

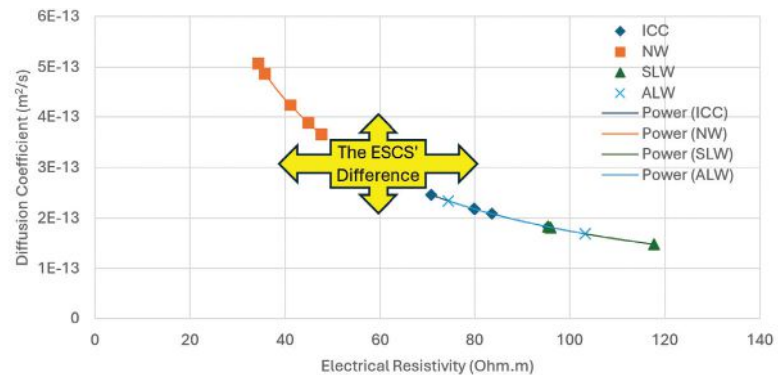
Lightweight Innovations Drive Durable, Sustainable Bridges

by Dr. Fariborz M. Tehrani, Expanded Shale, Clay and Slate Institute

As bridge owners and designers face intensifying demands for durability, resilience, and sustainability, the Expanded Shale, Clay and Slate Institute (ESCSI) continues to lead the advancement of lightweight-aggregate concrete (LWC) as a high-performance solution. The density of lightweight and sand lightweight concrete typically varies from 90 to 135 lb/ft³ (1440 to 2160 kg/m³), while the density of internally cured concrete using lightweight aggregate is comparable with that of normalweight concrete (NWC). Through decades of research, guidance, and collaboration, ESCSI and its members are helping shape a new generation of concrete bridge systems, engineered for long-term performance, not just initial cost.

A Smarter Approach to Concrete

Traditional NWC has served the bridge industry well, but its density contributes to larger dead loads and increased structural demands compared with LWC. LWC produced with expanded shale, clay, and slate (ESCS) offers a more efficient alternative to NWC. By reducing density while maintaining



Concrete containing expanded shale, clay, and slate (ESCS) has increased resistivity and reduced diffusion. Note: ALW = all-lightweight concrete; ICC = internally cured concrete; NW = normalweight concrete; SLW = sand lightweight concrete. Figure: Dr. Fariborz M. Tehrani.

required strength, LWC reduces the weight of superstructures, improves seismic performance, and facilitates design flexibility. The key contribution of LWC to seismic performance is reduced dead weight of the structure, which cuts seismic inertial forces, lowers lateral base shear demand, and decreases bending moments during an earthquake. Equally important, because LWC has a lower modulus of elasticity than NWC, it can better accommodate strain, temperature gradients, and traffic loads while reducing cracking caused by shrinkage. A lower modulus of elasticity provides higher flexibility and reduced strain-induced stresses caused by thermal and impact loads, and other sources of length and volume changes. These characteristics make LWC particularly well suited for bridge decks and pavement components where long-term durability is critical.

Built-In Durability Through Internal Curing

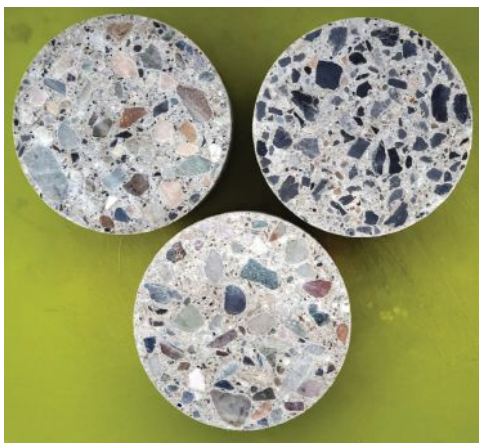
Cracking and chloride penetration remain leading causes of bridge deterioration. ESCSI-supported innovations directly target these issues through lightweight-aggregate technology and internal curing.

ESCS aggregates possess a unique internal pore structure that can

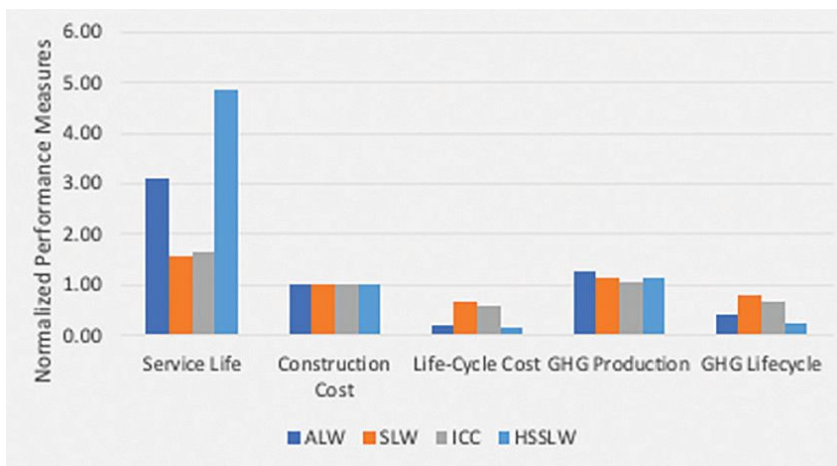
absorb and later release water into the surrounding cement paste. Prewetting lightweight aggregates enables this characteristic to convert pores to reservoirs for internal curing. This internal curing process improves hydration in concrete mixtures, reduces concrete shrinkage, and enhances the interfacial transition zone between aggregate and paste. The enhancement of the interfacial transition zone is due to the pozzolanic nature of ESCS surfaces and stronger hydrated cement infiltrating surficial pores to form stronger bonds. The result is a concrete matrix with lower permeability and improved resistance to chloride ingress, key factors in delaying corrosion of reinforcing steel and extending service life. (For details of the internal curing mechanism, see the FHWA article in the Summer 2024 issue of *ASPIRE*®.) For bridge owners, the characteristics of LWC translate into improved durability in aggressive environments, including those with marine exposure and cold regions where the use of deicing salts is prevalent.

Extending Service Life and Value

Perhaps the most compelling advantage of LWC is its impact on life-cycle performance. Recent research demonstrates that compared with



Cut surfaces of concrete samples: internally cured concrete (top left); sand-lightweight concrete (top right); normalweight concrete (bottom). Photo: Mineta Transportation Institute.



Sustainability performance measures of lightweight concrete. Note: ALW = all-lightweight concrete; GHG = greenhouse gas; HSSLW = high-strength sand lightweight concrete; ICC = internally cured concrete; SLW = sand lightweight concrete.

Figure: Dr. Fariborz M. Tehrani. Adapted from Mineta Transportation Institute.

conventional concrete, LWC and internally cured concrete can extend the service life of transportation structures by nearly five times in certain applications.¹ This extension dramatically reduces the maintenance, repair, and rehabilitation required for typical structures. In this same research, life-cycle cost analyses show associated savings of up to 85%, driven by reduced maintenance demands and longer replacement intervals.¹ At a time when transportation agencies are under pressure to do more with limited funding, these life-cycle benefits are driving an increased interest in LWC solutions.

Delivering Measurable Sustainability Gains

Sustainability is no longer optional in infrastructure projects; it is a core requirement. By enhancing durability and long-term performance, lightweight aggregates support meaningful reductions in the environmental impact of concrete structures.

Life-cycle assessments indicate that compared with conventional concrete, LWC can reduce greenhouse gas emissions by up to 76%. These assessments are based on predicted service life of concrete exposed to corrosive environments, such as areas where deicing agents are used or marine zones. Lower chloride diffusion within the body of the concrete containing lightweight aggregates is the key factor extending the service life of concrete, and hence reducing cost and environmental impact over the extended life-cycle of concrete. Results apply to concrete mixtures with normal- and high-strength concrete typically applied

for bridge decks exposed to various climate zones in northern America. Life-cycle results are presented per unit volume of concrete, but they can be extended to cover the entire bridge system, including substructure, safety barriers, joints, and other elements.² These greenhouse gas emission reductions are achieved through the following mechanisms:

- Lower material volume and structural demands due to reduced weight
- Decreased transportation energy for aggregate and concrete delivery
- Fewer repair cycles over the structure's lifespan

These attributes align directly with Federal Highway Administration initiatives such as Every Day Counts (EDC-7),³ which promote internally cured concrete and life-cycle-based sustainability practices.

Advancing Design and Practice

While LWC has been used successfully for decades, recent research supported by ESCSI is helping refine design approaches and expand adoption. Studies have shown that existing design provisions often underestimate LWC performance, particularly in areas such as modulus of elasticity and durability behavior.⁴ By developing improved predictive models and design recommendations, ESCSI is helping engineers accurately capture the benefits of lightweight aggregate and apply them with confidence in bridge applications.

Leading Toward the Future

As the industry shifts toward performance-based design and life-

cycle-focused decision-making, ESCSI continues to provide leadership at the intersection of innovation and implementation. LWC represents more than an incremental improvement. It offers a comprehensive solution, combining reduced structural demands, enhanced durability, extended service life, and lower environmental impact.

For bridge owners, designers, and contractors, the message is clear: concrete made with lightweight aggregates is stronger, performs better, lasts longer, and is more sustainable than conventional concrete. Through its ongoing work, ESCSI is ensuring that these benefits are realized across the next generation of concrete bridge infrastructure.

References

1. Tehrani, F. M. 2026. *Exploring the Stress-Strain Relationship of Lightweight Concrete to Enhance the Lifecycle Performance of Transportation Highways and Bridges*. San Jose, CA: San Jose State University Mineta Transportation Institute (SJSU-MTI). <https://transweb.sjsu.edu/research/2531-Stress-Strain-Relationship-Concrete-Highways>.
2. Tehrani, F. M. 2025. *Strategized Reduction of Greenhouse Gas Emissions Through Predicting and Extending the Service Life of Concrete Pavements and Bridges*. San Jose, CA: SJSU-MTI. <https://doi.org/10.31979/mti.2025.2447>.
3. Federal Highway Administration (FHWA). 2026. "Enhancing Performance with Internally Cured Concrete (EPIC²)."
https://www.fhwa.dot.gov/innovation/everydaycounts/edc_7/enhancing_epic.cfm.
4. Castrodale, R. 2021. *Lightweight Concrete Bridge Design Primer*. FHWA-HIF-19-067. Washington, DC: FHWA. https://www.fhwa.dot.gov/bridge/concrete/hif19067_Nov2021.pdf. 

Dr. Fariborz M. Tehrani is a professor at the Lyles College of Engineering at California State University, Fresno, founding scientific director of Pontis Research Group, and the director of the Expanded Shale, Clay and Slate Institute.