SJSU SAN JOSÉ STATE UNIVERSITY

FRESNO STATE
Discovery. Diversity. Distinction.

Exploring the Stress-Strain Relationship of Lightweight Concrete to Enhance the Lifecycle Performance of Transportation Highways and Bridges

Fariborz M. Tehrani, PhD, PE, ENV SP, PMP, SAP, F. ASCE

Project 2531
March 2026

Introduction

Transportation infrastructure in the United States faces increasing demands for durability, cost efficiency, and sustainability. Conventional normal-weight concrete (NWC), while widely used in U.S. transportation infrastructure, imposes significant dead loads on bridges and pavements, leading to higher structural demands and maintenance costs. Lightweight aggregate concrete (LWC), particularly when combined with internal curing techniques (ICC), offers a promising alternative by reducing density, improving hydration, and enhancing long-term durability. The primary goal of this research is to establish accurate stress–strain relationships for LWC and ICC and to evaluate their mechanical and transport properties under realistic conditions. The study measures potential improvements in durability and service life, assesses lifecycle cost and environmental impact, and identifies design limitations in current specifications. By providing empirical data and analytical models, the research supports the development of updated design guidelines and promotes the adoption of LWC and ICC in highway and bridge construction to support critical U.S. transportation infrastructure.

Study Methods

The research used a comprehensive approach that combined experimental testing, analytical modeling, and lifecycle analysis. Multiple concrete mixtures were prepared, including all lightweight (ALW), sand-lightweight (SLW), internally cured concrete (ICC), and high strength (HS) variants, which were compared against conventional normal-weight concrete (NWC). The research team used laboratory testing to measure key mechanical properties such as compressive strength, modulus of elasticity, Poisson's ratio, and splitting tensile strength. These tests were designed to establish accurate stress–strain relationships for each mix (i.e., how each type of concrete behaves when weight and pressure are applied).

Analytical investigations linked mechanical properties to durability characteristics such as chloride penetration and electrical resistivity, providing insight into the materials' resistance to environmental exposure. Service life predictions were developed to estimate chloride ingress over time. In addition to experimental work, the study employed analytical modeling to evaluate structural performance under realistic loading conditions and to predict long-term behavior. To assess sustainability and economic feasibility, a Life Cycle Assessment (LCA) was conducted to quantify greenhouse gas emissions associated with each concrete type. Lifecycle cost analysis was also performed to compare lifecycle costs, including long-term maintenance and replacement expenses.

Findings

The study confirmed that LWC and ICC meet structural performance requirements while offering significant durability and sustainability benefits. All tested mixes achieved target compressive strengths, including high-strength SLWs. Compared to conventional concrete, LWC is more flexible, which helps it better absorb movement and reduces the likelihood of cracking under traffic loads and temperature changes. Internally cured and lightweight mixes also improve how the concrete hydrates as it hardens, which limits shrinkage and helps prevent long-term damage.Durability assessments demonstrated that LWC produced with expanded shale, clay, and slate aggregates provides superior resistance to chloride ingress, extending service life by up to 4.8 times compared to NWC. Sustainability analysis revealed reductions of up to 76% in greenhouse gas emissions over the structure's lifecycle. Lifecycle cost analysis indicated savings of up to 85% due to reduced maintenance and extended service life. Despite these advantages, current design standards do not fully account for how well lightweight concrete performs. Updating existing design equations and removing overly conservative assumptions would allow agencies and engineers to more accurately reflect the real-world performance of these materials.

Policy/Practice Recommendations

The findings of this study strongly support the broader adoption of lightweight aggregate concrete and internally cured concrete in transportation infrastructure projects. Design codes should be updated to reflect the actual performance of these materials. Specifically, ACI and AASHTO specifications need to incorporate revised equations for modulus of elasticity (related to the material's flexibility) and remove outdated reduction factors that unnecessarily penalize lightweight concrete. Internal curing should be promoted as a standard practice because it improves hydration, reduces shrinkage, and enhances durability, particularly for bridge decks and pavements exposed to harsh environmental conditions. Agencies and practitioners should evaluate materials based on lifecycle performance rather than initial cost alone. This approach ensures that decisions account for long-term savings, reduced maintenance, and environmental benefits. The integration of lifecycle cost analysis and Life Cycle Assessment into project planning will help achieve sustainability goals and optimize resource allocation, ultimately saving time and money while reducing impacts to the environment. Furthermore, these practices align with federal initiatives such as the FHWA Every Day Counts (EDC-7) program, which encourages innovation and efficiency in infrastructure development.

About the Author

Dr. Fariborz M. Tehrani, PhD, PE, ENV SP, PMP, SAP, FASCE, is a Professor at CSU and the Director of ESCSI with expertise in SR-SEMM and 33 years of experience. Fariborz is a voting member of ACI, ASTM, and TRB; EMI ORC Vice Chair; and EMI's Liaison in ASCE STC. Fariborz has a BSc from Sharif University of Technology; an MSc from Amirkabir University of Technology; an MS and a PhD from UCLA.

To Learn More

For more details about the study, download the full report at transweb.sjsu.edu/research/2531

MTI is a University Transportation Center sponsored by the U.S. Department of Transportation's Office of the Assistant Secretary for Research and Technology and by Caltrans. The Institute is located within San José State University's Lucas Graduate School of Business.