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An Experimental Investigation of a Full-Scale Reinforced Lightweight Aggregate Embankment

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ABSTRACT:
This paper presents the result of an experimental investigation on a full-scale reinforced lightweight aggregate embankment. The reinforced body was expanded clay aggregates, reinforced with geotextile facing. Loadings included self-weight, static surcharge applied using concrete slabs on top of the embankment, and dynamic loads simulated by a vibrator on top of the concrete slabs as well as dropping weight impacts. The system was designed using load and resistance factor design. Measured parameters included lateral and vertical deformations, velocity, and acceleration during tests. This paper covers design and construction details of the built embankment. Results indicate viability of using lightweight expanded clay aggregate in the proposed mechanically stabilized earth walls with geotextile facing as a mean for accelerated construction of bridge abutments.

Keywords: Embankment, Mechanically Stabilized Walls, Lightweight Expanded Clay Aggregates, Geotextile.

1- Introduction

Sustainability and resilience have guided planning, design, and construction of numerous infrastructure project in recent decades [1]. These characteristics generally enhance efficiency and serviceability of projects, while optimizing resource allocations and reducing environmental impacts and risks [2]. Achieving such performance measures is often a resultant of efforts in areas of engineering mechanics and materials [3]. Mechanically stabilized earth (MSE) walls are examples of such efforts in the area of engineering mechanics, where reinforced earth mechanism facilitates substantial reductions in the cost and time of construction. Similarly, application of lightweight aggregates (LWA) provides advantages through the life cycle of infrastructure projects. For instance, the lightness and the ease of compaction of LWA contribute to substantial economic savings; and durability of certain LWA, such as lightweight expanded clay aggregates (LECA), contributes to the sustainability of infrastructure by increasing the life, and thus, reduction of the life cycle cost of the project [4]. Hence, application of reinforced LECA in MSE walls have great potentials to enhance performance of infrastructure projects through accelerated bridge construction strategy [5-7]. Numerous researchers have conducted experimental tests on road embankments and retaining backfills, including application of lightweight aggregates [5-11]. The conducted work in this paper follows the existing literature and investigates the full-scale prototype of a new MSE wall containing reinforced LECA with geotextile facing. Experimental investigations include static and dynamic loads, which are common in bridge abutments, such as self-weight, vibration, and impact loads.

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2- Design, construction and testing methodology

The embankment has a height of 6 m and a core width of 6 m, which extends to 12 m width and 30 m length to include stability and access slopes in the back and at each side of the main core, respectively. Figure 1 shows a general view of the completed prototype. The instrumentation reference tower and temporary guiding posts are visible in this figure. Lateral slopes are two horizontal to one vertical, and the back slope is at the natural slope of the aggregate, secured with precast tilt-up walls in the back to prevent failure or excessive movement. The measured natural slope at the back was 35 degree. Loading concrete slabs are present in the front of this figure, laid on the ground with approximate dimensions of 1.2 m by 0.6 m area and 0.2 m thickness. The weight of each slab is nearly 355 kg.

Fig.1. The general view of the prototype.

The design of the prototype followed the load and resistance factor design (LRFD) method by the Federal Highway Administration (FHWA) as outlined in the document FHWA-NHI-10-024 [12]. Design procedure included sliding, overturning, bearing, and internal stability linked with geotextiles and their interaction with aggregates. The design intended the internal stability due to pull-out of geotextiles to have the lowest factor of safety to create a safe testing environment. Figure 2 presents the transverse section of the embankment.

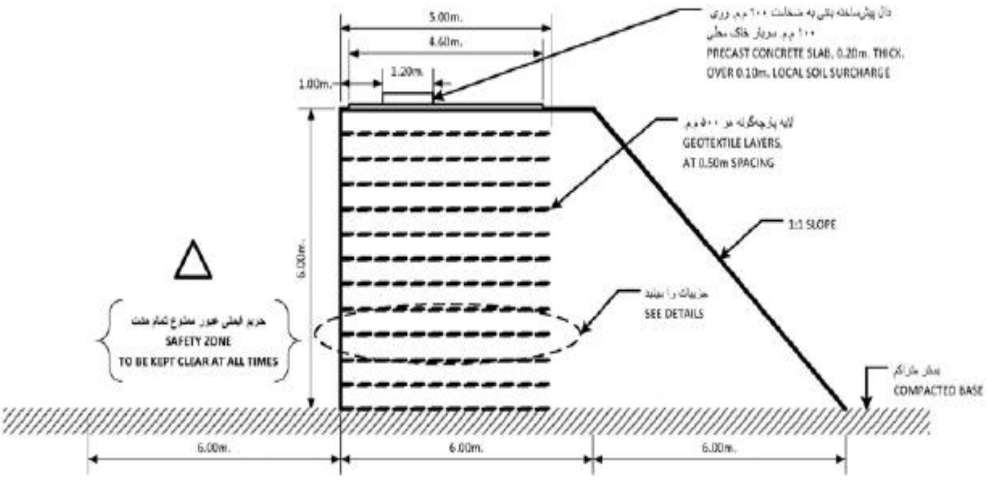

Fig.2. The section of the prototype.

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Construction of layers followed standard practices by the industry, as outlined in the figure 3 [13-14]. These practices included fabrication and erection of formworks without shoring, compaction of LECA, and securing geotextile sheets. The spacing between geotextile layers was 0.50 meter. Each layer contained three sub layers for compaction purposes, applied using a portable vibratory compactor. The required embedment length for geotextile layers was 4 m per design, bent into the layer for practical stability during construction. The bottom geotextile layer was directly on compacted ground. Concrete slabs provided proper normal force and resulted friction forces to secure the upper layer of LWA.

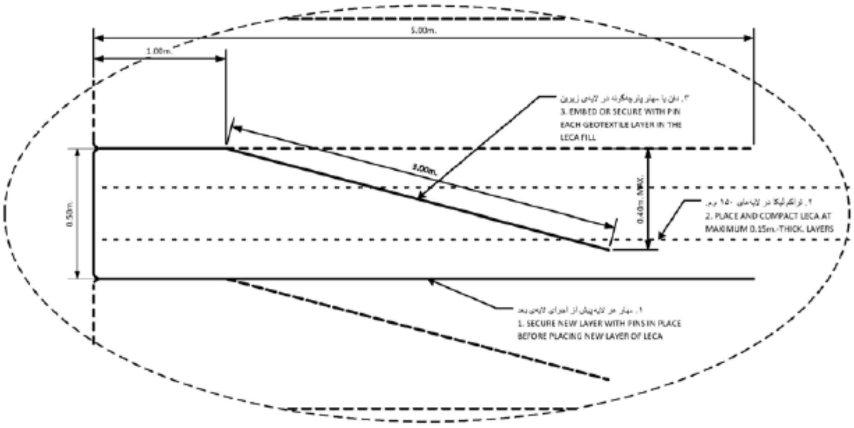

Fig.3. Construction details of the prototype.

The fill material was LECA, within 10-25 mm grading range (Figure 3). The prototype utilized more than 800 cubic meter of LECA in twelve layers reinforced with geotextiles and placed with a portable vibratory compactor to avoid unnecessary crushing of aggregates. Tables 1 and 2 list selected physical and mechanical properties of LECA and geotextile, respectively.

Fig.4. The close-up of placed LECA.

Table 1: Physical and mechanical properties of LWA by LECA [15]

Specification	Value
Volume weight (kg/m3)	350
Internal friction angle (degree)	35
Cohesion (Pa)	0

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Table 2- Physical and mechanical properties of geotextile by Laye Bafan [16]

Specification	Value
Weight (kg/m2)	500
Maximum longitudinal tensile strength (kN/m)	30
Elongation at maximum grab tensile strength (%)	75

Basic instrumentation devices included extensometers, accelerometers, and geophones, all connected to a data logger. Two guiding columns and one tower in the front were reference basis for measurements. Figure 5 shows the layout of devices on the face of the embankment. Figure 6 shows typical installation of instruments in selected layers. Measured results included horizontal deformation and accelerations at top, middle, and lower layers, plus vertical deformation at the top of the embankment.

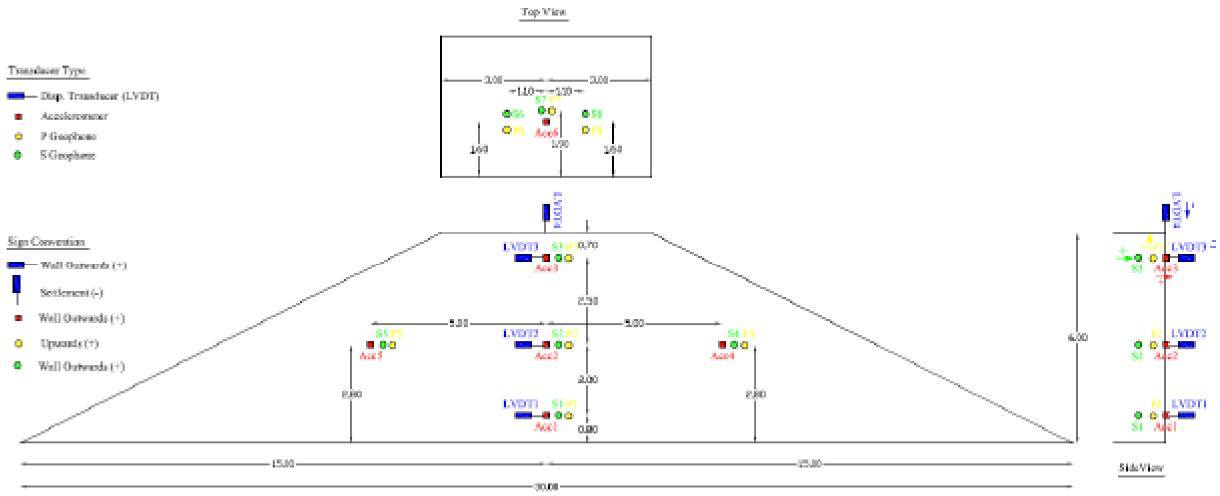

Fig.5. Layout of instrumentation devices.

Fig.6. Typical installation of instruments at the lower layer.

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3- Results

The first test began with the placement of eight concrete slabs with the total surcharge of nearly 10 kN/m^2 over a 2.4 m by 2.4 m area in front of the MSE wall. The resulted total vertical displacement of the wall at the top was 12 mm. The second test included a series of dropping-weight impact loadings in addition to the 10 kN/m^2 static loading. The heights of dropping included 0.15, 0.30, 0.60, and 0.90 m for a 3.5-kN-concrete slab over an area of 0.6 m by 1.2 m in front of the MSE wall. The applied load at 0.90 m drop based on the stiffness of the wall obtained from the static load approximately simulates the weight of one set of wheels of an 18-ton truck axle. Table 3 shows maximum deformations recorded for each test. Results indicate two trends for displacements: the increase of horizontal displacement with height, and the increase of displacements with dropping height. The variation of horizontal displacement with height is more substantial at lower layers than upper layers, where the ratio between horizontal displacements at middle and lower layers is several folds higher than the ratio of the same measure between top and middle layers. As the dropping height increases, the horizontal displacement increases nearly at the same ratio, indicating an elastic behavior. However, the horizontal displacement at the bottom layer does not show much difference due to high friction resistance between the compacted ground and the geotextile sheet. Further, the rate of increase in vertical displacement does not follow the same pattern and shows that ultimate vertical deformation approaches an ultimate value of nearly 1 mm.

Table 4: Summary of recorded displacements due to impact loadings

Maximum immediate displacement	Drop 1	Drop 2	Drop 3	Drop 4
Vertical displacement at top (mm)	0.16	0.38	0.99	1.0
Horizontal displacement at top layer (mm)	0.38	0.52	0.89	1.7
Horizontal displacement at middle layer (mm)	0.19	0.27	0.54	0.52
Horizontal displacement at bottom layer (mm)	0.03	0.06	0.05	0.04

4- Conclusions

This paper presented a summary of experimental investigations for a full-scale MSE wall containing reinforced LECA with geotextiles. The basis for design of the wall was LRFD method per FHWA guidelines. Design indicated the effectiveness of LECA in reducing the dimensions of embankment due to low weight and high friction angle. Ease of compaction accelerated construction operations without requiring any special equipment. Static testing showed that LECA embankment sustains nearly 10 kN/m2 surcharge load at 12 mm settlement. Dynamic testing using impact loads revealed that LECA embankment sustains the dropping-weight effect of the axle of an 18-ton truck with amplitudes of 1 mm vertical and 1.7 mm horizontal displacements.

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