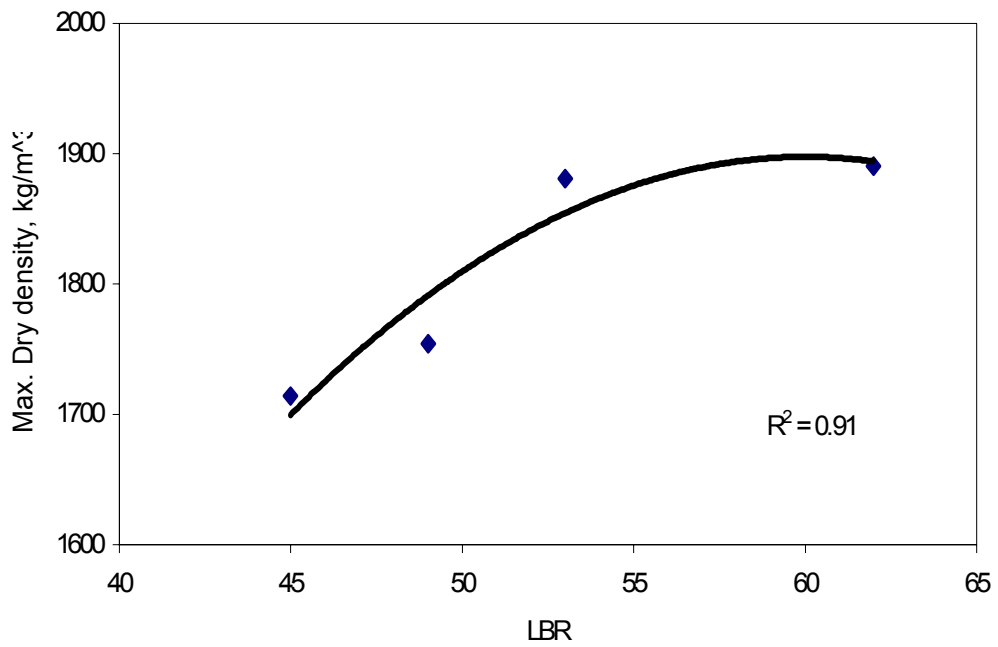


Figure 4 Strength-density relationship of test samples

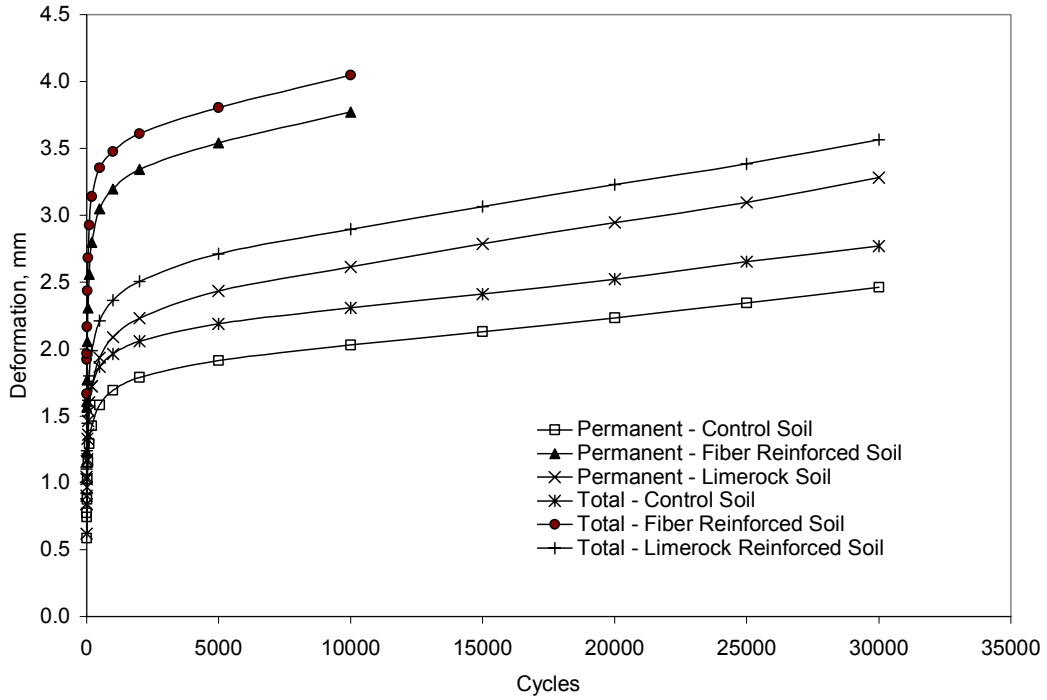


Figure 5 Average deformations as recorded for Orlando sand under soaked moisture condition

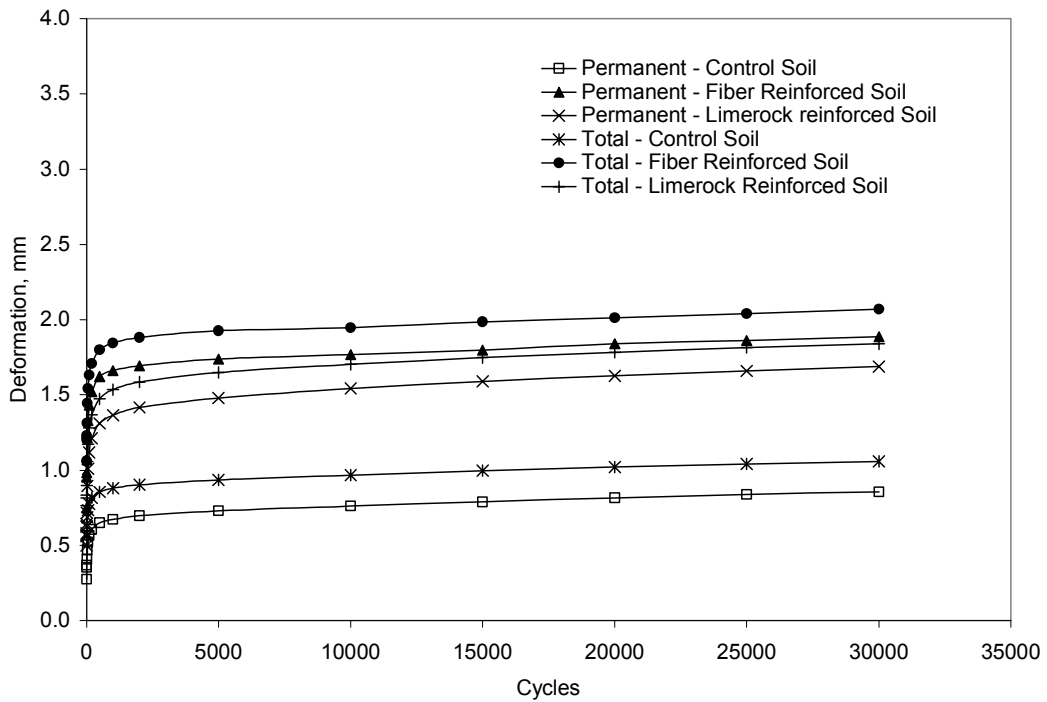


Figure 6 Average deformations as recorded for Orlando sand under optimum moisture condition

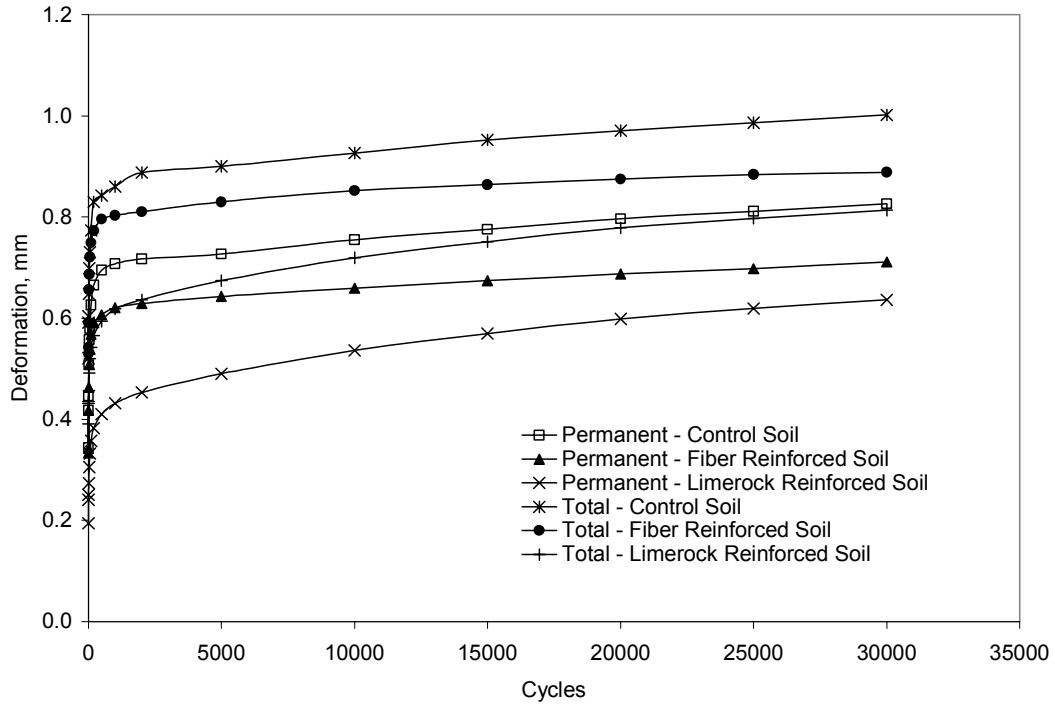


Figure 7 Average deformation as recorded for Orlando sand under drained moisture condition

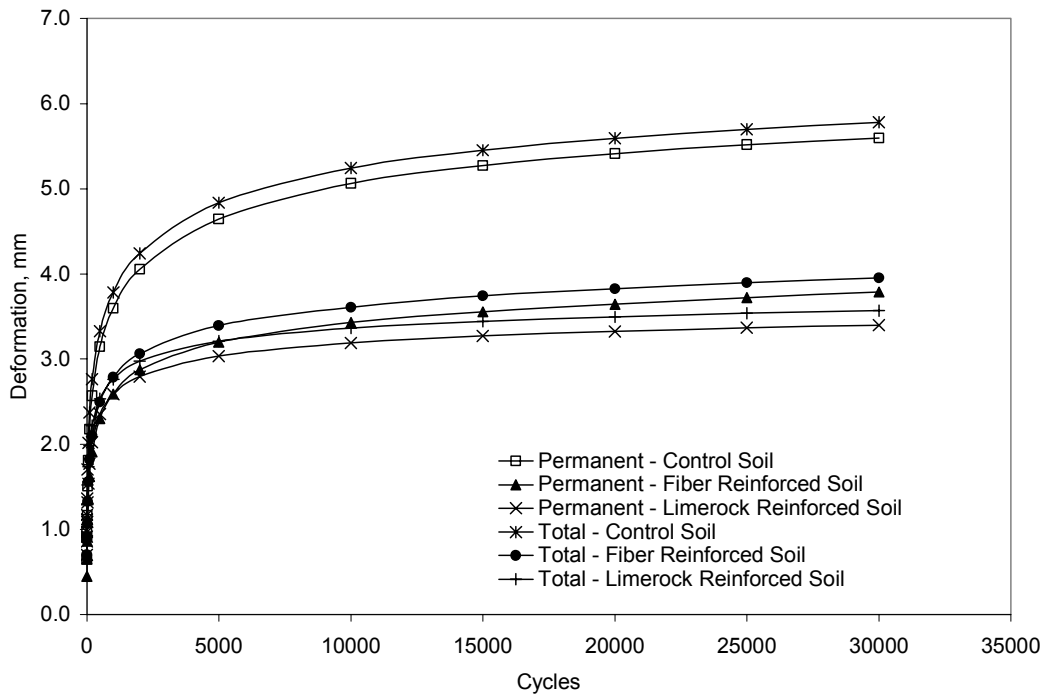


Figure 8 Average deformations as recorded for St. Augustine sand under soaked moisture condition

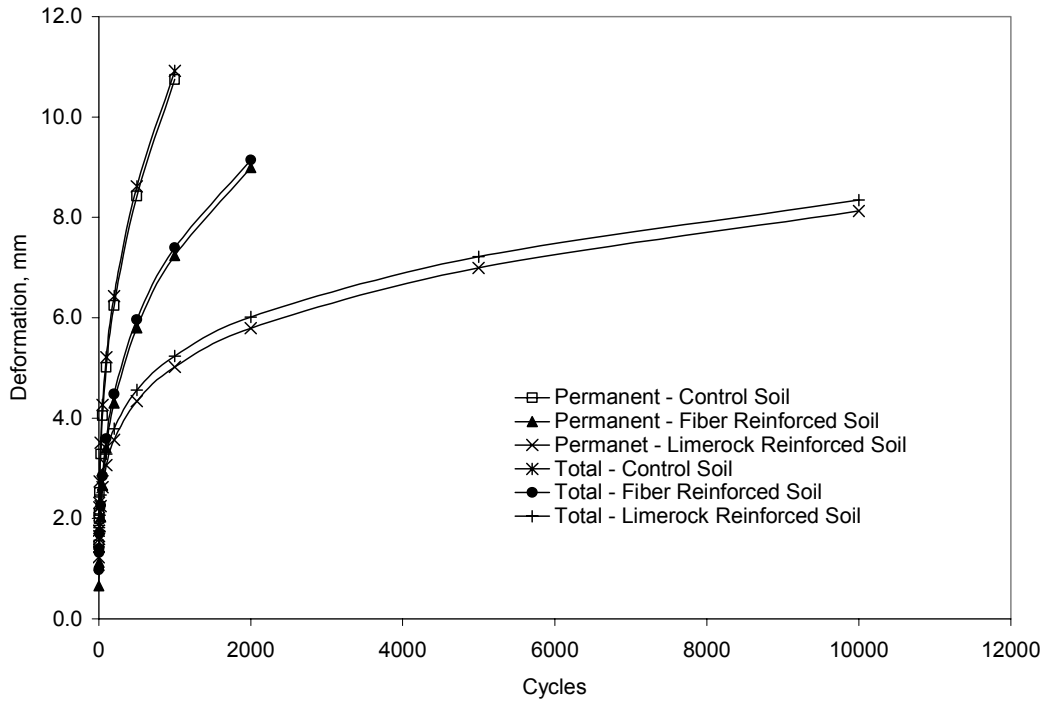


Figure 9 Average deformations as recorded for St. Augustine sand under optimum moisture condition

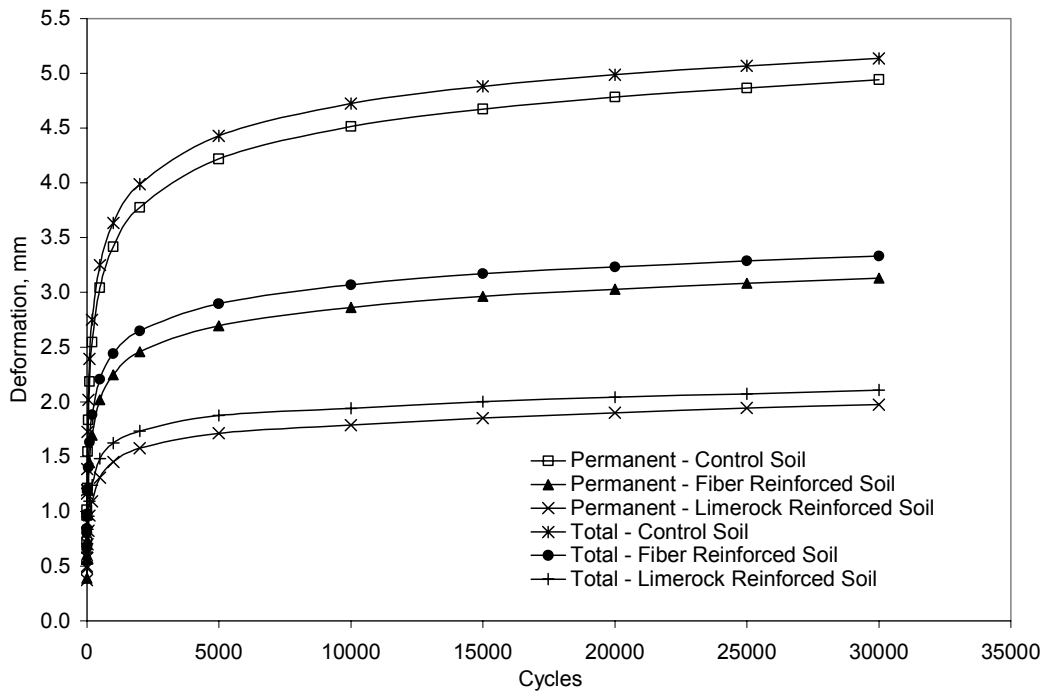


Figure 10 Average deformations as recorded for St. Augustine sand under drained moisture condition

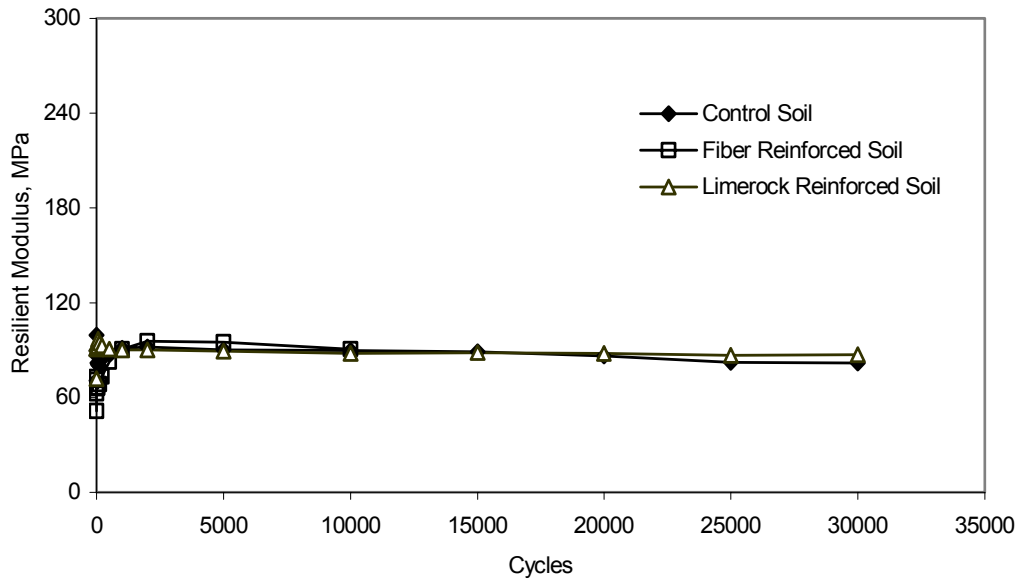


Figure 11 Resilient Modulus as recorded for Orlando sand under soaked moisture condition

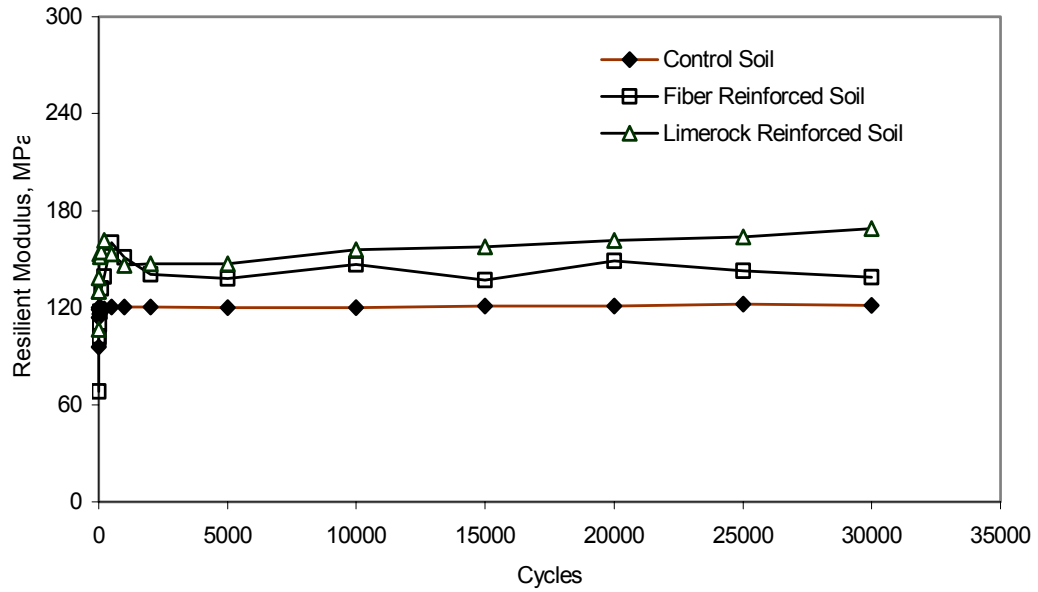


Figure 12 Resilient Modulus as recorded for Orlando sand under optimum moisture condition

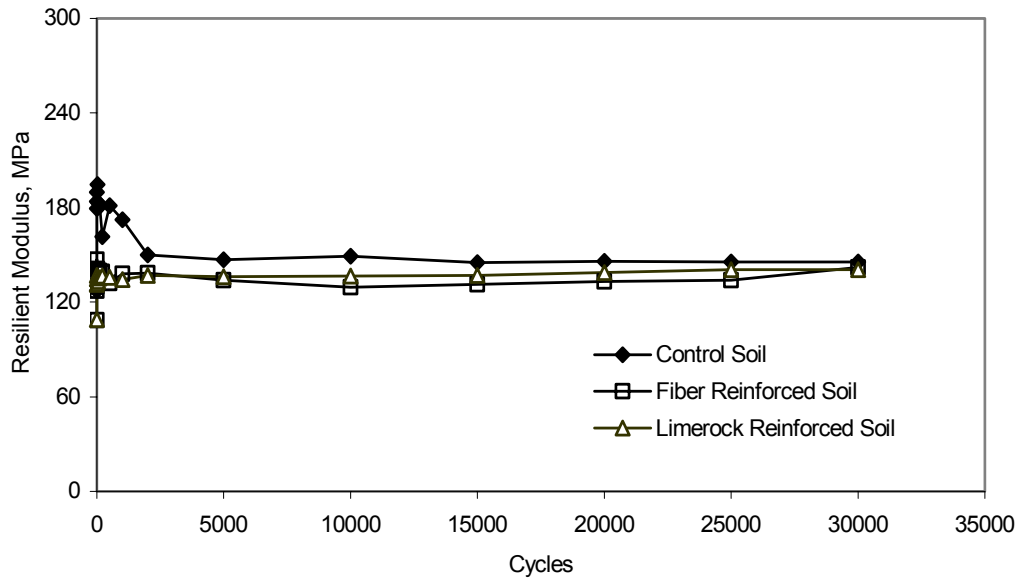


Figure 13 Resilient Modulus as recorded for Orlando sand under drained moisture condition

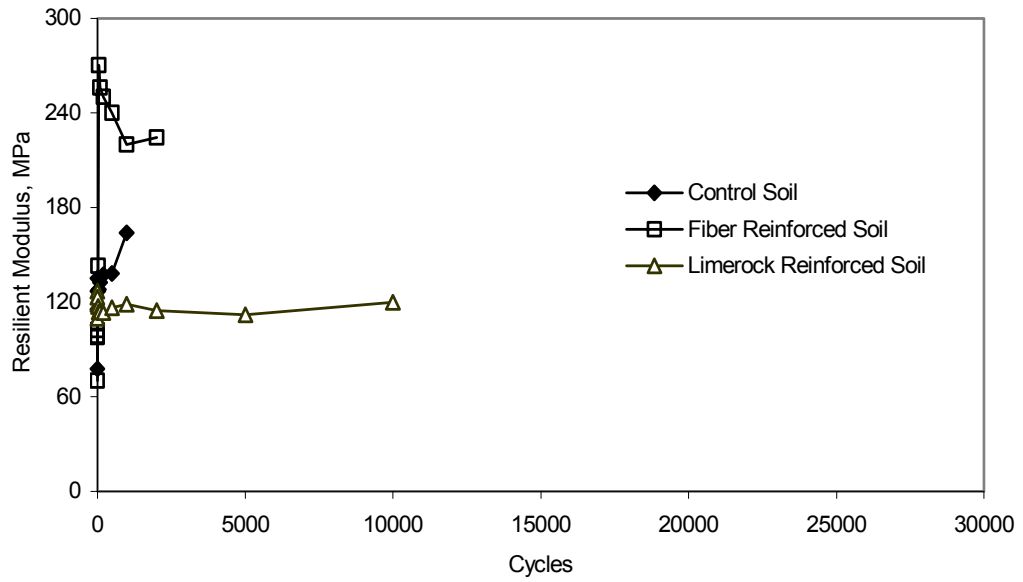


Figure 14 Resilient Modulus as recorded for St. Augustine sand under soaked moisture condition

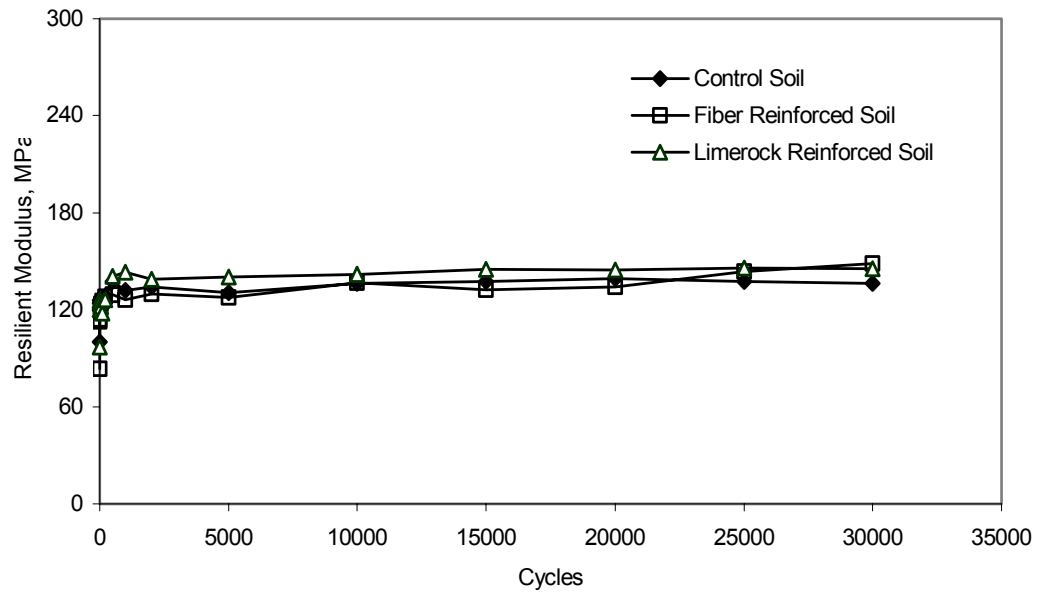


Figure 15 Resilient Modulus as recorded for St. Augustine sand under optimum moisture condition

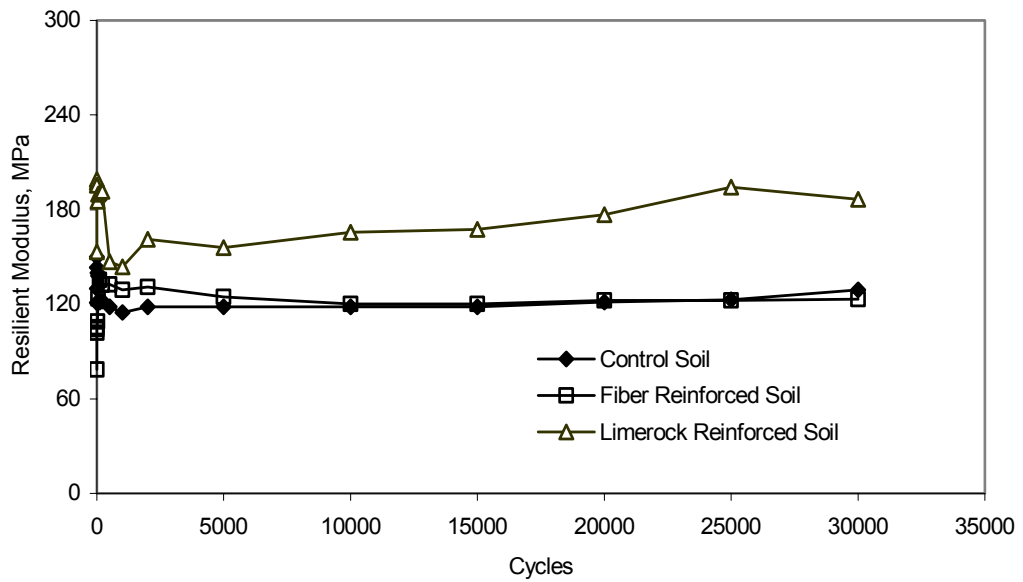


Figure 16 Resilient Modulus as recorded for St. Augustine sand under drained moisture condition