AN EXPERIMENTAL STUDY ON THE CREEP BEHAVIOR OF EXPANDED POLYSTYRENE (EPS) GEOFOAM UNDER SUSTAINED LOAD

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ABSTRACT

Expanded Polystyrene (EPS) Geofoam has been used as a lightweight fill material in a diversity of geotechnical projects worldwide. Its low density, high compressive resistance and faster construction time, amongst other advantageous characteristics, makes it a popular lightweight fill material. For design using EPS, one of the paramount traits is creep deformation; of greater significance to shear failure. In turn, the aim of this study is to display the results of long-term/creep tests performed earlier, on various types of EPS worldwide. This is in addition to the latest experimental program conducted at the McGill EPS durability facility.

The research work presented herein considers two densities of 100mm EPS geofoam samples (15 kg/m^3 and 22 kg/m^3). The long-term (creep) test results are displayed for two different stress levels (50% and 80% of the material's 5% compressive strength limit). The 15 kg/m^3 samples, exhibited an accumulated strain of 0.87% and 9.3% - after 2200 hours – respectively. The 22 kg/m^3 samples, exhibited 1.17% and 14.4% for the same stress magnitudes and time duration; indicating the dire effect of sustained compressive stress. The ongoing study serves to calibrate and validate empirical and numerical models, respectively.
Keywords: Expanded Polystyrene (EPS) Geofoam; Creep; Sustained load; Longterm; Durability.

INTRODUCTION

The American Society of Testing and Materials (ASTM) defines geofoam as a block or planar rigid cellular foam polymeric material used in geotechnical engineering applications (Arellano and Stark, 2009). Expanded polystyrene (EPS) – a type of geofoam – is currently one of the leading polymers; used in small strain geotechnical applications such as light weight fill embankments. In design of such embankments, EPS should be able to fulfill major design criterias of which assessment of creep is the most important aspect (Awol, 2012). The long-term deformation of EPS geofoam could be detrimental to structures supported by the geo-material despite its increasing popularity. Having advantageous traits – such as light weight and convenience in construction – has promoted its manufacturing worldwide. The variation in the manufacturing process of EPS Geofoam was undoubtedly the cause of different inherent mechanical and long-term characteristics. The scatter of results - related to the mechanical parameters of EPS Geofoam such as the modulus of elasticity and Poisson's ratio – is evident in the available earlier related efforts. Such inconsistency is not limited to the variation in material, but also a result of lack of standard test method(s). The sole standard, ASTM D1621-10 (Standard test method for compressive properties of rigid cellular plastics), can be used to a certain extent for testing EPS Geofoam. Other ASTM standards related to EPS Geofoam can only provide information about design considerations (ASTM D7180), physical properties and dimensions (ASTM D6817) as well as quality insurance (ASTM D7557).

As regards the creep behavior of EPS Geofoam, it can be explained as per Figure 1, below, comprising three stages. In the first stage, the primary creep stage, the rate of creep evolution decreases with time. Should the rate of creep be very low, the secondary creep phase would designate the range of steady state creep (known as stationary creep). Depending on the level of applied stress, the tertiary creep phase may or may not exist. The increase of micro-cracking at high levels of stress may lead to the tertiary phase.

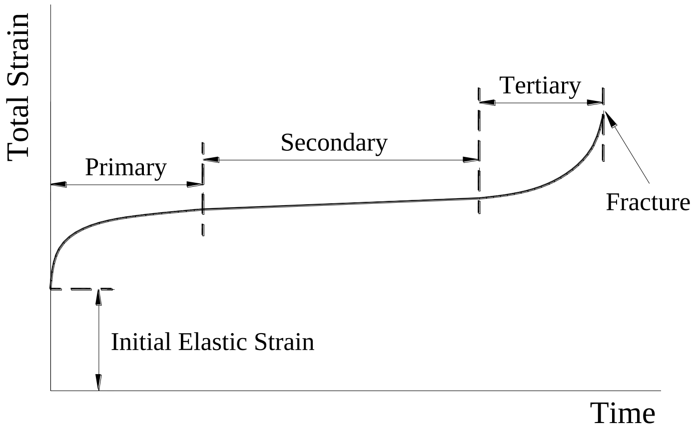

Figure 1: Typical strain history curve during creep deformation

The initial deformation (ε_o) represents a significant part of the total deformation (Sheeley, 2000). A number of parameters can affect the creep behavior of EPS, among which density, sample size, temperature and degree of loading. Creep deformations decrease with the increase of density (Sun, 1997). Figure 2 displays the long-term (creep behavior) of 100mm cubes of 18kg/m^3 density under three levels of sustained compressive load for a duration of 4000 hours (Srirajan et al., 2000). Despite the availability of some data, EPS geofoam long-term data is yet scarce and needs further effort and standardizing.

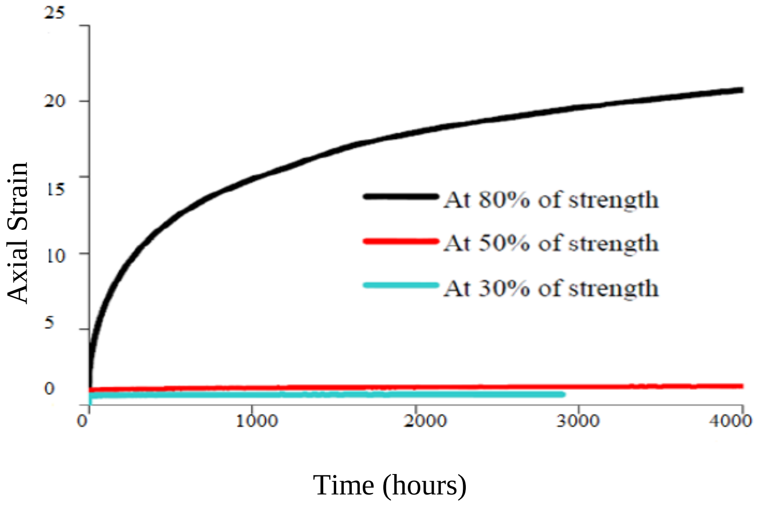

Figure 2: Creep behavior of 100mm cubes with a density of 18kg/m^3 at different stress levels (Srirajan et al., 2000)

Creep deformation results gathered from literature and laboratory tests exhibit inconsistency mainly due to a lack of standard procedure as well as different testing conditions (shape, size, density, temperature, etc…). EPS Geofoam parameters rely mainly on results from small size samples. Thus, for comparison purpose, the current experimental program is conducted on small size specimens. However, since small samples tend to exaggerate/overestimate the total deformation, 100mm cube samples are examined instead of the popular 50mm samples.

In earlier efforts regarding long-term (creep) tests, the applied sustained compressive load on EPS samples is chosen as a fraction of a particular strain-inducing load. Load levels inducing 5% deformation and 10% deformation are taken as the typical reference values. It is also common in previous efforts to apply 50% and 80% - of the load inducing 5% deformation – as sustained load on EPS samples. In addition to applied stress, EPS density is considered as one of the main parameters related to the developed total deformation.

Figure 3 depicts the stress-strain behavior of EPS Geofoam; particularly at 1%, 5% and 10% compressive strength, respectively. The compressive strength (ordinate) values shown in Figure 2 are also represented in the column indicating (100%) in Tables 1 and 2. EPS geofoam behaves as a linear elastic material up to 1% strain (elastic limit stress) and this strain value (1%) occurs during rapid-loading or short term compression tests. Beyond the yield strength of EPS, permanent strains occur and higher compressive strains (5% strain and 10% strain) are consequently used for long-term tests.

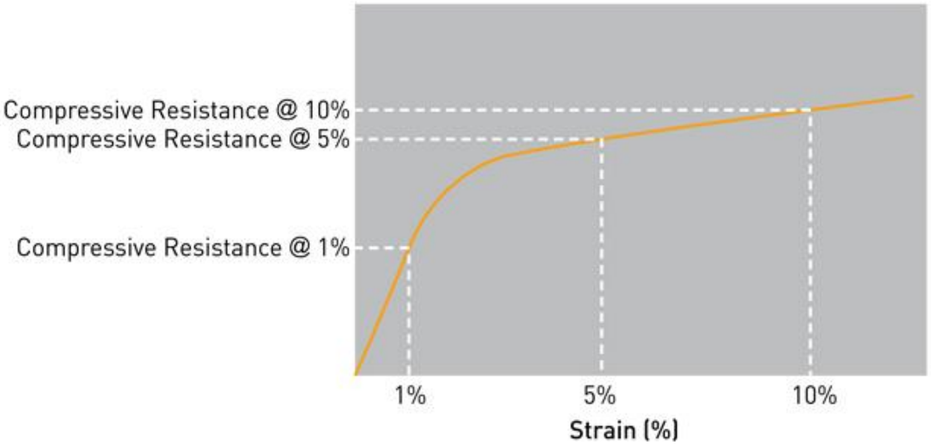

Figure 3: Stress-strain relationship for EPS Geofoam (www.geofoam.org)

OBJECTIVES

The primary aim of this ongoing study is to investigate the behavior of EPS geofoam under long term sustained constant load. Experimentally obtained time-strain relationships – for different levels of constant stress – will aid in calibrating popular time-dependent stress-strain (creep) models, at a later stage. Two of which are the “General Power-law” equation and “Findley’s” equation.

Furthermore, finite element modeling (FEM) of the EPS geofoam behavior under sustained load - using Plaxis 3D - is currently taking place; model verification is aided by the obtained experimental data of this study.

EXPERIMENTAL PROGRAM

The long-term (creep) test in this study is conducted on 100mm cubic samples with different densities (15kg/m^3 and 22kg/m^3) under 50% and 80% of the maximum compressive strength (equivalent to load level inducing 5% strain) of the EPS Geofoam. The ambient temperature was around 23^{o}C and the duration of the test was approximately 2200 hours for all samples.

Materials

To carry out the long-term tests, 100mm pre-cut cubic samples manufactured and provided by Plastifab Inc were made available. Two sample sets with two different densities (Figure 4) are used: A white sample (15 kg/m^3) and a green sample (22 kg/m^3). The tables below show the compressive strength for each type of Geofoam at different stress levels. The underlined force magnitudes in Tables 1 and 2 were applied during the creep test.

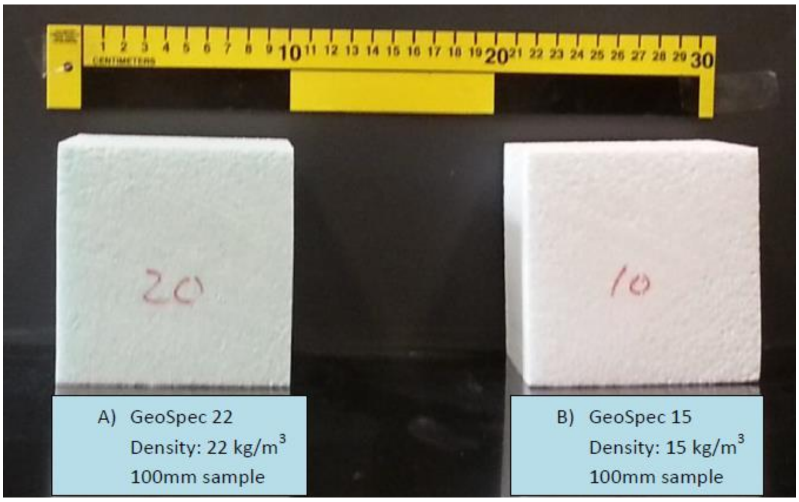

Figure 4: Geofoam cube samples (100 mm)

Table 1: Compressive strength of the white sample (15kg/m^3)

White Geofoam (15 kg/m^3)	**Applied compressive-strength percentage**	**100%**	**90%**	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
	Compressive strength (kPa); minimum @ 1% deformation	25	22,5	20	17,5	15	12,5	10	7,5	5	2,5
	Force (N)	250	225	200	175	150	125	100	75	50	25
	Compressive strength (kPa); minimum @ 5% deformation	55	49,5	44	38,5	33	27,5	22	16,5	11	5,5
	Force (N)	550	495	**440**	385	330	**275**	220	165	110	55
	Compressive strength (kPa); minimum @ 10% deformation	70	63	56	49	42	35	28	21	14	7
	Force (N)	700	630	560	490	420	350	280	210	140	70

Table 2: Compressive strength of the green sample (22kg/m^3)

Green Geofoam (22kg/m^3)	**Applied compressive-strength percentage**	**100%**	**90%**	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
	Compressive strength (kPa); minimum @ 1% deformation	50	45	40	35	30	25	20	15	10	5
	Force (N)	500	450	400	350	300	250	200	150	100	50
	Compressive strength (kPa); minimum @ 5% deformation	115	103,5	92	80,5	69	57,5	46	34,5	23	11,5
	Force (N)	1150	1035	**920**	805	690	**575**	460	345	230	115
	Compressive strength (kPa); minimum @ 10% deformation	135	121,5	108	94,5	81	67,5	54	40,5	27	13,5
	Force (N)	1350	1215	1080	945	810	675	540	405	270	135

Apparatus

The majority of the creep tests – in earlier efforts - were performed using hydraulic loading systems; cantilever dead weight loading frames or direct dead weight loading were also evident. In a series of preliminary tests at the McGill Geofoam durability facility, direct dead weight loading was examined onto 100mm cubic samples. The option was discarded after preliminary tests, since the deformations at each side of the specimen were not equal (an indication of non-uniform stress distribution). The alternative was building a new pneumatic uniaxial loading system (See Figure 5).

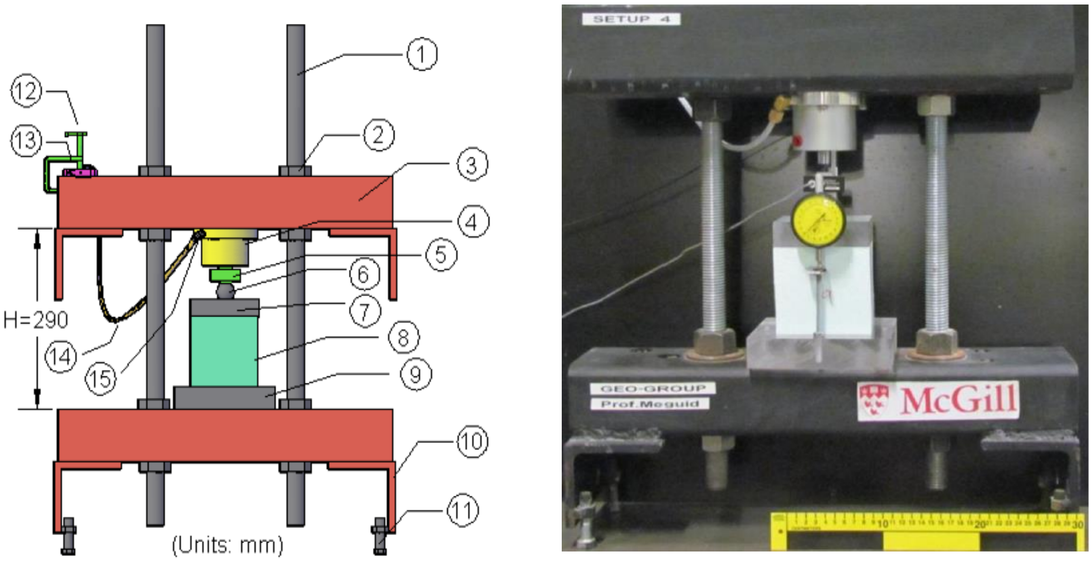

Figure 5: EPS Geofoam testing apparatus schematic (left) and as-built (right)

The components of the customized set-up – noted from 1 to 15 indicate respectively: threaded steel rod; hexagonal nut; hollow square steel section; air cylinder; load cell; steel ball; plexiglas top plate; geofoam sample; plexiglas base plate; steel L-channel; levelling screws; c-clamp; three-way air valve; rigid tubing and elbow pipe fitting.

Testing Procedure

The EPS Geofoam sample rests between a top and bottom plate of plexiglass. A load cell is coupled with a hardened steel ball and an air cylinder. The latter is connected to the top hollow square steel section and also to an air regulator through rigid plastic tubes. The hardened steel ball rests on a wedge made in the middle of the top plate of plexiglass in order to have a uniform distribution of stress. Displacements of the EPS samples are measured using two methods: (i) an LVDT, connected to the data acquisition system; placed behind the EPS sample with its springs resting on the bottom plexiglass plate; (ii) a dial gage placed in front the cubic EPS specimen with its measuring tip resting on a large square metal surface welded to a long screw (Figure 3).

Once the sample is placed on the bottom plate, the top hollow section is lowered gradually until a small gap/tolerance remains between the hardened steel ball and the top plate. The spring of the LVDT is regularly checked to ensure its adequate resting on the bottom plate. A similar procedure is applied to the dial gage with its tip resting on the centre of the square metal surface. The valves connected to the air cylinders are consequently shut down and air pressure is gradually applied to the four (4) set-ups until the piston of the air cylinder starts coming down and a uniform compressive stress is applied onto the cube samples. A slow incremental early pressure allows recording more data-points for the immediate deformation.

RESULTS AND DISCUSSION

Figure 6 and Figure 7, below, demonstrate the behavior of a total of four samples for a period of 2200 hours (3 months) approx.; where the density and sustained load level serve as the main study parameters. For the (white) 15kg/m^3 samples (Figure 6): A total deformation of 0.87% occurs under 50% loading; 85% of which occurs during the first hour which represents the initial deformation (ε_o). After the first 3 days, the deformation increases gradually until it reaches a plateau of 0.8mm approximately. As for 80% loading, the behavior of EPS exhibits significant change. The deformation rate increases to achieve a deformation as high as 9.3% after 3 months without arriving to a pseudo-constant plateau. The initial deformation (ε_o) represents only 17% of the total deformation at 2200 hours.

Figure 7 illustrates the behavior of 100mm cubic green samples (22 kg/m^3). A total deformation of 1.17% occurs under 50% loading and similarly to the white sample, most of the deformation develops over the first hour as 67.3% of the total deformation (at 2200 hours) takes place during this initial deformation (ε_o). The total deformation reaches a plateau at around 1.15mm. As for 80% loading, the deformation rate increases rapidly. A total deformation of 14.4% occurs and the initial deformation (ε_o) represents only 13.1% of this total deformation.

The study observations are consistent with the laboratory creep tests previously conducted by Srirajan et al. (Figure 2); wherein the 50% loading scenario yielded a total deformation less than 2% at 4000 hours; given the EPS density of 18 kg/m^3. As for the 80% loading, the total deformation significant as it reached 20% after 4000 hours. The corresponding values - in this effort at 2200 hours– are 9.3% and 14.4% for the white and green samples, respectively.

Furthermore in the current study, the deformation measurements given by dial gauges for both samples - under a 50% loading – were in good agreement with LVDT readings. A total deformation of 0.90% and 1.2% was noticed for the white and green samples, respectively; a difference of 3% approximately.

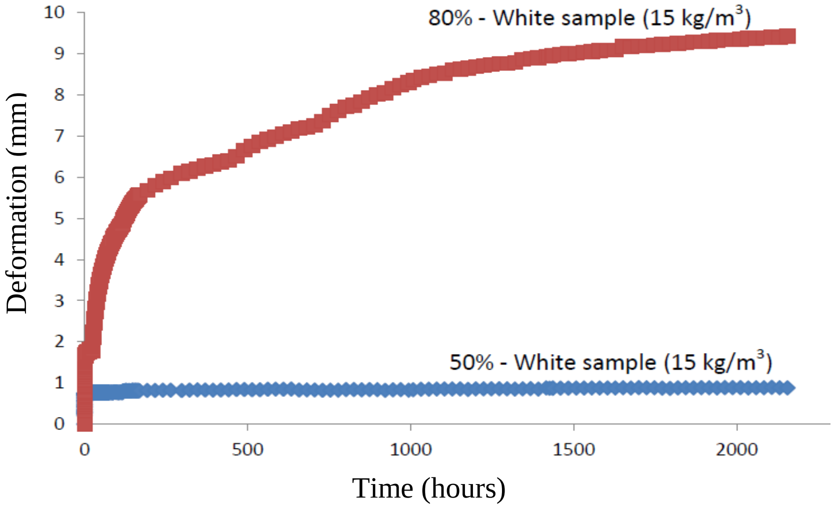

Figure 6: Time-deformation behaviour of white samples (15kg/m^3)

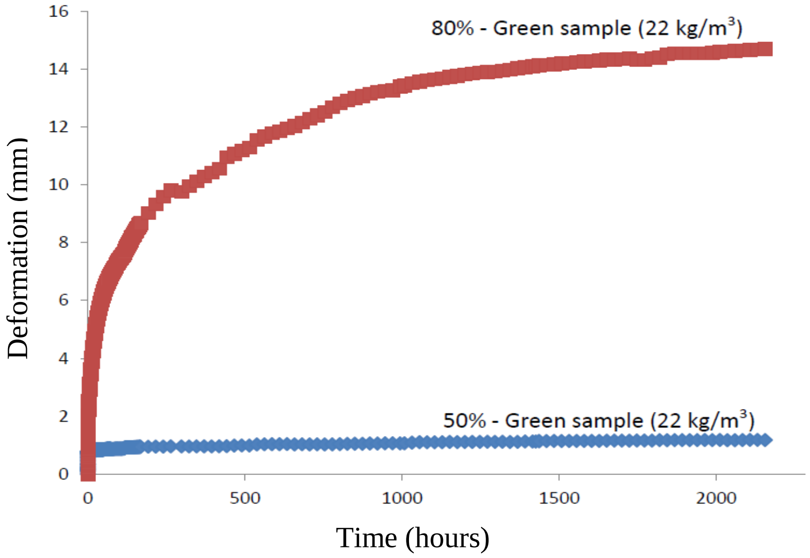

Figure 7: Time-deformation behaviour of green samples (22kg/m^3)

CONCLUSION

The research study presented herein investigates the long-term creep tests of 100mm EPS Geofoam cubes of two different densities (15 kg/m^3 and 22 kg/m^3); under two levels of compression sustained load (50% and 80% loading magnitude of the 5% deformation limit). The test duration extended to 2200 hours (3 months approx.); yielding the observations below:

1- The obtained long-term illustrated the significant influence of applied stress level onto total deformation; varying from 0.87% to 9.3% for 50% and 80% loading, respectively for 15 kg/m^3 samples. Whereas, the 22 kg/m^3 samples exhibited 1.17% and 14.4% for the same stress magnitudes, respectively.

2- For samples subjected to 50% loading: the initial deformation represents a sizeable portion of the total deformation for samples exhibiting an applied stress of 50%; 85% and 67.3% for 15 kg/m^3 and 22 kg/m^3, respectively. The importance of initial deformation decreases under an applied stress of 80%; 17% and 13.1%, respectively. At 50% loading, a pseudo-constant accumulated strain plateau is reached after 3 days; whereas strain continues to accumulate gradually for 80% loading.

3- In this research study, the effect of density cannot be adequately inferred upon. This necessitates equal load magnitude (of uniform stress) to be applied on samples of different densities.

RECOMMENDATIONS

Based on the outcome of this study, some suggestions are listed below for future work on long-term creep tests for EPS Geofoam blocks:

1- Additional long-term creep tests need to be carried out in consistency with ASTM D1621-10 (Standard test method for compressive properties of rigid cellular plastics) and to check repeatability in order to obtain a better basis for results comparison.

2- Due to the absence of an ASTM standard method for creep testing of EPS Geofoam, a standard test method needs to be developed and implemented in order to obtain consistent values for the mechanical parameters.

3- The effect of other parameters including sample size, density, sample shape, boundary conditions and temperature should be investigated further.

4- The durability of Geofoam under the coupled effect of sustained load and adverse (or real life) environmental conditions needs to be investigated.

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