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Construction and Design Guidelines for Lightweight Cellular Concrete as Pavement Subbase Material †

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Abstract: Lightweight cellular concrete (LCC) has gained attention in the pavement industry as a potential subbase material due to its workability, freeze–thaw resistance, and thermal insulation properties. Research has shown that LCC has sufficient strength to support pavement structures and reduce subgrade pressures. However, a successful application requires the consideration of construction provisions, such as equipment and quality control, and design parameters, such as strength requirements and structural coefficients. This paper provides recommendations for using LCC as a pavement subbase material, including when and how to design pavement with it.

Keywords: lightweight cellular concrete; construction guidelines; pavement design; subbase materials

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1. Introduction

Lightweight cellular concrete (LCC) or foamed concrete has gained attention in pavement industries due to its low density of 375 to 1600 kg/m^3 and homogenous structure of air bubbles throughout the mixture [1,2]. Studies have extensively examined its mechanical properties like compressive strength and elasticity modulus [3–6]. LCC has been successfully used as an alternative subbase to unbind granular material to solve the differential settlement on roadways in various locations in Canada and around the world [7–11]. LCC is proving to be an excellent alternative for pavement applications with improved bearing capacity [12,13]. However, there remains a requirement for a comprehensive assessment and set of recommendations for the incorporation of LCC into the design and construction of flexible pavements in Canada.

2. Investigation on Field Test Sections

In 2018 and 2021, two field test sections were constructed to evaluate the performance of LCC. The test sections involved three different densities (400, 475, and 600 kg/m^3) and thicknesses of LCC compared to the unbound granular subbase section. Different sensors were installed to monitor the pavement response and environmental conditions. The following sections summarize the findings from the construction process to post-construction performance tracking [14,15].

2.1. Construction Analysis

The results indicated in the past study that LCC subbase layers are a viable alternative to granular materials for reducing subgrade pressures by 78% during construction, with densities of 400 kg/m^3, 475 kg/m^3, and 600 kg/m^3 being effective [16]. When pouring LCC at lower temperatures (≤4 °C), insulating the layers after pouring may be necessary for proper curing. LCC subbase does not hinder drainage and can even improve it. However, construction methods, processes, and excessive vehicular traffic can impact performance. Careful design modifications such as LCC thickness, construction method, and training for construction crews are necessary to ensure good performance of LCC subbase pavements and limit the duration between LCC pour and asphalt paving operations.

2.2. Field Structural Evaluation

Regarding structural capacity, Oyeyi et al. documented that using LCC as a subbase material can significantly reduce subgrade pressure caused by traffic by three times compared to unbound granular subbase pavements (Figure 1) [15]. The pressure reduction depends on factors such as LCC layer thickness, pavement thickness, load magnitude, load distribution, tire pressure, and material characteristics. LCC subbase layers with a thickness of less than or equal to 250 mm could be used in areas with lower traffic volumes and smaller vehicles. Increased pavement depth reduces strains, and incorporating LCC subbase layers reduces strains more than unbound granular material. However, environmental conditions like temperature and moisture can affect the stresses and strains experienced at each layer (For instance, winter to have lower strain), and further investigation is necessary.

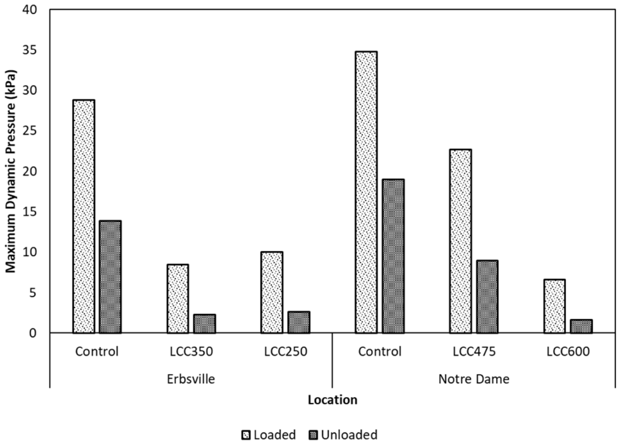

Figure 1. Maximum Dynamic Pressure Notre Dame and Erbsville [15].

3. Cost Analysis

Oyeyi et al. performed a life cycle assessment (LCA) for LCC pavements and compared them with the unbound granular subbase material (Granular A (GA) and B (GB)) pavements. Their results showed that up to 16% of CO$_2$ emission is reduced by substituting unbound granular material with LCC and reducing other harmful pollutants [16]. Based on the same maintenance and rehabilitation (M&R) schedule in [16], a preliminary life cycle cost assessment (LCCA) was performed. Figure 2 demonstrates the results [17]. This study considered only initial and M&R costs, but not the insulating capabilities of LCC which could contribute to the roadway longevity over frost susceptible subgrades.

The LCCA results showed that flexible pavement sections with granular A had between 10 and 13% and granular B between 4 and 6% lower total life cycle costs at the end of a 50-year analysis period compared with LCC subbases. The yearly cost commitment was also within the exact percentages. Initial construction contributed the most to all sections' total lifecycle costs. The initial construction costs for the control with granular A were 15%, 18%, and 21% lower than those with 400, 475, and 600 kg/m^3 LCC, respectively. These percentages were 7%, 10%, and 13% lower when using granular B. When only initial construction and maintenance LCCA phase costs were compared, the LCC sections yielded lower total life cycle costs, 400 kg/m^3 (6%), 475 kg/m^3 (5%), and 600 kg/m^3 (3%) than the control with granular A. Similarly, it was 12%, 11%, and 9%, respectively, less than the control with granular B. The costs increased with an increase in LCC density LCC. Total lifecycle cost was sensitive to changes in the cost of subbase material. Even with a 40 % LCC cost reduction, the granular A control section remained cheaper. However, a decrease in LCC cost by 40% caused the control with granular B to become more expensive than the LCC sections.

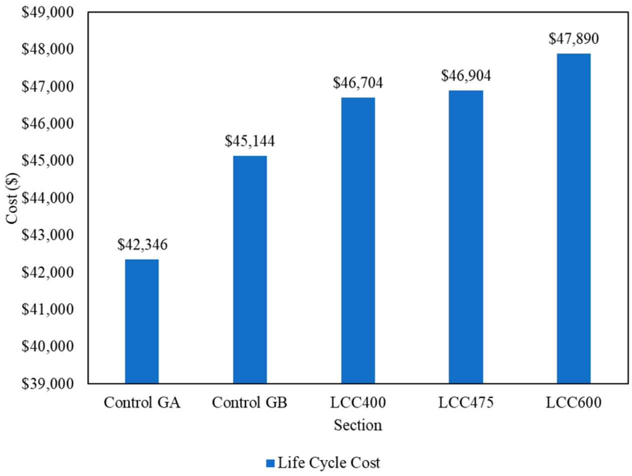

Figure 2. Total lifecycle cost of pavement design alternatives.

4. Recommendation of Use

LCC subbase can be a viable alternative to traditional subbase materials when weak subgrades need insulation. Thicknesses of at least 250 mm and densities between 400–600 kg/m^3 can improve performance and delay pavement failure.

Several methods can be used to design LCC subbase pavements, including granular base equivalent, MEPDG, and AASHTO 93. Linear elastic theory packages can also be used but may require adjustments. For example, WESLEA-generated strains and stresses could be reduced by a ratio of 0.2 and 0.65 for LCC between 400 and 600 kg/m^3. Other tools like WESLEA, KENLAYER, and PAVEXpress for better performance interpretation should supplement MEPDG analysis.

A structural coefficient of 0.22 is recommended for designing LCC pavements between 400–600 kg/m^3. The granular base equivalency strength coefficient is proposed to be 1.22 for 400 kg/m^3, 1.46 for 475 kg/m^3, and 1.91 for 600 kg/m^3. LCC subbase thickness can be reduced by 44–65% compared to unbound granular subbase.

In total, 600 kg/m^3 density LCC is recommended for major arterial roads, while minor arterial and collector roads can use 400 kg/m^3 and 475 kg/m^3 LCC. LCC subbase below 475 kg/m^3 should be at least 250 mm thick. Strain and stress patterns within the pavement structure should be considered when deciding on density for various road conditions and classes.

The timing for opening traffic after road construction is recommended after three days for 475 kg/m^3 density and 600 kg/m^3 density and seven days for 400 kg/m^3 density. The dry mix approach for LCC production is beneficial, and using slag or pozzolans can further reduce environmental damage.

Additionally, 475 kg/m^3 LCC is proposed over 400 kg/m^3 due to its stable pore structure, strength, and freeze–thaw resistance. Total lifecycle costs for 400 and 475 kg/m^3 LCC are comparable and less than 600 kg/m^3. Therefore, applying 475 kg/m^3 LCC is recommended due to its significant difference in performance from 400 kg/m^3 and relatively comparable performance to 600 kg/m^3.

5. Conclusions

This paper discusses the use of lightweight cellular concrete as an alternative pavement subbase material. Literature review, findings from field test sections, and results from LCA from past studies were reviewed. It presents preliminary lifecycle cost analysis (LCCA) information and provides recommendations for LCC use with flexible pavements. For future considerations, the freeze–thaw benefit of LCC should be considered in evaluation performance, an in-depth LCCA should be performed to consider social costs and insulation benefits associated with using LCC.

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