CREEP BEHAVIOR OF EPS GEOFOAM

S. Srirajan[1], D. Negussey[2] and N. Anasthas[1]

ABSTRACT

Expanded Polystyrene (EPS) Geofoam has now been used as a super lightweight fill for many geotechnical projects. Assessments of creep deformations in design have generally relied on test results from small size samples. A series of creep tests were performed on different sample sizes and stress levels for various densities. The results indicate that sample size is another factor that influences the time behavior of geofoam. Larger samples experience less creep deformation over a given time period and equivalent loading. An empirical equation was derived relating total strain with density, stress level and time. Field results are compared with predictions based on the empirical equation.

KEYWORDS: creep, EPS, geofoam, modulus, Poisson's ratio, strain, strength, stress,

[1] Research Assistant, and [2]Director, Geofoam Research Center, Syracuse University, Syracuse, NY 13244

INTRODUCTION

In design with geofoam, creep deformation rather than shear failure is the primary concern. After construction, geofoam is subjected to a constant dead load under which gaps between blocks continue to close and creep deformations occur. The live load due to traffic and associated deformations are generally transient. The post construction deformations of geofoam in creep mainly depend on the margin of dead loading.

Eriksson and Trank (1991) investigated the unconfined compression behavior of EPS geofoam specimens for three different sizes; 50 and 400 mm cubes and 200 mm x 200 mm x 165 mm blocks. The average density of these samples was 18 kg/m^3. The tests were performed at 1% strain per minute. Strength values determined at strain levels greater than 4% were found to be unaffected by sample size.

Sun (1997) performed one dimensional creep tests on 50 mm cube samples of 18 kg/m^3 density EPS geofoam using cantilever dead weight loading systems. The stress levels were approximately 30%, 50%, and 70% of 85 kPa compressive strength at 5% strain. The creep strains after 461 days were 0.8%, 3.0% and 14.4% for the corresponding stress levels. Creep deformation effects were observed to be negligible at stress levels of 30% of compressive strength and lower.

Duškov (1997) reported creep test results on cylindrical samples of EPS geofoam. In the first series, 20 kPa load was applied on 200 mm diameter, 100 mm height and 20 kg/m^3 density samples. A total strain of 0.20% was observed in 400 days in which 35% was observed to have occurred in the first day. In the second series, 150 mm diameter, 300 mm height and 15 and 20 kg/m^3 density samples were tested under two different stress levels. The first load of 10 kPa represented a relatively low loading and a second load of 20 kPa represented pavement over geofoam. The results of these tests indicated total strain of approximately 0.5% and 0.25% for the 20 and 10 kPa loadings, respectively. The results also show immediate strains of 0.3 and 0.15% for the two loading conditions, respectively. Observed differences in creep performance between the 15 and 20 kg/m^3 density samples were minor.

Horvath (1998) evaluated creep test results on 50 mm cube samples of 20 kg/m^3 density at stress levels of 30, 40, 50 kPa to model the stress-strain-time behavior of EPS geofoam using the Findley equation. Horvath obtained parameters for the Findley equation from the test results. The expression is appropriate for geofoam density of approximately 20 kg/m^3 and applied stress of 50 kPa or lower.

Sheeley (2000) performed creep tests using 50 mm samples of nominal 21 kg/m^3 density EPS geofoam at 30%, 50% and 70% of 98 kPa compressive strength at 5% strain. The results show that most of the strain occurred within the first two days for 30% and 50% loadings. For the sample loaded at 30% of compressive strength, a total strain of 0.95% occurred in 500 days in which 66% was observed in the first day. For the sample loaded at 50% compressive strength, a total strain of 1.35% occurred in 500 days in which 68% was observed in the first day. Increasing creep deformation was observed for the sample loaded at 70% compressive strength and only 4% strain developed in the first day. A total of 22% strain occurred in 500 days.

Elragi et al. (2000) studied EPS geofoam behavior under unconfined compression using conventional 50 mm as well as 600 mm cubes and cylindrical samples of 76 mm diameter. The nominal densities of the samples were 15 and 29 kg/m^3. All compression tests were performed at 10% strain per minute. In the large cubic and also cylindrical samples, vertical deformation was also observed for gauge length in the middle third of the height. The results indicate that the distribution of vertical strains over the height of a geofoam samples was not uniform. The conventional 50 mm cube samples significantly over estimate initial deformations and thus underestimate Young's modulus values for geofoam. The main cause for higher deformation of small samples was attributed to be due to seating and end effects near the geofoam and rigid platen-loading interface.

In advance of the creep test program, unconfined compression tests were performed using 50 mm and 300 mm cubic specimens at 10% strain rate per minute in accordance with ASTM D 1621. The results indicate that compressive strength determined at 5% strain is not significantly affected by sample size as shown in Figure 1. Previous results reported by Elragi et al. (2000) and Elragi (2000) were utilized to determine appropriate strengths for different densities in creep testing.

This paper presents creep results from testing specimens of different sizes and densities under different sustained stress levels. The purpose of the study was to investigate the effect of sample size and density on creep behavior of EPS geofoam and to derive an equation for creep strain in terms of density, applied stress and time.

TEST SPECIMENS

Creep tests were performed on EPS geofoam samples supplied by different manufacturers. Five different sample sizes of 50, 64, 100 and 300 mm cubes and 300 mm x 300 mm x 600 mm block were cut using a hot wire. The sample densities vary from about 12 to 30 kg/m^3.

TESTING SYSTEMS

Most of the creep tests were performed using a hydraulic loading system. Tests on 64 mm cubes were performed using cantilever dead weight loading frames. Additional tests were made on 300 mm cubic samples by direct dead weight loading.

Three samples of the same nominal density were tested simultaneously using cantilever dead weight frames. The amount of cantilever load required to produce a stress of 80% of the strength on the sample was determined using a load cell. This was repeated for 50% and 30% loadings. The samples were placed in position and the top loading plates were adjusted to make contact while keeping each loading arm horizontal (Photo 1). An adjusting wheel and weights attached to each loading arm were used for fine balance. Periodic deformation readings were then taken. The loading arms were periodically checked for alignment and adjusted as the tests resumed.

In the hydraulic loading system, displacement transducers were mounted at the upper and lower third positions along the face of 300 mm cubes and 300 mm x 300 mm x 600 mm high samples to monitor incremental movement. Displacement transducers were also mounted perpendicular to the faces to monitor lateral deformation as shown in Photo 2. The top plate was suspended from the actuator shaft and the loading head was lowered to make contact with the sample under manual control. The loading protocols were pre-set using a procedure file. Constant loading was maintained for the duration of creep tests under feedback control. A data acquisition system recorded the test data.

Creep tests were also performed by applying dead weight loading directly on 300 mm cubes and average axial deformations were obtained using three displacement transducers mounted over the top loading platens, as shown in Photo 3.

RESULTS

The stress strain plot for a creep test performed using a 100 mm cube is shown in Figure 2. The load was applied at a rate of 9.5 N per second for 28 seconds to apply a 27 kPa stress, which was then maintained for 2800 hours. The straight portion of the initial stress-strain curve was extended back and the curve was shifted to the origin to establish a corrected stress-strain curve. This procedure was followed for all creep results. Figure 3 shows the creep behavior of 100 mm geofoam samples at different stress levels. The measured axial strain includes the initial and creep deformation. Most of the corrected initial axial strain is due to recoverable deformation. For applied stresses less than 50% of the compressive strength, the total axial strains were typically less than 2 percent.

Figures 4 shows the total strain for four different sample sizes of 13 kg/m^3 density when subjected to 50% compressive strength. The results show that the initial strain increases with decreasing sample sizes. The average strain rate of smaller samples was higher than the average strain rate of larger samples. Figure 5 shows total strain for four different sample sizes of 18 kg/m^3 density when subjected to 80% compressive strength decrease with sample size. The average strain rates determined at 2500 minutes confirm that the smaller samples experienced larger average strain rates. The larger sample sizes experienced less creep deformation than smaller samples over a given time period and loading. Creep results obtained from 50 mm cube samples are therefore providing more conservative estimates for design.

Figure 6 shows the immediate strains for different density samples subjected to 30% and 50% of the compressive strength at 5% strain. The dotted and continuous lines represent 30% and 50% loadings, respectively. Differences in immediate strain at the same density and stress level are due to sample size and strain rate. Density has less influence in immediate strain for larger samples tested at similar stress levels lower than 50% of the respective compressive strengths. However, more scatters in data can be observed for the curves corresponding to 50% loading. Figures 7 and 8 show the magnitude of creep strain at 30% compressive strength for different sample sizes and densities over 24 and 48 hours of creep loadings. The load corresponding to 30% compressive strength for higher density geofoam is larger than the load corresponding to 30% compressive strength for lower density geofoam. These results show that creep strains decreased with increasing density. For a given load level, lower density geofoam experienced higher creep strain. Most of the creep strains for all samples took place in the first 24 hours. Figure 9 and 10 show similar results for samples tested at 50% of compressive strengths.

The immediate strain of samples tested at 50% loading was approximately 1.7 times the immediate strain of samples tested at 30% loading for a given sample size and density. In other words, the immediate strains are in direct proportion to the applied loads. It should be noted that Duškov (1997) also observed a linear relationship between immediate strain and load in reporting 0.15% and 0.3% deformation for the static stresses of 10 and 20 kPa applied on cylindrical samples.

From the test results of 50 mm cube samples, the following empirical equation was derived for immediate strain (ε_o) in terms of applied load and density.

$$\varepsilon_o = \left(\frac{P}{D-5}\right) * (0.26 - 0.005D) + 0.2 \qquad \text{for} \qquad \left(\frac{P}{D-5}\right) \le 0.5 \qquad \text{Equation (1)}$$

The following equation was derived for immediate strain from 300 mm samples.

$$\varepsilon_o = \left(\frac{0.3P}{D-5}\right) - 0.2 \qquad \text{for} \qquad \left(\frac{P}{D-5}\right) \le 0.5 \qquad \text{Equation (2)}$$

where

P = applied stress, kPa
D = density, kg/m^3

The load was applied at a rate of 9.5 N per second until the sample reached the desired stress level as was mentioned in the test procedure. The strain rate during ramp loading was determined for each test specimen and the results are summarized in Table 1. Since the same constant load rate was maintained for all sample sizes, strain rates varied depending on the size and density of the samples. For a given sample size, strain rates decreased with density. For a given geofoam density, strain rates decreased with increasing sample size. Elastic modulii were determined from the linear portion of the stress strain curve during the ramping phase. Figure 11 shows the general trend of increasing initial modulus with increasing density for different sample sizes. Elragi (2000) performed unconfined compression tests using 50 mm cubic samples with different strain rates and observed modulus values increased with higher strain rate. The results show that 50 mm samples exhibit less modulus values for a given density even though strain rates for these group of samples were higher than for larger specimens. Unconfined compression test results for 50 mm and 300 mm cubes at 10% strain per minute are compared to results from load-controlled ramp loading data of creep tests in Figure 12. These results further confirm that sample size has more significant influence in determination of modulus of EPS geofoam than for the range of strain rate effects considered in this investigation.

The axial deformations were observed globally and for the middle third of the height of large geofoam samples as was mentioned. Total or global strain was calculated using total deformation taken from the transducer connected to the actuator shaft. The axial stress strain relationship obtained from total and middle third measurements of 300 mm cubic geofoam samples of 28 kg/m^3 density are presented in Figure 13. The Initial modulus determined from middle third measurements is about 15 MPa. The modulus corresponding to the total deformation measurements of the same sample is 12 MPa. These results again indicate that end segments of the specimen experience greater deformation than the middle portion as observed by Elragi (2000) based on compression tests on both cubic and cylindrical samples of different densities. The results indicate that the elastic modulus determined for the middle third portion of the samples are higher than the elastic modulus determined for the entire length and even more from small 50 mm cube samples.

Figure 14 shows that the creep deformation for 50% loading calculated using the middle third measurement is about 10 percent less than calculated using total measurement. The lateral strain was calculated from two displacement transducers mounted on opposite sides of the specimen. Poisson’s ratio values were determined from the lateral strain and vertical strain at each time interval. Less difference is observed between total and middle third measurement of the same sample when loaded at 30% of the compressive strength as shown in Figure 15. The Poisson’s ratio determined using 300 mm cubic sample of 28 kg/m^3 density is represented in Figure 16. The results show that the Poisson’s ratio decrease from 0.2 to 0.1 when the sample was subjected to a constant load. The reduction is due to differential axial and lateral creep. The tests performed on different density samples show a maximum Poisson’s ratio of 0.3 at the end of ramping. The minimum Poisson’s ratio of 0.08 was obtained when the sample was subjected to a constant load at 3000 hours.

Creep results of 300 mm cubic block of 13 kg/m^3 density subjected to a dead load of 16.4 kPa over a period of 12 days are shown in Figure 17. The applied stress represents 30% of the unconfined compressive strength at 5% strain. The results show 0.08% creep strain following 0.48% initial strain. The same block was unloaded and then subjected to a dead load of 27 kPa over a period of 55 days. At 50% loading, the creep strain following 0.65% initial strain was continuing to increase but was less than 0.6% when the test was terminated.

PREDICTION OF CREEP DEFORMATION

Sample size significantly affects the creep behavior of EPS geofoam. Prediction of total strain based on test results from smaller samples would overestimate the actual strain. Thus, the results from 300 mm cube samples are used to derive an equation for creep related settlements.

In order to derive an equation for creep related settlements from two or three days of creep data, it is important to compare these test results with long term creep observations. Frydenlund and Aabøe (1996) reported creep performance of a model geofoam test embankment of 2 m height with full size blocks and compressive strength of 100 kPa. The results indicated approximately 1.1% strain over a period of 3 years, in which 64 percent of the total strain occurred within two days. Sheeley (2000) also observed that 66% of the total strain occurred in the first day for samples tested at 30 and 50% of the compressive strength as shown in Figure18. The creep behavior of EPS geofoam estimated using two or three day test results can provide guidance for actual total strain development for longer time periods.

Based on the test results from 300 mm cube samples, the following empirical equation for total strain (ε) was derived.

For working stress less than 25 % of strength $\varepsilon < 1\%$ and creep strains would be negligible.

For working stresses greater than 25% and less than 50 % of strength

$$\varepsilon = (3\alpha + 0.1) * [(-0.0004D + \beta) * \ln(t) + \gamma] \qquad \text{Equation (3)}$$

where ε = total strain, percent
σ = applied load, kPa
D = density of geofoam, kg/m^3 (12 kg/m^3 - 35 kg/m^3)
t = time, minutes

α, β, γ are parameters as defined below:

$$\alpha = \frac{\sigma}{7.5D - 41.3}$$

$$\beta = 0.230\alpha - 0.045$$

$$\gamma = -1.95\alpha + 0.985$$

For working stress greater than 50 % of strength $\varepsilon > 2\%$

According to this equation, the EPS geofoam would experience a total strain of less than 2% in 50 years when subjected to 50% compressive strength. That is, the stresses due to permanent or dead load can be up to 50 percent of the design compressive strength, if long-term creep deformation of up to 2% strain can be tolerated.

The record of 3 years of deformation of NRRL test embankment under a constant load of 52.5 kPa is shown in Figure 19. Also shown is the prediction of deformations based on results of small sample test results. These comparisons were reported by Frydenlund and Aabøe (1996). For the same density of 20 kg/m3 and applied stress of 52.5 kPa, predictions by the empirical equation proposed in this paper (equation 3) are included in figure 19. The agreement between the test embankment observations and the predictions by the proposed equation (3) is very good. Furthermore, the prior predictions indicate a continuing trend of deformation beyond 3 years. The actual observations and the predictions by the equation (3) indicate that the initial strain to be dominant and that creep strains beyond the first month of record were small by comparison. Both the observations and predictions by the equation (3) suggest any ongoing settlements occur at a very small rate and projected settlements to 50 years should remain below 2%. It is important to recognize that the initial strain of about 1% would occur essentially during construction. The post construction settlements that may be attributed to creep at 50% of compressive strength loading over 50 years would therefore be less than 1%. The current practice of limiting dead loads to 30% of compressive strength at 5% strain is conservative. Preliminary results from on going observations of high geofoam embankments also indicate trends of small construction settlements in creep. Working stresses for geofoam can be increased from 30% to 50% of compressive strength at 5% strain

CONCLUSION

- Compressive strengths determined at 5% strain or more are not significantly affected by sample size.
- The creep behavior of EPS geofoam depends on sample size. Small samples overestimate creep deformations of EPS geofoam due to end effects and more pronounced seating error.
- Density affects the creep behavior EPS geofoam. Denser samples experience less creep at the same level of loading.
- Density has little or no influence on immediate strains for larger samples tested at equal stress levels of 50% of compressive strength and lower.
- Immediate strains linearly increase with applied load for stress levels below about 50% of strength.
- Conventional 50mm cube samples underestimate the Young's modulus of EPS geofoam.
- Poisson's ratio values diminished as creep strains developed.
- Creep tests performed on large geofoam samples at different stress levels indicate up to 50 percent of the compressive strength can be used as working load for geofoam design.

ACKNOWLEDGEMENT

The authors thank the contributions EPS manufacturers for providing geofoam test samples. John Banas Jr and Richard W. Chave assisted with test equipment set up. The authors thank them all for their contributions. The financial support of Huntsman Chemical Corporation and FHWA-NY Division to the Geofoam Research Center at Syracuse University is gratefully acknowledged.

REFERENCE

ASTM D 1621, "Standard Test Methods for Compressive Properties Of Rigid Cellular Plastics", Annual Book of ASTM Standards, Section 4, Volume 04.06.

Duškov, M., 1997, "EPS as a Light Weight Sub-Base Material in Pavement Structures", Ph.D. Thesis, Delft University of Technology, Delft, The Netherlands.

Eriksson, L., and Trank, R., (1991) "Properties of Expanded Polystyrene, Laboratory Experiments", Swedish Geotechnical Institute, Linköping, Sweden.

Elragi, A., Negussey, D., and Kyanka, G., 2000, "Sample Size Effects on the Behavior of EPS Geofoam", Proceedings of the Soft Ground Technology Conference, ASCE Geotechnical Special Publication 112, Noordwijkerhout, The Netherlands.

Elragi, A., 2000, "Selected Engineering Properties and Applications of EPS Geofoam", Ph.D. Thesis, State University of New York, Syracuse, N.Y.

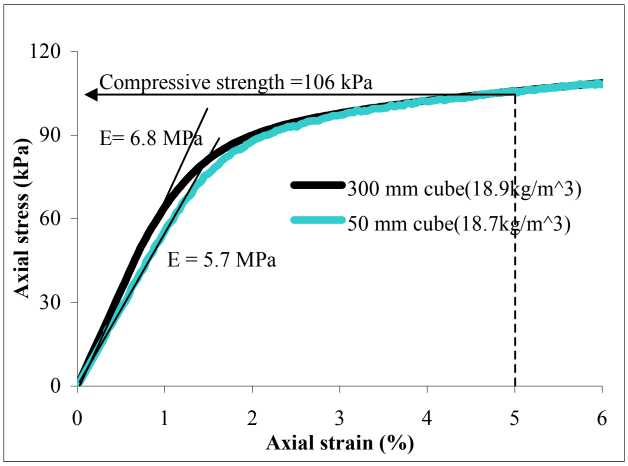
Frydenlund, T., E., and Aabøe, R., (1996), "Expanded Polystyrene-The Light solution" Proceedings of the International Symposium on EPS Construction Method, Tokyo, Japan, pp 31-46.

Horvath, J., 1998, "Mathematical Modeling of the Stress-Strain-Time Behavior of Geosynthetics Using the Findley Equation: General Theory and Application to EPS-Block Geofoam", Manhattan College Reserch Report No. CE/GE-98-3, Bronx, N.Y.

Sheeley, M., 2000, " Slope Stabilization Utilizing Geofoam" , Master's Thesis, Syracuse University, New York.

Srirajan, S., 2001, "Recycled Content and Creep Performance of EPS Geofoam in Slope Stabilization" Master's Thesis, Syracuse University, New York.

Sun, M.C., 1997, "Engineering Behavior of Geofoam (Expanded Polystyrene) and Lateral Pressure Reduction in Substructures", Master's Thesis, Syracuse University, New York.



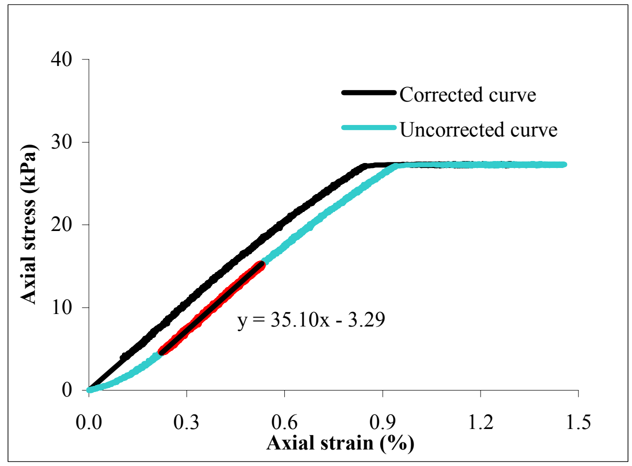
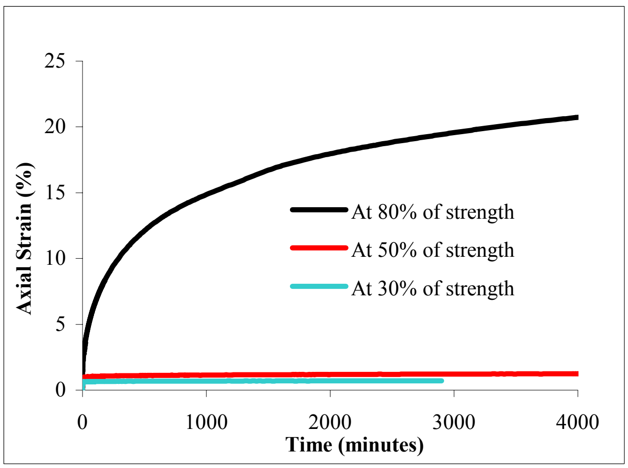


Figure 1. Unconfined compression behavior of EPS geofoam and effect of sample size

Figure 2. Axial stress vs axial strain for 100mm cube sample of 12.8kg/m^3 density at 50% stress level



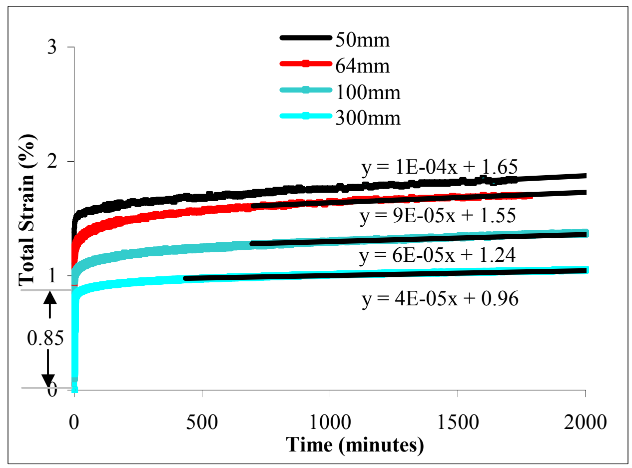
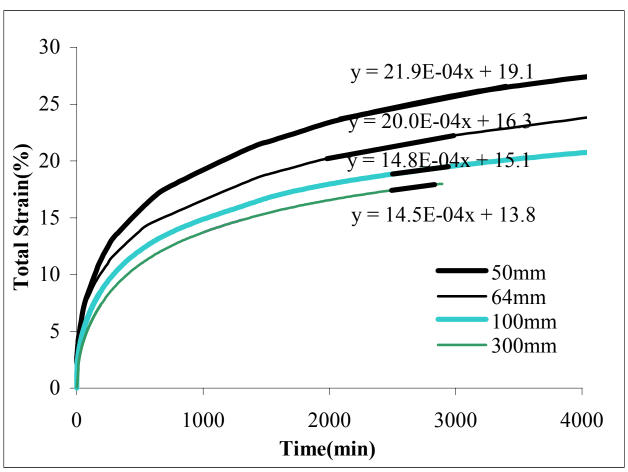


Figure 3. Creep behavior of 100mm cube of 18 kg/m^3 density at different stress levels

Figure 4. Creep behavior of 13 kg/m^3 density geofoam at 50% strength



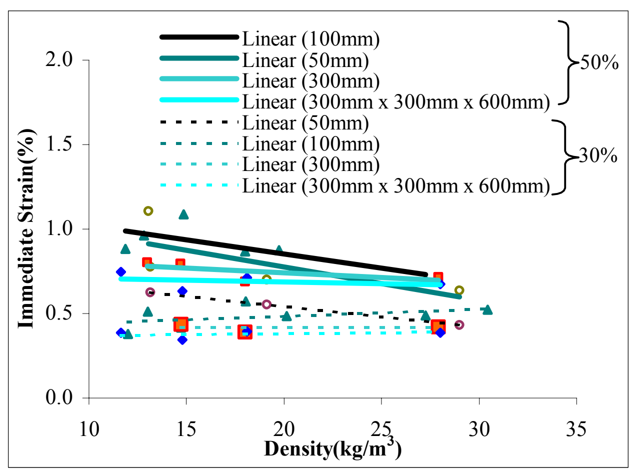
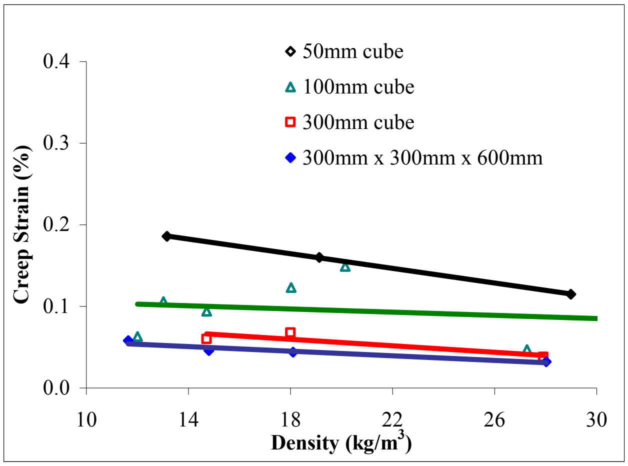


Figure 5. Creep behavior of geofoam of 18 kg/m^3 density at 80% strength

Figure 6. Immediate strain for samples loaded at 30 and 50 percent compressive strength



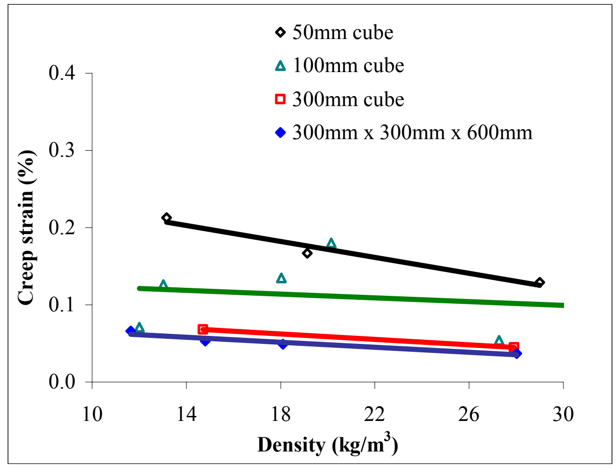
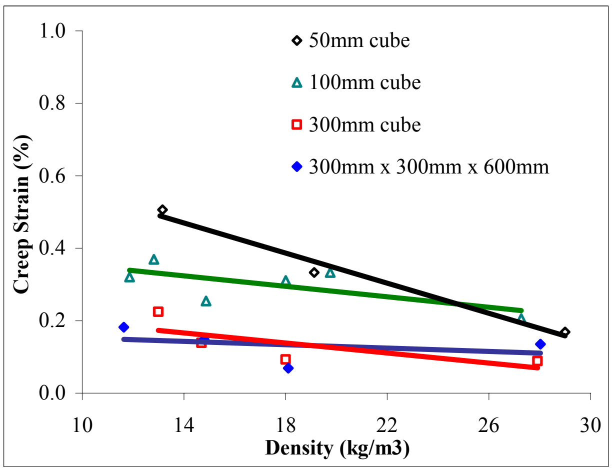


Figure 7. 24 Hour creep strain for samples loaded at 30% strength

Figure 8. 48 Hour creep strain for samples loaded at 30% strength



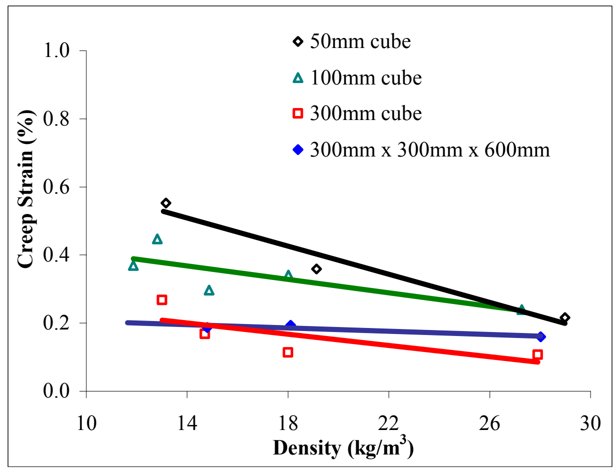
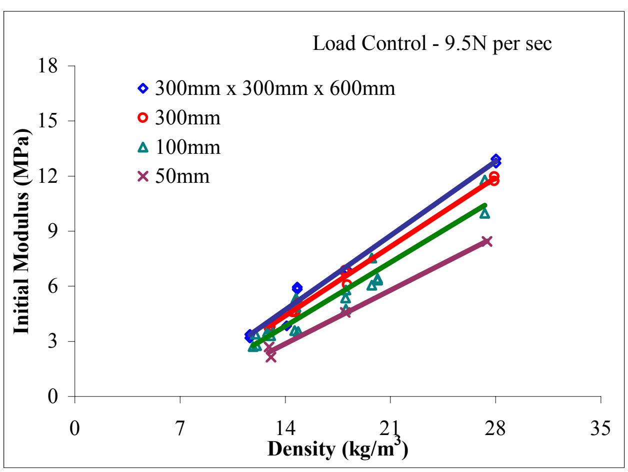


Figure 9. 24 Hour creep strain for samples loaded at 50% strength

Figure 10. 48 Hour creep strain for samples loaded at 50% strength



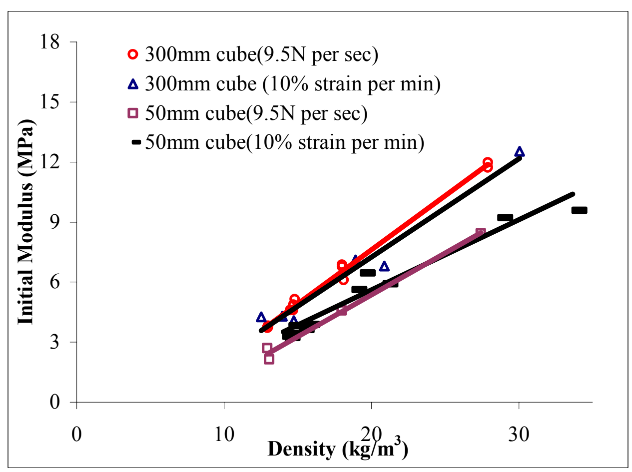
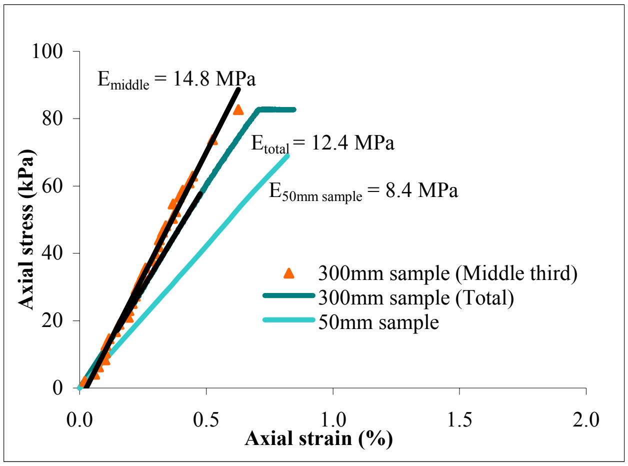


Figure 11. Initial modulus and density for different sample sizes

Figure 12. Initial modulus and density for load and displacement controlled tests



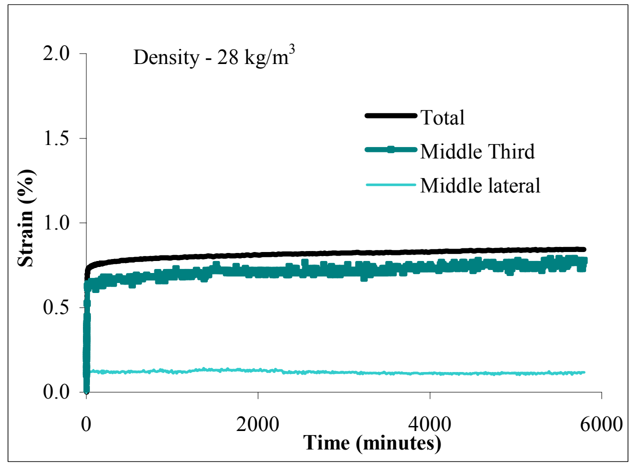
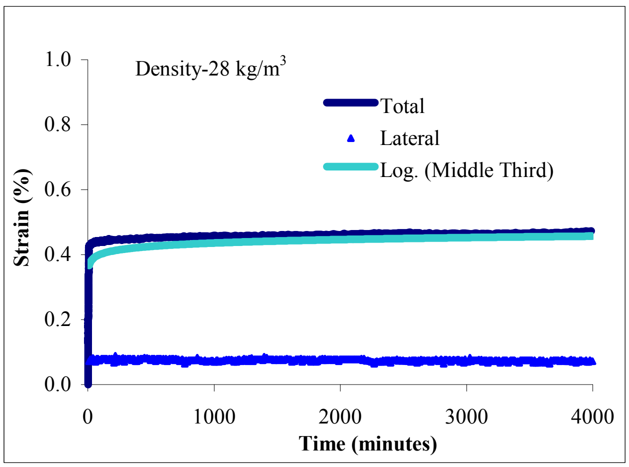


Figure 13. Axial stress vs strain for 300mm cube of 28 kg/m^3 nominal density

Figure 14. Creep behavior of 300mm cubic sample at 50% strength



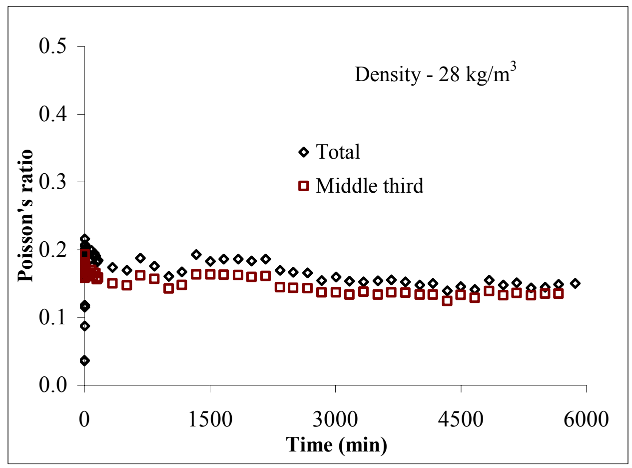
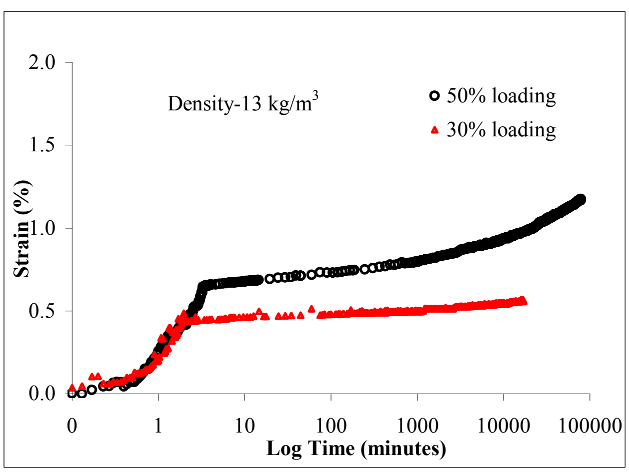


Figure 15. Creep behavior of 300mm cubic sample at 30% strength

Figure 16. Poisson's ratio for 300mm cube geofoam of 28 kg/m^3 density



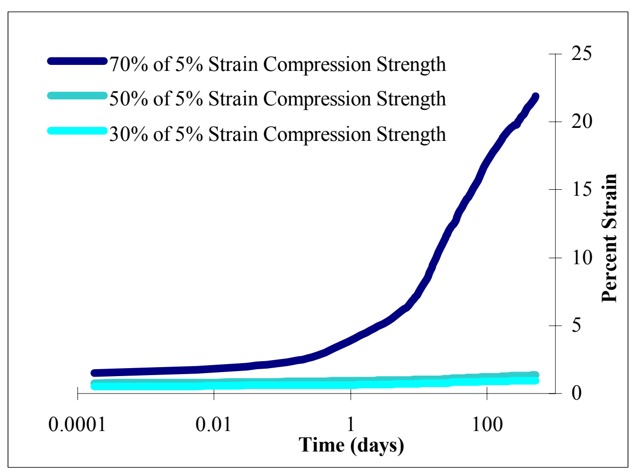


Figure 17. Creep results of 300mm cubic geofoam block tested at 30 and 50 % compressive strength

Figure 18. Creep results of 50mm conventional specimens (After Sheeley (2000))

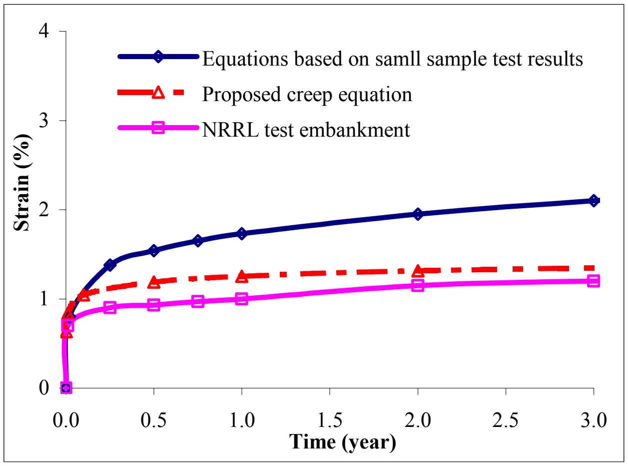


Figure 19. Comparisons between total strain predicted by equations and observations for NRRL test embankment. (After Frydenlund and Aabøe, 1996)

Specimen size (mm)	Strain rate (% strain / min)
50	1.6 - 5.6
100	0.5 -1.7
300	0.05 - 0.18
300 x 300 x 600	0.05 - 0.24

Table 1. Strain rate during ramp loading for different specimen sizes

Photo 1. Creep tests with rear loading cantilever frames

Photo 2. Creep test with hydraulic loading system on a 300 mm x 300 mm x 600 mm geofoam at 30% compressive strength

Photo 3. Creep test with dead loading on a 300 mm cube geofoam block at 30% compressive strength