USE OF EPS TO SUPPORT MULTIFUNCTION SPORTS FLOORS ON EXISTING STRUCTURES

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ABSTRACT

The use of expanded polystyrene (EPS) in the construction industry can lighten structures and optimize their performance through better use of tough materials. In Argentina, it is common use in slabs lightened for tall buildings and homes, where the material acts passively. However, there are not many applications where the EPS meets structural features similar to soils, such as under road pavement, fill embankments or buried pipes. Therefore, there is no sufficient information on the physical and mechanical properties of EPS made in local production. This information is a necessary prerequisite to proposed reliable solutions on interaction problems with EPS, soils and structures.

This paper presents an application case where EPS is used as transitional material between a new floor and an existing structure. The new floor will be used to carry out various sports activities. The existing structure corresponds to a big slab covering the pool at the College of Commerce "Manuel Belgrano" at Cordoba City. In this project, EPS was adopted as a solution to raise and level the sports floor without significantly increasing the level of load on the structure. For the purposes of making a rational design and verify proper performance of the work, a test plan was implemented for stress-strain characterization of locally produced EPS with different densities. The structural design alternatives were analyzed by numerical simulations using the finite element technique. From the results of the study the properties of materials and geometries for optimal design were decided.

INTRODUCTION

The expanded polystyrene (EPS) geofoam has established its position as an important and widely used material, and has been growing fast for the last forty years. It is a material that has been used in many countries as a lightweight and compressible geomaterial. The big popularity of this kind of material is due to its properties and characteristics, such as lightweight, compressible, water resistant, ease of use, and more. EPS applications in civil engineering construction can be divided into two groups: small-strain and large-strain applications [1]. Small-strain applications involve the use of EPS as lightweight fill, while large-strain applications are limited to its compressible function. So the required properties for EPS can vary with use. In general, the EPS properties are linked to the density of the finished product.

In geotechnical applications a compressible inclusion is typically placed between a below-soil structure and the surrounding soil. Because the inclusion is the most compressible component of the system, it will deform more readily than the other systems components under an applied stress or displacement. This compression can result in less load on the structure than if no inclusion were present [2].

Geofoam is adequate for compressible inclusions. Selection of appropriate geofoam material is based on consideration of its relevant engineering properties, durability, costs and environmental factors. For compressible inclusion applications, stiffness of the material in the primary direction of displacement is the most relevant property, equivalent in geotechnical design to the coefficient of subgrade reaction [2]. Different research on geofoam has been conducted to determine material properties such as stress-strain behavior from compression tests [1], [3], [4] cyclic stress-strain behavior [5], [6], behavior of geofoam blocks at the interface [7], and water absorption [8]. In addition, many papers have applications of geofoam in different engineering works such as embankments, bridge abutments, road widening, earth retaining structures, and buried pipeline systems [2], [9], [10], [11].

This paper presents an application case where EPS is used as a compressible inclusion between a new floor and an existing structure. The new floor will be used to carry out various sports activities. The existing structure corresponds to a big slab, approximately 20 meters of separation between supports, covering the pool at the College of Commerce “Manuel Belgrano” at Cordoba City. In this project, EPS was adopted as a solution to raise and level the sports floor without significantly increasing the level of load on the structure. In this case, the load increase arises from the filling material and new surcharge use. For making a rational design and verify proper performance of the work, a test plan was implemented for stress-strain characterization of locally produced EPS with different densities. Then, the structural design alternatives were analyzed by numerical simulations using the finite element technique. From the results of the study the appropriate properties of materials and geometries for optimal design were decided.

STRUCTURAL PROBLEM STATEMENT AND NUMERICAL MODEL

This study was conducted to assess the behavior of a technical solution to a roof remediation for a structure with large spans. The structure is made up of plane frames with lengths of approximately 20 meters, 5.90 meters apart from each other, determining a warehouse type building of 3000 m^2 (Figure 1). The study focuses on the analysis of the upper enclosure or roof of the structure. The upper enclosure is shaped by a structural package of three elements: an upper concrete diaphragm, expanded polystyrene core sitting on the existing slab. The analysis has been performed under the action of static and thermal loads.

Figure 1: Inside view of the structure

The structure analysis is intended for recreational or sporting activities, and an overload of 5 kN/m^2 is considered, as specified in the regulation of Argentina (CIRSOC 101) [12]. Structural analysis has been done through the use of computational tools through the implementation of finite element numerical models.

The parameters used in the models correspond to typical values for materials used, average values established by regulation CIRSOC 201 [13]. The thickness of the existing slab and EPS are considered constant, while for the concrete diaphragm were considered different thicknesses, which are characterized from the normal stiffness and bending.

Table 1: Parameters adopted for verification

Parameter	UNIT	Concrete diaphragm			
		0.04m	0.06m	0.08m	0.10m
Material model	---	Elastic			
Material behavior	---	Beam element			
Unit weight	kN/m^3	2400	2400	2400	2400
Axial stiffness (*EA*)	kN/m	4.72 x 10^5	7,08 x 10^5	9.44 x 10^5	1.18 x 10^6
Flexural stiffness (*EI*)	kNm^2/m	62.93	212.4	503.467	983,33
Equivalent thickness	m	0.04	0.06	0.08	0.10
Young modulus	kN/m^2	2 x 10^6	2 x 10^6	2 x 10^6	2 x 10^6
Poisson relation	---	0,15	0,15	0,15	0,15
Thermal expansion coefficient	1/ºC	1 x 10^{-5}	1 x 10^{-5}	1 x 10^{-5}	1 x 10^{-5}

Parameter	UNIT	EPS	Existing slab
Material model	---	Linear elastic	Elastic
Material behavior	---	Non porous	Bean element
Unit weight	kN/m^3	0.135	24
Permeability	---	Impermeable	Impermeable
Shear modulus	KN/m^2	1485,149	---
Young modulus	kN/m^2	3000	---
Poisson relation	---	0.01	---
Axial stiffness (*EA*)	kN/m	---	2,120x10^6
Flexural stiffness (*EI*)	kNm^2/m	---	5734,8

Calculations were made for a combination of scenarios consisting of varying the thickness of the diaphragm, link conditions and types of load distribution. This has led to 16 scenario analysis. Figure 2 shows the different elements of the model implemented. The analysis is performed on condition of static gravity loads.

There are two types of loads. Own weight, assumed uniformly distributed and overload (5 kN/m^2) distributed evenly throughout the section and uniformly distributed in the central area of the bay. The loads are combined according to the different scenarios presented. In order to establish the thickness recommended for expansion joints the thermal effects have been considered.

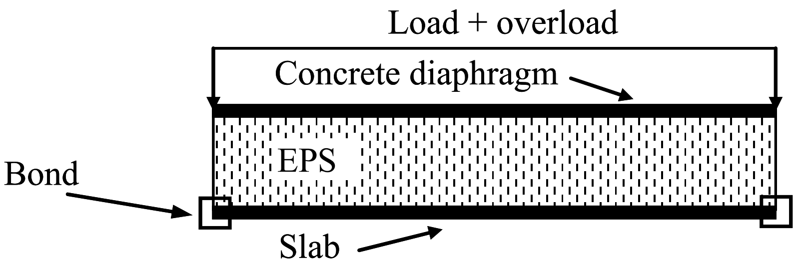

Figure 2: Model Scheme

EXPERIMENTAL PROGRAMME

Determination was made of the mechanical behavior of EPS produced in Cordoba, Argentina, with the aim of assessing the performance to be used as structural material to support the concrete diaphragm. Density tests were performed and the material stress-strain behavior evaluated. The tests have been conducted in accordance with ASTM D1622 (Density) [14] and C165 (Compression) [15]. Figure 3 compares the compressive strength for unit deformation of 1% and 5% of the samples tested with the values specified by ASTM D6817 for structural purpose [16]. Note that the results obtained are consistent with the general trend. The specimen shape was square and the size adopted in the tests was 150 mm.

The stress-deformation response of the test specimens of different densities are shown in Figure 4. It can be seen that the stress-strain response is highly nonlinear and the elastic zone is very small. It is, however, important to note that the shape of EPS stress–strain curve turns sigmoidal if straining is continued to higher range (beyond 60%) [1]. The slope of the initial linear-elastic portion of the stress–strain curve was taken as the elastic modulus. The increase in strain leads to a degradation in the modulus (Figure 5).

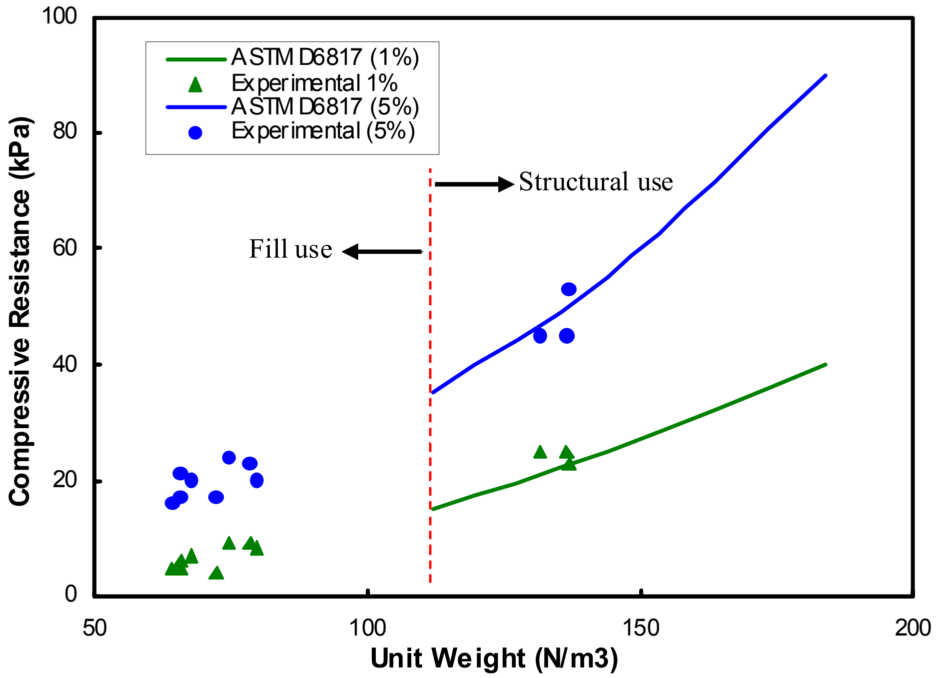

Figure 3: Relationship between compressive strength and unit weight for EPS

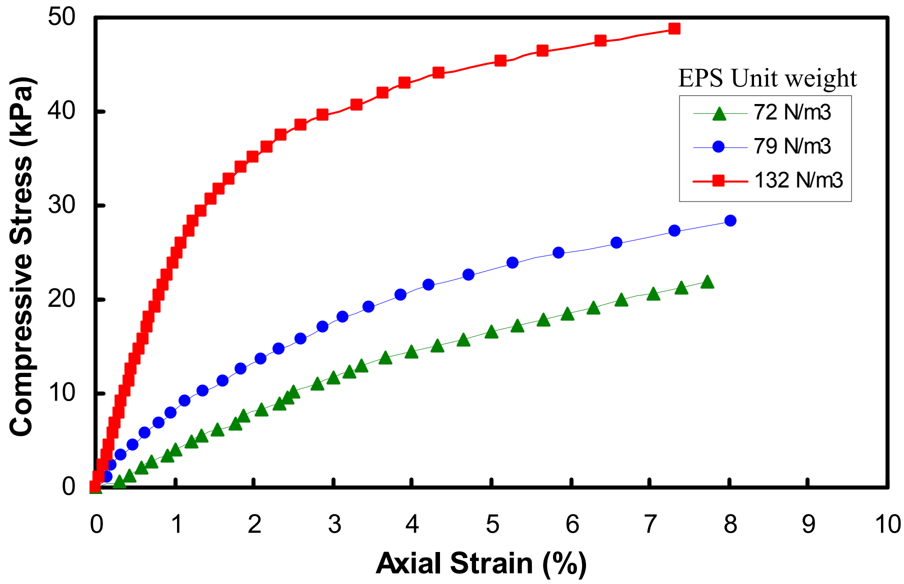

Figure 4: Stress–strain behavior of different tested specimens

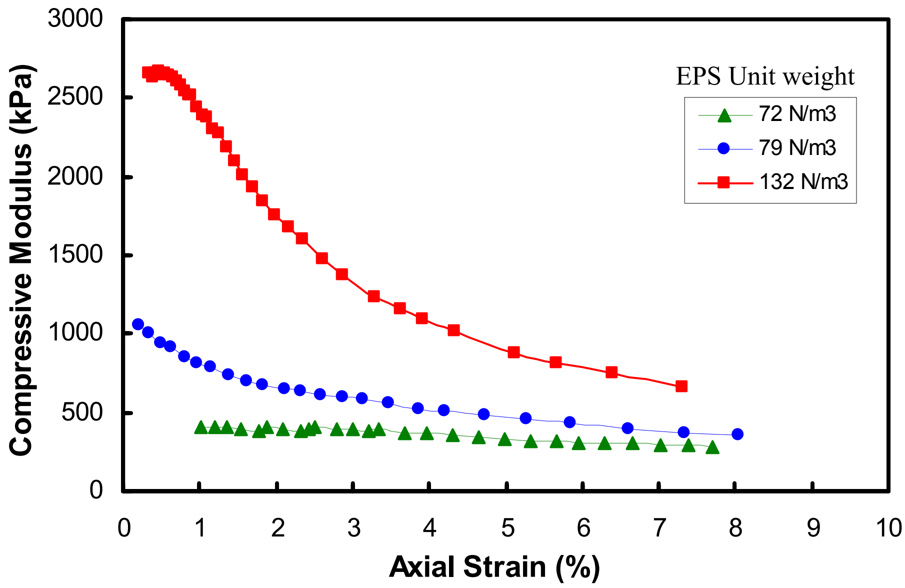

Figure 5: Compressive modulus–strain relationship

RESULTS AND DISCUSSION

The results of the models have helped determine the bending moment induced on diaphragms of different thicknesses supported on the EPS (Figure 6). The EPS has around 25 cm thickness. Overlay charts were constructed for bending moment and displacement normalized reference values corresponding to the last moment of the section and the acceptable deflection for the slab (Slab length/300). Sections of different diaphragm thicknesses have been checked, and the results show that levels of strain and stress on the EPS are admissible. For the purpose of recommending an optimum section, the moment and deformation criteria have been combined, resulting in characteristic points of design at the intersection of the curves (Figure 7). The characteristic point is defined as the intersection between these curves, which reconciles the level of internal stress with strain. Note that the thickness is around 6 centimeters.

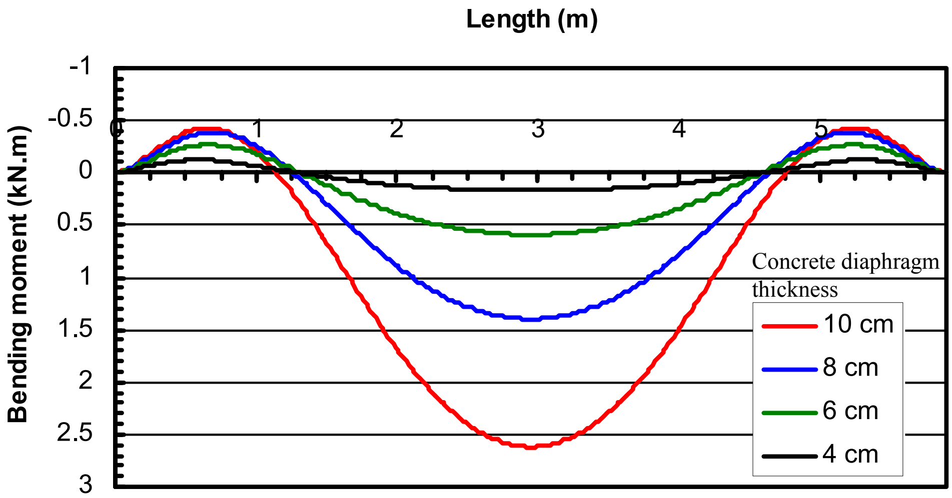

Figure 6: Induced bending moment in diaphragms of different thicknesses

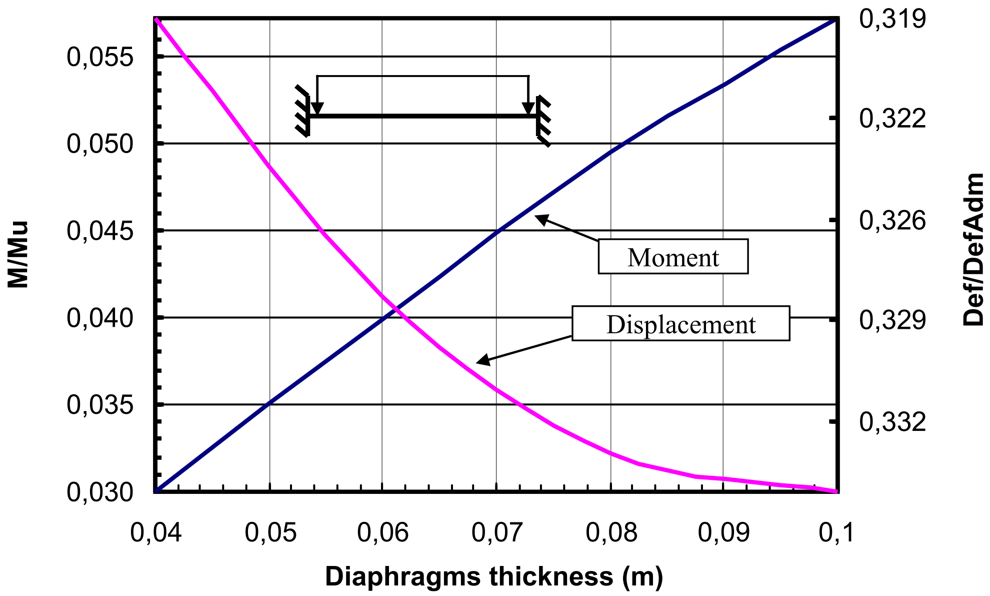

Figure 7: Relative bending moment and displacement of different diaphragms thicknesses

Finally, a thickness of 5 cm was adopted for the concrete diaphragm, and the thickness of EPS varied between 20 and 30 cm depending on the topography of the existing slab. The EPS used was a 135 N/m^3 density. Stress levels transmitted from the diaphragm into the core of EPS were evaluated. Maximum values were obtained in the order of 15 kPa, which are admissible for the material used.

The analysis of the diaphragm under thermal action (temperature changes), suggest different joint thicknesses depending on the size of the diaphragm panels to be build. In general, construction joints were taken within a range of 5 to 10 mm.

Figures 8 to 10 show stages of the construction work. Figure 8 shows a general view during the progress of work. Figure 9 shows a detail of the components of the structural package. In the concrete diaphragm, 5 cm thick, was placed 1 steel bar 6 mm in diameter every 20 cm in each direction. Figure 10 shows the finished work.


Figure 8: Work in progress. General view


Figure 9: Work in progress. structural package

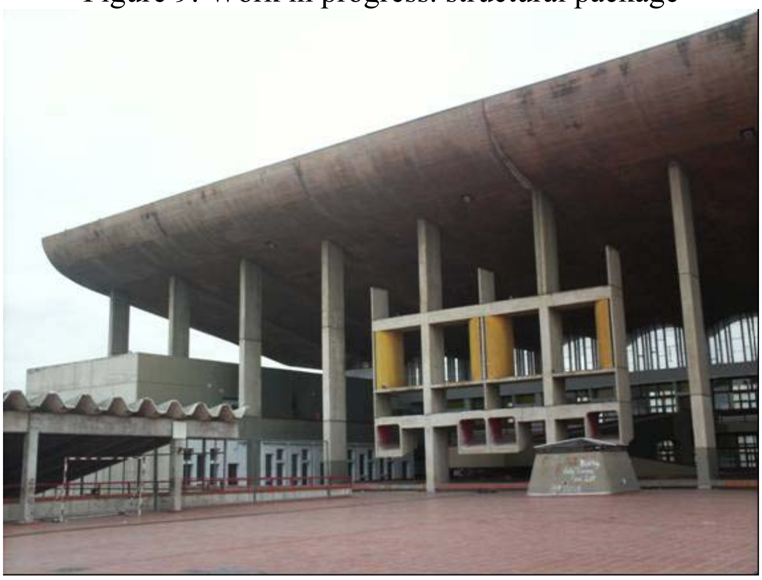
Figure 10: Finished Work. General view

CONCLUSIONS

The use of EPS with structural functions has been presented. This has been used to rework the roof of an existing structure without adding significant amount of dead load. Computational tools have been used to evaluate the structural behavior of the package proposed by the finite elements technique. On the other hand, this has been a pilot program that allowed characterizing stress-strain characteristics for EPS produced in the local environment at different densities. The results indicate that the EPS meet the requirements demanded by international standards.

With regard to the structural performance package it was concluded that: (a) the core of EPS in none case, for the scenarios analyzed, experienced stress states exceeding the allowable limits, (b) an increase in the height of the diaphragm increases its stiffness, so increasing the bending moment, (c) a diaphragm thickness close to 5 cm show a suitable behavior, when resulting moments and deformations are combined, and (d) The analysis of the diaphragm under thermal actions (temperature changes) suggest different joint openings depending on the size of the diaphragm panels ranging from 5 to 10 mm.

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