Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Behavior of EPS geofoam in compression

D.K.ATMATZIDIS & E.G.MISSIRLIS, University of Patras, Rio, Patra, Greece

ABSTRACT: Unconfined and triaxial compression tests were conducted on EPS geofoam samples with densities from 10kg/m^3 to 35kg/m^3 obtained from commercially produced blocks. Unconfined compression test results indicate that sample type (cube or cylinder), aspect ratio (0.5, 1.0, 2.0) and size (100 × 10^3 mm^3 to 12000 × 10^3 mm^3) have relatively insignificant effects on measured yield stress and compressive strength. Initial modulus of elasticity values increase significantly with increasing sample volume (up to 100% compared to 50 mm cubes). Poisson ratio values are positive (up to 0.15) for low axial strains, decrease as strains increase toward the elastic strain limit, and may become negative at about the elastic strain limit. At higher stress levels, the behavior of all EPS geofoams tested is definitely contractive. Samples tested in triaxial compression exhibit a "softer" behavior (lower yield stress, compressive strength and modulus of elasticity) compared to similar samples tested in unconfined compression.

1 INTRODUCTION

Expanded polystyrene (EPS geofoam) products in the form of blocks or plates are utilized for the construction of a variety of projects as light-weight material or compressible inclusion. For the design of structures where volumes of EPS geofoam are incorporated, it is necessary to have appropriate information on the behavior of EPS geofoam in compression. Most of the available design parameters are obtained from unconfined compression tests on small-size samples (50mm cubes). The properties used to define the shape of the stress-strain curves obtained from unconfined compression tests are the initial modulus of elasticity, E_i (slope of the initial linear segment of the stress-strain curve), the compressive strength, σ_{c10} (usually defined as the axial stress at 10% axial strain) and the yield stress, σ_y (point of intersection of the initial linear segment and the post-yield linear segment of the stress-strain curve). Furthermore, it is frequently necessary to obtain Poisson ratio values, v, to establish the elastic limit and to define a deformation or stress limit beyond which undesirable creep effects may appear.

An objective of numerous past experimental investigations was the establishment of correlations between σ_y, σ_{c10}, and E_i and the nominal density of EPS geofoam blocks (Magnan & Serratrice 1989, Eriksson & Trank 1991, Horvath 1995, Negussey & Sun 1996, Duskov 1997). Geofoam blocks are generally expected to be nonhomogeneous with respect to density (Horvath 1995) indicating the need to test large specimens in order to minimize the effect of density variability. Rather limited information is available on the effects of testing parameters on the properties measured by unconfined compression testing (Eriksson & Trank 1991, Frydenlund & Aaboe 1996, Duskov 1997, Elragi et al. 2001). Significant underpredictions of the initial modulus of elasticity values, E_i, have been reported when testing small specimens. A recent review indicates that there is a wide variability in the range of measured or assumed Poisson ratio values for EPS geofoam blocks (Elragi et al. 2001). Finally, it should be noted that due to the nature of many construction projects, EPS geofoam is expected to function in compression under lateral constrain or in a triaxial stress field. However, available information on the behavior of EPS geofoam in triaxial compression is very limited (Preber et al. 1994).

The information presented herein is part of an experimental investigation of the mechanical properties and behavior of commercially produced EPS geofoam blocks. Scope of this presentation is to offer additional information on the behavior of EPS geofoam in compression and, more specifically, to summarize results of a parametric study on the effect of testing parameters on the observed behavior in unconfined compression, to compare unconfined and triaxial compression behavior and to contribute to the ongoing effort of selecting safe design parameter values.

2 MATERIALS AND EXPERIMENTAL PROCEDURES

Commercially produced EPS geofoam blocks measuring 2.5m × 1.0m × 0.5m with nominal densities of 10, 15, 20, 25, 30 and 35kg/m^3 were obtained for the purposes of the investigation reported herein. Each block was cut into three approximately equal-sized parts along the length of the block and samples were obtained from the central as well as from the end portions. Samples are referred to in this text using the symbol EPS and the nominal density (i.e. EPS 15). The mean density values for the EPS geofoam types tested are 9.98, 15.07, 19.90, 24.20, 31.74 and 36.39 and the range of density values between samples from each EPS geofoam type was kept to ±10% of the nominal density. All samples were cut and shaped using hot wires.

Unconfined compression tests were conducted in order to evaluate the effect of sample geometry on the observed behavior of the EPS geofoams. Accordingly, tests were conducted on: (a) 50mm, 100mm and 150mm cubes, (b) 50mm, 100mm, 150mm and 250mm diameter cylinders with aspect ratio equal to 1.0, and (c) cylinders with 100mm diameter and aspect ratio of 0.5, 1.0 and 2.0. All tests were conducted at a strain rate of 10%/minute. A minimum of five samples were tested for each test parameter combination and average values were obtained for each material property as well as for the stress-strain curve. The shape of the stress-strain curves was corrected at very low strain levels in order to exclude seating problems.

Triaxial compression tests were conducted on cylindrical samples with diameter equal to 50mm and aspect ratio equal to 2.0. Testing procedures were similar to those used for testing soils. The samples were confined in a thin membrane and the triaxial testing chamber (cell) was filled with water. Initially, the samples were loaded in hydrostatic compression by applying cell pressure. Three different cell pressures were used for each EPS geofoam, corresponding approximately to 20%, 40% and 60% of the geofoam yield stress. Then the samples were "sheared" by increasing the axial load, at a strain rate of 1%/minute, until a substantial axial deformation (over 30%) was reached. During both loading stages of each test, the air in the voids of the samples was allowed to "drain". The volume change of the samples was recorded continuously during both loading stages in order to have appropriate information for the computation of average lateral strains. Unconfined compression tests (at σ_3=0 kPa as well as in-isolation) were also conducted using samples of the same size and at a strain rate equal to 1%/minute in order to facilitate comparison with results from triaxial testing.

3 UNCONFINED COMPRESSION

Most results obtained from unconfined compression tests have been presented in more detail elsewhere (Atmatzidis et al. 2001). It was observed that the shape, the size and the aspect ratio of the EPS geofoam samples tested have relatively insignificant effects on measured yield stress and compressive strength. However, size and aspect ratio have a significant effect on the values of the initial modulus of elasticity. Typical results illustrating these observations, as well as the anticipated scatter of data due to density deviations from nominal values, are presented in Figure 1 as a function of sample weight.

As a first order approximation, linear correlations were used to fit all available data. However, these correlations had a disadvantage in terms of physical interpretation since they yielded a negative intercept on the y-axis. Furthermore, visual observation of the data indicated a deviation from linearity at the low density range. Accordingly, power curves ($y=ax^b$) were used to correlate the available data, yielding correlation coefficients, R^2, between 0.946 and 0.983 for yield stress and compressive strength and between 0.823 and 0.933 for initial modulus of elasticity. These relations were used to obtain the "normalized" results shown in Figure 2 by introducing both nominal density and nominal volume of samples. Using property values of 50mm cubes (with 125×10^3mm^3 volume and at nominal densities) as reference values, it can be observed that a decrease of this volume by 20% results in a decrease of yield stress and compressive strength by 5% to 15% and in a decrease of initial modulus of elasticity by 26% to 30%. The effect is more pronounced for low density than for high density EPS geofoam. It can also be observed that increasing the sample volume by up to two orders of magnitude (from 125×10^3mm^3 to 12272×10^3mm^3), the yield stress values increase by 2% to 18%, the compressive strength values increase by 5% to 17% and the initial modulus of elasticity values increase by 49% to 66%. The rate of increase is more pronounced for volume increase of up to one order of magnitude approximately. It can further be observed that testing of short samples (aspect ratio 0.5) or tall samples (aspect ratio 2.0) yields underestimations and overestimations, respectively, of all three material properties. This effect is significant for the initial modulus of elasticity (-47% to –56% and +20% to +102%).

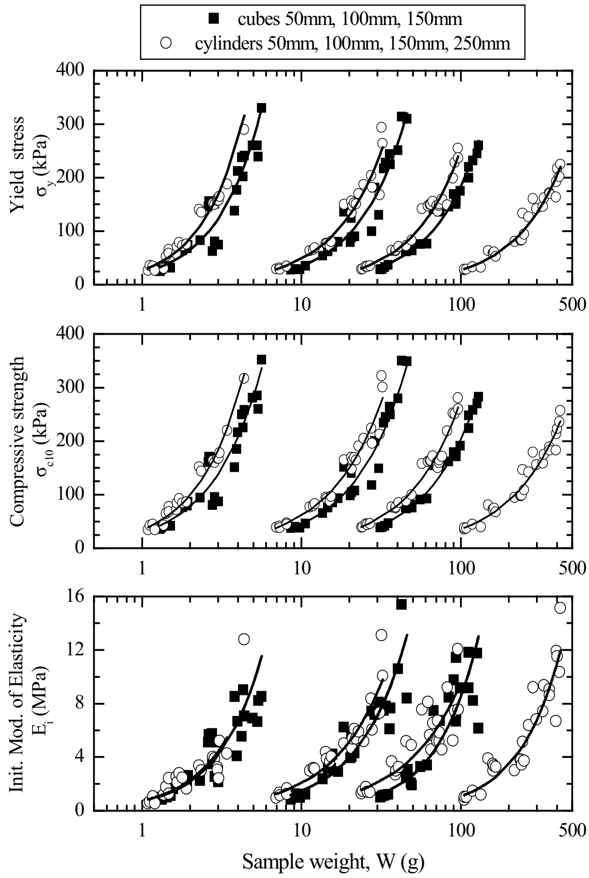

Figure 1. Correlations of data from unconfined compression tests.

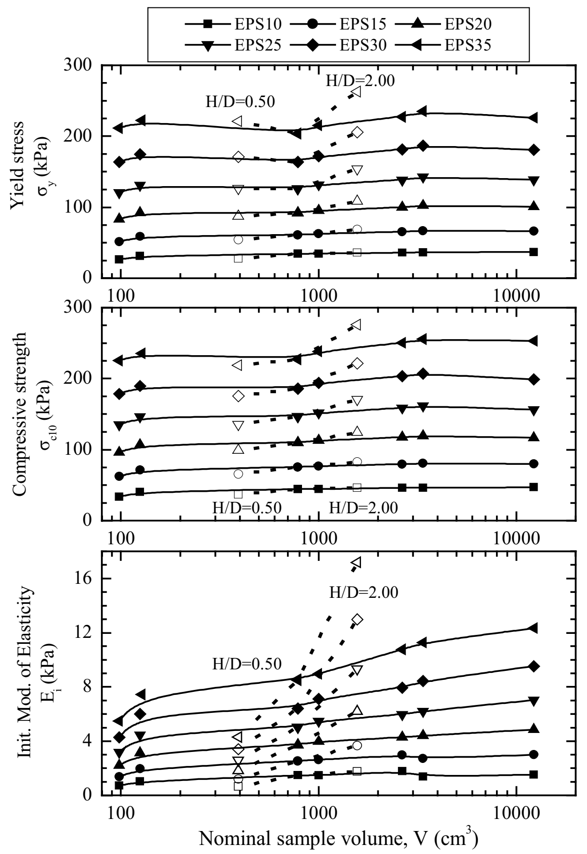

Figure 2. Effect of sample size and aspect ratio on unconfined compression test results.

The observed significant effect of sample size on initial modulus of elasticity values is in very good agreement with results reported by Elragi et al. (2001) who obtained a 100% increase for the initial modulus of elasticity by increasing the volume of standard 50mm cube samples by over three orders of magnitude.

Poisson ratio values for unconfined compression conditions were obtained for samples tested in the triaxial compression chamber with no confining stress (σ_3=0 kPa). Total volume change was monitored and was used to compute average lateral strains since overall axial strains were also recorded. In general, positive Poisson ratio values were computed even for axial strains exceeding the elastic limits of the EPS geofoams tested. Typical values for axial strains, ε_a, equal to 0.5%, 1.0% and 2.0% are shown in Figure 3. It can be observed that Poisson ratio values are not dependent on EPS geofoam density and are definitely positive for low axial strains. The values obtained are in good agreement with results presented by Elragi et al. (2001) who obtained values of approximately 0.1 using overall strains and higher when using strains along the middle third of the samples tested.

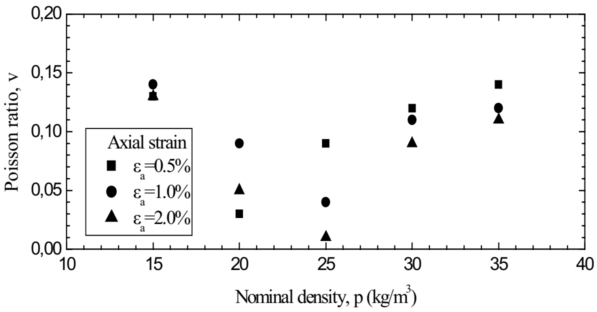

Figure 3. Poisson ratio values from unconfined compression tests.

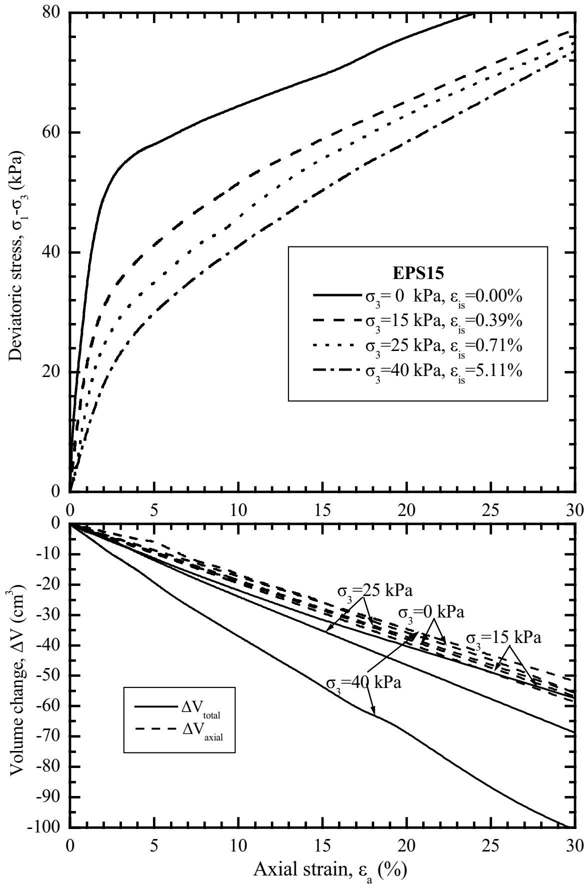

Figure 4. Typical average stress-strain and volume change curves from triaxial and unconfined compression tests.

4 TRIAXIAL COMPRESSION

The typical stress-strain curves shown in Figure 4 depict the behavior of EPS geofoam samples which have been subjected to hydrostatic compression before the application of increasing deviatoric stress. Under these conditions, it was observed that all samples tested exhibited a "softer" behavior than similar samples tested in unconfined compression (lower yield stress, compressive strength and modulus of elasticity). However, this trend is significantly eliminated if the complete stress history of the samples is considered by adding an initial segment to the stress-strain curves which corresponds to the hydrostatic compression stage of loading (i.e. plotting overall axial stress versus overall axial strain). Summarized in Table 1 are results obtained from such stress-strain curves. It can be observed that for initial loading (hydrostatic compression) well within the elastic range of each geofoam sample (15kPa to 25kPa or 8% to 26% of the yield stress), yield stress, compressive strength and modulus of elasticity values have, in most cases, minor differences from those obtained from unconfined compression tests. However, as initial hydrostatic compression stress increases, these differences become significant, especially for the values of the modulus of elasticity.

The typical volume change curves presented in Figure 4 confirm the contractive behavior of EPS geofoam at high axial strains (beyond the elastic limit). It can be observed that, regardless of cell pressure, σ_3, (hydrostatic compression), increasing axial strains are associated with continuously decreasing total sample volume (ΔV_{total}). It can further be observed that computed volume change due to axial deformation (ΔV_{axial}) is always smaller than the total volume change. Accordingly, the average lateral strains during this loading stage are definitely contractive. These arguments should be viewed as qualitative since Poisson ratio values should not be computed for strains higher than the limit of elastic behavior.

Based on volume change measurements during hydrostatic compression, Poisson ratio values were computed according to

Table 1. Comparison of results obtained from unconfined and triaxial compression tests.

	EPS15			EPS20			EPS25			EPS30			EPS35		
σ_3/σ_y	σ_y (kPa)	$\sigma_{c,10}$ (kPa)	E_i (kPa)	σ_y (kPa)	$\sigma_{c,10}$ (kPa)	E_i (kPa)	σ_y (kPa)	$\sigma_{c,10}$ (kPa)	E_i (kPa)	σ_y (kPa)	$\sigma_{c,10}$ (kPa)	Ei (kPa)	σ_y (kPa)	$\sigma_{c,10}$ (kPa)	Ei (kPa)
0	58	64	3536	76	83	3850	138	145	6850	160	168	7910	198	212	10900
0.1	41	62	2075	60	76	3497	-	-	-	138	148	8723	147	168	10877
0.2	44	57	2505	57	66	2473	109	128	7029	106	117	9324	156	182	8690
0.3	45	51	3005	43	64	3567	98	123	2889	110	141	6386	147	170	6772
0.4	32	63	2086	-	-	-	96	105	2514	-	-	-	-	-	-
0.8	24	56	2707	34	48	1305	-	-	-	-	-	-	-	-	-

established formulations (Timoshenko and Goodier, 1970) and are presented in Figure 5. The required modulus of elasticity values and the limits of elastic strain were obtained from unconfined compression (σ_3=0 kPa) tests. It can be observed that the computed values for Poisson ratio are positive when the axial strains are well below the elastic strain limit. As the elastic strain limit is approached, Poisson ratio values decrease and become zero or negative at approximately the elastic strain limit. Beyond this limit, Poisson ratio values are negative and for most tests range between –0.09 and –0.29. It also appears that EPS geofoams of higher density reach negative Poisson ratio values at lower axial strains than EPS geofoams of lower density.

Presented in Figure 6 are Poisson ratio values computed from measurements made during the second loading stage of triaxial compression tests (application of axial load). The values presented were computed for axial strain, ε_a, equal to 0.5% in addition to that obtained from hydrostatic compression. With very few exceptions, it can be observed that when geofoam samples already in a triaxial state of stress are loaded axially, they exhibit negative Poisson ratio values even if the loads are still within the elastic range.

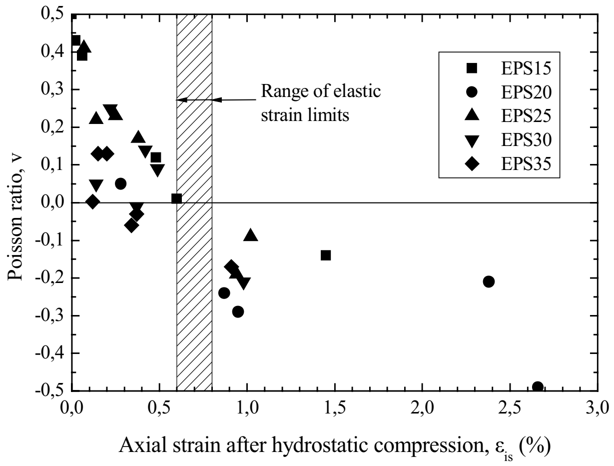

Figure 5. Poisson ratio values from hydrostatic compression tests

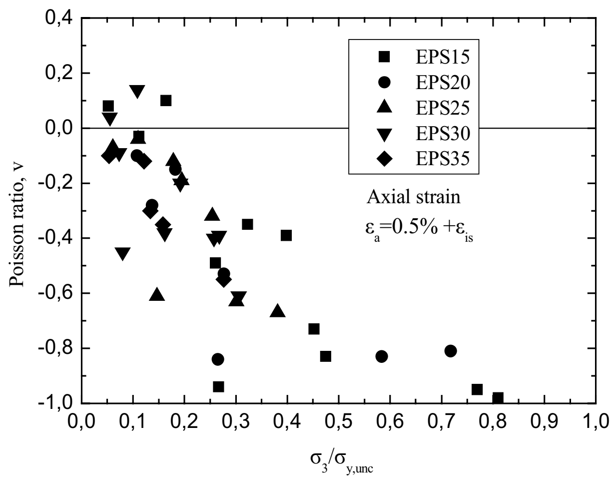

Figure 6. Poisson ratio values from triaxial compression tests

5 CONCLUSIONS

Based on the results of the experimental investigation reported herein, the following conclusion can be advanced:

1. Shape, size and aspect ratio of EPS geofoam samples tested in unconfined compression have relatively insignificant effects on measured yield stress and compressive strength, and testing of 50mm cubes appears to be satisfactory. However, size and aspect ratio have a significant effect on the initial modulus of elasticity which attains higher values (up to 100%) when the sample volume is up to two orders of magnitude larger than the “conventional” 50mm cube. When results from testing 50mm cubes are used for design purposes, expected strains or deformations may be overestimated by a factor of 2.
2. Results obtained from unconfined compression tests can be considered to represent adequately the mechanical behavior of EPS geofoams in applications where the materials are subjected to normal stresses well below their elastic strain limit or even their yield stress. When a more complex stress history is applied, such as that of “consolidation” under hydrostatic compression followed by shearing due to increased axial load, EPS geofoams exhibit a significantly “softer” behavior than in unconfined compression.
3. At low stress levels, characteristic of light-weight fills, the Poisson ratio of EPS geofoams has positive values of up to 0.15 which decrease as axial strains increase toward the elastic strain limit. Beyond this limit, EPS geofoams exhibit contractive behavior.

ACKNOWLEDGMENTS

This research was supported by the European Union and the Hellenic General Secretariat on Research through grant YPER 97 (YP 3-67), as well as by the Hellenic Association of Expanded Polystyrene Producers and the companies MONOSTYR, MONOTEZ and UNISOL.

REFERENCES

Atmatzidis, D.K., Missirlis, E.G. & Chrysikos, D.A. 2001. An investigation of EPS geofoam behavior in compression. *EPS Geofoam 2001; Proc. 3rd Intern. Symp., Salt Lake City, 10-12 December 2001.* (in print)

Duskov, M. 1997. Materials research on EPS20 and EPS15 under representative conditions in pavement structures. *Geotextiles and Geomembranes* 15 (1-3): 147-181.

Elragi, A., Negussey, G. & Kyanka, G. 2001. Sample size effects on the behavior of EPS geofoam. In J. L. Hanson & R. J. Termaat (eds), *Soft Ground Technology; Geotechnical Special Publication No. 112, Conf., Noordwijkerhout, 28 May – 2 June 2000.* New York: ASCE

Eriksson, L. & Trank, R. 1991. Properties of expanded polystyrene-Laboratory experiments. *Expanded Polystyrene as Light Fill Material, Technical Visit Around Stockholm, 19 June 1991.* Linkoping, Sweden: Swedish Geotechnical Institute.

Frydenlund, T.E. & Aaboe, R. 1996. Expanded polystyrene the light solution. *EPS Tokyo '96; Proc. Intern. Symp., Tokyo, 29-30 October 1996.* Tokyo: EDO.

Horvath, J.S. 1995. *Geofoam geosynthetic.* Scarsdale, N.Y: Horvath Engineering, P.C.

Magnan, J.P. & Serratrice, J.F. 1989. Proprietes mechaniques du polystyrene expanse pour des applications en remblai routier. *Bulletin Liaison Laboratoire Ponts e Chaussees*, No.164: 25-31. Paris: LCPC

Negussey, D. & Sun, M.C. 1996. Reducing lateral pressure by geofoam (EPS) substitution. *EPS Tokyo '96; Proc. Intern. Symp., Tokyo, 29-30 October 1996.* Tokyo: EDO.

Preber, T., Bang, S., Ching, Y. & Cho, Y. 1994. Behavior of expanded polystyrene blocks. *Transportation Research Record,* 1462:36-46.

Timoshenko, S.P. & Goodier, J.N. 1970. *Theory of Elasticity.* New York: McGraw-Hill Book Company.