

STRUCTURAL CALCULATIONS &amp; ANALYSIS — PROJECT ZS-2026-002

# Polar-Zonohedron Polyurethane-Foam Dome

## Studio — Limit-State Calculation Package



Verification of a 6.69 m × 3.97 m, 94-panel rigid-PU-foam zonohedron under ASCE 7-22 loads. Issued for review and stamp by the Engineer of Record.

<b>PROJECT</b> Zomes studio prototype (ZS-2026-002)	<b>SITE</b> Generic CONUS — baseline + severe envelopes	<b>RISK CATEGORY</b> II (ASCE 7-22 Tbl. 1.5-1)	<b>GOVERNING CODES</b> IBC 2024 · ASCE 7-22 · ASTM D1621/D790/C273/D1623
<b>MATERIAL CERTIFICATE</b> QSW26030006 — Nanjing Guocai Testing, May 2026	<b>WORST LIMIT-STATE D/C</b> <b>0.69</b> at FoS = 2.5 (refined FE, strength) · buckling 3.9× vs 3.0 required (full severe envelope, wood door bucks credited)		

<b>DOCUMENT NO.</b> ZS-2026-002-CALC-001	<b>REVISION</b> 1
<b>STATUS</b> Issued for EOR review	<b>DATE ISSUED</b> 2026-07-04
<b>PREPARED BY</b> Shereef Bishay	<b>SHEETS</b> see Contents

**For permit submission to the AHJ:** see the formal *Calculation Package* (companion document, ZS-2026-002-CALC-001). It contains the stamp-ready calculations in the format the permitting agency expects, without the methodology narrative or deep-link source-data references in this report.

[VIEW CALC PACKAGE →](#)
[DOWNLOAD PDF ↓](#)

**Scope & limitations:** this package certifies the dome envelope under short-term ASCE 7-22 wind / snow / dead loads at both bracketing envelopes, including the full severe envelope (160 mph / 100 psf). Door jamb/header material is recorded as African teak, modeled at a conservative structural-

lumber floor it comfortably exceeds (§ S4a); build QC verifies the installed members match the record. It does *not* certify: anchor / hold-down at the curb (EOR-deliverable), sliding / overturning at the foundation interface, fire resistance, life safety, MEP penetrations, door / window cur panel details, foundation curb in soil contact (civil / geotechnical scope), construction-phase loads, or long-term material behaviour (creep, U' temperature, fatigue). Full enumeration: **§ XII LIMITATIONS**.

ENGINEER OF RECORD — REVIEW & APPROVAL		AWAITING SIGNATURE
NAME (PRINTED)	SIGNATURE & DATE	
LICENSE NO. / STATE / EXPIRATION	DISPOSITION	
<p><i>Engineer's seal &amp; signature</i></p> <p><i>(affix wet seal here at issuance for construction)</i></p>		

## 1.0 – EXECUTIVE SUMMARY

---

# Limit-state verification of a 94-panel PU-foam dome.

This calculation package documents the structural verification of a 6.69 m × 3.97 m polar-zonohedron rigid polyurethane-foam dome — the *studio* model — under ASCE 7-22 loading. Every limit state — strength and stability — passes at the project factors of safety at both site envelopes. The governing stability check (buckling under the severe-envelope 100 psf ground snow) resolves through a three-model ladder: the bare shell that omits the door framing reads 2.1 against the required 3.0, foam-strength framing lifts it to 2.9, and the as-built framing — owner-confirmed hardwood bucks, credited at a deliberately low structural-lumber stiffness — reads **3.9 against the required 3.0**. The studio is certified for the full severe envelope; the recorded buck species (African teak, published stiffness 17–53 % above the modeled floor) closes the material question, with build-QC verification the only carry-forward.

---

## 1.1 Plain-language summary

Written for the project owner, the AHJ plan-checker, and other non-structural-engineering readers. The formal engineering synopsis follows in § 1.2.

This document analyses the structural strength of the studio — a dome-shaped building made of stiff polyurethane foam, roughly 6.7 m (22 ft) wide and 4.0 m (13 ft) tall, assembled from 94 diamond-shaped foam panels glued together at their edges. It is the larger sibling of the office dome (ZS-2026-001), analysed with the same methods and the same laboratory material data, but every number in this report is computed independently from the studio's own geometry. The question is the same: *is it strong enough?* Short answer: **yes at any typical U.S. site, with one qualification at extreme-snow sites** — the dome as modelled is rated for sites with anywhere within the bracketing envelopes — including the extreme 160 mph / 100 psf severe case — now that the door frame's real material is accounted for.

### How we checked

We checked it the same four ways as the office dome: century-old pencil-and-paper engineering math as the first screen, and three independent computer simulations (CalculiX and OpenSees — both established structural-engineering codes — plus an in-house solver written for cross-verification). Every method ran against two weather envelopes: a *typical CONUS* site (115 mph winds, 30 psf design snow) and a *severe* envelope (160 mph hurricane-grade winds, 100 psf snow) that brackets nearly every buildable site in the country.

### What we found

**At a typical site, the studio is comfortably strong everywhere.** The hardest-working panel reaches 46 % of its bending capacity under the worst gust; the glued joints reach 11 %; buckling capacity is 9 times the design snow (**baseline verdicts**).

**Under hurricane-grade suction at the severe envelope, the panels hold with real margin.**

The quick pencil-and-paper screen — which deliberately pretends each diamond panel is a much larger rectangle — flags the biggest panels at 110 % of capacity. When the panels are analysed with their true diamond shape and their real place in the dome, the demand is 56–

69 % of capacity (**D/C = 0.56–0.69**). The screen's pessimism on this panel shape was measured directly: it over-predicts by 49 %.

**The one number to watch is snow buckling at extreme sites.** Because the studio is wider and flatter than the office dome, deep snow works it harder against buckling. At the full severe envelope (100 psf ground snow — think high mountains), a first model that ignored the door's frame computed buckling capacity at  $2.1\times$  the design load where our safety criterion asks for  $3.0\times$  — and the predicted buckling pattern sat exactly in the panels around the door opening. That model was missing real structure: the door's jambs and header are African teak (owner-recorded). Crediting them at a deliberately stingy stiffness — below even low-grade construction lumber, and well under what African teak actually provides — moves the buckling pattern away from the door entirely and lifts the capacity to  **$3.9\times$  the design load (BLF = 3.9 vs 3.0)** — every value from three-level mesh-refinement studies, extrapolated to their limits rather than quoted from any single mesh). The criterion is met with 30 % to spare; the studio passes the full severe envelope. The intermediate answers ( $2.1\times$  with no frame,  $2.9\times$  with foam-strength frame) are kept in the report so a reviewer can see the result does not hinge on any single assumption. The critical buckling pattern sits in the panels around the door opening, and the analysis conservatively ignores the door's own frame — so the as-built structure is stronger there than the model. Options for heavier-snow sites are given in § X.

**The glued joints are again not the weak link.** Worst joint demand is 27 % of capacity at the severe envelope (**D/C = 0.27**) — same comfortable behaviour as the office dome, for the same geometric reason: the dome loads its joints along their strong direction.

### What this analysis can't tell you

Foam creeps under sustained load, embrittles under UV, and softens above about  $60\text{ }^{\circ}\text{C}$  — none of which short-term analysis captures. Using published creep data for similar foams we estimate the apex settles roughly 2 mm over fifty years under its own weight (§ IX), but batch-specific lab testing remains required follow-up. Fire and life-safety compliance, anchorage to the foundation, door/window detailing, and construction-phase loads are separate work, enumerated in § XII.

### The bottom line

Every strength check passes at the project factor of safety at both envelopes, with the refined worst-case panel at  $D/C = 0.69$ , and the governing stability check at  $3.9\times$  against the required  $3.0\times$  once the confirmed hardwood door bucks are credited at a conservative lumber floor. Both bracketing envelopes pass in full. A licensed structural engineer of record must review and stamp this analysis before construction; the package includes the calculations, code citations, and raw data needed for permit submission.

## 1.2 Synopsis

**Engineering verdict — strength.** The controlling strength check is panel plate bending on the largest rhombic panels (type 1, 1011 mm edge) under  $0.6D + W_{uplift}$  at the severe envelope (160 mph, Exposure D, C&C peak suction  $-8.98\text{ kPa}$ ): **PASS at FoS = 2.5, D/C = 0.56–0.69** by two independent refined analyses — the converged filleted full-dome FE (S6,  $D/C = 0.69$ ) and the converged single-panel rhombic FE (S7,  $D/C = 0.56$  simply-supported /  $0.27$  clamped). The Timoshenko inscribed-rectangle screening envelope reads 1.10 on the same case and is disclosed as exceeded: on the studio's elongated rhombi that envelope spans the full diagonal bounding box — twice the actual panel area — and its 49 % over-prediction is *measured* against the converged FE, not assumed (S2). The screening envelope is retained where it passes (all baseline checks; severe joints, compression, bearing).

**Engineering verdict — stability.** Eigenvalue buckling on the S3 shell mid-surface, carried through three-level mesh-refinement studies and extrapolated (S4), governs the severe envelope and resolves through a three-model ladder. The bare-shell model — no door framing — extrapolates to 2.12 under 100 psf-site balanced snow, with the verified mode a *local* panel-band mode in the door bay: precisely where that model removes stiffness. Foam-strength framing lifts it to 3.00 (2.91 with gravity). The issued basis credits the **owner-recorded African teak** jambs and header at a deliberately conservative structural-lumber floor (E = 8,000 MPa — below low-grade softwood, and 17–53 % below African teak’s published stiffness range) at their fit-measured 98 mm thickness: 6.26 → 5.04 → 4.50, extrapolating to **4.08** (3.92 with gravity) against the required FoS = 3.0 — **PASS with ≈30 % margin at the full severe envelope**, with the critical mode verified to sit in the panel field away from the door bay. The sharp-crease idealization still under-represents the real glued joints at every level, so all extrapolated values remain lower bounds. Wind-uplift eigenvalues are not a credible failure mode (suction puts the membrane in tension); their computed values exceed 3.0 at every level of every model, and the strength tiers govern the uplift case. Baseline-site snow buckling passes with extrapolated BLF = 7.1 before any framing credit. Species recorded: African teak (iroko / afrormosia class, published MOE ≈ 9.4–12.2 GPa vs the 8,000 MPa floor); build QC verifies the installed members match the record.

The joint limit states pass with wide margin (S3: tension 0.27, shear 0.18 at severe). Base-ring compression (0.21), local panel buckling (0.70), spherical-cap snap-through (0.23), and foundation bearing (0.04) all pass at severe. The complete matrix is Table 1; every number links to its machine-readable source artifact and reproduction command.

<p><b>0.69</b></p> <p>WORST REFINED STRENGTH D/C SEVERE-SITE C&amp;C UPLIFT, FOS 2.5</p>	<p><b>0.27</b></p> <p>WORST JOINT D/C SEVERE-SITE UPLIFT, FOS 2.5</p>	<p><b>3.9×</b></p> <p>BUCKLING CAPACITY VS DESIGN LOAD SEVERE 100 PSF SNOW, WOOD BUCKS CREDITED (CRITERION: 3.0×; FOAM- FRAME 2.9×, BARE SHELL 2.1×)</p>	<p><b>100 psf</b></p> <p>CERTIFIED GROUND-SNOW ENVELOPE (FULL SEVERE ENVELOPE AT FULL BUCKLING FOS)</p>
--	---	--	---

### 1.3 Verdict matrix

Two ASCE 7 site presets are evaluated. *Baseline* is the typical CONUS envelope (115 mph wind, 30 psf ground snow, Exposure C). *Severe* is the high-wind/high-snow envelope (160 mph, 100 psf, Exposure D). Every limit state is checked under every ASCE 7-22 load combination; only the worst case is shown here. FoS = 2.5 on strength, 3.0 on buckling — the identical basis carried by the linked JSON artifacts.

**TABLE 1 – VERDICT MATRIX (STUDIO)** Worst-case D/C ratios across all ASCE 7 load combinations, both site presets, all limit states.

LIMIT STATE	BASELINE D/C	SEVERE D/C	GOVERNING CASE	STATUS
Panel plate bending – screening envelope (Timoshenko inscribed rectangle, all 9 types; S2)	0.46	1.10	0.6D + W <sub>uplift</sub> (C&C peak)	EXCEEDED – REFINED FE GOVERNS
Panel plate bending – refined FE (filleted full-dome S6 / rhombic single-panel S7)	0.29	0.56–0.69	0.6D + W <sub>uplift</sub> (C&C peak)	PASS (REFINED)
Joint tension (adhesive, peeling)	0.11	0.27	0.6D + W <sub>uplift</sub>	PASS
Joint shear (adhesive, in-plane)	0.07	0.18	0.6D + W <sub>uplift</sub>	PASS
Membrane compression (11 base panels share D + S vertical reaction at 40.3° plane tilt)	0.08	0.21	D + S (cumulative)	PASS
Local panel buckling (SS plate)	0.26	0.70	D + S	PASS
Global buckling – snow (FE eigenvalue) (S3 shell mid-surface, mode 1 vs FoS = 3.0; S4)	0.42	0.77	balanced snow (100 psf site)	PASS – WOOD BUCKS CREDITED (3.92; LADDER 2.1 / 2.9 / 3.9 IN S4A)
Global buckling – wind uplift (FE eigenvalue) (tensile membrane state – not a credible buckling driver; finest-level factors quoted)	0.11	0.27	MWFRS uplift	PASS
Shell snap-through (hand-calc spherical cap)	0.07	0.23	D + S	PASS
Foundation bearing (100 kPa fair soil)	0.01	0.04	D + S	PASS

### 1.4 Reviewer questions answered

#### Q1 – Is the structure adequate?

**Baseline CONUS envelope: yes, unconditionally.** Worst strength D/C = 0.46 (screening envelope) / 0.29 (refined FE); worst stability utilization 0.33. **Severe envelope: yes on strength; stability rates the snow exposure.** Strength passes at D/C = 0.56–0.69 refined on the controlling wind case. Snow buckling at the full 100 psf severe snow reads a mesh-extrapolated BLF of 3.9 with the owner-confirmed hardwood door bucks credited at a conservative lumber floor (2.9 with foam-strength framing, 2.1 with no framing at all) vs the required 3.0 – PASS with ≈30 % margin. Both bracketing envelopes are certified in full; the recorded species (African teak) exceeds the assumed stiffness floor by 17–53 % (§ S4a), leaving only build-QC verification that the installed members match.

#### Q2 – What is the governing limit state?

**Wind governs strength; snow governs stability.** The controlling strength check is plate bending of the largest panels under severe C&C peak suction (refined D/C = 0.69). The

controlling stability check is the mode-1 snow-buckling factor (extrapolated 3.9 with the confirmed wood bucks credited; 2.9 foam-frame / 2.1 bare-shell sensitivity ladder at 100 psf), whose bare-shell mode shape is a local panel-band mode at the door bay — a location where the model conservatively omits the door framing stiffness (S4). This differs from the office dome, where bending was governing everywhere; the studio's larger diameter and shallower rise ( $h/D = 0.59$  vs  $0.68$ ) shift the critical mode to stability under deep snow.

### Q3 — Are the glued joints the weak link?

No. Despite being the weakest lab-measured property (joint tension 0.270 MPa ultimate), worst joint demand is  $D/C = 0.27$  (tension) / 0.18 (shear) at the severe envelope. The dome loads joints predominantly in in-plane shear where the bond is strong; peeling tension stays low. The office package additionally verified this insensitivity with a finite-stiffness joint sweep (rigid → free-hinge moved the controlling panel  $D/C$  by  $\pm 1\%$ , no panel by more than  $\sim 5\%$ ); the studio uses the identical joint construction and panel-edge geometry, and that methodology finding is carried by reference (S3).

### Q4 — Do the independent solvers agree?

Yes, where the geometry is well-posed. On the faceted CAD mid-surface the raw multi-solver envelope intentionally over-reads (kink-line singularity at panel creases — a geometric property, proven by the smooth-cap discriminator study, not a solver defect); it is reported as a diagnostic in S5. The issued strength reference is the geometrically-resolved (filleted) full-dome model (S6), cross-bracketed by the independent single-panel FE (S7) and the hand envelope. Buckling numbers come from CalculiX on the shell mid-surface with a mesh-convergence record (S4), replacing the office package's merged-tet eigenvalues whose lowest modes were demonstrably mesh-artifacts — an upgrade applied retroactively to the office model as a cross-check (its severe-snow factor extrapolates to 5.0 — comfortably passing, consistent with its issued verdict).

### Q5 — What must the EOR still decide or do?

(1) Confirm the project FoS scheme (2.5 strength / 3.0 buckling; § IV.3). (2) Accept the stability verdict at the full severe envelope (3.92 vs 3.0, with the 2.1 / 2.9 / 3.9 sensitivity ladder on record) — the door-buck species is recorded as African teak (published MOE  $\approx 9.4$ – $12.2$  GPa vs the modeled 8,000 MPa floor); carry the build-QC check that installed members match. (3) Accept the wind-pressure basis with its quantified sensitivities (§ V.4: +44 % coefficient headroom at severe; partially-enclosed case passes at 0.78) as the interim basis, and sponsor the one-time Chapter 31 wind-tunnel / validated-CFD study that closes the shape question for the product line. (4) Design the anchorage / hold-down load path against the demands in the calc package (enclosed 109 kN / partially-enclosed  $\approx 151$  kN net at severe) — the panel-to-curb connection detail is a Zomes-provided design input to be checked, not originated, by the EOR. (5) Confirm the seismic site overlay: a bounding no-credit screening shows wind governs this structure's lateral design (§ XII item 12), but site-specific parameters — typically via a geotechnical investigation in California — must confirm it per project. (6) Order the long-term follow-ups (creep, batch QC, workmanship knockdown) enumerated in § XII before multi-decade certification.

2.0 – SECTION II

# Project information.

TABLE 2 – PROJECT DATA

<b>Project name</b>	Zomes studio prototype
<b>Project number</b>	ZS-2026-002
<b>Document</b>	ZS-2026-002-CALC-001, Rev. 1
<b>Site</b>	Generic – bracketed by baseline + severe ASCE 7-22 envelopes; specific site TBD
<b>AHJ</b>	TBD (site-specific)
<b>Occupancy</b>	Group B / U accessory structure (studio / workspace)
<b>Risk category</b>	II
<b>Structure</b>	11-fold polar-zonohedron monocoque; 94 structural rhombic PU-foam panels, 76.2 mm, adhesive + mechanical fasteners; 11 foundation curb strips; one door bay
<b>Footprint / height</b>	6.69 m mean diameter (35.2 m <sup>2</sup> ) / 3.97 m apex

## 2.1 Scope of this report

**Within scope:** panel plate bending, adhesive joint tension/shear, membrane compression, local panel buckling, global (FE eigenvalue) buckling, spherical-cap snap-through, foundation bearing pressure, short-term deflection, and an indicative literature-based creep bound – under ASCE 7-22 dead, snow, and wind loads at two bracketing site envelopes. **Excluded** (enumerated with rationale in § XII): anchorage/hold-down and sliding at the curb, fire and life safety, door/window cut-out local detailing, the non-bonded exterior fibre-cement skin (owner's instruction), foundation-soil interaction, construction loads, and long-term material effects (creep certification, UV, temperature, fatigue).

3.0 – SECTION III

# Codes & standards.

TABLE 3 – GOVERNING DOCUMENTS

DOCUMENT	ROLE
IBC 2024	Governing building code framework
ASCE 7-22	Dead / snow / wind loads, combinations (§2.4 ASD)
ASTM D1622 / D1621 / D790 / C273 / D1623	Material test methods behind certificate QSW26030006
APA Y510L	SIP-industry analog informing the project FoS (no code exists for primary-structure foam buildings – see § IV.3)

4.0 – SECTION IV

# Structure & material.

## 4.1 IV.1 – Geometry & panel inventory

The studio is an 11-fold polar zonohedron: rings of 11 rhombic panels rising from an 11-curb foundation ring to the narrow apex diamonds, with one door bay (two half-panel columns + one panel over the header). Every geometric constant in this report is measured from the as-assembled structural CAD export (**geometry audit**) – not from nominal drawings – and the panel inventory carries *exact per-type counts* fitted from that same geometry the FE models mesh. The available studio nest-sheet DXFs were found to be a stale revision (~2.4 % smaller than as-assembled) and were deliberately not used; plate-bending demand scales with dimension<sup>2</sup>, so this choice removes a ~5 % unconservative bias the drawing route would have introduced.

**TABLE 4 – STUDIO PANEL INVENTORY (EXACT COUNTS, OBJ-FITTED)** *94 structural panels in 9 unique types. Diagonals define the Timoshenko screening rectangle; areas are true rhombus areas.*

TYPE	COUNT	EDGE (MM)	ACUTE (°)	DIAGONALS (MM)	AREA (M²)	ROLE
1	11	1011.2	80.37	1305 × 1545	1.008	upper ring – <b>governs bending</b>
2	12	1004.2	77.40	1256 × 1567	0.984	upper-mid ring
3	20	1017.1	63.75	1074 × 1727	0.928	two mid rings
4	11	1019.2	57.15	975 × 1790	0.873	mid ring
5	12	1002.7	52.49	887 × 1799	0.798	lower-mid ring
6	11	862.5	52.77	767 × 1545	0.592	base ring (bears on curbs)
7	4	703.0	81.15	915 × 1068	0.488	door-bay half-panels
8	1	808.9	45.77	–	0.469	panel over door header
9	12	1004.6	26.50	–	0.450	apex ring diamonds

Total panel area 75.0 m²; foam volume 5.71 m³; structure self-weight 13.44 kN (3,020 lbf). Door leaves, jambs, and the header trim (5 CAD blocks) are excluded from the structural set – reviewed piece-by-piece in the **geometry audit**; their omission is conservative wherever they add stiffness (notably the buckling mode of S4).

## 4.2 IV.2 – Material properties (lab-tested)

Identical material and certificate as the office model: rigid polyurethane foam,  $\rho = 240$  kg/m³, tested by Nanjing Guocai Testing Co. (certificate QSW26030006, May 2026; 5–6 specimens per property, three orthogonal directions). Worst-direction means used throughout: compression 2.47 MPa, flexure 2.17 MPa, parent shear 0.584 MPa, *joint* shear 0.410 MPa, *joint* tension 0.270 MPa (weakest property),  $E = 70.8$  MPa,  $\nu = 0.30$  assumed. Full digest: Appendix B.

### 4.3 IV.3 — Allowables & safety factors

Project scheme: **FoS = 2.5 on all strength limit states, 3.0 on buckling** (SIP-industry analog per APA Y510L; owner decision, documented for the EOR's explicit confirmation — there is no published code for primary-structure foam buildings). Allowables: bending 0.868 MPa, compression 0.988 MPa, joint shear 0.164 MPa, joint tension 0.108 MPa. A stricter per-limit-state alternative (bending 3.0, joint tension 3.5, buckling 3.0–3.5) is documented in the repository roadmap; under it the refined controlling bending D/C becomes 0.67–0.83 — still PASS — and the joint checks remain comfortable, so the strength verdict is not sensitive to that choice. The pipeline that generates the linked JSON artifacts uses this same FoS basis, so every downloadable number matches the report verbatim.

## 5.0 – SECTION V

## Loads & load combinations.

### 5.1 V.1 – Dead load (D)

**D = 0.179 kPa** panel self-weight as surface pressure ( $\rho \cdot g \cdot t$ ). No collateral dead load is carried by the shell; the non-bonded exterior skin is excluded by owner instruction and would add capacity, not demand, if bonded.

### 5.2 V.2 – Snow load (S) – ASCE 7-22 Ch. 7

Domed-roof provisions (§7.4.4): **p<sub>f</sub> = 1.005 kPa baseline / 3.352 kPa severe** balanced at the crown, with the unbalanced leeward-band case (2·p<sub>f</sub> peak) checked in every combination. No slippery-surface reduction is taken.

### 5.3 V.3 – Wind load (W) – ASCE 7-22 Ch. 26/27/30

Velocity pressure at the 3.97 m apex: **q<sub>z</sub> = 1.378 kPa baseline / 3.232 kPa severe**. Main system (MWFRS) envelope uplift  $-1.419 / -3.329$  kPa; components-and-cladding peak suction  $-3.831 / -8.984$  kPa from the domed-roof analogy (external GC<sub>p</sub> =  $-2.6$  edge zone plus enclosed internal pressure  $\pm 0.18$ , combined 2.78) – the same coefficient basis as the office package; C&C inward  $+2.315 / +5.429$  kPa.

### 5.4 V.4 – Wind-pressure basis: applicability & sensitivity

Two aspects of the wind basis are engineering judgments rather than code-prescribed values, and both are independent of the site – they are disclosed and quantified here (**full sensitivity record**):

**(a) Shape applicability.** ASCE 7's pressure figures cover smooth spherical domes; the faceted zonohedron is analysed *by analogy* to them. No code figure covers this shape literally, and a plan reviewer is entitled to ask what happens if the true shape-specific coefficients are harsher. Quantified headroom: the refined severe-site strength check reaches D/C = 1.0 only at a combined coefficient of 4.01 vs the 2.78 used (**+44 % coefficient headroom**); at baseline the headroom is 3.4×. The definitive product-line closure is an ASCE 7 Chapter 31 wind-tunnel study (or validated CFD equivalent) establishing shape-specific pressures once for all sites – carried as a required follow-up in § XII.

**(b) Enclosure classification.** The issued basis assumes an *enclosed* building (GC<sub>pi</sub> =  $\pm 0.18$ ). The door bay is a large fraction of one bay, and if the assembly is classified *partially enclosed* (GC<sub>pi</sub> =  $\pm 0.55$ ) net pressures rise 13.5 %: refined severe bending 0.69 → **0.78**, baseline 0.29 → 0.33, joints 0.27 → 0.31 (uplift buckling is not a credible failure mode – S4 – and its computed crease-band factors remain above 3.0 under the reclassified loads), net severe anchorage demand 109 →  $\approx 151$  kN – **every check still passes**. Even the combined conservative case (a +25 % external-coefficient premium *and* partially-enclosed classification, +37 % net) the refined severe check reads 0.95. The enclosure classification must be confirmed from the door/glazing design at permit time; the governing severe-envelope check (snow buckling) is unaffected by the wind basis.

## 5.5 V.5 — Load combinations (ASCE 7-22 §2.4 basis, wind at 1.0 W)

Combinations evaluated as computed by the pipeline: D; D + L; D + S (balanced and unbalanced); D + W (inward and uplift); D + 0.75(S + 0.6 W); 0.6D + W (uplift-critical); plus a 1.2D + 1.6S strength-format screening row. **Deliberate conservatism:** wind is applied at its full value (1.0 W) in the governing combinations rather than the 0.6 W factor ASCE 7-22 §2.4 permits for ASD — i.e. strength-level wind is checked against ASD allowables, a ~1.67× premium on every wind-governed D/C in this package relative to the code-minimum ASD basis. The governing strength combination everywhere is  $0.6D + W_{\text{uplift}}$  with the C&C peak suction (net 8.88 kPa outward at severe); the governing stability case is balanced snow.

## 6.0 – SECTION VI

## Analysis methodology.

The studio inherits the office package's four-tier methodology — hand calculation, multi-solver shell FE, geometrically-resolved (filleted) shell FE, and single-panel FE — plus one upgrade made for this report and applied to both models: eigenvalue buckling on the well-posed shell mid-surface. Methodology studies performed on the office model (smooth-cap solver discriminator, fillet-radius convergence, finite-stiffness joint sweep) are model-independent physics and are cited rather than re-derived; every *number* in this report is computed from studio geometry.

### 6.1 VI.1 — Hand calculation (screening envelope)

Timoshenko simply-supported rectangular-plate bending applied to each panel type's diagonal rectangle,  $\beta$  from Table 8. This is intentionally the most conservative tier: the rectangle spans the full diagonals (2.0× the rhombus area) and the panel is treated as isolated. Improvement over the office run: the envelope is evaluated for *all nine* panel types, not only the largest — on elongated rhombi the governing type is not automatically the largest-area one (demand  $\propto \beta(\text{aspect}) \cdot a^2_{\text{short}}$ ). Joint, compression, local buckling, snap-through, and bearing checks are closed-form as in the office package, with one correction: the base-ring compression resolution angle uses the *measured* panel plane tilt (40.3° from vertical, PCA-fitted; the office run had used a nominal 15° — immaterial there at  $D/C \leq 0.15$ , and corrected in the studio pipeline from the start).

### 6.2 VI.2 — Shell FE & the filleted production model

Per-panel forces are computed by three independent codebases on the same corner-network mid-surface (6,161 nodes / 12,032 triangles at the 200 mm production target): the in-house CST+DKT solver, OpenSees ShellMITC4, and (opt-in) OpenSees ShellDKGT. On *faceted* geometry all shell formulations exhibit unbounded bending stress at panel-crease kink lines — a geometric singularity, proven by the office smooth-cap 4-way discriminator ( $\pm 7\%$  agreement on smooth geometry, 2–4× spread on faceted). The issued strength reference is therefore the **filleted** full-dome model (20 mm crease fillets, ShellMITC4, 13.3k nodes), whose convergence was demonstrated in the office fillet-radius sweep (0.3–0.4 % per refinement step) and which is run here on studio geometry at the production configuration (S6).

### 6.3 VI.3 — Eigenvalue buckling (S3 shell mid-surface)

New in this package (and retro-applied to the office as a cross-check): CalculiX `*BUCKLE` on the S3 shell mid-surface with pressure-only reference load, 6 modes, and a *three-level mesh-refinement study* — subdivision depths 3/4/5, i.e. 6,161 / 24,353 / 96,833 nodes, each level a genuine 4× element refinement (**method & results**). The office package's original buckling numbers came from the merged-tet volume mesh, whose sliver elements made the lowest eigenvalues non-repeatable (documented in the repository roadmap); the shell mid-surface eigenvalues are repeatable, and under refinement they decrease from above with a stable geometric ratio ( $\approx 0.41$  per level for snow), so the issued basis is the *extrapolated limit* of the sequence — not any single mesh. That limit is itself a defensible lower bound: the sharp-

crease faceted idealization under-represents the stiffness of the real 76 mm glued joints (the same geometric conservatism the strength tiers resolve with the fillet — a filleted CalculiX buckling run is not numerically possible, as the mm-scale fillet-ribbon elements fail CCX's shell-to-solid expansion, so the fillet credit remains unclaimed margin here). Wind-uplift eigenvalues do not extrapolate — suction puts the dome membrane in tension and the computed factors are local crease-band artifacts — so uplift stability is dispositioned by physics (no credible buckling mode) plus the strength tiers. Gravity-in-reference sensitivity, measured at the 24k-node level: -2.6 % on the governing factor.

#### 6.4 VI.4 — Volume-FE tier status

The office package included a diagnostic volume-tet tier (linear stress + joint-traction recovery on a merged tet mesh). For the studio, the merged-tet mesh cannot be built: the corner-merge step produces a geometry that fails tetgen's PLC stage — the same documented limitation that blocked the office model's high-resolution re-mesh. Because that tier was diagnostic-only in the office package (its stress magnitudes carried a formal do-not-trust caveat), its absence here does not remove any issued number: strength comes from the shell tiers (S6/S7), joint demand from the hand envelope (S3), and buckling from the shell eigensolution (S4). The gap and its conservative treatment are disclosed in § XII.

#### 6.5 VI.5 — Software validation evidence

Carried from the office package (model-independent): square SS/clamped plate benchmarks vs Timoshenko for every shell code; uniaxial unit-cube smoke tests; three-way tet-solver cross-checks; the smooth-cap 4-way agreement study; and the stress-recovery fix regression suite. See smooth-cap study, solver-disagreement diagnosis, and Appendix A for reproduction. The studio pipeline additionally carries 25 automated regression tests (geometry registry, inventory counts, material allowables, load signs, parser round-trips).

7.0 – SECTION VII

# Analysis results.

## 7.1 S1 – Capacity under typical (baseline) loads

At the baseline CONUS envelope every check passes with wide margin: screening-envelope bending 0.46, refined FE bending 0.29, joints 0.11 / 0.07, compression 0.08, snow-buckling BLF 7.1 extrapolated (utilization 0.42), uplift eigenvalue  $\geq 26$  at the finest level (utilization 0.11), bearing 0.01. The structure is not working hard at any typical site; the interesting engineering is entirely at the severe envelope (S2, S4).

## 7.2 S2 – Panel bending under severe-site uplift (controlling strength check)

Combination  $0.6D + W_{uplift}$ , C&C peak suction  $-8.98$  kPa, net outward reference pressure  $8.88$  kPa. Three tiers bracket the demand on the governing type-1 panel (1011 mm edge,  $80.4^\circ$ ):

TABLE 5 – CONTROLLING-CHECK BRACKET (SEVERE, FOS 2.5)

METHOD	$\Sigma_B$ (MPa)	D/C	CONSERVATISMS RETAINED
Timoshenko inscribed-rectangle envelope	0.956	<b>1.10</b>	rectangle = $2.0 \times$ panel area; isolated panel; SS edges
Single-panel rhombic FE (converged, SS)	0.487	<b>0.56</b>	isolated panel; SS edges (clamped bracket: 0.27)
Filletted full-dome FE (converged)	0.602	<b>0.69</b>	none of the above; door framing still omitted

**Verdict: PASS at D/C = 0.56–0.69.** The screening envelope exceeds 1.0 on panel types 1–3 (1.10 / 1.10 / 1.06) and is disclosed as exceeded rather than quoted as the permit figure; its 49 % over-prediction on this panel shape is measured directly against the converged FE (S7). This is the honest difference from the office package, where the near-square worst panel let the envelope pass at 0.99 and be retained as the headline. The studio's more elongated rhombi make the diagonal-rectangle model *geometrically* inapt – the two refined tiers, which agree with each other from opposite directions (isolated panel vs full dome), carry the verdict.

## 7.3 S3 – Joint demand assessment

Worst hand-calc joint demand at severe: **tension D/C = 0.27, shear 0.18** (baseline 0.11 / 0.07). As with the office dome, joints are not the governing limit state despite the lab-weakest properties: dome geometry converts panel uplift mostly to in-plane joint shear. The office finite-stiffness joint sweep (311 discrete joint springs, rigid  $\rightarrow$  calibrated  $\rightarrow$  free-hinge) moved the controlling panel D/C by  $\pm 1$  % (no panel by more than  $\sim 5$  %); the studio's identical joint construction (same adhesive, same 76.2 mm bond depth, same edge-length scale) carries that insensitivity finding by reference. The volume-FE per-triangle traction recovery of the office package is unavailable here (§ VI.4); the hand envelope it had validated (envelope  $\geq$  FE p99 in every office case) is used directly, uncorrected – i.e. conservatively.

### 7.4 S4 — Buckling: the governing severe-site check

**Full method & data.** Mode-1 factors across the three-level mesh-refinement study (pressure-only reference; per-level artifacts and the extrapolation record are linked):

**TABLE 6 — EIGENVALUE BUCKLING, MESH-REFINEMENT RECORD (S3 SHELL MID-SURFACE)**

CASE	6,161 NODES	24,353	96,833	EXTRAPOLATED	REQUIRED	STATUS
Balanced snow — severe	3.56	2.71	2.36	<b>2.12</b>	≥ 3.0	CRITERION EXCEEDED
Balanced snow — baseline	11.87	9.03	7.88	<b>7.08</b>	≥ 3.0	PASS
Wind uplift — severe / baseline <small>(tensile membrane; factors are crease-band artifacts that do not extrapolate)</small>	≥ 11.3 / ≥ 26.5 at every level			n/a	≥ 3.0	PASS (STRENGTH TIERS GOVERN)

The snow sequences decay with a stable geometric ratio (0.407 measured on both sites) and are extrapolated to their limit; the governing severe-snow value is **2.12** (2.07 with gravity included in the reference load — a -2.6 % sensitivity measured at the 24k-node level). Mode 2 at the finest mesh is 3.27, above the criterion; the exceedance is confined to mode 1. Because the sharp-crease idealization progressively under-stiffens the real glued joints as the mesh refines, the extrapolated limit is a lower bound on the physical structure — the fillet credit demonstrated by the strength tiers is additional, unclaimed margin here.

**The mode shape matters.** The mode-1 eigenvector (verified from the solver output at both the 24k and 97k levels — same band, same breadth) is a *local* panel-band mode centred on the door bay at mid-height — not a global snap-through of the shell. The bare-shell FE carries the door bay with its half-panels but *without* the door jambs and header, i.e. it removes stiffness exactly where this mode localizes.

#### S4a — Door-frame stiffness credit (issued stability basis)

Since the critical mode lives in the bay whose framing the bare-shell model omits, the framing was reinstated and the full refinement study repeated at three credit levels (**study records**). The two jambs and the header enter as shell members at their fit-measured 98 mm plank thickness (the jamb value, applied to all three members as a floor); the operable door leaves remain excluded; the corner network fuses the members to the adjacent half-panels exactly as panels fuse to each other. The **issued basis credits the owner-recorded African teak bucks** (iroko / afrormosia class; published MOE ≈ 9.4–12.2 GPa, density ≈ 660 kg/m<sup>3</sup>, naturally durable) at a deliberately conservative structural-lumber floor; E = 8,000 MPa — 17–53 % below the species' published range and below even low-grade softwood at ~9,600 MPa (ρ = 600 kg/m<sup>3</sup>, ν = 0.30 isotropic simplification). Two pessimistic bases are retained as the sensitivity ladder: the same members at foam strength (E = 70.8 MPa — the no-material-data bound), and the bare shell with no framing at all.

**TABLE 6A — SEVERE SNOW BUCKLING: DOOR-FRAME CREDIT LADDER**

BASIS	6.3K NODES	24.6K	97K	EXTRAPOLATED	+ GRAVITY	VS 3.0
Bare shell (frame omitted)	3.56	2.71	2.36	2.12	2.07	SHORT
Frame at foam strength (no-material-data bound)	5.09	4.02	3.50	3.00	2.91	4 % SHORT
<b>Frame as recorded African teak (lumber-floor E, issued)</b>	6.26	5.04	4.50	<b>4.08</b>	<b>3.92</b>	PASS +30 %

On both credited bases the mode-1 eigenvector moves off the framed bay into the immediately adjacent panel field (verified from the finest-level eigenvectors) — the frame credit is fully realised and the verdict no longer hinges on framing detail. A member-thickness sensitivity confirms the same: raising the members from 76.2 to 98 mm moved the coarse-level factor only +1.7 % (the frame works by bracing the bay in-plane, not by member bending), and the wood stiffness could be overstated by a factor of several before the criterion is threatened. Interpretation: at the full 100 psf severe ground snow the structure retains a 3.9× margin against the design load vs the prescribed 3.0× — **PASS**. The species record (African teak) satisfies the material assumption with 17–53 % headroom; build QC verifies the installed members match the record. Disposition: § X.

## 7.5 S5 — Multi-solver envelope (diagnostic)

**Raw envelope numbers:** on the unfilleted faceted mid-surface the default two-solver envelope (in-house DKT + ShellMITC4) reads, per limit state at severe (all governed by wind\_cc\_peak): plate bending 2.05, membrane compression 2.37, local plate buckling 3.03, and membrane tension 22.5 — the last dominated by crease-line values on a single base-bay panel. Including the opt-in ShellDKGT solver (the known 4–6× faceting outlier) raises these to 3.04 bending / 29.9 tension. All of these are diagnostics of the kink-line geometric singularity — bending stress at a rigid panel crease grows without bound under mesh refinement — and are reported for transparency, not as verdicts. The office smooth-cap discriminator (four solvers within ±7 % on smooth geometry) established that this is a property of the faceted CAD abstraction, resolved physically by the real joint's finite geometry, and numerically by the fillet (S6).

## 7.6 S6 — Filleted full-dome FE (issued strength reference)

**Production run record:** ShellMITC4 on the 20 mm-filleted mid-surface, 13,337 nodes / 13,492 quads / 94 panels. Panel-interior worst-fiber bending, FoS 2.5: severe — snow 0.28, MWFRS 0.25, **C&C peak 0.69 (controlling)**; baseline — 0.10 / 0.09 / 0.29. Convergence basis: office fillet-radius sweep ( $r = 5\text{--}50$  mm, 0.3–0.4 % change per refinement), model-independent methodology applied at the production configuration ( $r = 20$  mm, 100 mm target).

## 7.7 S7 — Single-panel rhombic FE, all types

**Convergence + all-types record:** the governing type-1 panel meshed as a true rhombus (quad mesh,  $h = 200 \rightarrow 25$  mm converged), severe-site reference pressure 8.88 kPa. Centre-fiber D/C at FoS 2.5: 0.56 (SS) / 0.27 (clamped) — the physical edge restraint lies between. All nine panel types swept at  $h = 50$  mm: refined D/C ranges 0.21–0.56 and *rank the types in the same order* as the screening envelope, confirming type 1 governs. Measured envelope-vs-FE conservatism on type 1: 49 % of demand.

## 7.8 S8 — Risks outside FE scope

Identical category list to the office package, restated for the studio with its own numbers where available: creep (indicative 50-year apex sag  $\approx 2$  mm gravity-only, § IX); door/window cut-out local stress concentration (the door-bay half-panels are carried as panels, but corner concentrations at the opening are not resolved — the door-region panel types 7–8 sit at refined D/C  $\leq 0.28$  with 3.5× margin to absorb the published 2–3× concentration factor); workmanship variability on field-glued joints (0.7–0.8× industry knockdown not baked in;

joint D/C 0.27 tolerates it); UV/temperature; wind-cycle fatigue. Each carries a required follow-up in § XII.

8.0 – SECTION VIII

## Limit-state code checks.

The complete machine-readable check set – every panel type × every ASCE 7-22 combination × every limit state, at the same FoS basis as this report – is the acceptance record: `acceptance-severe.json` · `acceptance-baseline.json` (with human-readable `.txt` companions). Screening-envelope rows above 1.0 appear there exactly as discussed in S2 – the JSON is not sanitized; it records the envelope exceedance and this report's §§ S2/S6/S7 resolve it.

**TABLE 7 – SCREENING ENVELOPE BY PANEL TYPE (SEVERE, WORST COMBINATION, FOS 2.5)** *Timoshenko diagonal-rectangle model; refined-FE column from S7.*

TYPE (EDGE / ACUTE)	COUNT	ENVELOPE $\Sigma_B$	ENVELOPE D/C	REFINED FE D/C (SS)
1 – 1011 mm / 80.4°	11	0.956	1.10	0.56
2 – 1004 mm / 77.4°	12	0.951	1.10	0.55
3 – 1017 mm / 63.7°	20	0.916	1.06	0.52
4 – 1019 mm / 57.2°	11	0.837	0.96	0.49
5 – 1003 mm / 52.5°	12	0.737	0.85	0.44
6 – 863 mm / 52.8°	11	0.550	0.63	0.33
7 – 703 mm / 81.2°	4	0.457	0.53	0.28
8, 9 – remaining	13	< 0.45	< 0.52	< 0.28

9.0 – SECTION IX

---

## Serviceability.

### 9.1 IX.1 – Short-term deflection

From the filleted full-dome FE (**records**): baseline D+S 5.8 mm ( $\approx L/1160$ ); severe D+S 15.1 mm ( $\approx L/440$ ); transient severe C&C gust peak 34.3 mm ( $\approx L/195$ ). No code deflection limit applies to a foam monocoque; conventional L/240 sustained and L/180 transient yardsticks are met in all cases.

### 9.2 IX.2 – Long-term creep (indicative)

Literature-based Findley bound (**basis**), same  $\phi_{50} = 1.5$  assumption set as the office package: sustained gravity-only apex sag  $\approx 0.9$  mm day<sup>-1</sup> (linear decomposition of the baseline D+S filleted run:  $5.75 \text{ mm} \times 0.179/1.184 \rightarrow \approx 2.2$  mm at 50 years. A bounding, unrealistic full-severe-snow-held-permanently scenario reads  $\approx 38$  mm. These are indicative bounds, not certification; batch-specific 1000-h ASTM D2990 testing is required follow-up (§ XII) before any multi-decade service claim.

## Conclusions & rated site envelope.

**Strength: PASS at both envelopes.** Refined worst-case panel bending  $D/C = 0.69$  at the severe envelope (0.29 baseline); joints 0.27; every other strength check at or below 0.70.

**Stability: PASS at both envelopes.** Snow-buckling capacity (mesh-extrapolated lower bounds) is  $7.1\times$  design at baseline before any framing credit, and  $3.9\times$  at the severe 100 psf envelope with the recorded African-teak door bucks credited at a conservative lumber floor (ladder:  $2.1\times$  bare shell,  $2.9\times$  foam-strength frame) against a required  $3.0\times$ .

**Rated site envelope (derivation):** wind to **160 mph Exposure D** and snow to the **full 100 psf severe ground snow**, both at the full factors of safety (governing stability margin 3.92 vs 3.0 on the issued wood-frame basis; strength margins per Table 1; uplift buckling is not a credible mode and its computed factors exceed 3.0 at every level of every model). The certified envelope covers the design conditions of essentially every CONUS site; anything beyond it (e.g.  $> 100$  psf alpine sites) is outside the analyzed envelope and needs per-site work.

**Conditions attached to the stability verdict** – and fallbacks should either fail at submittal:

1. **Frame material – recorded.** The issued 3.92 credits the jambs/header at an  $E = 8,000$  MPa structural-lumber floor; the recorded species, African teak (published  $MOE \approx 9.4\text{--}12.2$  GPa), exceeds it by 17–53 %. Remaining action: build-QC verification that the installed members match the record.
2. **Fallback if a future unit substitutes a non-structural buck material:** the foam-strength basis (2.91) still rates 96 psf ground snow, and a perimeter rib on the panels flanking the door bay – sized by the EOR against the recorded mode-1 shape – recovers the full envelope.
3. **Sites beyond the severe envelope** ( $> 100$  psf ground snow or  $> 160$  mph): outside this package's analyzed range; per-site engineering required.

**Design recommendations** (carried from analysis observations): (a) the anchorage / hold-down design at the curb remains the permit-critical open deliverable – net uplift at severe is quantified in the calc package; (b) field-joint workmanship QC per the office package's program; (c) the door-buck species is recorded (African teak); carry it into each unit's build documentation so QC closes the S4a check per build.

11.0 – SECTION XI

---

## Conclusion & recommendation for the EOR.

This package is prepared for review and stamp by a licensed structural engineer. The preparers' recommendation: **approve for construction at sites within the full bracketing envelopes** ( $\leq 160$  mph / Exposure D wind;  $\leq 100$  psf ground snow), conditional on (1) EOR confirmation of the FoS scheme (§ IV.3), (2) completion of the anchorage design, and (3) the § XII follow-up program for long-term effects. For heavier-snow sites, select and execute one of the three § X closure options first. The verdict rests on two independent converged FE analyses that agree from opposite modelling directions, a fully-disclosed conservative screening tier, a stability analysis carried through an explicit three-level mesh-refinement study and rated on its extrapolated lower bound, with a verified mode shape, and laboratory material data – with every number in this document linked to its machine-readable artifact and reproduction command.

## Limitations & required follow-up.

1. **Anchorage / hold-down design** – not in this package; EOR deliverable; permit prerequisite. Net severe uplift quantified in the calc package.
2. **Sliding / overturning at the foundation interface** – civil/geotechnical scope.
3. **Long-term creep certification** – 1000-h ASTM D2990 on this foam batch (two temperatures) before multi-decade claims; § IX bound is literature-based and indicative.
4. **Door / window opening local detail** – corner stress concentrations at the cut-outs are not resolved by the panel-level models; door-region panels carry  $\geq 3.5\times$  refined margin against the published 2–3 $\times$  concentration factor, and the door-bay buckling item is dispositioned in § X, but a local model is required if opening geometry changes.
5. **Volume-FE tier unavailable** – the merged-tet mesh cannot be built for this geometry (tetgen PLC failure, same documented limitation as the office high-resolution export). All issued numbers come from tiers that do not depend on it; joint FE traction recovery is replaced by the (validated-conservative) hand envelope.
6. **Workmanship knockdown** – field-glued joint quality variability (industry 0.7–0.8 $\times$ ) not baked into allowables; tolerated by margins (joint D/C 0.27) but should be covered by a QC program.
7. **UV / temperature / moisture aging** – lab data is 23 °C / 50 % RH; unprotected exposure requires testing or reliance on the (excluded) exterior skin.
8. **Wind-cycle fatigue** – no S-N data on file for this foam.
9. **Fire resistance & life safety** – outside structural scope (a fire-protection engineer / code consultant deliverable, with product fire testing); foam requires a code-compliant thermal barrier evaluated separately.
10. **Construction-phase loads** – erection sequence, temporary supports, and handling stresses not analysed.
11. **Exterior fibre-cement skin** – excluded (non-bonded) per owner instruction; if later bonded it adds capacity and should be re-evaluated for compatibility, not strength.
12. **Shape-specific wind pressures** – the dome-analogy coefficient basis is disclosed and its headroom quantified in § V.4, but it remains an analogy at any site. One-time product-line closure: an ASCE 7 Ch. 31 wind-tunnel study or validated CFD equivalent establishing shape-specific pressures for the faceted zonohedron. Until then, § V.4's sensitivities are the defence.
13. **Enclosure classification** – the issued basis assumes an enclosed building; the classification depends on the door/glazing design and must be confirmed per ASCE 7-22 §26.2 at permit time. The partially-enclosed sensitivity passes all checks (§ V.4) but is not the issued basis.
14. **Door-buck material** – recorded: African teak (iroko / afrormosia class; published MOE  $\approx$  9.4–12.2 GPa vs the modeled 8,000 MPa floor; § S4a). Remaining action is build-QC verification that installed members match the record; the foam-strength fallback basis (96 psf rating) plus the published sensitivity ladder cover any contingency.
15. **Seismic (site overlay)** – a bounding no-credit screening (**Cs = S\_DS, R = 1**) shows the wind cases exercise the shell, joints, and anchorage harder than seismic at either envelope for this 13.4 kN structure; this is a screening, not a seismic design. California jurisdictions typically require site-specific parameters via a geotechnical investigation; the seismic overlay and any required system-factor judgment are per-site EOR work.

16. **Site specificity** – this package brackets generic envelopes; site-specific loads (topographic factors, drift from adjacent structures, soil values per CBC §1806 or geotech report) must be confirmed by the EOR at permit time.

13.0 – SECTION XIII

---

## Engineer-of-Record approval.

This report and its companion calculation package (ZS-2026-002-CALC-001) are issued for the review, markup, and approval of the Engineer of Record. The signature block on the cover governs; disposition options are Approved / Approved with comments / Revise and resubmit.

## 14.0 – APPENDICES

# Appendices.

## 14.1 A – Reproduction commands

Every number in this report regenerates from the repository with:

```
# geometry & inventory
python tools/extract_panels_from_obj.py --obj "assets/Studio Files/structural-full-studio-highest-resolution.obj" --out repor
python tools/build_panel_inventory.py --model studio

# hand-calc + acceptance (both sites)
python tools/run_check.py --model studio baseline
python tools/run_check.py --model studio severe
python tools/run_full_analysis.py --model studio severe
python tools/run_acceptance.py --model studio severe

# shell tiers
python tools/inhouse_shell_panel_forces.py --model studio severe
python tools/solve_shell_quad_opensees.py --model studio severe
python tools/opensees_full_check.py --model studio severe
python tools/solve_shell_filletted_opensees.py --model studio severe
python tools/single_panel_rhombic_fe.py --model studio

# buckling (three-level refinement study + extrapolation record)
python tools/ccx_shell_buckle.py --model studio severe --target-size-mm 200 --tag=-ts200
python tools/ccx_shell_buckle.py --model studio severe --target-size-mm 100 --tag=-ts100
python tools/ccx_shell_buckle.py --model studio severe --target-size-mm 50 --max-depth 5 --tag=-ts50
python tools/build_buckling_convergence.py --model studio severe

# door-frame credit studies (S4a). Issued basis = confirmed wood bucks
# at the structural-lumber floor; foam-strength + bare-shell retained
# as the sensitivity ladder. Repeat the three levels per basis:
python tools/ccx_shell_buckle.py --model studio severe --include-door-frame --frame-material wood --target-size-mm 50 --max-d
python tools/build_buckling_convergence.py --model studio severe --prefix=-doorframe-wood
python tools/ccx_shell_buckle.py --model studio severe --include-door-frame --target-size-mm 50 --max-depth 5 --tag=-doorfram
python tools/build_buckling_convergence.py --model studio severe --prefix=-doorframe

# regression tests
python -m pytest tests/ -q
```

## 14.2 B – Material test report digest

Certificate QSW26030006 (Nanjing Guocai Testing Co., May 2026). Means, worst direction in bold: density 240 kg/m<sup>3</sup> (D1622); compression **2.47**/2.58/2.62 MPa, modulus **70.8**/72.2/79.1 MPa (D1621); parent shear **0.584**/0.649 MPa, G 31.4/32.0 MPa (C273); flexure **2.17**/2.28 MPa, modulus **62.8**/68.9 MPa (D790); joint tension **0.270** MPa (D1623); joint shear **0.410** MPa, G 24.1 MPa (C273-joint). Poisson 0.30 assumed.

### 14.3 C — Panel inventory

Table 4 (§ IV.1) is the issued inventory. Machine-readable: panel-inventory.json; full per-block fit table (110 rows): fit\_panels.txt; derivation of every registry constant: geometry-audit.md.

### 14.4 D — Raw FE output index

- acceptance-severe.json / -baseline.json — canonical check records
- shell-buckling-convergence-severe-doorframe-wood.json — confirmed-wood door-frame refinement record + extrapolation (issued stability basis; per-level -ts50, -with-gravity)
- shell-buckling-convergence-severe-doorframe.json — foam-strength-frame refinement record (sensitivity ladder; per-level -ts50, -with-gravity)
- shell-buckling-convergence-severe.json / -baseline.json — bare-shell refinement records + extrapolation (conservative disclosure basis)
- shell-buckling-severe.json / -baseline.json — finest-level eigenvalue records (per-level: -ts200, -ts100, -ts50, -with-gravity)
- full-analysis-shell-filleted-severe.txt / -baseline.txt — issued strength reference runs
- rhombic\_panel\_fe\_results.csv — single-panel convergence + all types
- opensees-full-check-severe.txt / opensees-acceptance-severe.json — multi-solver diagnostic envelope (also -baseline, -with-dkgt variants)
- inhouse\_dkt\_shell\_severe\_forces.csv, opensees\_shell\_quad\_severe\_forces.csv, opensees\_shell\_filleted\_severe\_forces.csv — per-panel forces
- full-analysis-severe.txt / sanity-check-severe.txt — hand-calc logs (also -baseline)
- Mode shapes, meshes, and VTU visualisations under `reports/studio/` in the repository (excluded from web deploy for size)

### 14.5 E — References

1. Timoshenko & Woinowsky-Krieger, *Theory of Plates and Shells*, 2nd ed., 1959.
2. ASCE 7-22, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*.
3. IBC 2024, International Building Code.
4. APA Y510L, *Structural Insulated Panels* (FoS analog).
5. QSW26030006 inspection & testing report, Nanjing Guocai Testing Co., 2026.
6. CalculiX 2.23 (Dhondt & Wittig); OpenSees 3.7 (PEER); scikit-fem; gmsh.
7. Shared methodology studies (this repository): smooth-cap 4-way discriminator, fillet convergence, finite-stiffness joint sweep, creep analysis.

### 14.6 F — Glossary & symbols

**D/C** — demand-to-capacity ratio at the stated FoS;  $\leq 1.0$  passes. **BLF** — buckling load factor: multiple of the reference load at which the linearised structure buckles. **FoS** — factor of safety (ultimate  $\div$  allowable). **C&C** — components & cladding wind pressures. **MWFRS** — main wind-force resisting system. **SS** — simply supported. **p99** — 99th percentile over mesh entities (robust to mesh-singular hot-points). **Screening envelope** — deliberately conservative closed-form bound used to triage; where it passes, no further analysis is needed; where it exceeds 1.0, refined tiers govern.