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Behavior of a Geosynthetic Reinforced Sand

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SYNOPSIS The method of geosynthetic reinforced earth incorporates a flexible but tension resistant synthetic material in soil to increase the tensile resistance of the composite. In this study, both static and dynamic responses of an Ottawa 30-40 sand reinforced with a nonwoven geosynthetic, Bidim C-34, were investigated. Static triaxial tests were first conducted to examine the influence of the reinforcement on strength, Young's modulus, and Poisson's ratio of the composite soil. Cyclic triaxial tests and resonant column tests were then conducted to examine the variation of shear modulus and damping ratio at different strain amplitudes. The influence of geosynthetic on both static and dynamic properties of sand was discussed.

INTRODUCTION

Geosynthetic Reinforced Earth. Geosynthetic Reinforced earth is a composite of soil and geosynthetic reinforcement which improves the strength property of soil by introducing tensile strength into the soil-reinforcement composite. With the increasing number of success of its application, ease and low cost, the geosynthetic reinforced earth construction has become popular throughout the world. Although design criteria were developed for a number of applications, such as retaining walls, foundations and embankments, a better understanding of the behavior of geosynthetic reinforced earth is still needed for a sound design of reinforced earth structures. Further studies, are therefore, imminent to update the design criterion for geosynthetic reinforced earth structures.

With reinforcing inclusion, the conventional assumptions of isotropy and homogeneity on soils can no longer apply to the geosynthetic reinforced earth. The basic study of geosynthetic reinforced earth, therefore, experiences the difficulty of finding proper test methods and devices. As scaled and full size model tests are usually very costly, some common soil strength test devices, such as direct shear test device and triaxial test device were first used in studying the effectiveness of geosynthetic reinforcement.

While most studies have been conducted under static loading, it is important to study the response of geosynthetic reinforced earth under dynamic loading. The main objective of this study was to investigate the dynamic property and behavior of a geosynthetic reinforced sand by using conventional cyclic triaxial test apparatus and resonant column test device. By varying cyclic strain levels and reinforcing patterns, it was hoped that the effectiveness of geosynthetic in strengthening and stiffening granular soils under dynamic loading can be better understood. In this study, triaxial tests were conducted to investigate both the static strength and the dynamic properties of a horizontally reinforced soil subjected to vertical cyclic loading. Resonant column tests however, were specifically intended to investigate the damping characteristic and the small-strain dynamic properties of the reinforced soil under torsional vibration due to the introduction of flexible reinforcing inclusion.

Origin and Recent Development. It is said that human learned the technique of soil reinforcement from animal kingdom such as a swallow nest built of mud with straw as reinforcement. The earliest human application of earth reinforcement dates back to the ancient Roman Empire when ancient Romans used reed mat in road construction over soft ground. In the Middle East and the Far East, the reinforcing of large earth structures using reeds, rushes or bamboo was reported to have lasted for millennia (Rankilor, 1981).

However, the recent systematic study of earth structure reinforcement which led to increasing application in modern construction was due to the French architect and engineer, Henri Vidal, who first helped the French Highway Administration to apply metal strip reinforced earth on highway retaining wall successfully in 1967 and 1968 (Ingold, 1982). In 1968, Oleg Wager of the Swedish Geotechnical Institute described in a paper about using sheet piling reinforced earth for embankment stabilization.

In order to study the mechanism of earth reinforcement, a series of triaxial tests were conducted on a dry sand reinforced with discs of aluminum foil by Long, et al. in 1972. An anisotropic cohesion concept to describe the reinforcing effect was presented based on the test results. At about the same time, a series of triaxial tests using orthogonal woven fiberglass as reinforcing material was conducted by Yang in 1972 and an enhanced confining pressure concept was proposed to account for the effect of reinforcement (Ingold,1982). Later studies on the stress-strain behavior of a geosynthetic reinforced sand using several various kinds of geofabrics also concluded that the inclusion of reinforcement increases the ultimate strength of sand under triaxial compression (Holtz, et al., 1982, Gray, et al., 1986).

Based on the theoretical analysis and experimental observation, a schematic application of steel rod reinforced earth on foundation was developed by Bassett, et al. (1978). The study of geosynthetic reinforced embankment and wall has accelerated in the last decade (Broms, 1978, Ingold, 1982, Leshchinsky, 1989). An empirical procedure for the seismic design of reinforced earth walls using laboratory shake table test results was developed by Richardson, et al. (1975). Results of the study involving testing a prototype metal strip reinforced earth wall and four other existing commercial walls showed a reasonable agreement between the measured forces and forces predicted using the above-mentioned empirical procedure (Richardson, et al., 1977).

The ancient application of reinforced earth structure involved natural reinforcing materials such as bamboo, reed, wood etc. Galvanized steel strip was considered an optimal reinforcing material by Vidal after an extensive study (Vidal,1978). Although metal is highly susceptible to corrosion, it was found that even in an aggressive soil environment, the type of galvanized steel strip available for earth reinforcing has a useful life span of more than 120 years (Darbin, et al., 1978). In the early 1960's, a synthetic polymer material was introduced into civil engineering construction (Rankilor,1981). The material, which was called geofabric, geotextile, geomembrane, or geogrid, etc. is now collectively called geosynthetic. Being a relatively new application, the durability of geosynthetic embedded in different soil environment is still questionable. However, its advantage for being versatile in material composition, fabrication pattern and thickness variation has brought itself into an overwhelming popularity in the earth reinforcing industry.

LABORATORY TESTS ON A GEOSYNTHETIC REINFORCED SAND

Ottawa 30-40 Sand. A commercially available white clean sand, Ottawa 30-40 sand was used throughout the study. Its gradation characteristics give the coefficient of uniformity, Cu, of 1.43 and the coefficient of curvature, Cc, of 1.21. The sand was classified as SP, poorly graded sand, based on the Unified Soil Classification System. The maximum and minimum dry unit weights of the sand were determined as 112.19 pcf and 97.52 pcf, respectively. The unit weight of 107.35 pcf was used in this study. It is equivalent to the unit weight of the sand at 70% relative density.

Bidim C-34 Nonwoven Geosynthetic. Bidim C-34, a needle punched nonwoven geosynthetic was used as reinforcing material. Tab.1 shows the typical physical properties of Bidim C-34 Engineering geosynthetic provided by the manufacturer. The Bidim C-34 geosynthetic was cut into circular discs with diameter slightly smaller than the overall sample diameter to facilitate the sample preparation.

Tab.1. Physical Properties of Bidim C-34
Engineering Fabrics
Source: Quline Corporation

Bidim Product Code No.-U.S.		C-34
Bidim Product Code No.-Internat'l		U-34
Mass Per oz/yd^2 Nominal		8.0
Mass Per gm/M^2 Nominal		270
Surface Thickness-Mils (ASTM D-1777)		
	0.005 bar	90
	2.000 bar	41
-Milimeters		
	0.005 bar	2.3
	2.000 bar	1.05
Porosity-(calculated)	0.005 bar %	91
	2.000 bar %	81
Nominal Permeability* 10^{-3}M/sec		3
Planar Permeability* 10^{-3}M/sec		.6
Grab Tensile (ASTM D-1117) lbs/force		255
Grab Elongation (ASTM D-1117) %		75
Trapezoid Tear Strength lbs/force (ASTM D-2263)		125
Mullen Burst Strength psi		400
Restrained Tensile Test* lbs-force/in		120
Elongation %		35
E.O.S.** D_5		70
D_{50}		100
Abrasion Resistance		135
Heat Resistance F @ 50 psi Loading		480
Puncture Strength (ASTM D-751 Modified)		125

* Monsanto Test
** Corps of Engineers Test

As the thickness of geosynthetic varied with pressure, a thickness versus logarithmic pressure curve was established as shown in Fig.1. Based on the curve, the thickness of the reinforcement under different confining pressure was accounted for in determining the sample height for density control.

In order to investigate the variation of reinforcing effect due to the increase in reinforcing layer, a number of reinforcing patterns were used as shown in Fig.2.

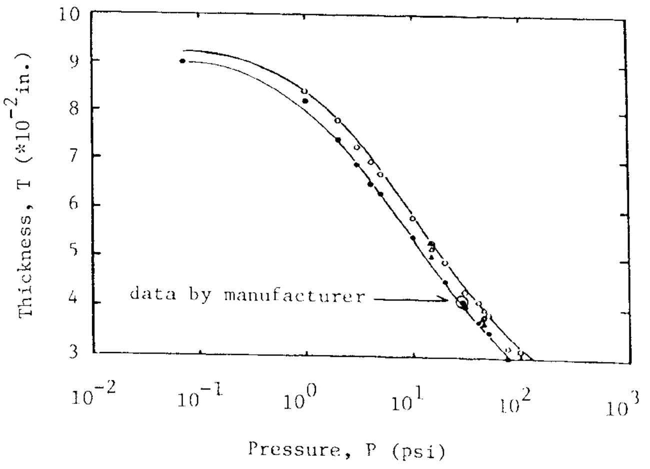
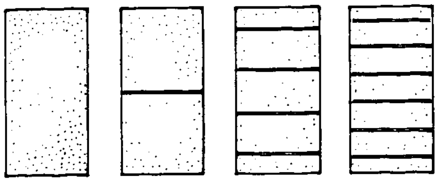
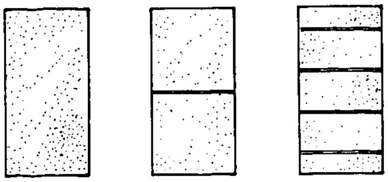


Fig. 1 Thickness Versus Pressure Relationship of Bidim C-34 Geosynthetic



Static Triaxial Test



Cyclic Triaxial and Resonant Column Test

Fig. 2 Reinforcing Patterns

Test Equipment and Test Program Triaxial cells capable of testing 6-inch diameter samples were used in both static and cyclic triaxial tests. An MTS closed-loop servo electrohydraulic universal testing machine was used to evaluate the dynamic properties at strains greater than $5\text{x}10^{-4}$. The confining pressure was applied from a pressure control panel through a graduated burette, used to measure the sample volume change during the test.

A Drnevich Free-Free Torsional Resonant Column Apparatus was used to study the dynamic properties at strain amplitudes smaller than $5\text{x}10^{-4}$. Samples used in resonant column tests are also 6 inches in diameter and 12 inches in height.

Dry Ottawa 30-40 sand samples were prepared and tested under drained condition. Two different confining pressure, 15-psi and 45-psi ,were used for each reinforcing pattern in each type of tests. Static triaxial compression test was first conducted to determine the stress-strain relationship of both reinforced and nonreinforced samples. The equivalent Poisson's ratio of each sample was also determined and later used to control the shear strain amplitudes in the cyclic triaxial test.

In cyclic triaxial tests, four different strain levels were used. Two samples were prepared at each reinforcing pattern and tested under the same confining pressure. Each of the two samples was tested sequentially at two different strain levels, one at $1\text{x}10^{-3}$ and $2\text{x}10^{-2}$, the other $1\text{x}10^{-2}$ and $5\text{x}10^{-2}$.

Resonant column test was conducted on samples prepared and tested under the same conditions as those used in the cyclic triaxial test. A summary of the test program is shown in Tab.2.

Tab.2. Summary of Test Program

	Static Triaxial Test	Cyclic Triaxial Test	Resonant Column Test
Equipment	MTS, Triaxial Cell	MTS, Triaxial Cell	Free-Free Resonant Column Device
Relative Density (%)	70	70	70
Confining Pressure (psi)	15, 45	15, 45	15, 45
Reinforcing Spacing (inches)	None 6, 3, 2	None 6, 3	None 6, 3
Shear Strain Range	NA	$1*10^{-3}$ to $5*10^{-2}$	10^{-7}to10^{-4}
No. of Tests	8	12	6

ANALYSIS AND DISCUSSION OF TEST RESULTS

Static Triaxial Test Results The stress-strain relationships for the static triaxial test under 45-psi confining pressures are shown in Fig.3. The figure indicates that the ultimate strength of the reinforced samples exceeds that of the nonreinforced samples and the difference increases with increasing number of layers of reinforcing geosynthetic. Similar observation was also found for the tests under 15-psi confining pressure. The peak stress difference versus the number of layers of reinforcing geosynthetic relationship is shown in Fig.4. The figure gives a clear indication of the increase in ultimate strength due to the increase in the number of layers of reinforcing geosynthetic.

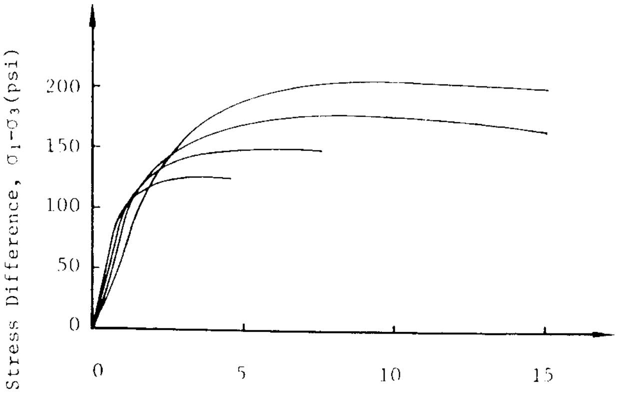


Fig. 3 Stress-Strain Relationship for Samples Tested at 45-psi Confining Pressure

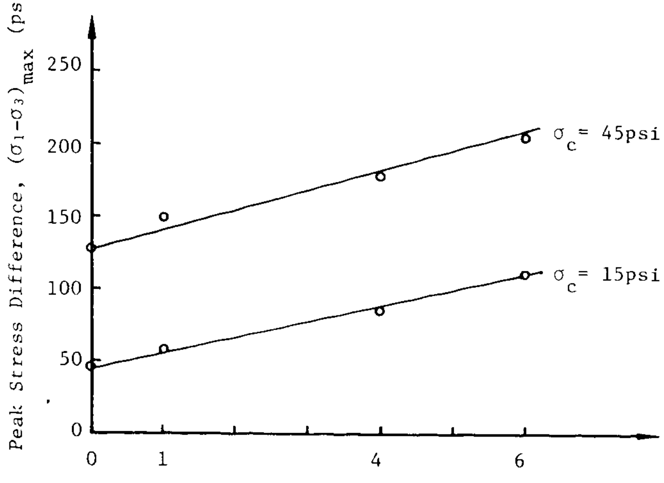


Fig. 4 Peak Stress Difference Versus Number of Reinforcing Layer Relationship

In addition to the effect of increase in ultimate strength, Fig.3 also shows that, for the type of reinforcing material used, there is a tendency of the decrease in the initial stiffness of reinforced samples. The amount of this reduction in stiffness increases with increasing number of reinforcing layers. The initial Young's modulus versus number of reinforcing layer curves as shown in Fig.5 summarize this softening tendency.

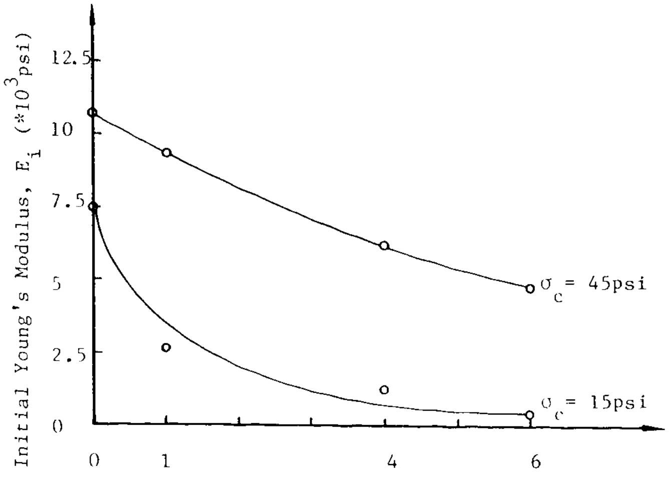


Fig. 5 Initial Young's Modulus Versus Number of Reinforcing Layer Relationship

The lateral strain versus axial strain curves for the static triaxial tests under 45-psi confining pressure are nonlinear and the slope of each curve representing the equivalent Poisson's ratio of a sample varies continuously at low axial strain, and approaches a constant value as the axial strain increases. The relations are approximated as shown in Fig.6. The equivalent Poisson's ratio ranges from 0.30 to 0.83. The result also indicates that the high compressibility of the reinforcing material causes the decrease in the equivalent Poisson's ratio. This decrease in the equivalent Poisson's ratio is especially significant at low axial strains when the compression of reinforcing material accounts for the major part of axial deformation.

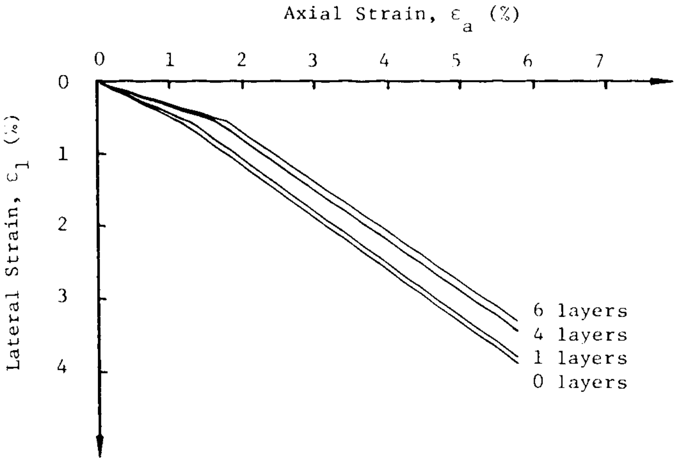


Fig. 6 Approximate Lateral Strain Versus Axial Strain Relationship at 45-psi Confining Pressure

Since two different confining pressures were used in the static triaxial test, Mohr's circles for each test at its peak vertical stress together with failure envelopes for each of four different reinforcing patterns were summarized in Fig.7. It shows that samples without reinforcement exhibit frictional resistance with zero cohesion, while the other three sets of reinforced samples exhibit a near identical friction angle and a cohesion intercept which increases with increasing number of reinforcing layers. The variation of cohesion intercept with the number of layers of reinforcing material is presented in Fig.8.

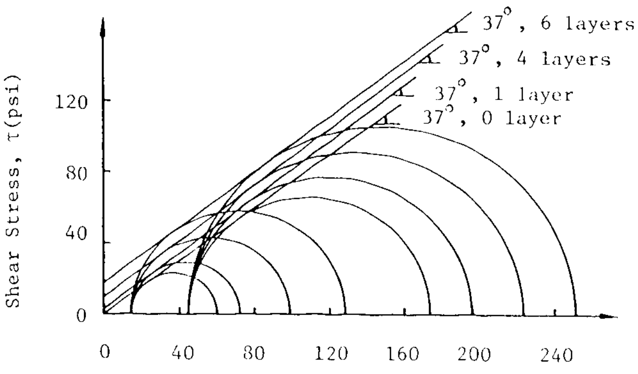


Fig. 7 Mohr-Coulomb Envelopes for Different Reinforcing Patterns

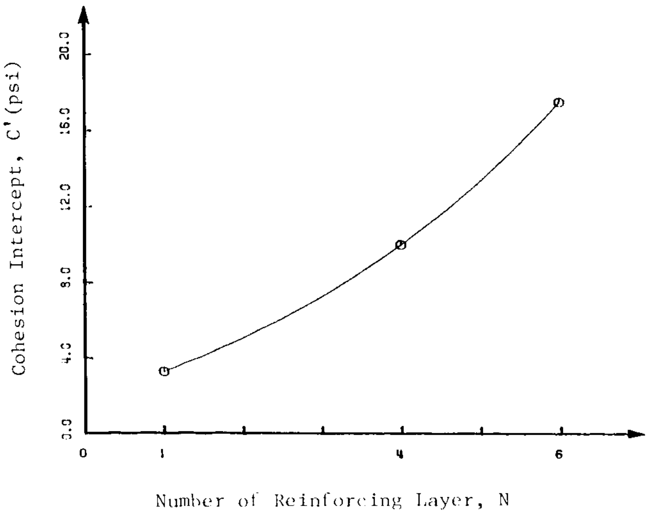


Fig. 8 Cohesion Intercept Versus Number of Reinforcing Layer Relationship

Cyclic Triaxial Test Results. As anticipated from the static triaxial test results, for the type of reinforcing fabric used, the shear modulus of reinforced samples decreases with increasing number of reinforcing layers at strain levels of 10^{-3}. This tendency of decrease in shear modulus; however, becomes less significant as the shear strain increases. When the shear strain increases to $5x10^{-2}$, the shear modulus of reinforced sample increases instead of decreases with increasing number of reinforcing layers as shown in Fig.9.

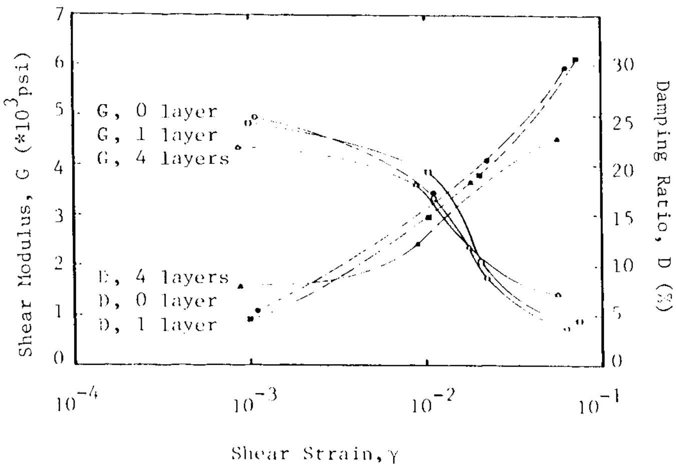


Fig. 9 Shear Modulus and Damping Ratio Versus Shear Strain Relationship for Cyclic Triaxial Test at 45-psi Confining Pressure

Also shown in Fig.9 are the shear damping ratio versus shear strain relations. In general the damping ratio of a reinforced sample is smaller than that of nonreinforced one at a large strain and it decreases with the number of layers of reinforcement. The tendency of sand to dilate at a large strain causes the increase in material damping. This tendency to dilate is, however, buffered in the sand sample with the inclusion of geosynthetic, and consequently its material damping is not as large as that of the nonreinforced samples.

At a small strain, because of the high compressibility of geosynthetic, samples with reinforcement have greater material damping than those without reinforcement.

Resonant Column Test Results. In resonant column tests, a high frequency cyclic torsional load was applied. The type of geosynthetic reinforcement used also caused the reduction in the small-strain stiffness of reinforced samples. The shear modulus versus shear strain relation-ships for both nonreinforced and reinforced samples under 45 psi confining pressures are shown in Fig.10. It indicates that, at the shear strain of 10^{-6}, the shear modulus of each sample, reinforced or nonreinforced, approaches a constant maximum value. Also, the nonreinforced sample exhibits the highest stiffness while the reinforced samples show the decreasing stiffness with increasing number of reinforcing layers. Fig.11 shows the maximum shear modulus versus number of reinforcing layer relation under the two confining pressures.

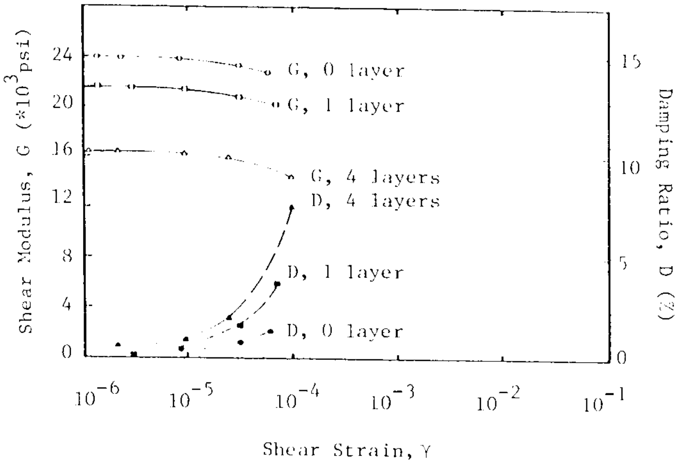


Fig. 10 Shear Modulus and Damping Ratio Versus Shear Strain Relationship for Resonant Column Test at 45-psi Confining Pressure

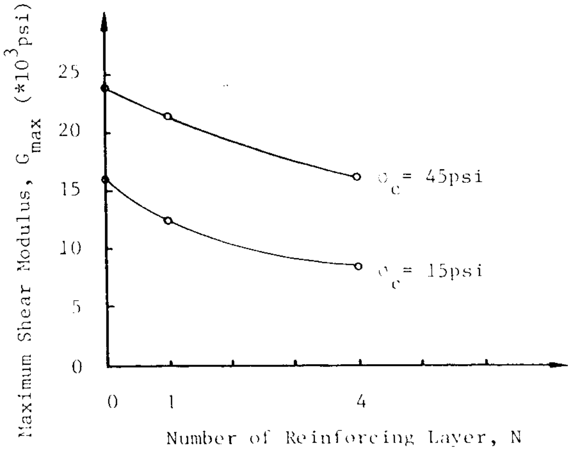


Fig. 11 Maximum Shear Modulus Versus Number of Reinforcing Layer Relationship

The shear damping ratio versus shear strain relations for the samples tested with resonant column test device are also shown in Fig.10. The sample with the most reinforcement exhibits the highest material damping as expected, while the nonreinforced sample shows the lowest damping.

CONCLUSIONS

Static triaxial test results indicate the trend of increase in ultimate strength and cohesion intercept, and decrease in initial Young's modulus and equivalent Poisson's ratio with the number of reinforcing layers due to the high compressibility of the reinforcing fabric used. For the same reason, a significant increase in strain is required to achieve the ultimate strength.

Similar strain-dependent strengthening and stiffening effects of a reinforcing fabric were also observed in samples under dynamic or cyclic load. In other words, depending on the magnitude of induced strain amplitudes, the reinforced soil may have lower or higher shear modulus and damping as compare to that of nonreinforced soil.

REFERENCES

ASTM, Dynamic Geotechnical Testing, ASTM, STP654, 1977.

ASTM, Soil Improvement, ASTM,1978

Bassett, R. H., and Last, N. C., "Reinforcing Earth Below Footings and Foundations," Proceedings of the ASCE Symposium on Earth Reinforcement, Pittsburgh, Pennsylvania, Apr., 1978, pp. 203-231.

Broms, B. B., "Design of Fabric Reinforced Retaining Structures," Proceedings of the ASCE Symposium on Earth Reinforcement, Pittsburgh, Pennsylvania, Apr., 1978, pp. 282-304.

Darbin, M., Jailloux, J.-M., and Montuelle, J., "Performance and Research on the Durability of Reinforced Earth Reinforcing Strips," Proceedings of the ASCE Symposium on Earth Reinforcement, Pittsburgh, Pennsylvania, Apr., 1978, pp. 305-333.

Drnevich, V. P., "Undrained Cyclic Shear of Saturated Sand," J. of the Soil Mech. and Found. Div., ASCE, Vol. 98, No. SM8, Aug., 1972, pp. 807-825.

Gary, D. H., and Al-Refeai, T., "Behavior of Fabric- Versus Fiber-Reinforced Sand," J. of Geotech. Eng., ASCE, Vol. 112, No. 8, Aug., 1986, pp. 804-820.

Hardin, B. O. and Drnevich, V. P., "Shear Modulus and Damping in Soils: Measurement and Parameter Effects," J. of the Soil Mech. and Found. Div., ASCE, Vol. 98, No. SM6, Jun., 1972, pp. 603-624.

Holtz, R. D., Tobin, W. R., Burke, W. W., "Creep Characteristics and Stress-Strain Behavior of a Geotexitile-Reinforced Sand," Proceedings of the Second International Conference on Geosynthetic, Las Vegas, Nevada, Aug., 1982, pp. 805-809.

Holtz, R. D., "Special Applications-State of the Art and General Report," Proceedings of the ASCE Symposium on Earth Reinforcement, Pittsburgh, Pennsylvania, Apr., 1978, pp. 77-97.

Ingold, T. S., "An Analytical Study of Geosynthetic Reinforced Embankments," Proceedings of the Second International Confenrence on Geosynthetic, Las Vegas, Nevada, Aug., 1982, pp. 683-688.

Leshchinsky, D., and Boedeker, R. H., "Geosynthetic Reinforced Soil Structures," J. of Geotech. Eng., ASCE, Vol. 115, No. 10, Oct., 1989, pp. 1459-1478.

Rankilor, P. R., Membranes in Ground Engineering, John Wiley & Sons Inc., New York, 1981.

Richardson, G. N., and Lee, K. L., "Seismic Design of Reinforced Earth Walls," J. of the Geotech. Eng. Div., ASCE, Vol. 101, No. GT2, Feb., 1975, pp. 167-188.

Richardson, G. N., Feger, D., Fong, A., and Lee, K. L., "Seismic Testing of Reinforced Earth Walls," J. of the Geotech. Eng. Div. ASCE, Vol. 103, No. GT1, Jan., 1977, pp. 1-17.

Vidal, M. H., "The Development and Future of Reinforced Earth-Keynote Address," Proceedings of the ASCE Symposium on Earth Reinforcement ASCE, Pittsburgh, Pennsylvania, Apr.,1978, pp. 1-61.

Wager, O., "Stabilitetsforbattrande Spontkonstruktion for Bankflyllningar," Swedish Geotechnical Institute, Reprint and Preliminary Report, No. 28, Stockholm, 1968, pp. 21-24.