DEVELOPMENT OF EPS GEOFOAM TO REDUCE LATERAL PRESSURE BEHIND RETAINING WALLS

By

Salem Ali Salem Azzam

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfilment of the
Requirements for the Degree of
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In
Civil Engineering – Public Works

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Title of Thesis: Development of EPS Geofoam to Reduce Lateral Pressure Behind Retaining Walls

Key Words: Geofoam, Geosynthetics, Lateral Pressure, Retaining Walls.

Summary:
Expanded polystyrene (EPS) Geofoam has long been used as a geotechnical highly compressible and lightweight alternative material with an approximate weight less than 1% compared to soil. Several infrastructure projects require the use of large retaining walls with lengthy free heights. The classical backfill behind such walls typically consists of heavy compacted soils, which add more loads and lead to wall outsized dimensions. As a lightweight material, EPS Geofoam significantly reduces the loads imposed on retaining walls and underlying soils, and is not just a soil backfill replacement material but is intended to solve engineering challenges. A pilot study intended to characterize the properties and interface behavior of the EPS Geofoam was planned, including developing a finite element model to simulate the behavior of rigid retaining walls with Geofoam inclusion. Two main concepts of Geofoam inclusion were studied, the reduced earth pressure (REP) and the zero earth pressure (ZEP) concepts. Static loading conditions (at rest and active pressures) were modeled to determine the reduction in the coefficient of lateral pressure after using Geofoam. From the main outcomes, it was found that a 5 cm Geofoam inclusion is enough to make a 1 m rigid wall act as flexible wall. It was also found that the coefficient of lateral earth pressure can significantly be reduced by 50% in some cases.

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Sincerely,

Salem A. Azzam, 2018

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NOMENCLATURE

X_k characteristic value

K_n statistical probability distribution factor

γ_E Partial factor of young's modulus for EPS

γ_{ys} Partial factor of yield stress for EPS

ABBREVIATIONS

UC unconfined compression test

DST Direct Shear Test

mDST modified direct shear test

FEM finite element method

EPS Expended polystyrene Geofoam

D dry interface

HS Hardening soil

W wet interface

CR rough concrete

CS smooth concrete

S coarse sand soil

F EPS Geofoam

REP reduction earth pressure

ZEP Zero earth pressure

MCS Monte Carlo simulation

E&T Ertugrul and Trandafir stress reduction curves

K&B Karpurapu and Bathurst stress reduction curves

P.Cell earth pressure cells

c' effective cohesion of EPS beads

E_{50}^{ref} secant stiffness

E_{oed}^{ref} tangent stiffness

E_{ur}^{ref} unloading/reloading stiffness

σy yield stress

h wall height

K_a active coefficient of lateral earth pressure

K_o coefficient of lateral earth pressure at rest

R_{inter} strength reduction factor for interfaces

t thickness of EPS buffer

Z depth from ground surface

α' effective adhesion at foam-foam interface

γ unit weight

δ' effective friction angle at foam-foam interface

υ Poisson’s ratio

ρ density

σ_{xx} lateral relative effective stress

σ_{yy} vertical relative effective stress

ϕ' effective angle of internal friction of EPS beads

ψ dilatancy angle

E_{ti} Tangent Young’s modulus

E Young’s modulus

COV coefficient of variation

ABSTRACT

Expanded Polystyrene (EPS) or EPS Geofoam has long been used as a compressible lightweight alternative for soil backfills to reduce lateral pressure behind retaining walls. Uncertainty in material properties and lack of design parameters are the main constraints to using local EPS in geotechnical applications. In this research, the main goal was to characterize the EPS properties and to calibrate a standard numerical model to capture the behavior of rigid and flexible walls with EPS inclusion. A laboratory-testing program was conducted to measure the shear strength parameters of EPS as well as the interface properties between EPS and other materials such as soil and concrete. A reliability analysis was considered to develop the partial resistance factors required for the EPS main properties. The EPS reliable properties were then utilized in the hardening soil constitutive model of the Finite Element (FE) program Plaxis to accurately assess the material and the interface behaviors. Accordingly, rigid and flexible retaining walls with EPS inclusions with variable thicknesses were modeled using Plaxis 2D and 3D, whereas models outcomes were verified against results from the literature as well as measurements from an instrumented physical prototype that was assembled as part of this research. From the major outcomes, an EPS inclusion with a relatively thin thickness to wall height ratio is sufficient to change the behavior of the backfill soil behind rigid walls from at-rest to active conditions. Also it was found that the lateral pressure on flexible walls can be significantly reduced by up to 25% using a relatively thin EPS inclusion due to soil arching mechanism. Correlations to calculate the expected amount of reduction in the lateral pressure were presented depending on EPS density, thickness, and wall type.

CHAPTER.1 INTRODUCTION

Design of earth retaining structures involves a complex balance between loads and resistances, while stability must be approached systematically in order to achieve the desired safety factors against internal (structural capacity) and external (geotechnical or soil shear resistance) failures. The main components of a wall geotechnical stability are adequate soil shear strength to support the required bearing pressures, adequate soil friction to prevent excessive sliding at the foundation level, and adequate geometry and soil backfill weights to resist wall overturning. For typical cantilever retaining walls, the overall geotechnical stability requires adequate resistance against lateral earth pressures that are mainly exerted due to soil backfills or embankments behind the wall.

A classical approach to achieve the desired geotechnical stability against external failure is to base the design upon load combinations that exceed the predicted maximum loads. One of the most commonly used earth retaining system is the gravity and cantilever reinforced concrete walls, which are one of the most economic systems compared with other complex systems such as the diaphragm walls with multi-anchors. However, several projects such as underground metro stations, multi-story underground public garages, bridges, highways, pipe lines, and other types of infrastructure require the use of large retaining walls with exposed free heights that could exceed the design code limits. Using soil backfill behind such walls shall exert large lateral pressures leading to wall outsized dimensions. Eventually, a considerable increase in the amount of construction materials such as cement, steel, and quality aggregates is expected.

A new approach to achieve the wall geotechnical stability against failure can be achieved by using of a lightweight backfill material as a replacement for the soil backfill. Hence, the geotechnical safety factor can be achieved by reducing the actual loads instead of increasing the stiffness of the concrete wall. Durable polymer materials can be used for that purpose in several geotechnical applications, and Expanded Polystyrene (EPS) is considered as one of the most durable Geosynthetics materials. EPS has long been used globally as a lightweight alternative for soil backfill because its approximate weight represents less than 1% of the soil bulk density, at the mean time its porosity is very low.

As a lightweight alternative, EPS can significantly reduce the lateral loads imposed on retaining walls and underlying soils, and is not just a soil backfill replacement material but is intended to solve engineering challenges. Adapting EPS does not only translate into savings in the overall construction cost, but also the sustainability of construction materials, in addition to reducing the demand for polluting components such as cement which have a positive impact on the environment and the energy consumption.

Internationally, the main problem of using the EPS as an alternative for soil backfill behind walls is the non-availability of various geotechnical design parameters. There is also a shortage in the research outcomes that contain information from verified full-scale prototypes that model the interaction between the concrete wall and the EPS backfill (either using EPS blocks or a thin EPS inclusion or buffer). Locally, there are no reliable information about the EPS mechanical properties and characteristics, Even in the literature there is no partial resistance factors available for the EPS shear strength parameters. Although there is a progressive dependency on EPS in various geotechnical and infrastructure projects, there is still insufficient researches conducted on this topic.

Two main concepts of EPS backfill behind retaining walls can be adopted, the Zero Earth Pressure (ZEP) and the Reduced Earth Pressure (REP) concepts. The ZEP concept is simply by replacing the entire volume of the soil backfill behind the wall by Geofoam blocks, which will eventually lead to almost no lateral pressure on the wall but will be an expensive solution because EPS blocks are costly compared to soil backfill. The other concept is the REP which depends on using a thin EPS inclusion or buffer behind the wall (act as a thin buffer between the wall and the soil backfill) to reduce the lateral pressure by a certain percentage, and at the mean time to avoid using large volumes of such an expensive material. It is worth noting that in the literature there is no clear design approach especially for the REP concept.

In this research, a full-scale pilot study intended to evaluate the performance of the locally manufactured EPS was planned, starting with EPS shear strength characterization using a serious of laboratory unconfined axial compression load tests, then the interface properties of EPS and other materials such as soil and concrete were determined using a serious of direct shear tests, and finally modeling the entire problem (retaining wall with EPS backfill or inclusion) by the fabrication of a fully-instrumented large-scale laboratory prototype. The prototype instrumentation included displacement gauges and pressure cells, all connected with a digital data logger, to accurately measure the lateral stresses acting on the wall surface while using an EPS buffer with a certain density and thickness. The measurements acquired from the prototype were used to verify a Finite Element (FE) model using Plaxis 2D and 3D, which was needed for replication purposes and application on rigid and flexible retaining walls with Geofoam inclusion. All the material properties inserted in the FE models were measured in the laboratory during the initial material testing stage, and also the reliability of these properties was assured using partial resistance factors that were calibrated as part of this research using the reliability-theory. The FE model was successfully calibrated and verified against the prototype measurements as well as results from the literature.

Under static loading conditions, and from the verified FE model results, design charts were released for the values of the active and the at-rest lateral pressure coefficients when EPS inclusion is used as a buffer behind rigid and flexible retaining walls. A parametric study was conducted considering the EPS thickness normalized to the wall height, and that in order to provide a correlation to calculate the expected amount of reduction in the lateral pressure for any EPS thickness used. Finally, a design problem for a retaining wall was considered to sense the amount of reduction that can be achieved in the lateral pressure and translated to smaller reinforced concrete wall sections. This thesis are subdivided into nine chapters as follows:

Chapter 1: Includes a brief introduction about the research topic, problem statement, research purpose, and thesis contents.

Chapter 2: Includes a comprehensive literature review about different types of retaining walls and design methods, EPS Geofoam physical and mechanical characteristics, EPS general in various geotechnical applications, and EPS inclusion behind retaining walls to reduce lateral earth pressure.

Chapter 3: Includes the research main objectives, the exploited research methodology including the experimental testing program, the numerical modeling, and the verification technique used.