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The Use of Foamed Glass Aggregate (FGA) as a Lightweight Fill Above Culverts

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California State University Transportation Consortium

CALIFORNIA STATE UNIVERSITY LONG BEACH

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16. Abstract
Transportation infrastructure—including buried utilities, drainage systems, and culverts—is frequently subjected to significant external stresses arising from existing conditions and new construction, especially in urban environments where deformation and failures can lead to significant operational and safety consequences. Lightweight fills offer a viable strategy to mitigate these stresses by reducing imposed loads. This study investigates the use of lightweight fills, specifically Foamed Glass Aggregate (FGA), as a sustainable solution to support California Senate Bill 1 (SB1) efforts to repair and maintain culverts, as well as for new construction applications. A numerical investigation was conducted to evaluate the performance of culverts backfilled with FGA compared to conventional fills. Models were developed for reinforced concrete box culverts and corrugated steel pipe culverts, and parametric analyses were performed across a range of configurations. Results indicate that FGA significantly reduces soil stresses, structural demand, deformation, and settlement compared to conventional fills. This study also developed design and construction guidance and proposed updates to Caltrans manuals to facilitate implementation in practice. The findings demonstrate that FGA is an effective, sustainable alternative for improving culvert performance in California and beyond, helping agencies better address aging infrastructure and increasing construction demands.

17. Key Words
Backfill soils lightweight, materials lightweight, aggregates box culverts, corrugated pipe culverts.

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Executive Summary

Transportation infrastructure, including buried utilities, drainage systems, and culverts, is usually subject to considerable external stresses that may arise from existing conditions or new construction. Added stresses from new construction are particularly common in urban areas with abundant buried infrastructure and in the vicinity of construction projects. To mitigate the effects of excessive stress on existing buried infrastructure, including culverts, lightweight fills can be used in lieu of conventional fills. This research project investigates the use of lightweight fills as a sustainable strategy to “Fix Culvert” in support of California Senate Bill 1 (SB1) efforts and for new construction. The study focuses on foamed glass aggregate (FGA) as an emerging, innovative, and sustainable lightweight fill.

Many culverts and drains in California are in need of repair. California Senate Bill 1, the Road Repair and Accountability Act of 2017, provides additional funding for the State of California to address the deferred maintenance needs of the transportation system's assets and designates an annual allocation of $400 million, specifically, for culverts and bridges. This law requires Caltrans to meet the preliminary performance outcomes and indicates that "Not less than 90 percent of culverts [should be] in good or fair condition" by the end of 2027. This research project offers innovative means for stress mitigation above deformed culverts that require repair or new construction above existing culverts. The research findings can be extended beyond SB1, which addresses the repair of existing culverts, as lightweight fills can also be used in new designs to reduce construction costs. It is notable that the outcome of this research could extend beyond California to other states nationwide.

This study aimed to evaluate the use of foamed glass aggregate (FGA) as a strategy to “Fix Culvert” in contribution to SB1 efforts. A numerical investigation was conducted to assess the advantages of using FGA lightweight fills instead of traditional fills above buried structures, such as drains, culverts, and wildlife passages. Numerical models were developed to compare the mechanical responses of culverts backfilled with conventional and lightweight fills. Parametric analyses were performed using the developed models to explore the benefits across various configurations of reinforced concrete (RC) box culverts and corrugated steel pipe (CSP) culverts. The results showed that FGA lightweight fills considerably reduce culvert straining actions, soil stresses on culverts, shape deformation, and settlement. These findings will help identify culverts that could benefit from lightweight fills based on their specific attributes.

To facilitate the integration of the FGA as a lightweight alternative in California and as a backfill above drainage structures, a set of design and construction guidelines was prepared for this study. Finally, changes to the Caltrans Geotechnical Manual and the Caltrans Highway Design Manual were proposed.

1. Introduction

According to the California Transportation Asset Management Plan (TAMP; Caltrans, 2022), the California State Highway System (SHS) includes 212,759 culverts and drainage facilities within the SHS boundaries, which Caltrans is responsible for planning, developing, maintaining, and operating. Drainage, including culverts and other highway drainage assets, is one of the four primary SHS asset classes selected by the California Transportation Commission (CTC) for inclusion in the TAMP and for which Caltrans has been building an inventory. As per the TAMP, the typical drainage asset is a 12- to 60-inch diameter/width plastic polymer, steel/aluminum, or concrete pipe or box culvert; any culvert with a width that spans 20 feet or longer is classified as a bridge and recorded on the National Bridge Inventory (NBI).

Many culverts and drains in California are in need of repair. California Senate Bill 1, the Road Repair and Accountability Act of 2017, provides additional funding for the State of California to address the deferred maintenance needs of the transportation system's assets and designates an annual allocation of $400 million, specifically, for culverts and bridges. This law requires Caltrans to meet the preliminary performance outcomes and indicates that "Not less than 90 percent of culverts [should be] in good or fair condition" by the end of 2027. In response to SB1, Caltrans published a decision document (Caltrans, 2018) defining the term “Fix Culvert.” The document provides criteria for determining whether a culvert or drain meets repair requirements and for selecting the appropriate repair strategy based on the asset's attributes. One attribute is the culvert cross-sectional shape, which measures the extent of cross-sectional deformation relative to the original design shape. Excessive deformation is indicative of a threat to the culvert's structural stability and warrants repair. The mitigation activities on drainage systems, including culverts, to repair the deformation count towards the definition of “Fix Culvert.”

1.1 Overview of the Problem

Buried utilities and drainage systems, including culverts, are usually subject to considerable external stresses, which may be existing or added by new construction. Added stresses from new construction are particularly common in urban areas with abundant culverts and in the vicinity of construction projects (Mahgoub & El-Naggar, 2019). For instance, transportation agencies often preserve existing culverts when highway embankments are constructed as part of road widening projects (Sun & Ashurst, 2024). In many instances, added stresses on existing culverts from new construction can exceed their capacity, leading to failures. Accordingly, it is essential to verify the structural integrity of culverts when significant additional loading is proposed, as per the Caltrans Highway Design Manual (Caltrans, 2020).

To mitigate the effects of increased stresses on existing culverts, lightweight fills can be used in lieu of conventional fills (e.g., Mahgoub & El-Naggar, 2019; Sun & Ashurst, 2024). Lightweight fills have found a multitude of applications in transportation infrastructure in which conventional fills pose challenges. Lightweight fills have advantages over their conventional counterparts from engineering, environmental, and economic perspectives. Lightweight fills are much lighter than conventional fills, which makes them favorable in projects where excessive vertical and/or lateral stresses are a concern. Lightweight fills also induce much smaller vertical and lateral stresses than conventional fills when used to backfill above and around culverts. Lightweight fills have been successfully used to mitigate stresses above culverts, including Expanded Polystyrene (EPS; Sun & Ashurst, 2024), Tire-Derived Aggregate (TDA; Mahgoub & El-Naggar, 2019), and foamed glass aggregate (FGA; Loux & Filshill, 2021).

FGA is derived from foam glass, a technology introduced in the 1920s to produce insulation panels for building envelopes. FGA has been used as a lightweight fill alternative in Europe since the 1990s (Loux et al., 2019a) and was recently introduced to the US through US-based producers (Loux, 2018). Notably, FGA is made from 100% recycled container glass, aligning with the CalRecycle Beverage Container Recycling Program's mission. The Environmental Protection Agency (EPA) estimated that 9.8 million tons of glass containers were generated in 2018 (3.3% of municipal solid waste), but only 31.3% were recycled (EPA, 2024). By diverting post-consumer glass from landfills and transforming it into a useful construction material, FGA can help address broader environmental challenges associated with low glass recycling rates in the US and support more sustainable infrastructure development.

1.2 Research Objectives

This project investigates the use of foamed glass aggregate (FGA) as a strategy to “Fix Culvert” in support of SB1 efforts. The specific objectives of the project include (1) synthesizing the state of practice of the use of lightweight fills over culverts in California; (2) compiling and evaluating case studies of FGA use in transportation fill application with a focus on their use above drainage assets; (3) performing numerical analysis to compare the mechanical response of culverts under FGA fills as alternative to conventional fills; and (4) developing recommendations for design guidelines and construction controls for the use of FGA as fills for culverts.

1.3 Report Organization

This report consists of seven sections:

- Section 1. Introduction and Background. This section provides an overview of the problem and the research objectives.
- Section 2. Practices of Lightweight Fill Use in Transportation Infrastructure. This section summarizes lightweight fill practices in transportation infrastructure projects in the US.

- Section 3. Engineering Properties of Foamed Glass Aggregate. This section summarizes the engineering properties of FGA products from 25 manufacturers across 16 countries.
- Section 4. Case Studies of Foamed Glass Aggregate Usage. This section documents case studies on the use of FGA as a lightweight fill in applications requiring construction above underground drainage structures, such as pipes, culverts, and sewers.
- Section 5. Numerical Investigation. This section presents a numerical investigation to evaluate the benefits of using FGA lightweight fills in place of conventional fills above culverts, either to alleviate stresses on existing culverts or to optimize the design of new culverts.
- Section 6. Design and Construction Guidance. This section provides design and construction guidance for the use of FGA fills above culverts. It serves as a basis for proposed changes in the *Caltrans Geotechnical Manual* and the *Caltrans Highway Design Manual*.
- Section 7. Summary and Conclusions. This section summarizes the study presented in this report and its conclusions.

2. Practices of Lightweight Fill Use in Transportation Infrastructure

According to the *Caltrans Ground Modification Manual* (Caltrans, 2021), lightweight fills are used in California to minimize the effects of applied loads, aiming to (1) prevent or greatly reduce embankment settlement; (2) decrease active pressure behind retaining walls and abutments; (3) lower the driving force in landslide repairs; and (4) enhance the embankment's seismic resistance. Primarily, Caltrans uses lightweight fills to reduce embankment settlement at bridge approaches and to lessen landslide driving forces. When dealing with thick, soft soil deposits, partial excavation of native material beneath the embankment, followed by backfilling with lightweight material, helps balance the overall load. The required excavation volume depends on the unit weights of the native material and the lightweight fill, with heavier materials requiring more removal. Although lightweight fill cannot always fully offset additional embankment loads, it can reduce them to tolerable levels.

Common materials for lightweight fills include Expanded Polystyrene (EPS) geofoam, Lightweight Cellular Concrete (LCC), and natural volcanic materials; other options such as expanded shale, wood fiber (sawdust), and shredded tires are also used. Expanded shale is rarely employed due to its high cost, and wood fiber is seldom used because large quantities are unavailable. Shredded tires have been used in a number of Caltrans projects, and their use is encouraged by the California Department of Resources Recycling and Recovery (CalRecycle) to reduce tire stockpiles.

When choosing a lightweight fill, Caltrans (2021) suggests considering (1) the availability of lightweight fill materials; (2) their engineering properties relevant to settlement and slope stability analysis (for example, for granular lightweight fills, unit weight and shear strength should be evaluated, whereas for continuum fills (e.g., EPS and LCC), unit weight and compressive strength should be evaluated); (3) durability, water absorption, corrosion potential, and other material-specific characteristics; and (4) the costs of using lightweight fill compared to traditional methods.

A recent survey by Morsy and Zornberg (2025) showed that FGA fills have previously been used at least once by Arkansas, Louisiana, Michigan, New Jersey, North Carolina, Pennsylvania, and Wyoming DOTs. The survey respondents from Michigan, Pennsylvania, and Wyoming DOTs reported challenges with using FGA fills, including high costs. Additionally, respondents from the Michigan and Wyoming DOTs reported limited availability and distant shipping as additional barriers to projects in their respective states.

Although there were not enough projects to compare construction times for FGA fills and traditional fills, respondents shared their experience with the projects in their states.

Respondents reported that FGA costs typically include transportation, which can vary significantly depending on the distance between the production plant and the construction site. Their cost comparison likely did not include other costs associated with using traditional fills on problematic foundation soils, particularly ground improvement, which would be omitted when using lightweight fills.

The Pennsylvania DOT recently developed a design manual and specifications for FGA fills. Other respondents provided special provisions developed for the use of FGA fills in their states. In addition to the developed specifications, the respondents indicated that they rely on manufacturer guidelines. Table 1 lists the requirements for the gradation and mechanical properties of FGA fills by state DOTs, respectively, obtained either from survey responses or from provided specifications. Table 2 summarizes the design and construction considerations for FGA fills by state DOTs, obtained either from survey responses or from provided specifications (Morsy & Zornberg, 2025).

Table 1. Requirements for the Mechanical Properties of FGA Fills by State DOTs (Morsy & Zornberg, 2025)

State DOT	Unit Weight (pcf)	Constrained Compression Resistance (psi)	Friction Angle (deg)
Michigan	15–25 (target 15) “Compaction to 80% of the original lift thickness is desired and must not be exceeded (a final nominal thickness of 19 inches is expected based on a 24-inch original thickness). Density acceptance testing is waived.”	–	–
Pennsylvania	< 15 dry loose (ASTM C29/C29M Method C) < 20 moist loose (ASTM C29/C29M Method C)	48.6 at 10% strain (EN 1097-11:2013) 104 at 20% strain (EN 1097-11:2013)	45 for normal stresses up to 1200 psf (Guidance) 38 for normal stresses up to 3000 psf (Guidance)
New York	< 18 pcf moist loose (ASTM C29 Method C)	> 100 at 20% strain (EN 1097-11)	

Table 2. Design and Construction Considerations of FGA Fills by State DOTs (Morsy & Zornberg, 2025)

Does your agency specify…	Michigan DOT	Pennsylvania DOT	Wyoming DOT
…considerations for buoyancy/uplift when designing with FGA fills?	Yes, while it was not a factor in the trial project, it should be considered in future projects for the 500-year flood event.	Yes	Yes
…considerations for long-term water absorption of FGA fills in design?	No, it is assumed that water will always be drained.	No	There has been a discussion on FGA water absorption, especially during hurricanes. It was concluded that water absorption is not an issue.
…a minimum slope at which FGA fills have to be constructed with?	Not at this point.	No	No, for the current project, a reinforced slope 1:1.5 was used.
…compaction practices for FGA fills that differ from those for conventional fills?	Yes, compaction should follow the special provision to avoid material breakdown. "Do not place and compact layers more than 24 inches in thickness when using tracked equipment and not more than 12 inches in thickness when using a walk behind plate compactor;" and "Place and spread the first layer of FGA on the geotextile without damaging the geotextile or breaking down the FGA."	Yes, 4 passes with tracked equipment of a specific ground pressure.	Yes
…special drainage systems when designing with FGA that differ from those typically used with conventional fills?	No, standard practice is adopted.	No, standard practice is adopted.	Yes, a robust drainage system has been used, including a 3 ft-thick drainage blanket around the sides and base. This was a design requirement to prevent saturation.
…practices to limit crushing of FGA fill particles during construction?	Yes, compaction should follow the special provision to avoid material breakdown. "Wheeled equipment is	Yes, "during construction, vehicles and other construction equipment may have limited travel over the	Yes

Does your agency specify…	Michigan DOT	Pennsylvania DOT	Wyoming DOT
	prohibited on the FGA," and "Do not operate equipment directly on the geotextile."	FGA layer after a minimum of 6 inches of compacted capping material is placed."	
…a minimum cover thickness (if any) above FGA fills?	Yes.	Yes. "The minimum compacted lift thickness of capping material in non-live load situations will be 6 inches."	Yes, a cover of around 6–8 ft.
…a minimum thickness between FGA fills and roadway structures?	Yes, a cover of > 4 ft below pavements.	Yes, a cap is used. "The anticipated dynamic loads in flexible pavement systems must be properly considered in the pavement design where FGA is an underlying layer."	-
…separation between FGA fills when placed adjacent to other soils?	Yes, a nonwoven geotextile is used to completely encapsulate FGA.	Yes, a geotextile is used.	Yes, a drainage blanket.

3. Engineering Properties of Foamed Glass Aggregate

Foamed glass aggregate (FGA) is a discrete fill derived from foam glass, a technology introduced in the 1920s to produce insulation panels for building envelopes. It has been used as a lightweight fill alternative in Europe since the 1990s (Loux et al., 2019a). In the literature, FGA is also referred to as glass-foam aggregate (e.g., Betti et al., 2014), granulated foamed glass (e.g., Aabøe & Øiseth, 2004), foamglass aggregate (e.g., Frydenlund & Aabøe, 2014), foam glass gravel (e.g., Hibbert, 2016), cellular glass aggregate (e.g., Aabøe & Øiseth, 2004; Skogstad et al., 2005; Zegowitz, 2010), and foamed recycled glass aggregate (e.g., Arulrajah et al., 2015a, 2015b). Foamed glass should not, however, be confused with expanded glass, which is a broader term that may include foamed glass and other products that may differ from foamed glass in properties.

Foamed glass aggregate was first used in Norway to counter frost driven by the cold Scandinavian climate (Loux et al., 2019b). Thereafter, FGA found applications in several other European construction markets and was recently introduced to the US (Loux, 2018) through US-based producers. A few producers or distributors have been identified in the US, and several producers have been identified outside the US, including in Norway, Germany, the UK, Italy, the Czech Republic, the Netherlands, Sweden, Finland, Estonia, Hungary, Japan, Switzerland, Austria, Poland, and Russia. Table 3 summarizes the properties of commercially available FGA fills.

Foamed glass aggregate is manufactured from recycled glass treated with a foaming agent such as gypsum, limestone (Hibbert, 2016), glycerin, manganese dioxide (Ghafari et al., 2019), and, most commonly, silicon carbide (Aabøe & Øiseth, 2004; Hibbert, 2016). The color of the FGA produced depends primarily on the foaming agent: It can be ash gray when silicon carbide is used, dim gray when glycerin is used, and sienna when manganese dioxide is used (Ghafari et al., 2019). The recycled glass used as a feedstock in producing FGA in the US is sourced from toxin-free glass waste such as curbside-collected container glass (Loux et al., 2019b).

The manufacturing process involves milling glass waste into a fine powder, mixing it with a foaming agent, and heating the mixture in a kiln to activate the foaming agent. Foamed glass exits the kiln on a cooling belt in the form of a foamed glass cake (Loux et al., 2019a) that consists of approximately 8% glass and 92% gas (Aabøe & Øiseth, 2004). The abrupt drop in temperature induces thermal stresses that crack the foamed glass cake into gravel-size aggregates (Aabøe & Øiseth, 2004; Zegowitz, 2010; Loux et al., 2019a). The predominant particle size of the produced aggregate ranges from 10 to 75 mm (Aabøe & Øiseth, 2004; Zegowitz, 2010; Loux et al., 2019a). The individual particles of FGA produced in this process are composed of closed-cell glass matrices with entrapped gas bubbles introduced by the foaming agent (Aabøe & Øiseth, 2004; Loux, 2018).

Generally, FGA offers high shear strength and stiffness, drainability, insulation, chemical stability, and favorable electrochemical properties (Hibbert, 2016). In addition to its function as a lightweight fill to reduce stress, FGA can also be used to prevent frost heave under roadway structures and to insulate around underground structures and utilities.

Table 3. Properties of Commercially Available FGA Fills (Morsy & Zornberg, 2025)

Producer	Grain Size Range (in.)	Grain Density (pcf)	Dry Unit Weight (pcf)	Porosity	Compressive Strength (psi)	Friction Angle (deg)
AeroAggregates UL-FGA G15	0.375–2.5	25	12–15 Uncompacted 13.3–16.7 at CR = 1.11 15–18.8 at CR = 1.25	0.5 Uncompacted 0.38 at CR = 1.25	104 at Strain = 20%	41–55
Glavel	0.375–4	33.7	9–10 Uncompacted 10–11 at CR = 1.11 11.25–12.5 at CR = 1.25	–	110–110 at Strain = 20% 155–160 at Strain = 30%	–
A-Glass	0.39–2.36	–	9.4	92.8–188.5 at CR = 1.1–1.3	–	–
Bi-Foam BFS 160	–	–	15–20	–	–	–
Ecoglas	0.39–2.36	–	8.1–10.6	–	91.4 at Strain = 10%	40
Energocel	–	18.1–21.2	9.4–10.9 Uncompacted 13.7 at CR = 1.4	–	–	–
Foamit	0.39–2.36	–	11.1–15.1 Uncompacted 13.7–17.5 at CR = 1.15–1.25	–	130.5 at 20%	36–40
Geomaterials	0.39–2.36	20–23.1	11.2–14.4	–	116 at Strain = 10% at CR = 1.3	42–45
Glapor SG800	0.63–2.48	–	6.3–7.5 Uncompacted 8.1–9.7 at CR = 1.3	0.15 at CR = 1.3	> 39.2 at Strain = 2% > 87 at Strain = 10%	–
Glapor SG600	1.26–2.48	–	8.4–10.6 Uncompacted 12.2–13.7 at CR = 1.3	0.15 at CR = 1.3	> 53.7 at Strain = 2% > 116 at Strain = 10%	–
Glapor SG_2000_FGSV	1.26–2.48	15.6–18.7	8.4–10.6 Uncompacted	–	> 53.7 at Strain = 2% > 116 at Strain = 10%	40–42
Glasopor	0.39–2.36	23.7	11.2	–	11.6–17.4	45
Hasopor	0.39–2.36	23.7	11.2	–	11.6–17.4	45
Hoger	0–2.48	–	9.1	–	–	–

Producer	Grain Size Range (in.)	Grain Density (pcf)	Dry Unit Weight (pcf)	Porosity	Compressive Strength (psi)	Friction Angle (deg)
ICM Glass Citadel	1.18–2.36	–	8.1-9.4	–	102.3–117.5 at Strain = 10%	–
ICM Glass SolidRock	0.79–1.57	–	10.6–11.9	–	190–224.8 at Strain = 10%	–
Misapor 10/50 (Standard Plus)	0.39–1.97	23.9	10–11.9 Uncompacted 11–13 at CR = 1.1 12–14.2 at CR = 1.2 13–15.4 at CR = 1.3	0.5 at CR = 1.1 0.45 at CR = 1.2 0.4 at CR = 1.3	55.1 at CR = 1.1 75.4 at CR = 1.2 95.7 at CR = 1.3	–
Misapor 10/75 (Standard)	0.39–2.95	–	7.8–9.4 Uncompacted 8.6–10.3 at CR = 1.1 9.4–11.2 at CR = 1.2 10.2–12.2 at CR = 1.3	–	29 at CR = 1.1 45 at CR = 1.2 60.9 at CR = 1.3	–
PoliCell NORM	0.39–2.36	23.1	8.1–9.36	0.55	104.4 at Strain = 10%	–
PoliCell HARD	0.39–2.36	23.1	< 11.23	0.55	145 at Strain = 10%	–
Refaglass	0–2.48	–	9.36	–	–	–
Savelpor	0.39–1.97	–	< 12.5	–	99.6 at CR = 1.3	–
Supersol L2	0.032–2.95	25-31.2	18.7–25 Compacted	–	–	> 30
Veriso LDV	0.39–2.36	13.7–18.7	8.11–10.61	–	> 84.1 at Strain = 10% at CR = 1.3	42–45
Veriso LFV	0.39–2.48	13.7–20	8.11–10.61	–	> 84.1 at Strain = 10% at CR = 1.3	42–45

Note. CR = Compaction Ratio

Table 3. Properties of Commercially Available FGA Fills (Morsy & Zornberg, 2025) (cont.)

Producer	**Potential of Hydrogen (pH) Value**	**Chloride Content (ppm)**	**Sulfate Content (ppm)**	**Water Absorption (%) by Weight**	**Water Absorption (%) by Volume**	**Hydraulic Conductivity (cm/s)**	**Soundness (% Loss by Magnesium Sulfate)**	**Soundness (% Loss by Sodium Sulfate)**
AeroAggregates UL-FGA G15	9.2–9.33	< 10	11	0–60 (typ. 25)	0–10 (typ. 6)	3	4.1–14	3.1–6.9
Glavel	–	< 10	< 10	62	47	0.086	–	4.7–5.3
A-Glass	–	–	–	–	–	–	–	–
Bi-Foam BFS 160	–	–	–	–	–	–	–	–
Ecoglas	–	–	–	–	< 10	1–10	–	–
Energocel	–	–	–	< 10	< 3.5	–	–	–
Foamit	10	–	–	60 after 28 days 100 after 365 days	–	10	–	–
Geomaterials	–	–	–	–	< 10	> 0.1	–	–
Glapor SG800	–	–	–	–	–	0.038	–	–
Glapor SG600	–	–	–	–	–	0.038	–	–
Glapor SG_2000_FGSV	–	–	–	< 10	–	0.038	–	–
Glasopor	–	–	–	–	–	–	–	–
Hasopor	–	–	–	–	–	–	–	–
Hoger	–	–	–	–	–	–	–	–
ICM Glass Citadel	–	–	–	–	–	–	–	–
ICM Glass SolidRock	–	–	–	–	–	–	–	–
Misapor 10/50 (Standard Plus)	5.5	–	–	–	< 6 after 28 days	3	–	–

Producer	Potential of Hydrogen (pH) Value	Chloride Content (ppm)	Sulfate Content (ppm)	Water Absorption (%) by Weight	Water Absorption (%) by Volume	Hydraulic Conductivity (cm/s)	Soundness (% Loss by Magnesium Sulfate)	Soundness (% Loss by Sodium Sulfate)
Misapor 10/75 (Standard)	5.5	–	–	–	< 9 after 28 days	3	–	–
PoliCell NORM	–	–	–	< 40	–	–	–	–
PoliCell HARD	–	–	–	< 40	–	–	–	–
Refaglass	–	< 1	–	2–5	–	–	–	–
Savelpor	–	–	–	–	11	–	–	–
Supersol L2	–	–	–	< 30	–	0.03–1	–	–
Veriso LDV	–	–	–	< 40	< 10	0.1–1	–	–
Veriso LFV	–	–	–	< 40	< 10	0.1–1	–	–

4. Case Studies of Foamed Glass Aggregate Usage

Projects involving the use of FGA as a lightweight fill were selected and documented as case studies. This compilation focused on applications for constructing fill structures on underground drainage structures, such as pipes, culverts, and sewers.

4.1 South Capitol Street

This project involved constructing the new South Capitol Street Bridge, also known as the Frederick Douglass Memorial Bridge, in Washington, DC. The project was undertaken for the District Department of Transportation (DDOT) in September 2019. The design-build contractor was South Capitol Bridgebuilders, a joint venture between Archer Western Construction LLC (Walsh Group) and Granite Construction Company. The project represents the largest infrastructure project undertaken by DDOT to date, with a total construction cost of approximately $441 million. Information about this case study was obtained from the AeroAggregate case study brochures (Personal Communication, 2024).

The bridge serves as a critical transportation link over the Anacostia River, carrying commuter traffic between Washington, DC; Prince George's County, Maryland; and Southern Maryland. In addition to the bridge, the project included reconstruction and reconfiguration of the Suitland Parkway/I-295 interchange, as well as construction of two new interchanges at either end of the bridge.

A key challenge in the project was the presence of two large, aging sewer lines, each exceeding 9 ft in diameter, located near the south interchange. These utilities were considered critical and fragile, and their relocation was not feasible. The combination of soft subsurface soils and the need to construct new embankments in close proximity to the sewers required minimizing additional loading to avoid overstressing the structures. To address this constraint, FGA was selected as a lightweight fill material to raise the grade for the new interchange while minimizing surcharge on the underlying soft soils and the existing sewer infrastructure. Approximately 11,000 cubic yards of FGA were placed as part of the project. This solution allowed the design-build team to meet geometric requirements for the interchange while maintaining acceptable stress levels on the buried utilities.

4.2 I-95 Section CP-2

This project involved construction along I-95 Section CP-2 in Philadelphia, Pennsylvania. The project was undertaken for the Pennsylvania Department of Transportation (PennDOT), with construction activities including the placement of lightweight fill in December 2017. The contractor for the project was Walsh Construction. Information about this case study was obtained from the AeroAggregate case study brochures (Personal Communication, 2024).

A key challenge in the project was constructing an approximately 18-ft-high embankment over a 100-year-old brick sewer. The Philadelphia Water Department identified the sewer as a critical and sensitive structure and required that no additional load be imposed on it. This constraint, combined with existing utilities and subsurface conditions, necessitated a lightweight fill solution. FGA was selected as the lightweight fill material to meet the design requirements while minimizing stress on the underlying sewer. To satisfy the zero-net increase in stress criterion, approximately 3 ft of existing soil was excavated prior to placement of the lightweight fill. This allowed the construction of the full 18-ft embankment without increasing surcharge on the buried utility.

Approximately 7,000 cubic yards of FGA were placed as part of the project. The embankment was constructed with a 1H:1V slope, which provided stable side slopes while allowing construction access along the face and eliminating the need for retaining walls. Construction was successfully carried out in winter, including periods of snowfall in December, demonstrating the material's constructability under adverse weather conditions.

4.3 Route 6/10 Interchange

This project involved reconstructing the Route 6/10 interchange in Providence, RI. The project was considered the largest design-build project in the history of the Rhode Island DOT (RIDOT). The construction took place between 2018 and 2024. Information about this case study was obtained from Loux and Filshill (2021, 2022) and Palombo and Paiva (n.d.).

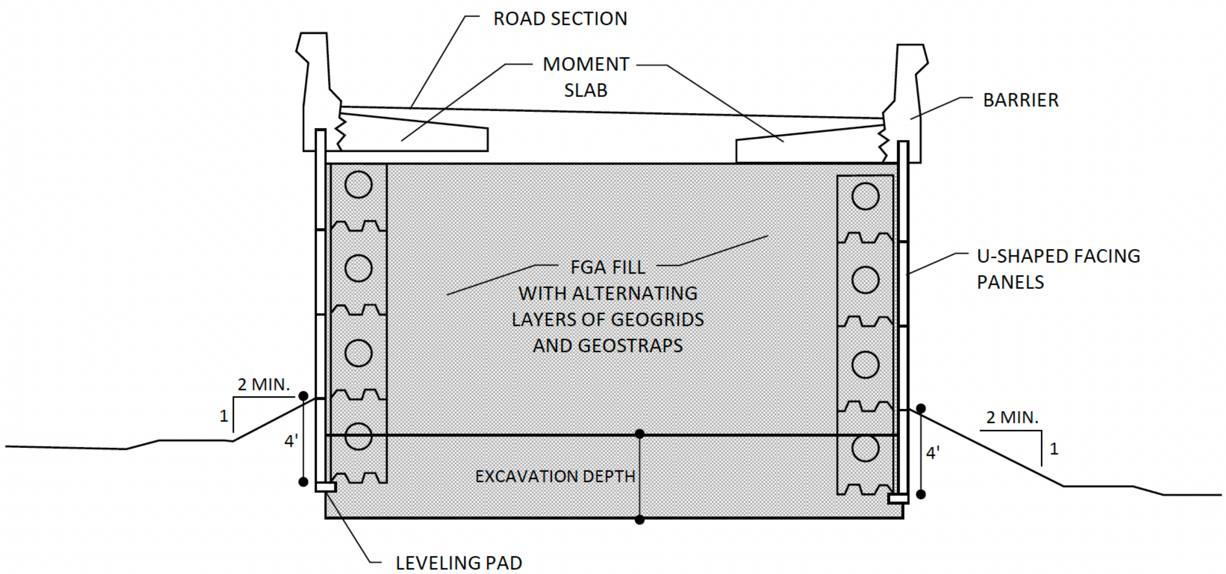
The project involved ramp construction over challenging subsurface soils and existing subsurface utilities, including a large 100-year-old brick sewer. The relocation of the existing utilities was not feasible, and construction above them would have increased the stresses exerted on them, which was not permitted. Accordingly, a solution had to be devised to achieve a net-zero increase in stress on the subsurface utilities.

A number of other solutions were considered, including soil-mixed rigid inclusions, EPS geofoam, foamed concrete, and expanded shale aggregate. According to Palombo and Paiva (n.d.), EPS geofoam was considered too costly and involved undesirable practical limitations; foamed concrete involved undesirable practical limitations and uncertainties, including time for installation; expanded shale aggregate required excessive over-excavation to satisfy the net-zero stress constraint; and ground improvement was found to be a very costly and time-consuming solution, costing more than $5 million and adding more than six months to the construction schedule.

RIDOT and the design-build team decided to use back-to-back MSE walls with FGA lightweight fill. The near-surface existing soil had to be excavated to compensate for the added weight of the walls and satisfy the zero-net increase in stress criterion for the subsurface buried utilities.

Figure 1 shows a cross-section of the ramp, which reached a maximum height of 40 ft. The excavation depth varied with wall height up to 6.2 ft. The MSE walls were constructed with 4-ft U-shaped precast concrete panels and alternating layers of geogrid and geostrap reinforcements extended between the backs of the opposite wall facings.

Figure 1. Typical Cross-Section of Ramp (Redrawn from Loux & Filshill, 2022)



A total of 21,000 cubic yards of FGA fill was used in this project. The use of FGA lightweight fill with MSE walls in this project reduced the number of trucks required for fill delivery and the time needed for ramp construction. This led to more than $3 million in savings when compared to the second-cheapest design alternative.

5. Numerical Investigation

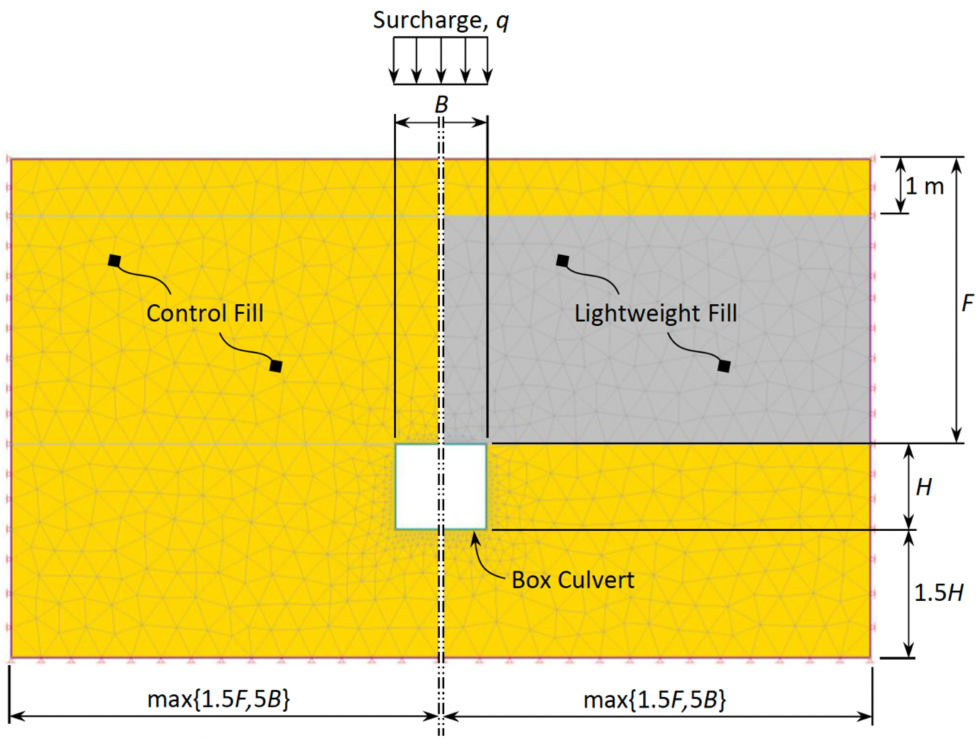
A numerical investigation was conducted to evaluate the benefits of using FGA lightweight fills in place of conventional fills above culverts, either to alleviate stresses on existing culverts or to optimize the design of new culverts. Numerical models were developed for box and CSP culverts to compare their mechanical behavior under conventional and lightweight fills. The models were validated using experimental data from physical models. Parametric evaluations were then conducted using the developed numerical models to assess the extent of these benefits across a range of culvert configurations.

5.1 Numerical Model Description

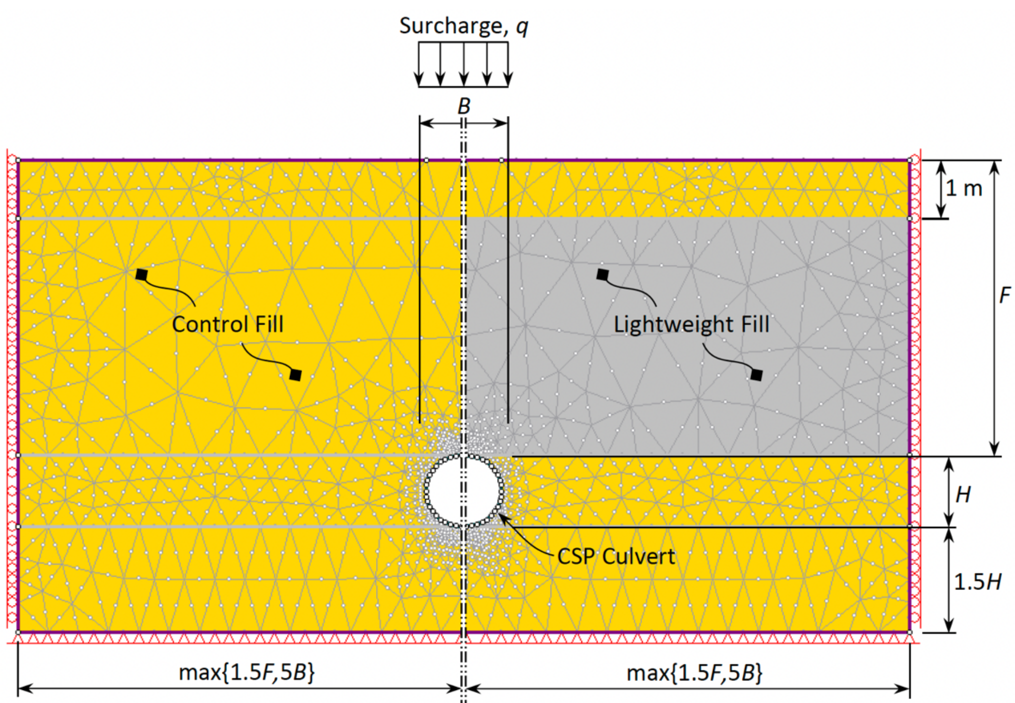
The numerical model was developed using a two-dimensional finite element analysis code under plane strain conditions. Figure 2 shows side-by-side finite element models for a control conventional fill condition (left) and a lightweight fill condition (right). In both models, the culvert, subjacent soil, and adjacent soil were activated to initialize soil stresses around the culvert. An at-rest lateral earth pressure coefficient of 0.4 was assumed. Displacements were then reset before the superjacent fill was activated. This allows calculation of displacements in the model attributable only to the placement of the superjacent fill. For the lightweight fill, a 1-m-thick capping layer of control fill was used to comply with current practices for lightweight fills (e.g., Morsy & Zornberg, 2026). This capping layer serves multiple functions, including acting as a buffer between the FGA fill and surface live loads, which may have detrimental effects on particle crushability in the long term.

In the box culvert models, the mesh comprised 3-noded triangular elements and was substantially refined around the culvert, with 20 elements per culvert side, to minimize mesh-dependent effects. In the CSP models, the mesh comprised 6-noded triangular elements and was refined around the culvert, with 40 elements (81 nodes) along the culvert's perimeter. The bottom boundary of the model was fixed in both the horizontal and vertical directions, whereas the side boundaries were fixed in the horizontal direction and allowed to displace vertically. The top boundary was allowed to displace in both directions. Each side boundary was placed at a horizontal distance of 1.5 times the fill height, F, or 5 times the culvert width, B, whichever was greater, to minimize side boundary effects. The angles of repose of the control and lightweight fills used in this study were 40° and 45°, respectively. Therefore, any soil-arching displacement in the superjacent soil due to differential settlements between the culvert and the adjacent soil would occur well within the chosen side boundaries.

Figure 2. Side-by-Side Finite-Element Models for Culverts with a Control Fill (Left) and a Culvert with a Lightweight Fill (Right): (a) Box Culvert and (b) CSP Culvert



(a)



(b)

The soils were modeled using a Mohr-Coulomb elastic-plastic model. The properties of the control fill and lightweight fill are summarized in Table 4. The control fill properties were assigned based on an exemplary sand fill (120-Nevada sand) used in the model calibration and validation. The FGA lightweight fill properties were assigned to a representative typical FGA fill based on properties reported by 25 FGA manufacturers across 16 countries (Morsy & Zornberg, 2026). A representative elastic modulus for the FGA fill was calculated from secant constrained modulus values estimated from one-dimensional compression tests by Ullah et al. (2025) and Nicks et al. (2024) at compression strains less than 1%, assuming a Poisson's ratio of 0.30. A cohesion intercept of 1 kPa was assigned to the soil models to avoid numerical errors. The soils subjacent and adjacent to the culverts were modeled using the control fill properties.

The box culvert was modeled using reinforced-concrete beam elements based on the Timoshenko beam formulation. The reinforced concrete material was modeled as elastic with a unit weight of 25 kN/m^3, an elastic modulus of 2.5 GPa, and a Poisson's ratio of 0.2. The soil-culvert interface was modeled using interface elements with an interface stiffness coefficient of 10. This coefficient scales the interface shear stiffness based on the elastic modulus of the surrounding soil. The finite-element code calculates the interface normal shear stiffness as 10 times the interface shear stiffness, which is a typical ratio of the interface normal to shear stiffnesses. The CSP culvert was modeled using beam elements. The culvert material was modeled as elastic with a unit weight of 78.5 kN/m^3, an elastic modulus of 200 GPa, and a Poisson's ratio of 0.3. The soil-culvert interface was modeled using interface elements with an interface stiffness coefficient of 10.

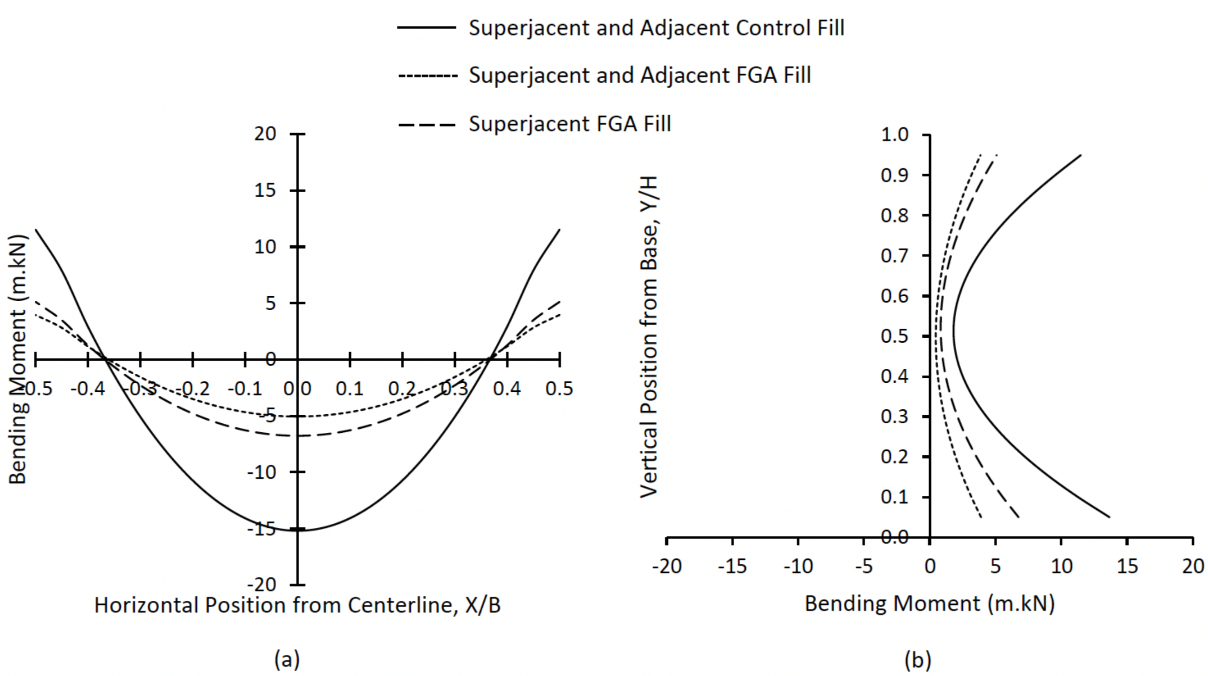
Table 4. Properties of the Control and Lightweight Fills

Parameter	**Control Fill**	**FGA Lightweight Fill**
Unit Weight	16.9 kN/m^3	4.0 kN/m^3
Elastic Modulus	30 MPa	20 MPa
Poisson's Ratio	0.28	0.30
Angle of Internal Friction	40°	45°
Angle of Dilatancy	8°	15°

Preliminary simulations were conducted to evaluate the benefits of using lightweight fills when used both adjacent and superjacent to culverts versus only superjacent to culverts. In these simulations, a baseline culvert model measuring 1.5 m × 1.5 m with an envelope thickness of 0.2 m was used. The simulations used a baseline fill height of 5 m, with no surface surcharge. Figure 3 compares the bending moments in the culvert's envelope when the lightweight fill was placed both adjacent and superjacent to the culvert and when it was placed only superjacent to the culvert. Both cases resulted in a significant reduction in bending moments compared to the control fill case. As shown in Figure 3, placing the lightweight fill both adjacent to and superjacent to the culvert reduced the maximum bending moment in the culvert envelope by an estimated 66% compared to the control fill case. When the lightweight fill was placed only superjacent to the culvert, the reduction in the maximum bending moment in the culvert envelope was estimated at 53% compared to the control fill case.

While the results suggest added benefits to using lightweight fills adjacent to the culverts, the difference may not be large enough to outweigh the often-prohibitive initial costs of synthetic fill materials (Morsy & Zornberg, 2026). Engineers may conduct a cost-benefit analysis to evaluate the economics of both cases. In this study, lightweight fills were used only superjacent to culverts to evaluate the benefits of this economic alternative, which is likely applicable not only to the design and construction of new culverts but also to mitigating existing and/or added external stresses on existing culverts.

Figure 3. Comparison of Bending Moments in the Culvert's Envelope Under Different Fill Configurations: (a) Bending Moments in the Culvert's Roof and (b) Bending Moments in the Culvert's Side Wall



5.2 Parametric Evaluation

The box culvert model was validated using the experimental results from several centrifuge physical models by Abuhajar et al. (2015, 2016), including the bending moment in the culvert's roof and side walls. The CSP culvert model was validated using experimental results from several full-scale physical models by Kearns et al. (2020) and Simpson et al. (2015), including axial thrust and bending moment within the culvert envelope. The comparisons indicate good agreement between the numerical predictions and the experimental measurements.

The validated numerical model was used to conduct a parametric study evaluating the benefits of using FGA lightweight fills in place of conventional fills across a range of culvert configurations, including culvert thickness, size, fill height, and surface surcharge. The ranges of culvert attributes and configurations were selected based on prevalent culvert characteristics in California. This information was obtained from the inventory being developed by the California Department of Transportation (Caltrans) districts as part of the state culvert inspection program (Caltrans, 2025). Tables 5 and 6 summarize the numerical investigation program for RC box and CSP culverts, respectively.

Table 5. Numerical Simulation Program for RC Box Culverts

Series	**Fill Type**	**Culvert Thickness (m)**	**Culvert Size (m)**	**Fill Height (m)**	**Surcharge (kPa)**
Thickness	Control; FGA	0.1; 0.2; 0.4; 0.6	1.5	5	0
Size	Control; FGA	0.2	0.5; 1.5; 3.0	5	0
Fill Height	Control; FGA	0.2	1.5	2; 5; 10; 20	0
Surcharge	Control; FGA	0.2	1.5	5	0; 150; 300; 450

Table 6. Numerical Simulation Program for CSP Culverts

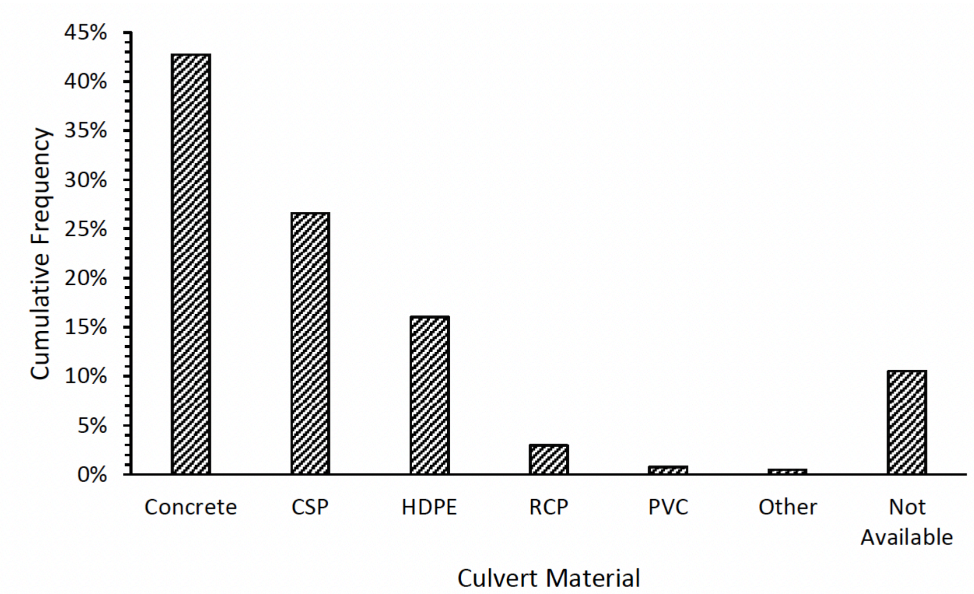
Series	**Fill Type**	**Moment of Inertia (mm^4/mm)**	**Culvert Diameter (m)**	**Fill Height (m)**	**Surcharge (kPa)**
Moment of Inertia	Control; FGA	25; 39; 179; 182	1.2	5	0
Size	Control; FGA	39	0.3; 0.8; 1.2	5	0
Fill Height	Control; FGA	39	1.2	2; 5; 10; 20	0
Surcharge	Control; FGA	39	1.2	5	0; 150; 300; 450

Figure 4a presents statistics for the culverts in the database by type: The top two culvert types were concrete and CSP. Accordingly, this study focused on those two types.

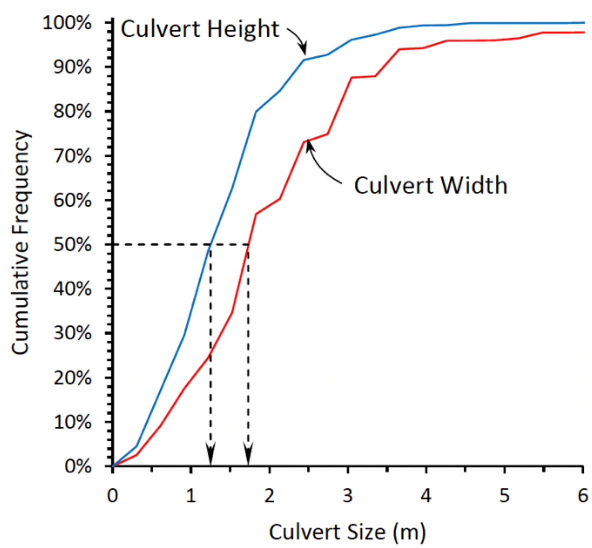
Box culverts ranging from 0.5 m to 3.0 m in size were considered in the investigation program. This range covers more than 80% of the culverts in the database by size, as shown in Figure 4b. The baseline culvert size was selected as 1.5 m × 1.5 m, which is close to the 50th-percentile culvert size in the representative database. Culvert thicknesses ranging from 0.1 to 0.6 m were considered in this study to evaluate the possibility of reducing culvert envelope thicknesses below typical ranges when using lightweight fills. A baseline thickness of 0.2 m was selected as a suitable envelope thickness for the baseline culvert size.

CSP culverts ranging from 0.5 m to 3.0 m in size were considered in the investigation program. This range covers more than 80% of the culverts in the database by size, as shown in Figure 4c. The baseline culvert size was selected as a circular section with a diameter of 1.2 m. While this size is considered relatively large compared to the database culverts (93% percentile), it represents culverts that have been likely used under high fills or structures that could be used for purposes other than drainage, such as wildlife passages. Additionally, CSPs with designations 2-2/3×1/2, 3×1, and 5×1 (National Corrugated Steel Pipe Association, 2018), studied herein, are commercially available in this size, allowing a direct evaluation of the culvert's stiffness at the same size. CSP with designation 2-2/3×1/2 was chosen as the baseline CSP because it is commercially available in smaller sizes (0.3 m and 0.8 m), which cover a wider size range in the representative culverts database.

Figure 4. Representative Culvert Distribution in Caltrans District 11: (a) Type of Culverts; (b) Size of Concrete Box Culverts; and (c) Size of CSP and HDPE Culverts



(a)



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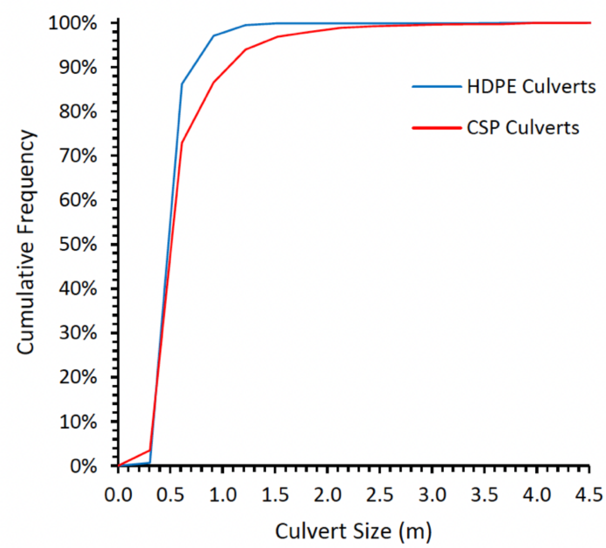


(c)

Fill heights up to 20 m were investigated as part of this program to evaluate the fill height below which the effect of the lightweight fill may not be pronounced. The minimum fill height evaluated in this program was 2 m, including a 1 m capping layer constructed from conventional soil (see Figure 2). The effect of surface surcharge was also investigated with magnitudes up to 450 psf applied over the width of the culvert (see Figure 2). Since the evaluation of the surface surcharge effect is peripheral to this study, the baseline scenario assumed no surface surcharge.

5.3 Results and Analysis

Figure 5 compares the predicted bending moments in the culverts' roofs. As expected, the bending moments in the culvert envelope increased with increasing culvert thickness (Figure 5a), increasing culvert size (Figure 5b), increasing fill height (Figure 5c), and increasing surface surcharge (Figure 5d). The bending moments in the culverts with lightweight fills were much smaller than those with conventional fills. Across all culvert sizes, thicknesses, fill heights, and surface surcharges, the maximum bending moment in the culvert's envelope could be reduced by 25% to 70% when using the FGA fill in place of the control conventional fill. This percentage is most sensitive to fill height.

Figure 5. Comparison of Bending Moments in the Culverts' Roofs: (a) Various Culvert Thicknesses; (b) Various Culvert Sizes; (c) Various Fill Heights; and (d) Various Surcharges

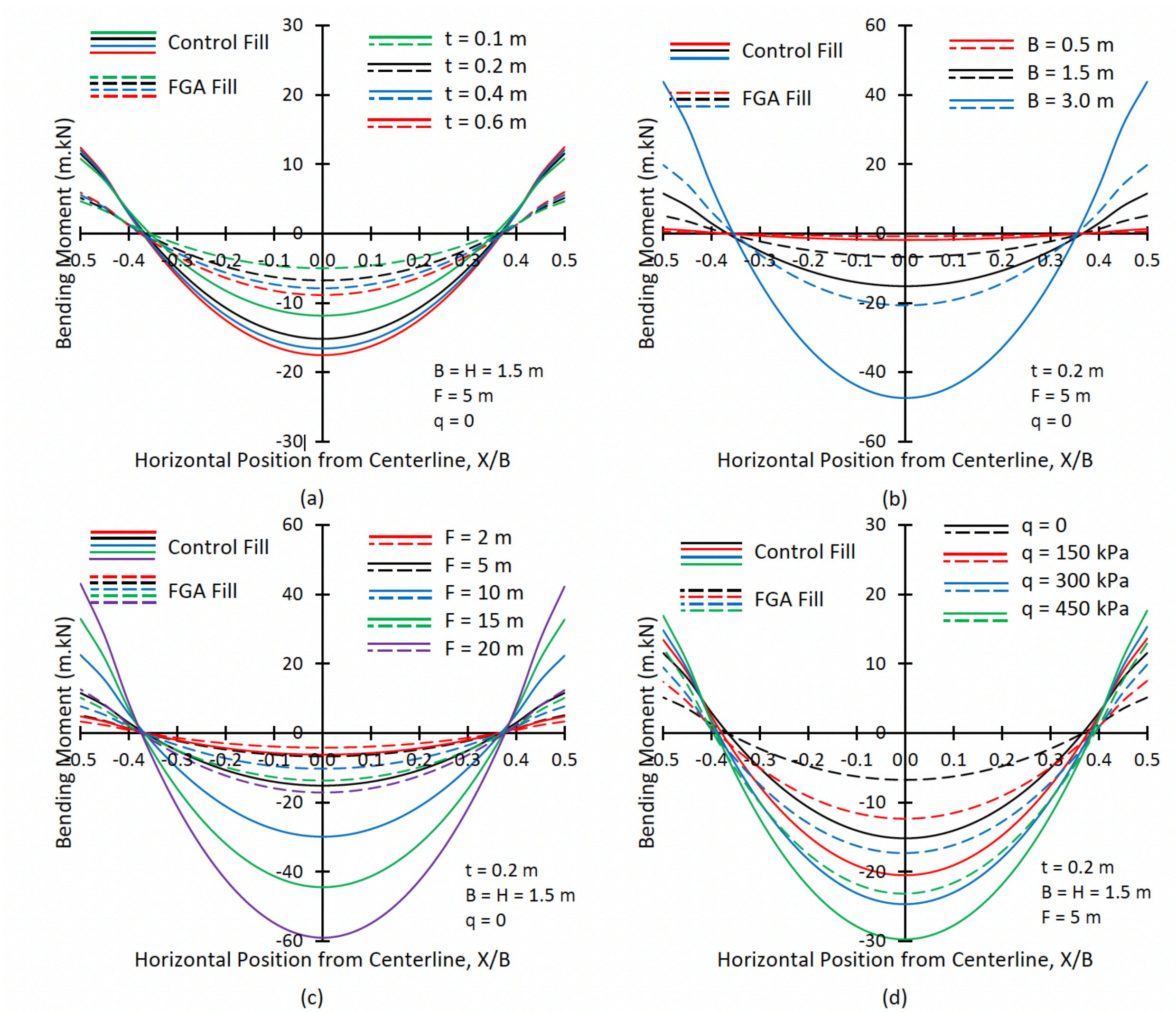
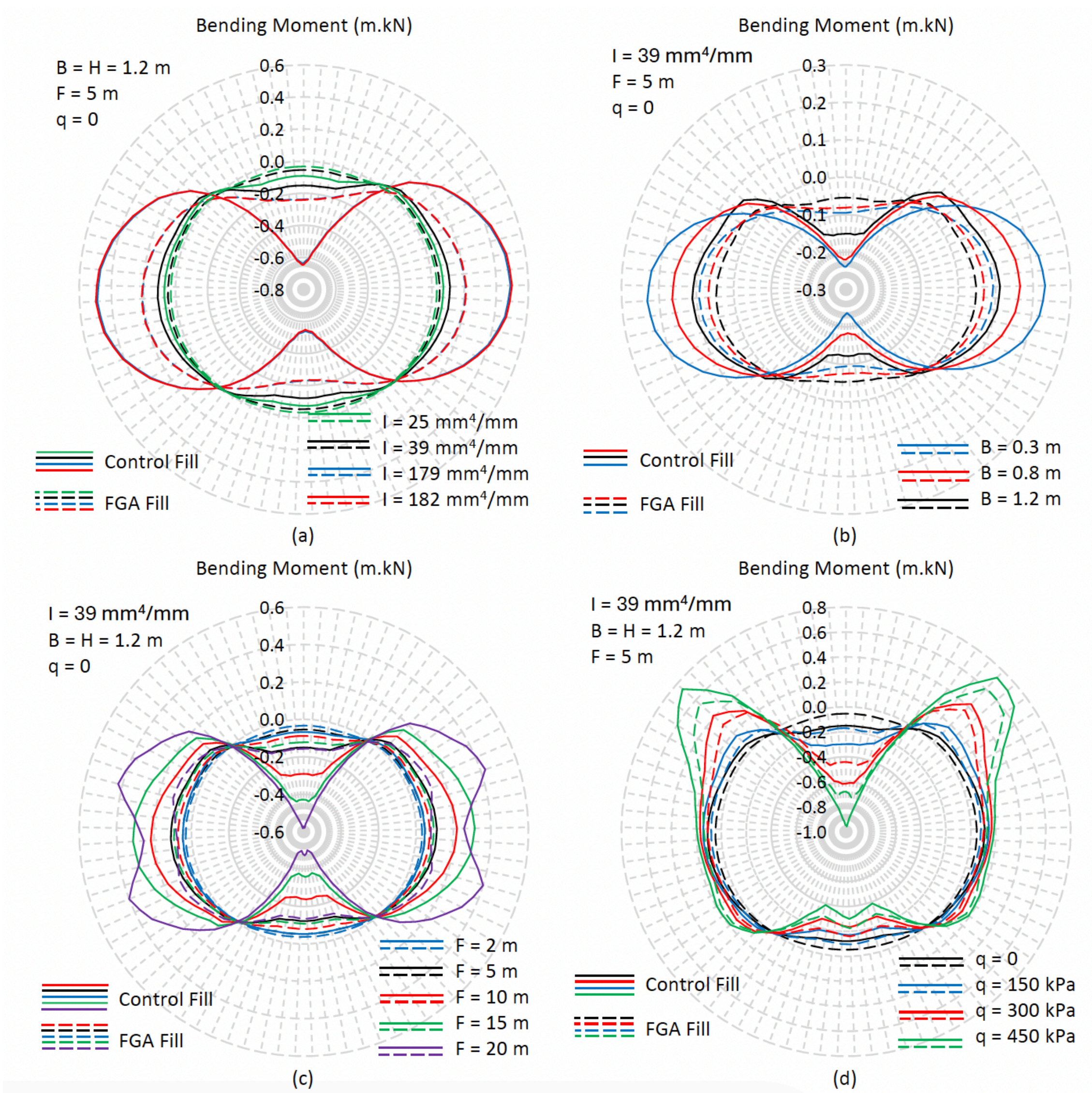


Figure 6 compares the predicted bending moments in the culverts' envelope. As expected, the bending moments in the culvert envelope increased with increasing culvert stiffness (Figure 6a), decreasing culvert size (Figure 6b), increasing fill height (Figure 6c), and increasing surface surcharge (Figure 6d). The bending moments in the culverts with lightweight fills were much smaller than those with conventional fills. Across all culvert sizes, thicknesses, fill heights, and surface surcharges studied herein, the maximum bending moment in the culvert's envelope could be reduced by 24% to 73% when using the FGA fill in place of the control conventional fill. This percentage is most sensitive to fill height and surface surcharge.

Figure 6. Comparison of Bending Moments in the Culvert Wall: (a) Various Culvert Wall Stiffnesses; (b) Various Culvert Diameters; (c) Various Fill Heights; and (d) Various Surcharges



6. Design and Construction Guidance

Designing with lightweight fills follows conventional design frameworks. However, some considerations should be made when using lightweight fills to ensure they retain their properties over the long term. This study proposes the following design and construction guidance for the use of FGA lightweight fills based on the practices synthesized in Sections 2 and the FGA properties compiled in Section 3.

6.1 Derivation of Design Parameters

Similar to conventional fills, ultralightweight fill properties should be evaluated to ensure their suitability in a given fill application. This includes evaluation of physical, mechanical, hydraulic, and electromechanical properties as necessary for the project. Fill parameters should be evaluated to ensure they meet the project's specifications. Custom testing equipment for alternative guidance may be necessary for FGA fills with large particle sizes that cannot be tested by conventional equipment. Based on the data compiled herein (Section 3), the following parameters can be used as guidance when designing with FGA fills.

Physical Parameters

- As-delivered loose dry unit weight: < 15 pcf.
- In-place compacted moist unit weight: < 25 pcf.
- Particle size range: 3/8 in. to 4 in. (by producer).
- Fines content after compaction: < 15%.
- Soundless loss (Magnesium Sulfate): < 30% per AASHTO T 104.

Mechanical Parameters

- Angle of internal resistance: > 34° per AASHTO T 236.
- Compressive strength at 10% strain: > 7,000 psf per EN 1097-11.
- Compressive strength at 20% strain: > 15,000 psf per EN 1097-11.

Hydraulic Parameters

- Highly permeable and drainable.
- Water absorption (by producer).

Electrochemical Parameters

- Resistivity: > 1500 ohm.cm per CT 643.
- pH value: > 5.5 per CT 643.
- Chloride content: < 500 ppm per CT 422.
- Sulfate content: < 1500 ppm per CT 417.

6.2 Considerations for Placement and Compaction

Like conventional fills, FGA fills should be placed and compacted in uniform lifts. However, unlike regular fills, FGA should not be over-compacted to prevent excessive crushing of FGA particles, which could increase its unit weight. Loux et al. (2019) recommend placing FGA fills in 2 ft lifts when compacting with tracked equipment, such as excavators or dozers. In confined, inaccessible areas, FGA could be placed in 1 ft lifts when compacting with small-sized compactors, such as plate compactors. Construction equipment, other than for placement and compaction, should not be operated on exposed FGA fills to minimize particle crushing and prevent over-compaction.

6.3 Evaluation of In-Place Fill Unit Weight

Like conventional fills, FGA fills require compaction evaluation, which can be achieved by comparing the in-place unit weight after compaction to a specified unit weight. This evaluation should ensure that discrete fills are neither under-compacted nor over-compacted.

For FGA fills with large particle sizes that cannot be tested using conventional equipment, in-place unit weight after compaction can be evaluated using alternative methods and compared to a specified target unit weight set by design. For instance, steel boxes of known volumes and weights can be placed in the area where fill is placed. After fill placement and compaction, the steel boxes can be removed and weighed to determine the in-place compacted unit weight, which can be compared to a specified target unit weight. This method was successfully implemented in the Eleventh Street Bridge project by District DOT (Wall & Castrodale, 2019).

Evaluation can also be achieved by observing and verifying a method-based specification (Loux et al., 2019b). The in-place unit weight after compaction is then compared to a specified target unit weight set by design, which could be an acceptable range established by fill producers to meet desired properties. For instance, Loux et al. (2019b) recommend compacting FGA to a compaction ratio of 1.25 (the ratio of compacted to uncompacted unit weights).

6.4 Considerations for Stability Against Buoyancy

Like other ultralightweight fills, FGA may float when submerged under water, which requires designing against buoyancy. In cases where groundwater is present, dewatering may be necessary. Additionally, structures using ultralightweight fills such as FGA should ensure fill stability against buoyancy. Florida DOT (2022) requires that lightweight fill embankments be designed with a factor of safety of 1.2 against buoyancy and lateral movement due to the 500-year storm. Caltrans (2021) requires that lightweight fill structures be designed considering the 100-year flood event. Cutoff walls (Caltrans, 2021) or a sufficient counterweight (Schaefer et al., 2016) should be used to achieve a minimum safety factor. AeroAggregates (2020) suggests applying a factor of safety of 1.5 to the estimated buoyant unit weight of FGA fills.

Based on the evaluation of current practices, it is recommended that ultralightweight fill structures be designed with a factor of safety against buoyancy/uplift of 1.3 at a minimum under normal operational conditions and 1.1 under extreme conditions (recommended values are based on EM 1110-2-2100 recommendations for buoyancy/uplift stability of concrete structures; U.S. Army Corps of Engineers, 2005).

6.5 Considerations for Surface and Subsurface Drainage

While FGA fills have high hydraulic conductivity, allowing water to drain quickly through their pore network, drainage is needed to prevent water retention that could increase the fill's bulk unit weight. Drainage is also needed to mitigate the buoyancy/uplift effect on lightweight fill structures during flood events.

Based on the evaluation of current practices, it is recommended that drainage systems be designed to prevent water from infiltrating ultralightweight fills. This could be achieved by surface drainage systems. Any infiltrating water can be addressed by subsurface drainage systems below the ultralightweight fill, including a drainage blanket and/or a network of perforated drainage pipes.

6.6 Requirements for Protective Capping Layers

Ultralightweight fills require capping layers that serve multiple functions, including counteracting uplift/buoyancy during flood events, providing topsoil for vegetation, serving as a subbase course for pavements, facilitating surface drainage for water diversion, offering confinement to minimize deformation, and protecting against damage by weathering, live loads, fire, ultraviolet exposure, differential icing, and/or hydrocarbons. The material and the thickness of the capping layer need to be determined based on its desired functions.

Based on the information evaluated in this study, capping thicknesses varied significantly by project, by transportation agency specification, and across the published literature. For FGA fills, the DOT survey results suggest a soil capping layer thickness of 6 inches to 8 feet and a minimum thickness of 4 feet below pavements. AeroAggregates (2020) recommended a minimum thickness of 6 inches for FGA fills that do not involve live loads (e.g., traffic loads); the capping layer thickness for structures involving live loads should be determined by design.

6.7 Requirements for Separation from Contiguous Soils

FGA fill particles are typically much larger than those in conventional soils, which require separation from contiguous soils using geotextiles to prevent particle migration from the neighboring soils into the large voids of the FGA fills. Geotextiles must be seamed or overlapped; a typical 12-inch overlap may suffice in most applications and conditions. In cases where significant displacement is expected, such as construction on soft soils, a larger overlap may be needed (Loux et al., 2024). To minimize damage to geotextiles during installation, it is recommended not to leave them exposed for more than 14 days and to handle them carefully during placement of capping layers (e.g., AeroAggregates, 2022).

6.8 Proposed Changes to Caltrans Geotechnical Manual

Appendix A provides a list of proposed changes to "Section 5.2 Lightweight Fills" of the *Caltrans Geotechnical Manual* (Caltrans, 2021) based on the design and construction guidance presented in this report. The changes were prepared using language, style, and level of detail that match those used in the current manual for other lightweight fills commonly used by Caltrans.

6.9 Proposed Changes to Caltrans Highway Design Manual

"Chapter 850 – Physical Standards" of the *Caltrans Highway Design Manual*(Caltrans, 2020) provides tables for the maximum fill height above drainage systems, including culverts, for various types, shapes, and design configurations. However, those maximum fill height limits are established based on conventional fills. To account for the possible use of lightweight fills above drainage structures, the following statement is proposed for inclusion in "Chapter 820 – Cross Drainage: Topic 829 – Special Considerations: 829.2 Bedding and Backfill (3) *Height of Cover*":

> Where lightweight fill is used in lieu of conventional fill, the tabular values for maximum height of overfill or cover do not apply directly. The allowable height of overfill or cover shall be established by special design using the actual unit weight and engineering properties of the lightweight fill and the project-specific loading, settlement, groundwater, and uplift conditions. Special designs are to be submitted to the Division of Structures for review, or the Division of Structures may be directly requested to prepare the design.

6.10 Possible Use Limitations

Transportation Constraints

Ultralightweight fills, including FGA, are synthetic materials that require manufacturing and transportation from the nearest manufacturing plant to the desired jobsite. Oftentimes, this transportation can be quite distant and costly, depending on the distance between the source and the jobsite. It is notable, however, that the number of transportation truckloads and trips of ultralightweight fill is usually dictated by material volume rather than material weight, since the latter is unlikely to exceed truck haulage capacities.

Installation Sensitivity

Unlike conventional fills, FGA fills require special considerations during and after placement to minimize damage during installation, as discussed earlier. Excessive compaction of FGA fills can increase their in-place unit weights, defeating the purpose of using ultralightweight materials. This may inadvertently occur due to particle crushing, often caused by driving construction equipment directly on the fill.

Characterization Difficulty

Large-sized FGA particles cannot be characterized using conventional testing equipment. The properties of these fills can vary significantly across manufacturers or manufacturing plants (e.g., Ullah et al., 2026). That is, relying solely on reported properties may not be suitable for all project scales. In addition, the characterization data on the mechanical behavior of some fill types are scarce or limited to tests conducted on samples with modified gradation.

Leachate Toxicity

Studies have shown insignificant toxicity in FGA leachate, with concentrations of hazardous materials reported to be much lower than those of drinking water standards (Arulrajah et al., 2015; Lenart & Kaynia, 2019). However, more studies are necessary to evaluate the leachate chemistry of FGA fills produced by different glass feedstocks. Currently, information regarding the leachate analyses of FGA produced by different manufacturers and manufacturing plants is scarce.

7. Summary and Conclusions

A numerical investigation was conducted to evaluate the benefits of using FGA lightweight fills in place of conventional fills above culverts, either to alleviate stresses on existing culverts or to optimize the design of new culverts. Numerical models were developed for box and CSP culverts to compare their mechanical behavior under conventional and FGA lightweight fills. The models were validated using experimental data from physical models. Parametric evaluations were then conducted using the developed numerical models to assess the extent of these benefits across a range of culvert configurations.

FGA lightweight fills were found to result in significant reductions in culvert straining actions, soil stresses on culverts, culvert deformation, and culvert settlement. Across all culvert sizes, thicknesses, fill heights, and surface surcharges studied herein, the maximum bending moment in the culvert's envelope could be reduced by 25% to 70% when using FGA lightweight fills in place of conventional fills. This percentage is most sensitive to fill height. Given the often-prohibitive initial costs of synthetic fill materials, the benefits of using FGA fills were quantified across varied culvert configurations to provide insight into which culverts would benefit most from such alternative fills. The outputs of this study shall assist in identifying, based on culvert attributes, which culverts could benefit from lightweight fills.

To facilitate the integration of the FGA as a lightweight alternative in California and as a backfill above drainage structures, a set of design and construction guidelines was prepared for this study. Finally, changes to the *Caltrans Geotechnical Manual* and the *Caltrans Highway Design Manual* were proposed.

Appendix A. Proposed Changes to Caltrans Geotechnical Manual: Ground Modification

The following list contains proposed changes to "Section 5.2 Lightweight Fills" of the *Caltrans Geotechnical Manual – Ground Modification* (subsections to be renumbered upon new subsection insertions):

1. Add the following row to Table 3 of the manual. Lightweight Fill Materials

Lightweight Fill Type	Range of Density (pcf)	Range of Specific Gravity
Foamed Glass Aggregate	15 to 25	0.2 to 0.5

2. Add a new subsection titled "5.2.X. Foamed Glass Aggregate"

Foamed glass aggregate (FGA) is a discrete fill manufactured from recycled glass treated with a foaming agent such as gypsum, limestone (Hibbert, 2016), glycerin, manganese dioxide (Ghafari et al., 2019), and, most commonly, silicon carbide (Aabøe & Øiseth, 2004; Hibbert, 2016). The fill is extremely lightweight and exhibits excellent mechanical properties (shear strength, compression stiffness, and creep resistance), electrochemical properties, and drainage performance. In addition, FGA is highly resistant to frost action, fire, chemical reaction, decay, and ultraviolet radiation. Construction with FGA is insensitive to weather conditions and requires no specialty equipment. While transportation can be costly if the project site is far from the manufacturing plant, FGA can be transported in large quantities and fewer truckloads to offset transportation costs. The FGA fill particles are crushable if specific construction guidelines are not followed.

1. Edit the title of subsection 5.2.3. to "5.2.3. Investigations (EPS, Cellular Concrete, and FGA)"

2. Add a new subsection titled "5.2.X. Design Method (FGA)"

The design of FGA must balance the need for load reduction with stability, compressibility, and drainage requirements. Because foamed glass aggregate behaves as a lightweight granular fill, the engineering properties are influenced by gradation and by particle crushing during handling and compaction. At this time, no widely accepted U.S. highway design guideline exists for foamed glass aggregate; and therefore, project-specific design parameters should be established using representative material from the proposed source. Design should take advantage of the load reduction and high internal friction angle of FGA, which can substantially reduce vertical and lateral forces.

The design process for FGA includes:

- Design for external (global) stability. This includes consideration for settlement, bearing capacity, and slope stability under the projected loading conditions.

- Design for internal stability within embankment mass. The designer must ensure the FGA can support the overlying pavement and traffic loads without excessive particle crushing and post-construction compression.

- Design of the appropriate pavement system over FGA. Communicate with District Materials regarding the most appropriate pavement design.

- Design for uplift pressure. This is necessary if high groundwater exists and if the 100-year flood level creates a high head in surrounding areas. In some cases where uplift is an issue, a cutoff wall may be necessary.

- The foundation under the FGA must be prepared and compacted to create a smooth surface and dry condition. In cases where groundwater exists, dewatering may become necessary. A geotextile should be used to separate FGA fill from surrounding soils.

Morsy (2026) provides information about the physical, mechanical, hydraulic, and electrochemical properties of FGA. In addition, FGA is not considered hazardous for transportation infrastructure applications.

1. Edit the title of subsection 5.2.6. to “5.2.6. Reporting (EPS, Cellular Concrete, and FGA)”

2. Add a new subsection titled “5.2.X Considerations for Construction (FGA)”

Morsy (2026) provides information about important construction considerations, such as:

- Considerations for placement and compaction

- Evaluation of in-place fill unit weight

- Requirements for separation from contiguous soils

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About the Author

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Dr. Amr Morsy is a professional civil engineer with experience in both academia and industry, with a focus on geotechnical engineering, transportation geotechnics, environmental geotechnics, and climate adaptation. He obtained his B.Eng. and M.Sc. degrees in civil engineering from Cairo University in 2011 and 2013, respectively, and his PhD in civil engineering from The University of Texas at Austin in 2017. He worked as a postdoctoral fellow at The University of Texas at Austin in 2018 and as a practicing geotechnical engineer from 2018 to 2020. He later worked as a Research Associate at Loughborough University on the ACHILLES program grant from 2020 to 2022. He has been an Assistant Professor at California State University, Long Beach, since 2022.

As part of his academic experience, Dr. Morsy conducts research on geotechnical infrastructure deterioration and asset management, climate change impacts on geotechnical infrastructure, and geotechnical solutions for the sustainable built environment. He has excelled in physical and numerical modeling of geotechnical and geoenvironmental engineering systems, as well as in infrastructure instrumentation and laboratory experimentation. He participated in research projects sponsored by the Transportation Research Board of the National Academies of Sciences, Engineering, and Medicine, the Engineering and Physical Sciences Research Council of the UK Research and Innovation, the US Federal Highway Administration, the Geosynthetic Institute, Texas and Indiana Departments of Transportation, and geosynthetic manufacturers.

As part of his professional consulting experience, Dr. Morsy conducts rigorous analyses, designs, and forensic evaluations for a range of slopes, retaining walls, reinforced soil structures, deep excavations, bridge foundations, waste containment facilities, tailings dams, and embankment dams. He has assisted expert witnesses in cases involving the collapse and poor performance of earth retaining structures. He has provided solutions to geotechnical problems in a number of environmental remediation projects involving the cleanup of superfund sites. He has conducted multi-phase flow analyses for several infrastructure features, including earthworks, embankment dams, and cover systems. Some of the consulting projects he has participated in served the US Environmental Protection Agency, the New York State Department of Environmental Conservation, the New York State and Indiana Departments of Transportation, the Tennessee Valley Authority, New Jersey Transit, and several multinational private and public corporations.