Hammered Earth Insulated Wall

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Question answered	What does the existing research suggest about an insulated rammed-earth wall system for Fernley, and what still needs verification?

Summary

Formerly titled Fernley Insulated Rammed-Earth Wall. The research version is unchanged at 2.0. Fernley, Nevada remains the demonstration site; rammed earth remains the engineering name of the material.

A long-life double-wythe structural, thermal, moisture and construction-cost research baseline

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1. Purpose or subject

Develop a defensible research baseline for a long-life rammed-earth exterior wall for the proposed FPSA demonstration in Fernley, Nevada. The study integrates structural/seismic requirements, thermal performance, moisture management, insulation durability, inter-wythe connectors, preliminary material quantities, and the existing human-versus-robot labor scenario. Approved for FPSA project

inclusion and website publication as a research baseline. It remains subject to engineering development and is not a permit-ready design or contractor quotation.

2. Summary

The recommended research baseline is a one-story, approximately 24-inch double-wythe wall:

10 inches reinforced and stabilized interior structural rammed earth

6 inches unfaced cellular-glass insulation

1 inch drained and ventilated cavity

7 inches stabilized exterior protective rammed earth

The inner 10-inch wythe is the primary structural wall, interior finish and useful thermal mass. The cellular-glass core supplies the principal thermal resistance. The 1-inch cavity is a deliberate rain-management space. The exterior 7-inch wythe is a base-supported, laterally restrained reservoir cladding and physical/weather shield rather than the primary roof-bearing structure.

Correction to earlier working notes: Fernley is in Lyon County, and the 2024 IECC assigns Lyon County to Climate Zone 4B, not 5B. [3] Fernley has adopted the 2024 IBC, IRC and IECC with the 2024 Northern Nevada amendments. [1] The Northern Nevada table lists Fernley at Seismic Design Category D2, 120 mph ultimate wind speed for the residential criteria table, severe weathering and an 18-inch frost depth. [2]

For a 2024 IECC Zone 4 mass wall, the prescriptive mass-wall insulation entry is R-8/R-13; the second value applies when more than half of the insulation is on the interior of the mass wall. [4] In the proposed assembly, the insulation is outside the primary 10-inch structural/thermal-mass wythe. The outer 7-inch earth wythe complicates classification, so final code treatment must be confirmed by the Fernley building official and the project engineer rather than

assumed from the table alone.

Six inches of FOAMGLAS T3+ at published thermal conductivity λ ≤ 0.036 W/(m·K) provides approximately RSI 4.23, or about R-24 in U.S. units, for the cellular-glass layer alone. The product is inorganic, vapor-tight, noncombustible and rated at ≥500 kPa compressive strength. [5] This is substantially more insulation than the Zone 4 mass-wall prescriptive value if the proposed configuration is accepted under that path, but a project-specific whole-wall calculation remains required.

The moisture strategy is intentionally redundant. Rammed earth is treated as a reservoir cladding that may become wet. The exterior wythe is separated from the insulation by an approximately 1-inch drained and ventilated cavity with protected drainage/weep openings. Building-science guidance recommends this approach for reservoir claddings such as masonry and identifies approximately 1 inch as an appropriate ventilated drainage cavity in comparable assemblies. [6, 7] The design therefore does not depend on an exposed foam system or on a buried polymer weather membrane remaining perfect for centuries.

The structural baseline is more conservative than the earlier 8-inch inner / 6-inch outer concept. Recent 2026 quasi-static research tested cement-stabilized rammed-earth walls 250 mm thick (about 9.8 inches) and found that steel-bar reinforcement improved lateral load capacity, ductility and energy dissipation. [8] Additional 2026 testing found improved seismic performance from strengthening measures including cement stabilization, steel reinforcement and edge restraint. [9] Those studies do not constitute a Nevada design method, but they support using approximately 10 inches—not 8 inches—as the current structural research baseline in Fernley D2 conditions.

The 300-year figure remains an evaluation horizon, not a warranty or claim that every concealed component will last 300 years. The wall is instead designed around multi-century structural intent, protected inaccessible components, replaceable weathering components, drainage, inspection provisions and explicit maintenance/replacement assumptions.

The modeled robot-versus-human savings remain a scenario calculation. The $60 productive human hour, $1 robot hour, one supervisor per 16 robots and equal-productivity base case are user-defined inputs, not verified market facts. No current evidence demonstrates a humanoid robot crew constructing this complete wall at the modeled cost or productivity.

3. Detail and evidence

Current Fernley code context

The City of Fernley states that the 2024 building codes were adopted in June 2025 and that plans submitted from January 1, 2026 are to use the 2024 codes. The adopted set includes the 2024 IBC, IRC and IECC together with the 2024 Northern Nevada amendments. [1]

The current Northern Nevada design-criteria table lists Fernley as Seismic Design Category D2 with 120 mph wind speed in the residential criteria table, severe weathering, moderate-to-heavy termite exposure and an 18-inch frost line. [2] These conditions make an unusually thin, unreinforced exterior earth wall an unsuitable default research assumption.

Climate zone correction and energy-code implication

The 2024 IECC climate-zone table assigns Lyon County, Nevada to Climate Zone 4B. [3] This supersedes the earlier working assumption that Fernley was 5B.

The 2024 IECC mass-wall prescriptive insulation table gives Zone 4 except Marine a mass-wall entry of R-8/R-13. The code note states that the second R-value applies where more than half the insulation is on the interior of the mass wall. [4]

For FPSA, the key building-physics objective is to keep the interior structural earth on the conditioned side of the primary insulation so it remains thermally coupled to the indoor environment. The recommended cellular-glass layer therefore sits outside the 10-inch interior structural wythe. The 7-inch outer wythe is treated as a protective, base-supported rainscreen/reservoir cladding.

Because this is an unusual double-wythe earth assembly, the document does not claim automatic prescriptive compliance; the authority having jurisdiction must determine the applicable compliance path.

Recommended wall geometry

Working baseline:

Interior conditioned space

10-inch reinforced, stabilized structural rammed-earth wythe

6-inch unfaced cellular-glass insulation

1-inch clear drained and ventilated cavity

7-inch stabilized exterior rammed-earth wythe

Exterior

Nominal overall thickness: approximately 24 inches.

The inner wythe carries the building’s principal wall loads and provides interior thermal mass. The outer wythe bears vertically on its own foundation/plinth support and is restrained laterally; it should not hang from inter-wythe ties.

Why 10 inches for the structural wythe

A 2026 Structures study tested cement-stabilized rammed-earth walls 250 mm thick and reported that steel-bar reinforcement improved lateral strength, ductility and energy dissipation under quasi-static loading. [8] A separate 2026 Structures study compared unreinforced walls with cement stabilization, steel bars and edge restraint and reported meaningful differences in seismic capacity. [9]

These tests are evidence that reinforced/stabilized rammed earth can be engineered for improved seismic performance; they are not code approval for the proposed Fernley dimensions. Project-specific calculations remain mandatory.

North American precedent also exists for insulated composite rammed-earth construction. A NAREBA/BCIT program reported full-size insulated stabilized rammed-earth columns using an insulation core and inter-wythe reinforcing configurations. The authors emphasized that the sample size was small and the results preliminary. [10] This supports the concept of insulated double-wythe construction but not a direct copy of connector spacing or reinforcement details.

Structural load path

The proposed load path should be:

Roof diaphragm → continuous engineered bond beam → 10-inch interior structural rammed-earth wythe → foundation.

The exterior 7-inch wythe should follow:

Exterior cap/top restraint → laterally restrained exterior earth wythe → dedicated foundation/plinth support.

Inter-wythe connectors should primarily transfer out-of-plane restraint loads, not the full gravity weight of the exterior earth.

Continuous bond beam and reinforcement

A continuous engineered bond beam is recommended over the inner structural wythe. It should be positively anchored to the earth wall and roof diaphragm. The exterior wythe should have its own top restraint/cap so a large concrete element does not bridge directly across the insulation layer.

Vertical reinforcement should be concentrated and designed where demanded by analysis: corners, wall ends, both sides of large openings, intersections and intermediate locations required by wind/seismic calculations. The research article deliberately does not prescribe a bar size or spacing without a project-specific Nevada structural calculation.

New Mexico’s earthen-building code is not applicable law in Nevada, but it provides a useful U.S. precedent for testing and stabilization. It defines stabilized rammed earth as qualifying soil that either passes the specified wet-strength test

or contains at least 6 percent Portland cement by weight; it also requires testing and continuous bond-beam provisions in its prescriptive system. [11] FPSA uses this only as comparative evidence, not as Fernley code.

Stabilization baseline

Use approximately 6 percent Portland cement by dry soil mass as the initial cost/testing scenario, subject to actual soil testing and structural design. The preferred engineering approach is performance-based: test the project soil, adjust the mix only as needed, and document compressive strength, wet strength, shrinkage, moisture behavior and constructability.

Reducing cement while meeting verified performance may improve embodied carbon and cost. Increasing cement solely for convenience should not be assumed to improve the 300-year objective without considering cracking, shrinkage and compatibility.

Cellular-glass core

FOAMGLAS T3+ is the primary durability research candidate. Published properties include $\lambda \leq 0.036$ W/(m·K), Euroclass A1 noncombustibility, ≥500 kPa compressive strength, dimensional stability, vapor tightness and closed glass cells. [5]

Six inches equals 0.1524 m. Using the published λ:

RSI = 0.1524 / 0.036 = approximately 4.23 m^2·K/W.

R-US = 4.23 × 5.678 = approximately R-24.0.

This is the insulation layer only. The project should not rely on an assumed earth R-value to establish code compliance. A final whole-wall thermal model should include actual rammed-earth conductivity/density, connector bridges, bond-beam/base details, corners and openings.

Why cellular glass leads the current comparison

Cellular glass is favored for the inaccessible core because the critical properties are durability and failure behavior rather than maximum R-value per inch. It is inorganic, noncombustible, dimensionally stable and resistant to capillary water transport. [5]

Stone wool remains a valid vapor-open comparison and XPS remains the economic/R-value benchmark, but neither replaces the primary cellular-glass research case at this stage. No reviewed source proves that cellular glass, stone wool or XPS will remain fully functional for 300 years. The design therefore minimizes dependence on replacement-inaccessible components and keeps the 300-year figure as an evaluation horizon.

Moisture management

The central moisture rule is: assume rain will eventually penetrate the exterior earth; give it a gravity path back outside before it reaches the insulation or structural wythe.

Building Science Corporation describes masonry, concrete and similar materials as reservoir claddings that absorb water and recommends a drainage space plus drainage plane and airflow control. [7] Its wall guidance describes a ventilated/drained cavity of about 1 inch behind reservoir claddings, with openings at the base and top to support drainage and back ventilation. [6]

For the FPSA wall this leads to:

Exterior earth as the first rain-shedding/protective layer.

Approximately 1-inch clear cavity kept free of earth/mortar debris.

Protected drainage/weeps at the base.

Ventilation openings at the top where appropriate.

Cellular glass inboard of the cavity.

A durable air-control strategy at or near the exterior face of the inner structural earth wythe.

No inward-sloping connector geometry that encourages water tracking.

The cavity should not be counted as dependable insulation. Its purpose is water management and drying.

Wall base

The inner structural rammed-earth wythe requires a durable capillary break above the foundation. The outer earth wythe should start on a high, splash-resistant mineral plinth rather than extend directly to grade. The cavity must discharge to the exterior through a durable sloped shelf/flashing arrangement.

Fernley’s current design table lists an 18-inch frost depth and severe weathering. [2] The foundation, plinth and drainage system must therefore be engineered to local soil, frost, seismic and site-drainage conditions.

Wall top and roof

The outer wythe requires a replaceable cap/coping with positive slope and drip geometry. A substantial roof overhang should be treated as part of the moisture-control system rather than merely an architectural feature. Final overhang dimension should be optimized for wall height, orientation, wind-driven rain and passive-solar objectives.

Openings

Windows and doors are the highest-detail-risk locations because they interrupt structure, insulation, cavity drainage and exterior earth. Every opening should use a sill-pan and flashing strategy that drains to the exterior or into the drained cavity without directing water onto the structural inner wythe. Flashings and seals that are likely to have shorter lives should be accessible for inspection and replacement wherever practical.

Inter-wythe connectors

The preferred research connector is a low-conductivity corrosion-resistant composite such as BFRP, with Type 316 stainless steel as the metallic fallback/comparison. Ordinary galvanized carbon-steel ties should not be the

300-year research baseline because their protective zinc coating is sacrificial and concealed replacement would be difficult.

Connector spacing, diameter, embedment and edge/opening reinforcement are intentionally unresolved until structural calculations are performed. The NAREBA/BCIT work establishes that insulated rammed-earth wythes with reinforcing connections have been experimentally investigated, but it does not establish the final Fernley connector design. [10]

One-story research constraint

The first FPSA demonstration should remain one story. This reduces seismic mass, overturning, wall slenderness and construction complexity while allowing the full wall concept to be measured before considering multi-story applications.

A typical clear wall height in the range of approximately 8 to 9 feet is a reasonable research target. At 9 feet, a 10-inch inner wythe has a simple height-to-thickness ratio of 10.8. This is an analytical observation, not a code limit or approval criterion.

Earth quantity

The revised assembly contains 17 inches total of rammed earth: 10 inches interior plus 7 inches exterior.

Per square foot of wall face:

17/12 = 1.4167 ft^3 of earth.

1.4167/27 = approximately 0.05247 yd^3 per wall ft^2.

For 1,000 ft^2 of wall:

approximately 52.47 yd^3 finished earth volume before loose-volume/yield adjustments.

This is only about 6 percent more earth than the original 16-inch monolithic study wall, which contained approximately 49.38 yd^3 per 1,000 wall ft^2.

Using the prior working supplier-screening benchmark of $25/yd³ solely as a scenario input:

raw earth = approximately $1.31 per wall ft².

That benchmark must be replaced with a current Fernley-area material and delivery quotation before budgeting.

Stabilizer quantity sensitivity

Using the earlier provisional dry-density sensitivity of 1,710 kg/m³, 1,000 ft² of the 17-inch earth wall contains roughly 68,600 kg of dry earth. Six percent cement corresponds to approximately 4,116 kg, or roughly 97 bags at 94 lb each.

At the earlier $14-$22/bag research sensitivity:

cement = approximately $1.35-$2.13 per wall ft².

raw earth plus 6 percent cement = approximately $2.66-$3.44 per wall ft² before delivery, testing, screening, water, processing loss and labor.

These are scenario calculations, not current Fernley supplier quotations.

Preliminary nonlabor model

The former $19.47/ft² fixed nonlabor allowance should be retired as a validated-looking figure. It may remain only as a historical comparison.

The revised nonlabor model is:

N = earth + stabilizer + formwork + equipment + cellular-glass insulation + connectors + drainage/weather detailing + structural reinforcement/bond beams + other required wall protection/detailing.

Current provisional components, excluding cellular glass and structural reinforcement:

Earth plus 6% cement: approximately $2.66-$3.44/ft² scenario.

Formwork/system: $5.00/ft² provisional.

Equipment: $3.00/ft² provisional.

Inter-wythe connectors: $0.50-$1.50/ft² research allowance.

Drainage/base/top/opening detailing: $1.00-$3.00/ft² research allowance.

Other finish/weather/detail allowance: $5.00/ft² provisional.

Subtotal before cellular glass and structural reinforcement:

approximately $17.16-$20.94/ft².

Define:

I = cellular-glass cost per wall ft² from an actual project quotation.

R = structural reinforcement, bond beam and associated anchorage cost per wall ft² from engineered quantities.

Therefore:

N = approximately $17.16-$20.94 + I + R per wall ft².

The article does not invent I or R. Those remain unresolved until supplier and structural-design quantities are available.

Human-versus-robot scenario

Retain the transparent scenario equations rather than converting them into a market-price claim.

User-defined inputs:

Human productive labor rate = $60/hour.

Robot operating scenario = $1/robot-hour.

Supervision scenario = one $60/hour human per 16 robots.

Robot productivity base case = equal output per paid robot hour and paid human hour.

Middle labor case H = 2 equivalent productive labor hours per wall ft².

Contingency = 20 percent of modeled direct wall cost.

Sixteen robots plus one supervisor:

(16 × $1) + $60 = $76 per crew clock hour.

At 16 equivalent labor-hours of output per crew hour:

$76 / 16 = $4.75 per equivalent robot labor hour.

Human middle-case formula:

C_H = 1.20 × [N + (60 × 2)].

With N = $17.16-$20.94 + I + R:

C_H = approximately $164.59-$169.13 + 1.20(I + R) per wall ft².

Robot middle-case formula:

C_R = 1.20 × [N + (4.75 × 2)].

C_R = approximately $31.99-$36.53 + 1.20(I + R) per wall ft².

Because both cases use the same N, the modeled absolute difference remains $132.60 per wall ft² in this middle scenario. The percentage reduction depends on the final nonlabor cost and therefore should not be restated as the earlier 79.2 percent once I and R are added.

Most importantly, the $1 robot-hour, 1:16 supervision ratio and equal-productivity case are exploratory assumptions. No reviewed manufacturer or field evidence demonstrates a humanoid robot crew delivering the complete Fernley wall at that cost or productivity.

Robot productivity sensitivity

The earlier sensitivity framework remains appropriate. If p is robot output per paid hour divided by human output per paid hour, the supervised robot labor rate is $4.75/p per equivalent productive hour, assuming all modeled tasks remain robot-capable and the supervisor remains assigned to 16 robots.

This should eventually be replaced with measured task logs from a test wall: soil preparation, batching, formwork, reinforcement, placing, ramming, insulation

placement, connector placement, cavity detailing, cleanup, waiting, human intervention and rework.

300-year evaluation framework

The 300-year period is a life-cycle research horizon. It does not mean:

the original wall requires no maintenance for 300 years;

cellular glass is proven for 300 years;

connectors are guaranteed for 300 years;

flashings, windows, roof membranes or sealants last 300 years;

or the building can be represented by a single undiscounted initial cost.

The design goal is instead:

very long-lived mineral/earth structural layers;

protected inaccessible insulation;

corrosion-resistant or noncorroding connectors;

drainage before waterproofing dependence;

replaceable and inspectable flashings/caps/opening components;

documented maintenance intervals;

and provisions for future monitoring.

Monitoring provisions

The wall should include inexpensive permanent provisions for future investigation without requiring embedded electronics to survive for centuries:

replaceable sensor conduits;

documented connector locations;

inspection access at selected base/top details;

reference points for future moisture probes;

and separate construction/test coupons made from the actual project soil and stabilization mix.

Concrete comparison

The equally insulated concrete comparison remains unfinished and must not be implied by this paper. A future comparison should use the same wall face area, structural loading, openings, thermal target, moisture-control boundary, finish requirements and 300-year maintenance framework. Concrete thickness should be selected for structural requirements, then insulation added to achieve the same whole-wall thermal target.

Evidence limitations

This is a targeted engineering desk review, not a stamped structural design, code opinion, hygrothermal simulation, life-cycle assessment or contractor estimate.

Current evidence supports:

Fernley’s adopted code set and design criteria. [1, 2]

Lyon County’s current IECC climate-zone assignment. [3]

The 2024 IECC mass-wall insulation values. [4]

Cellular-glass thermal, fire, vapor and compressive properties. [5]

A drained/ventilated approach for reservoir claddings. [6, 7]

Improved seismic behavior from reinforcement/stabilization in recent rammed-earth testing. [8, 9]

North American precedent for insulated composite stabilized rammed-earth testing. [10]

U.S. earthen-code precedent for stabilization/testing and bond-beam concepts. [11]

Current evidence does not establish:

permit approval of this 24-inch Fernley wall;

the final reinforcement schedule;

the final connector spacing;

300-year component life;

the actual project soil properties;

the final whole-wall U-factor;

the final hygrothermal performance;

a current cellular-glass delivered price in Fernley;

or demonstrated robotic construction cost/productivity.

4. Status and next step

Status: approved research article for FPSA project inclusion and website publication. The recommended working baseline is now the approximately 24-inch one-story Fernley assembly: 10-inch reinforced/stabilized structural inner earth, 6-inch cellular glass, 1-inch drained cavity and 7-inch base-supported/laterally restrained exterior earth.

This is the current approved FPSA research baseline in 04-research-library. Approval authorizes publication of this research article; it does not establish a construction drawing, validated 300-year component life, or proven construction cost savings.

What needs specialist review

Nevada-licensed structural engineer:

confirm design loads, wall thickness, soil strength criteria, reinforcement, bond beam, foundation anchorage, exterior-wythe restraint, BFRP/316 connector design, roof diaphragm and opening details.

Building-envelope specialist:

perform a project-specific thermal-bridge and hygrothermal analysis, including cellular-glass joints, cavity ventilation, plinth, capillary break, cavity discharge, wall top, windows and doors.

Geotechnical/materials laboratory:

characterize the actual project soil and trial mixes; test compacted density, compressive strength, wet strength, shrinkage and selected stabilizer percentages.

Fernley Building Department:

confirm the accepted code-compliance path for the unusual double-wythe mass-wall assembly and any alternate-material/design documentation required.

Supplier/estimator:

obtain current delivered pricing for cellular glass, cement/stabilizer, aggregate/soil processing, reinforcement, BFRP or stainless ties, formwork and equipment.

Demonstration test

Before committing to the house, construct a full-height instrumented wall panel that includes:

foundation/plinth interface;

inner structural wythe;

selected reinforcement;

cellular glass;

inter-wythe connectors;

drained cavity;

outer earth wythe;

top cap/bond detail;

and at least one representative opening.

Record quantities, labor by task, robot time if tested, supervisor/human intervention, waiting, rework, equipment duration, temperatures, moisture and cracking. Retain material samples and document all concealed components.

Decision criterion

Do not advance the wall from research baseline to construction baseline until the test panel and specialist reviews show that the assembly can meet structural, moisture, thermal and code requirements at a cost and workload consistent with FPSA’s goals.

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Sources and next research question

Bracketed references identify the supporting sources below. Sources are used for the specific statements described above; none of them independently validates the complete FPSA wall.

Each source address is printed in full so this page, the PDF, and the library document carry the same citation detail. The earlier PDF showed titles only because the export kept the addresses as hidden links, not because any source was withheld.

[1] City of Fernley — Building Codes and adopted 2024 code set — https://www.cityoffernley.org/76/Building-Codes

[2] City of Fernley / NNICC — 2024 Northern Nevada Code Amendments and Fernley design criteria —

https://www.cityoffernley.org/DocumentCenter/View/29853/2024-NNICC_Code_Amendments_Final_2-20-2025

[3] International Code Council — 2024 IECC Table R301.1 climate zones; Lyon County, Nevada = 4B — https://codes.iccsafe.org/content/IECC2024V1.1/chapter-re-3-general-requirements

[4] International Code Council — 2024 IECC R402.1.3 mass-wall insulation table — https://codes.iccsafe.org/s/ILECC2024P1/chapter-4-re-residential-energy-efficiency/ILECC2024P1-RE-Ch04-SecR402.1.3

[5] FOAMGLAS — T3+ cellular-glass product data — https://www.foamglas.com/en/products/fgbt3slabs

[6] Building Science Corporation — BSI-120 Understanding Walls — https://buildingscience.com/documents/building-science-insights-newsletters/bsi-120-understanding-walls

[7] Building Science Corporation — Reservoir Claddings — https://buildingscience.com/documents/information-sheets/reservoir-claddings

[8] Structures (2026) — Seismic performance of steel bar rammed earth walls — https://www.sciencedirect.com/science/article/pii/S2352012426003760

[9] Structures (2026) — Research on seismic capacity evaluation of rammed earth walls — https://www.sciencedirect.com/science/article/pii/S2352012426011537

[10] Sustainability (2013) — Contemporary Rammed Earth Construction and Research in North America — https://www.mdpi.com/2071-1050/5/2/400

[11] New Mexico Construction Industries Division — 14.7.4 NMAC earthen building materials — https://www.srca.nm.gov/nmac/nmregister/xxxiv/14.7.4amend.html

Evidence labels used in this paper

Observed/published evidence means a claim reported by an identified source. A code requirement or design criterion is attributed to the jurisdiction/code cited. A scenario input is a user-selected or prior working input and is not treated as an observed market fact. A calculation follows stated inputs. A proposal or baseline is the current FPSA research recommendation and still requires verification.

Next question to investigate

What do the full-scale Fernley test panel and Nevada structural/envelope reviews require us to change in wall thickness, reinforcement, connector spacing, moisture detailing, cellular-glass thickness and actual cost before this assembly can become a construction baseline?