Structural Lightweight Aggregate as a Backfill Material for the Retaining Structures

Dr. Dada S. Patil[1], Alware Azain Zafar[2], Nihal Layak Ali Sayyed[3] & Ayman A. Khan[4]

[1]Associate Professor, Civil Engineering Department, AIKTC, SoET, Panvel, Navi Mumbai, India
[2]Final Year Civil Engineering Student, AIKTC, SoET, Panvel, Navi Mumbai, India
[3] Final Year Civil Engineering Student, AIKTC, SoET, Panvel, Navi Mumbai, India
[4]Final Year Civil Engineering Student, AIKTC, SoET, Panvel, Navi Mumbai, India

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Abstract - *If structural grade lightweight aggregates (LWAs) are utilized, in place of usual locally available soil, in backfill and above the soft soils for the retaining structures, they offer advantages in terms of geotechnical physical properties like increased stability, high thermal resistance, high permeability and reduced density. High angle of internal friction (angle of shearing resistance) leads to improved stability; reduced specific gravity enhances the physical properties. A closely controlled manufactured aggregate gradation leads to an open texture, which in turn results in high permeability. The porosity getting developed during the LWA manufacturing process results in improved thermal resistance. The various LWAs that can be used as backfill materials are Light Expanded Clay aggregates (LECA), Expanded Shale, Slate, Perlite, Pumice, Sintered Fly Ash LWAs, etc. LWA fills are approximately half the weight of fills consisting of common materials. The decreased load, combined with high internal friction angle lead to decrease in vertical and lateral earth forces by more than one-half. This leads to economy owing to the fact that the sizes of various parts of retaining structures are reduced, thereby resulting in saving in quantities of concrete and reinforcement steel. The paper discusses engineering and economical benefits of using LWAs as backfill materials. Few cases from the developed countries are mentioned. A need to adopt this approach on a wider scale in India is highlighted.*

Key Words: LWA Fill, Lateral Earth Pressure, Drainage, Weight, Retaining Structure, Unit Weight, Permeability, etc.

1. INTRODUCTION

Shales, clays and slates have been expanded in rotary kilns to manufacture structural grade LWAs for use in masonry work and concrete, for more than 8 decades. Huge quantities of these aggregates are used in structural concrete constructions, with widespread availability across USA and other developed countries [1]. An idea of utilizing these aggregates for geotechnical application originates primarily from their enhanced physical properties. The particle shapes of LWAs vary from angular to round with intrinsically high interstitial voids which are due to a narrow range of particle sizes. There are two basic requirements for LWAs to be used for the geotechnical applications. First is high interstitial void content typical of closely controlled manufactured granular coarse aggregates, which are similar to a clean, crushed stone. Second is high pore volume enclosed within the cellular particle [1].

When slates, clays and shales are subjected to temperatures more than 1100^0 C in rotary kilns, a cellular structure gets formed. It comprises of non-interconnected spherical pores which are surrounded by a strong and durable ceramic matrix having characteristics same as that of vitrified clay bricks [1]. Oven dry specific gravities of LWAs vary. However, the values are between 1.25 to 1.40. High inter-particle void content along with low specific gravity leads to bulk dry densities usually in the range of 720 kg/m^3 [1]. Compaction of LWAs in a way similar to that used with crushed stone results in a highly stable interlocking network. This results in development of in-place moist densities less than 1040 kg/m^3 [1].

Expanded Shale, Clay and Slate (ESCS) fills need no specialized machineries or forms for their installation. Usual equipment available on site can be made use of for placing them in all weathers. They are easy to handle and more importantly, durable under extreme weather conditions [2]. They don't need liners. They also don't require additional measures to prevent buoyancy issues. ESCS fills are angular artificial LWAs which are freely draining and strong structurally [2]. Water moves very easily through ESCS fills. Hence, there is no need to place special drainage channels throughout the fill.

When used as a backfill material against retaining wall, LECA reduces the weight on the rear of the structure by approximately 75%, as compared to usual fill material [3]. Differential settlement between embankment fill and piled bridge abutments is minimized by using LECA [3]. Rear wall block drainage is not needed as LECA is a free-draining material.

2. GEOTECHNICAL PROPERTIES OF LIGHTWEIGHT AGGREGATE FILL

2.1 Shear Strength

Structural grade LWAs provide cohesionless, granular fill which derives stability due to inter-particle friction. Angle of internal friction of more than 40^0 was reported in an extensive testing on large specimens of size (250 mm x 600 mm) [4]. Triaxial compression tests carried-out on LWAs from six plants, which included variations in moisture content, gradations and compaction levels indicated high angles of internal friction. With an in-place moist compacted unit weight less than 960 kg/m^3, it can be realized that lateral pressures, overturning moments and gravitational forces become one-half of that of commonly used backfill soils [4]. The extensive direct shear tests carried-out by Valsangkar and Holm [5], given in table 1 revealed high angles of internal friction.

Table-1: Angle of Internal Friction (Direct Shear Test) [5]

	Angle of Internal Friction (Degrees)	
Material	**Loose**	**Compact**
Minto	40.5	48.0
Solite	40.0	45.5
Limestone	37.0	N/A
Solite (1)	39.5	44.5

2.2 Permeability

Attempts to know the permeability of unbound LWAs were not conclusive due to inability to measure uncontrolled increased water flow rate passing through an open-graded structure. This phenomenon has also been experienced in the field, where huge water volumes have been shown to pass through LWA drainage systems [1]. Exfiltration applications of LWAs have shown a capacity to efficiently cope-up with huge quantities of storm water runoff. Subterranean exfiltration systems offered reasonable alternatives to infiltration ponds by not utilizing expensive property areas and totally eliminating long-term maintenance issue in case of open water storage [1].

2.3 Compressibility

Large-scale compressibility tests conducted on LWA fills revealed that the curvature and slope of the LWA fill stress-strain curves in confined compression were similar to those seen for limestone samples [5]. Cyclic plate-bearing tests carried out on LWA fills resulted in vertical subgrade reaction responses which were similar for LWA and normal weight aggregate (NWA) samples [6].

2.4 In-Place Compacted Moist Density

Two basic aspects of LWA fill modify the usual interpretation of Proctor test results. Firstly, absorption of LWA is more than that of natural soils. Some of the water added during the test gets absorbed within the aggregate particle. This does not influence inter-particle physics (surface lubrication, bulking, etc.). Secondly, unlike cohesive natural soils, LWAs consist of small amounts of fines, thereby restricting the density increase owing to the packing of fines between large particles. The process of compacting LWA fill is not to obtain highest in-place density, rather it is to aim for an optimum density which can impart high stability without considerably increasing compacted density [1]. In many projects, in-place compacted moist density did not exceed 960 kg/m^3, as per specification requirements [1].

2.5 Interaction between Geotextiles and Lightweight Aggregate Fills

Valsangkar and Holm [7] revealed outcomes of testing programs on interaction between LWA fills and geotextiles which comprised of variables of various aggregate types and densities, aggregate thickness layer and types of geotextile. The overall roadbed stiffness was observed to be unaffected when LWAs were utilized instead of NWAs for small deflections and initial load applications. These tests were followed by a large-scale test [5], which led to conclusion that the comparison of friction angles between LWA or NWA and geotextiles showed that interface friction characteristics are better for LWAs than NWAs.

3. STRUCTURAL LIGHTWEIGHT AGGREGATE AS A BACKFILL MATERIAL FOR THE RETAINING STRUCTURES

Referring ESCSI [2], typical design values for the usual soil backfill materials are: Soundness loss < 6%, abrasion resistance 10-45%, compacted in-place bulk density 15.7- 20 kN/m^3, angle of internal friction for sand and gravel 30^0-38^0, loose bulk density 14-16.5 kN/m^3 and pH value 5-10.

For ESCS LWAs, typical values are: Soundness loss < 6%, abrasion resistance 20-40%, compacted in-place moist bulk density 6-10 kN/m^3, angle of internal friction 35^0-45^0 +, loose bulk density 4.5-9 kN/m^3, pH value 7-10 and chloride content 10-70 ppm.

Referring cantilever retaining wall in fig. 1, active earth pressure at base is $p_a = k_a \Upsilon H$ and the total active trust on the wall per unit length of wall is $P_a = k_a \Upsilon H^2/2$ [8]. It acts at H/3 from the base, through the centroidal of the pressure distribution diagram.

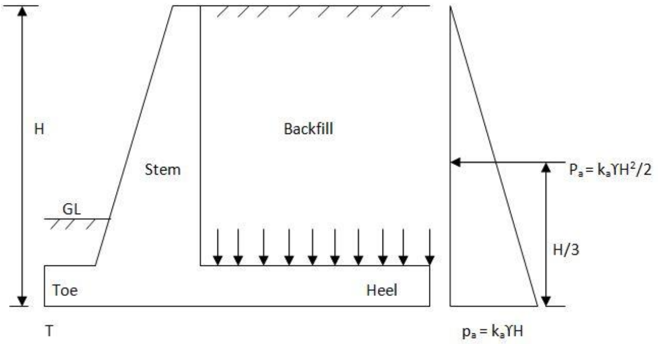


Fig -1: Active Earth Pressure of Dry Cohesionless Soil-Rankine's Theory [8]

If Φ is the angle of internal friction of soil, coefficient of active earth pressure, ka = (1-sinΦ) / (1+sinΦ).

Considering usual soil backfill material: let Φ = 32^0 and compacted in-place moist bulk density ϒ = 19 kN/m^3. Therefore, ka = 0.47/1.53 = 0.307.

Assuming overall wall height H as 7 m, total active thrust per metre length of wall P_a = (0.307 x 19 x 7^2) / 2 = 142.90 kN. It acts at (7/3) = 2.33 m from the base.

Overturning moment about the toe T is (142.90 x 2.33) = 332.95 kNm.

For the same wall, considering LWA backfill: let Φ = 42^0 and ϒ = 8 kN/m^3. Therefore, k_a = 0.33/1.67 = 0.197.

P_a = (0.197 x 8 x 7^2) / 2 = 38.61 kN, acting at (7/3) = 2.33 m from the base.

The lateral active earth thrust is reduced by (142.90 – 38.61) = 104.29 kN. Hence, the wall becomes safer against sliding, due to the use of LWAs.

Overturning moment about the toe T is (38.61 x 2.33) = 89.96 kNm.

Overturning moment is reduced by (332.95 – 89.95) = 243 kNm. Hence, the wall becomes safer against overturning, because of using LWAs.

Further, assuming the stem height as 6.6 m and heel length as 3 m, the resultant weight of the backfill on the heel slab per metre length of the retaining wall is (6.6 x 3 x 1 x ϒ).

For ϒ = 19 kN/m^3, weight is 376.2 kN and for ϒ = 8 kN/m^3, weight is 158.4 kN.

Thus, the reduction in backfill material weight on heel slab by using LWA fill is (376.2 – 158.4) = 217.8 kN.

These calculations clearly indicate that the sizes of stem and base slab will be greatly reduced if LWA is used as a backfill material. This will lead to less consumption of materials like concrete and reinforcing steel, thereby resulting in considerable economy.

If the water table rises to the top of the backfill in certain situations, like rainy season, the backfill will be under submerged condition such that $\Upsilon_{sub} = (\Upsilon_{sat} - \Upsilon_{water})$.

The lateral active earth pressure distribution diagram gets modified as shown n fig. 2.

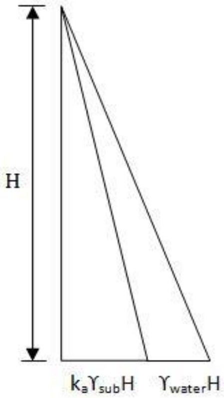


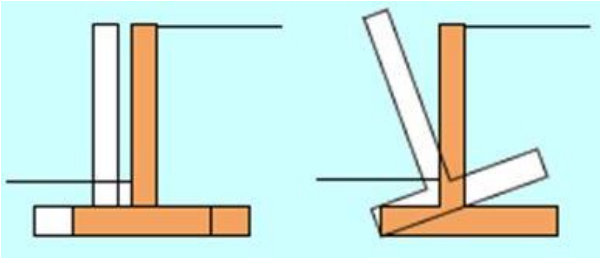
Fig.-2: Submergence Effect on Lateral Earth Pressure [8]

From fig. 2, it can be seen that the pressure at the base increases to ($k_a\Upsilon_{sub}H + \Upsilon_{water}H$). For common backfill material, this holds completely true owing to the fact that the water will be held in the void spaces of the saturated soil particles, thereby exerting extra lateral pressure. Saturation reduces Φ to some extent, thereby increasing k_a.

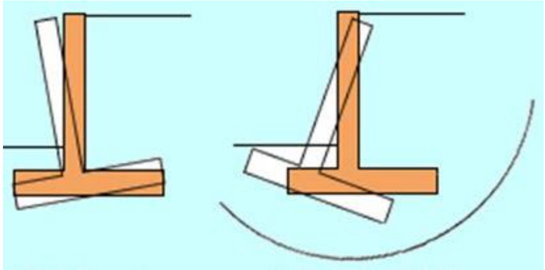
However, if LWA fill is submerged, aggregates absorb water due to their porous nature; they become partially or fully saturated; moreover water will drain out easily due to high permeability.

There will be negligible reduction in the value of Φ; so k_a will not increase considerably. This results in lateral earth pressure much lower than that of submerged soil backfill.

Retaining wall failures may occur through the various modes shown in fig. 3.



a) Sliding b) Overturning



c) Soil Bearing Failure d) Global Instability Failure

Fig. - 3: Modes of Failures of Retaining Wall

4. USE OF LWA BACKFILL FOR THE RETAINING STRUCTURES IN DEVELOPED COUNTRIES

In developed countries, LWA backfill for the retaining structures are practiced on a reasonable scale. Few Cases are mentioned.

Fig.- 4: ESCS LWA Backfill behind Segmental Retaining Wall, Bluff Restoration, Natchez, Mississipi [2]

Fig. - 5: ESCS LWA Backfill behind MSE Walls, Indiana [2]

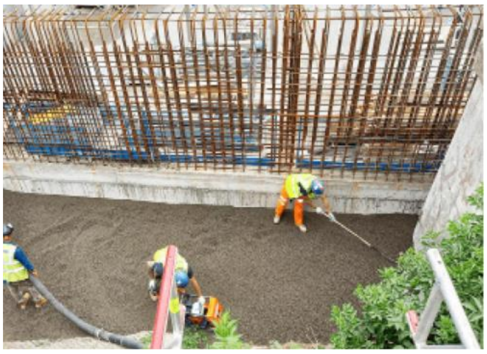


Fig. - 6: LECA LWA Fill behind Retaining Wall, Bristol [3]

5. SCOPE FOR UTILIZING LWA FILLS FOR THE RETAINING STRUCTURES IN INDIA

In India, LWA fills are not used; rather locally available soils, with desired geotechnical properties, are utilized. This leads to uneconomic outcome in terms of bulky sizes of the retaining wall components, requiring huge quantities of concrete and steel. Drainage of water is also an issue of concern. Therefore, there is a scope for using LWAs as backfill materials on a large scale. Manufactured LWAs of required sizes are easily available in various parts of India. These materials are environment-friendly, leading to a sustainable development.

6. CONCLUSIONS

As compared to traditional backfill materials, the decrease in weight and lateral earth pressure brought about by LWA fills can avoid potential sliding, slip and titling, overturning and bearing failures. The sizes of various components of retaining wall can be reduced resulting in to economy. Drainage can be greatly improved. Low density of LWA, with ease of handling and placing make them potential materials to be used as backfill materials.

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AUTHORS' BIOGRAPHIES

Dr. Dada S. Patil is working as an Associate Professor in Civil Engineering Department in AIKTC, Panvel, Navi Mumbai, India. His areas of interest are Structural Engineering, Advanced Concrete Technology, Geotechnical Engineering, etc.

Mr. Alware Azain Zafar is a final year civil engineering student in AIKTC, SoET, Panvel.

Mr. Nihal Layak Ali Sayyed is a final year civil engineering student in AIKTC, SoET, Panvel.

Mr. Ayman A. Khan is a final year civil engineering student in AIKTC, SoET, Panvel.