Status of ASCE Standard on Design and Construction of Frost Protected Shallow Foundations[1]

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INTRODUCTION

The discusser has comments on two aspects of geofoam material properties addressed in this paper:

1. mechanical (stress-strain-time) and
2. thermal.

Although the term *geofoam* was not used by the authors, it is used here to refer to the geosynthetic thermal-insulation materials that are the key component of a frost-protected shallow foundation (FPSF) system. The discusser's comments focus on generic geofoam products consisting of solid panels of either block-molded expanded polystyrene (EPS) or extruded polystyrene (XPS) which are used in the majority of FPSF applications worldwide.

MECHANICAL PROPERTIES

The mechanical behavior of geofoam must be considered in FPSF systems because the thermal resistivity of the geofoam is partially a function of its thickness. Thus there is a need to limit the geofoam compression that occurs in service under applied stresses from the soil backfill plus any other loads. The authors state correctly that the normal stress to which the geofoam should be subjected must be something less than the *compressive strength* of the geofoam material. However, the discusser disagrees with the design approach presented in the paper which is based on limiting stresses to the compressive strength divided by some empirical safety factor. The reason is that there is an alternative design approach that provides much greater insight into and confidence in the end result. This alternative approach is simple to use in practice and has already seen worldwide acceptance and use, especially for other geofoam applications such as lightweight fills for roads.

The basis of this alternative approach derives from the fact that the parameter of compressive strength for geofoam materials such as EPS and XPS is arbitrary and arguably irrelevant to actual material behavior in practice. To begin with, the more-or-less standard test used worldwide to determine compressive strength is performed at a relatively rapid rate, typically 10% strain per minute. This means that the stress-strain behavior determined by a standard test provides no inherent, fundamental insight into creep behavior of the geofoam. As discussed subsequently, geofoam creep is a very important consideration. Other relevant aspects of a standard test are illustrated using Figure A which depicts the results from a standard test on a specimen of EPS. Although this figure is for a specific density of EPS, the behavior of other densities of EPS is qualitatively identical and the behavior of XPS is similar. The important points illustrated in Figure A are:

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[1] By L. S. Danyluk and J. H. Crandell, in "Innovative Design and Construction for Foundations and Substructures Subject to Freezing and Frost," C. K. Tan (ed.), *Geotechnical Special Publication No. 73*, ASCE, 1997.

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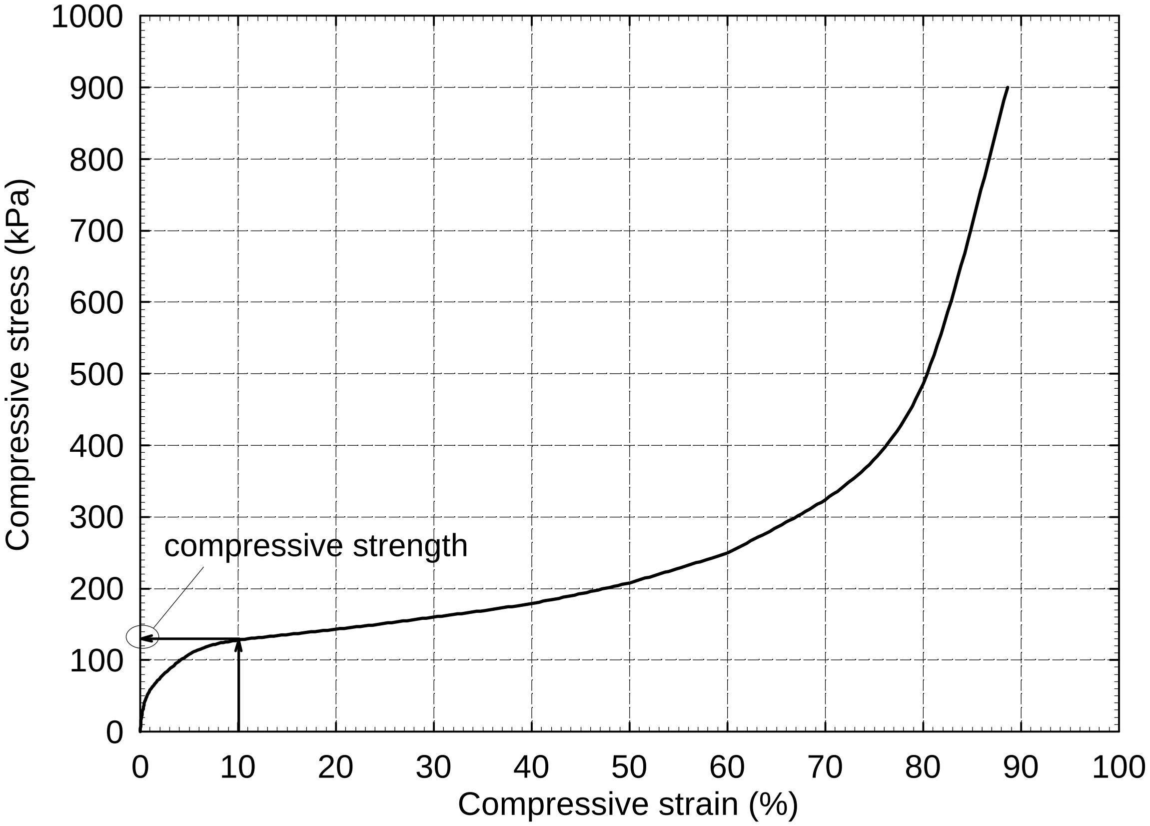

Figure A. Stress-strain behavior of block-molded EPS (density = 21 kg/m^3 (1.3 lb/ft^3)) under rapid loading [from Horvath 1995]

1. When loaded in compression, the specimen never fails in the traditional sense of material rupture but essentially crushes one-dimensionally back to solid polystyrene. Consequently, the concept that there is even a parameter that might be called a "strength" in the classical civil-engineering use of this term is questionable.

2. The compressive strength for EPS is defined arbitrarily. ASTM standards define it as the compressive stress at 10% strain (an alternative definition is used for XPS because of a slight behavioral difference). Thus for the specimen shown in Figure A, the compressive strength is 130 kPa (2700 lb/ft^2 or 19 lb/in^2) as indicated in the figure. However, as can be seen in Figure A there is nothing fundamentally unique or even noteworthy about a strain level of 10% other than that it occurs after an initial zone of yielding of the EPS under rapid loading.

However, the most-significant shortcoming of compressive strength as defined traditionally is that it provides no insight into creep behavior of the geofoam. This is illustrated using Figure B which shows isochronous stress-strain curves up to 10000 hours (14 months) for a different specimen of EPS (the behavior of EPS of other densities as well as XPS is qualitatively identical). These curves were developed from long-term compressive creep tests. For comparison, a portion of the stress-strain curve obtained in a standard rapid-loading test on the same material is also shown in Figure B. Note that the compressive strength for this material (145 kPa (3000 lb/ft^2 or 21 lb/in^2)) falls well off Figure B.

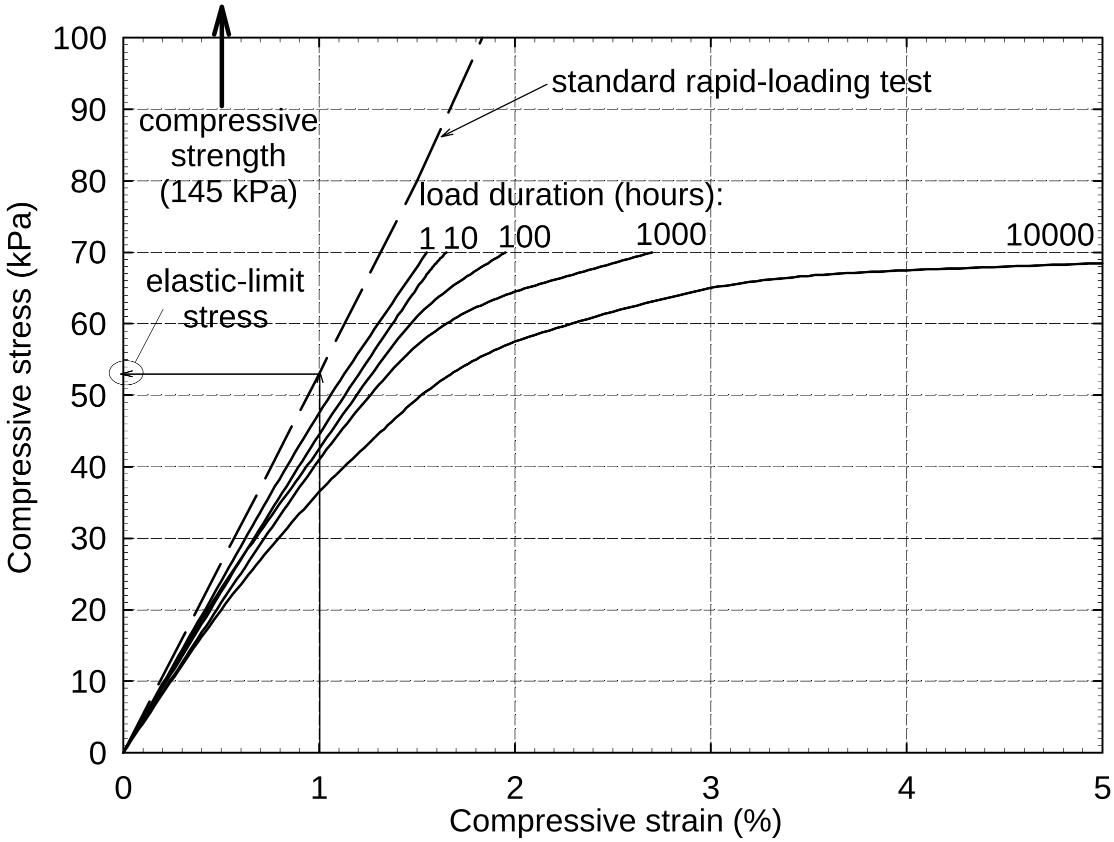

Figure B. Isochronous stress-strain curves for block-molded EPS (density = 23.5 kg/m^3 (1.47 lb/ft^3)) [from Horvath 1995]

The most-important point made using Figure B is that to keep long-term compressive strains within acceptable levels for applications such as FPSF systems, stress levels have to be kept low relative to compressive strength. The consensus that has evolved is that for EPS of any density, the long-term compressive stress should be kept below what is called the *elastic-limit stress* which is defined as the compressive stress at 1% strain in the standard rapid-loading test (Horvath 1995). For the test specimen in Figure B, the elastic-limit stress is 53 kPa (1100 lb/ft^2 or 7.7 lb/in^2) which is about 30% of the compressive strength. Note how creep strains increase rapidly for stresses above the elastic-limit stress yet still below the compressive strength. It is important to note that the elastic-limit stress is both easy to determine exactly from the standard rapid-loading test or, lacking test data, can be estimated accurately from correlations with EPS density (Horvath 1995). Another benefit of limiting applied stresses to the elastic limit of the geofoam material is that cyclic loads will not produce plastic (non-recoverable) deformations that could negatively affect the thermal performance of the geofoam.

Available data indicate that XPS also exhibits an elastic-limit stress that could be used in the same manner to define an upper-bound long-term stress level to be used in practice. Based on the limited data to which the discusser has had access to date, it appears that the strain level corresponding to the elastic-limit stress for XPS is lower than that for EPS, in the range of 0.5% to 0.75%. As a result, the elastic-limit stress for XPS may be as low as about 20% of its compressive strength, a proportionately greater reduction from compressive strength than for EPS. In addition, with XPS there is a need to consider its inherent cross-anisotropic mechanical properties where appropriate (block-molded EPS is mechanically isotropic).

In summary, the discusser's opinion is that the limiting compressive stress for geofoam applications such as FPSF systems where strains need to be controlled is better defined using a theoretically sound and explicit approach based on elastic-limit stress as opposed to using compressive strength with some empirical reduction factor (safety factor). The benefit of using the elastic-limit stress as a design parameter has already proven itself in practice in other areas of geofoam technology.

THERMAL PROPERTIES

All polymeric geofoam materials absorb water once buried in the ground. As a minimum, the absorbed water decreases the thermal efficiency of the geofoam material because it increases the coefficient of thermal conductivity. For some geofoam materials, the absorbed water will also detrimentally affect the mechanical properties as well. Therefore, an appropriate allowance for water absorption should be made in design.

The amount of absorbed water has been observed to vary widely even for a given geofoam material. As discussed in detail in Horvath (1995), there are many variables affecting geofoam water absorption. In the discusser's opinion, this makes development of a useful, accurate predictive model and/or standardized laboratory test for water absorption a practical impossibility. Therefore, any guidelines for absorbed water to be assumed in design of geofoam should be derived solely from long-term observation of actual applications in practice or test installations that replicate actual applications. The discusser also suggests that the use of other design details, particularly the use of a geomembrane cover over the geofoam and/or a drainage layer (geosynthetic drainage composite or high-permeability soil) adjacent to the geofoam, should be considered more in the future in FPSF applications. As discussed in Horvath (1995), experience in Finland, for example, has shown that the use of a geomembrane cover over a horizontal layer of EPS geofoam in an FPSF system can keep absorbed water to negligible levels (< 1% by volume) even after years of service.

APPENDIX. REFERENCES

Horvath, J. S. (1995). *Geofoam geosynthetic*, Horvath Engineering, P.C., Scarsdale, N.Y., U.S.A.

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