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Deflection Model of Sheet Pile Wall with the Lightweight Geocomposite Backfill Soil-EPS Stabilized with Waste of Buton Asphalt

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Abstract: The Earth improvement on active zone of retaining structure became an effective and reliable method to increase the stability of retaining wall. In this study, the performance of Lightweight Geocomposite Material (LWGM) as a backfill were investigated by measuring the retaining wall deflection and compared with other materials. The LWGM were created by mixture soil with Expanded Polysterene (EPS) and its stabilized with Waste of Buton Asphalt (WBA). The compositions of LWGM consists of 7% of WBA and 0.30% of EPS based on dry density of soil in form of block with dimension 0.20×0.20×0.59 m. The laboratorium-scale model using container steel with dimension of 1.50×0.60 and 1.40 m in height while the sheet pile model using 3.2 mm steel plate with dimension 1.20×0.59 m. Based on the results, it shows that the utilisation of LWGM backfill could reduce the deflection of sheet pile compared to coarse agregat for 80% and EPS geofoam for 60%.

Key words: Lightweight geocomposite material, deflection, sheet pile, EPS, waste of buton asphalt

INTRODUCTION

Land optimization in infrastructure development in stepped gradient is often faced with the problem of slope collapse. The slope stabilization is an effort to increase the moment of retaining landslide, either by applying chemical or mechanical method. Thus, the structure is able to withstand the driving forces which may cause the slope failure (Das, 2012).

A study conducted by Ireland showed that 68% of the main problems in retaining walls are due to pile material such as clay and grained material (Olson, 1993). The same thing was stated by Koerner and Koerner (2013) which found that the failure of 171 retaining walls with geogrid and geotextile reinforcement, 61% were using conventional embankment material in the form of sand or clay (Koerner and Koerner, 2013). This is inseparable from the severe problems of the material where the large lateral Earth pressure on the retaining wall as an internal load will be greatly influenced by the density of the material as a pile that works as an internal load. Further, the groundwater content changes caused by rainfall (Olson, 1993; Yoo and Jung, 2006; Vahedifard *et al*., 2017) and the loads that work directly on the pile (Dave and Dasaka, 2012) are external factors that must be taken into account in the design of the retaining wall stability.

The slope reinforcement method, principally can be performed by enlarging the opposing component's moment by strengthening the structure or strengthening the active area by stabilization techniques such as : the utilisation of geogrid (Hossain *et al*., 2012), fiber (Harianto *et al*., 2008), cement (Consoli *et al*., 2013) and lime (Haghi *et al*., 2006; Rocco, 2012). However, the self-weighting problem of embankment material often causes large deformation problems in the underlying soil layer, especially, over the soft soils (Rygg and Sorlie) (Aaboe *et al*., 2019). In other words, the fill behind the wall must have high bearing capacity to the external loads and not generate the settlement on the foundation layer due to its own weight.

The use of EPS as a lightweight embankment material has begun, since, the 1960s. The EPS has excellent technical characteristics, such as: density (g) 10-40 kgm^{-3}, compressive strength (σ) 100 kPa and strain (ε) up to 10%, nonetheless, this material cannot be decomposed by nature (Horvath, 1994) geofoam: An Introduction to Material Behaviour, 1994). However, because it is very light, this material is very easily influenced by lift caused by the changes in the ground water level can experience changes in shape due to fuel oil and is high in price (Negussey and Jahanandish, 1993). Further, its application requires adjustments to field conditions and limited technical properties for the field requirements (Abdelrahman, 2010). This limitation then became the foundation for developing lightweight embankment material by compiling soil with EPS (Abdelrahman *et al*., 2013; Liu *et al*., 2016; Ojuri and Ademola, 2016) or by adding stabilization material (Abdelrahman, 2010; Okonta, 2015).

Chemical soil stabilization is the most effective method of soil improvement in embankment work in which cement and lime are the most commonly used materials. Technological advances have encouraged the development of stabilization materials that no longer depend on the use of cement and lime because they

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are considered environmentally unfriendly in the production process (Das, 2012). This has led to the development of studies using waste materials such as fly ash, natural materials and bio-stabilization using bacteria.

Kurniaji (2010) revealed that the natural asphalt of Buton itself had become a national product with deposits reaching 677.247 million tons. In the extraction process of this asphalt from its granular form, it produces a waste material which is called Waste of Buton Asphalt (WBA) by the local society. The volume of the material remaining from this process can reach 15-20%. The X-Ray Diffraction (XRD) test results showed that the mineralogical composition of WBA consisted of gypsum ($CaSO_4$), calcite ($CaCO_3$), quartz (SiO_2) calcium sulfide oldhamite (CaS) and magnesite ($MgCO_3$). These mineral compositions indicate that this material has a potential to be used as a stabilizing material in soft soils.

Based on the explanation above, this research is intended to explore further the mechanical performance of the two waste materials working as a geo-composite material. The objective of this study is to analyze the performance of LWGM by comparing it with coarse aggregate and block of geofoam backfill, presented by the behavior of lateral deflection of sheet steel pile under a static load.

MATERIALS AND METHODS

In this research, the physical and mechanical properties of materials used were investigated by conducting several tests based on ASTM Standards. However, several methods were adopted from the work of the previous researcher.

Materials: Soft soil was excavated from Hasanuddin University project site. This material is used as a foundation soil and the main component in LWGM block. By plotting the Atterberg test on the Casagrande diagram where the Liquid Limit (LL) and the Plasticity Index (PI) are respectively within 58.37 and 29.29%, it shows that the soft soil is classified as clay with high plasticity (CH). Meanwhile, for the mechanically properties, the soft soil has dry density (gd) of 13.75 kNm^{-3}, optimum moisture content 32% and 0.057 MPa for unconfined compression strength.

Expanded Polystyrene (EPS) was fabricated material obtained from the EPS manufacture in South Sulawesi, Indonesia. There are two forms of EPS used in this research, beads and block which have the same density for 17 kgm^{-3}. The EPS beads varying from 2-4 mm in diameter were used to create LWGM block as the soil portion substitution. While the block EPSs in the dimensions of 10×10×59 cm were used as a lightweight embankment behind the wall.

Coarse aggregates were used for backfill material. The materials used were filtered by using sieve No. 4. the mechanical properties based on the compaction test present that this granular material has dry density (g_d) for 2.02 kNm^{-3} and optimum water moisture (w_{opt}) for 7.45%. Lightweight Geocomposite Material (LWGM). The production of LWGM block was adopted from our previous work. Based on the unconfined compression testing, it shows that the maximum strength of this geocomposite material is reached when it consists 7% of WBA and 0.3% of EPS based on the dry density of soil. The dimension of LWGM block is 0.59 m in length, 0.20 m in width and 0.20 m in height.

Experimental procedure

Laboratory-scale testing apparatus: The behavioral studies of lateral deflection on a sheet pile were designed as showed in Fig. 1. This laboratory model was based on manual calculation of sheet pile by using Factored Moment Method (FMM) and Factored Strength Method (FSM) in order to define an embedment depth (Budhu, 2010). The result showed that the depth sheet pile embedded (d) varied from 0.57 m until 0.62 m. there were three different backfill materials used to analyze the deflection comportment.

Testing tank: The experimental testing to analyze the behavior of lateral deflection on a sheet pile with different density of backfills was carried out on a testing tank, made of steel 4 mm and acrylic 10 mm. The testing tank has 1.50 m in length, 0.60 m in width and 1.40 m in height. Several stiffness materials were installed around the tanks wall to avoid the deflection when models were loaded.

Sheet pile model: Retaining structure model on this experiment used steel plate with 3.2 mm in thickness, 1.20 m in length and 0.59 m in width. The sheet pile was embedded 0.60 m in to the soft soil. The installing of sheet pile was executed by using a hydraulic pump and an embedded side was tapered to ease this process.

Deflection measurement: The lateral deflection on the sheet pile wall was measured by using LVDT. Two LVDTs were placed at the top (10 cm) and in the middle (5 cm) of the sheet pile wall. Further, the system measurement was loaded using load cell of 100 kN. All the measure instruments were connected to the data logger and computer.

Experimental preparation setup: The groundwork process in this experiment was modelled into sub grade layer as a foundation of the retaining structure and installing the lightweight materials as a soil improvement on an active zone. All the instruments of this experiment were presented in Fig. 2.

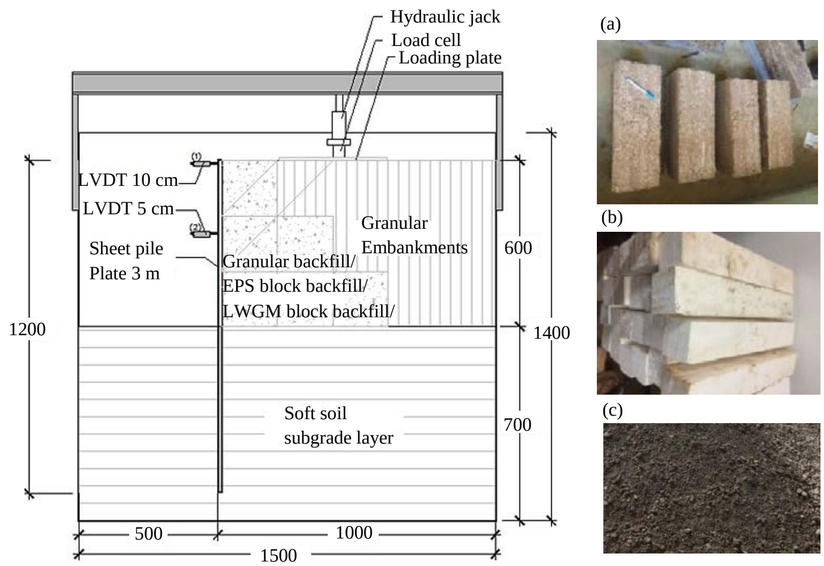

Fig. 1(a-c): Design of physical model, (a) LWGM block, (b) EPS block and (c) Coarse agregat

Fig. 2(a-h): Testing apparatus of physical model, (a) Testing tank, (b) Loading frame, (c) Hydraulic pump, (d) Data Logger, (e) PC desktop (f) Load cell 100 kN (g) Loading plate 20 mm and (h) LVDT

In the field application, the maximum density of compacted by vibratory rollers only reaches 85-95% of laboratories density (Guyer, 2013). Therefore, the density of subgrade soil applied in this experiment was 95% on the wet side, so is for the granular coarse for the backfill. The subgrade layer thickness was 80 cm and it was compacted by applying static compaction method and it was separated in three layers (Sharma and Deka, 2016; Cui and Delage, 1996). In order to control the compacted soil density, sand cone test was conducted in each layer.

The flexible sheet pile of steel was embedded vertically on the subgrade soil by using a guide apparatus that held the sheet pile. In order to facilitate the installation of sheet pile in to the ground, one side of sheet pile was tapered. Further, it was injected by using hydraulic jack with constant pressure until depth of embedment was reached.

Three backfill materials with different densities were placed behind the retaining system in order to examine the behaviour of deflection of the sheet pile from each model. The LWGM block and EPS block were arranged in stepped form. Further, to ensure the EPS blocks were uniform, shear connectors of nail were installed in between each block.

Load testing used 20 mm steel plate as a model of strip footing placed over the granular embankment to avoid direct contact with the reinforced active zone. Three models were conducted by applying incrementally load using hydraulic jack until failure condition was reached. Relation between load and lateral deflection of sheet pile became the parameter to analyse the performance of LWGM.

RESULTS AND DISCUSSION

The experiment, primarily, observed the behavior of sheet pile with unimproved backfill under a static load in order to achieve an initial data for the comparison purpose. Later, two models were examined at the same circumstances. The lateral deflection profiles of the sheet pile (d) under the maximum vertical stress (qu) from each material were presented in Table 1.

The results in Table 1 obviously demonstrate that the increasing of vertical stress increases the lateral movement of sheet pile. It noticed that a LWGM backfill has higher capacity to accept vertical load than the comparative materials with 142.63 kNm^{-2}, this value increases 2 times compared to coarse aggregate for 74.43 kNm^{-2}. This clearly indicates the influence of WBA as a stabilized agent for soft soil. When compared to the EPS block, although, the strength stress tend to be similar, EPS block provides the greater lateral deflection by 48.77 mm at peak stress. This behavior is inseparable from EPS nature characteristic where it was very light and low in EPS/EPS interface shear resistance (Arellano *et al*., 2011), so, its cannot resist the horisontal driving force from the granular embankment. Moreover, the compressible inclusion of EPS allows this material to deform verticallly 5% up to 10% (Horvath, 1997).

The behaviour of lateral deflection along the sheet pile at peak stress were analyzed by plotting LVDT's reading on the same graphic, as presented in Fig. 3. Figure 4 determine the deflection pattern along the flexible sheet pile structure where the pattern of agregat coarse and the EPS block tends to be linear compared to the LWGM block. These results corresponds to the findings of Nasr (2014) in which the lateral deflection of the improved layer is smaller than that of the unimproved (Nasr, 2014). This condition is a prove that the improved backfill could reduce the lateral deflection along the sheet pile. In the other words, utilisation LWGM as improved backfill on active zone effectively reduce lateral pressure over the retaining structure.

The relation between magnitude of vertical stressesand lateral deflection at the top of sheet pile (LVDT 1) for each backfill model presented in Fig. 4. A comparison are made at the same stress in order to observe the performance of LWGM where peak load for coarse agregat by 74.63 kNm^{-2} used as a baseline. The deflection value for the aggregate

Table 1: Sheet pile deflection on peak load

Type of backfill	Peak load (qu, kNm^{-2})	Deflection (δ, mm) LVDT 1	LVDT 2
Coarse aggregates	74.43	24.07	12.14
EPS block	132.16	48.77	24.51
LWGM block	142.63	26.14	11.79

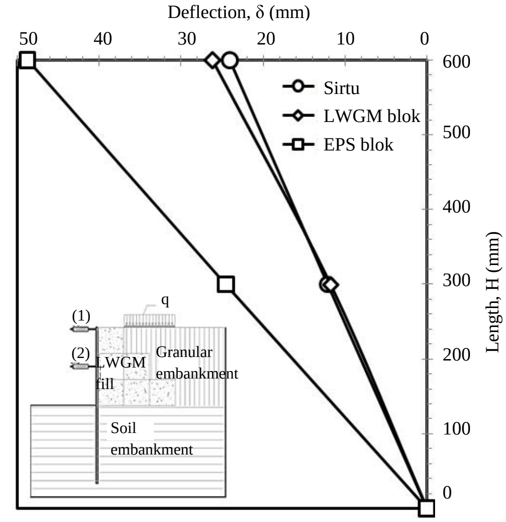

Fig. 3: Profile of lateral deflection on sheet pile

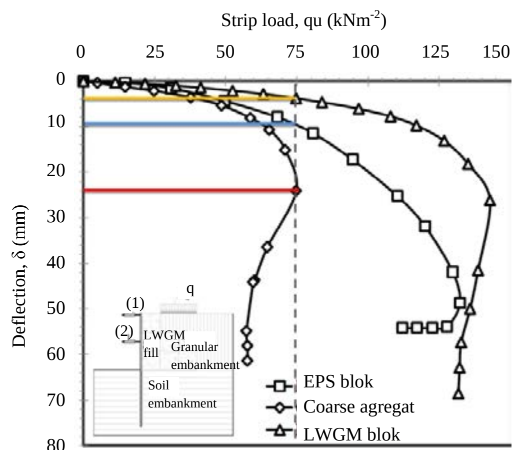

Fig. 4: Correlation of lateral deflection behavior due to loading effect (measurement obtained from LVDT 1)

material sirtu, EPS block and LWGM blocks ere 24.07, 9.63 and 3.89 mm, respectively. This comparison shows that the use of LWGM block material can significantly reduce the deflection of retianing wall for 84% when compared to coarse agregat and 60% compared to the EPS blocks.

CONCLUSION

The experiment of laboratory-scale model conducted toward the behavior of lateral deflection on the retaining structure wall by comparing the three types of backfill material with different density. Based on the results, the conclusions can be drawn as follows:

The comparison of LWGM against EPS blocks and coarse aggregates shows that in addition to material density, the modulus of stiffness of the material also has a significant contribution to the lateral deflection that occurs along the sheet pile structure.

The use of LWGM material is able to reduce the lateral pressure that occuralong the retaining structure shown by the reduction of lateral deflection that occurs over the sheet pile wall. The LWGM is able to reduce lateral deflection by 80% compared to coarse aggregate material and 60% compared to EPS blocks.

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