STRUCTURAL CALCULATIONS — PROJECT ZS-2026-002 (STUDIO)

Polar-Zonohedron PU-Foam Dome

Studio — Structural Calculation Package

94-panel rigid-polyurethane-foam monocoque, 6.69 m diameter × 3.97 m apex. Prepared for Engineer-of-Record review, seal, and submission to the Authority Having Jurisdiction.

PROJECT	PROJECT ADDRESS	PERMIT APPLICATION NO.	RISK CATEGORY
Zomes studio prototype (ZS-2026-002)	_____ (site TBD)	_____	II
CODES	**MATERIAL CERTIFICATE**		
IBC 2024 · ASCE 7-22	QSW26030006 (attached by reference)		

The narrative engineering-review companion (methodology, solver cross-checks, and deep-linked source data for every number here) is the ENGINEERING REVIEW REPORT.

ENGINEER OF RECORD — SEAL & SIGNATURE AWAITING WET SEAL

NAME (PRINTED)	SIGNATURE & DATE
_____	_____
LICENSE NO. / STATE / EXPIRATION	**PERMIT SUBMISSION**
_____	_____

Engineer's seal

(affix wet seal here for permit submission)

1.0 — SHEET 1 — SCOPE

Calculations performed in this package.

1. Panel plate bending — screening envelope (all 9 panel types) + refined FE verdict
2. Adhesive joint tension and shear at panel bonds
3. Base-ring membrane compression
4. Local panel buckling (classical SS plate)
5. Global buckling — FE eigenvalue on the shell mid-surface (snow + wind uplift)
6. Global shell snap-through (classical spherical cap)
7. Foundation bearing pressure
8. Net wind uplift / anchorage demand (design input for the EOR's anchor design)
9. Foundation reactions for the geotechnical designer
10. Deflection vs IBC Table 1604.3

Two bracketing site envelopes are computed throughout: **baseline** (V = 115 mph Exp. C, p_g = 30 psf) and **severe** (V = 160 mph Exp. D, p_g = 100 psf). Factor of safety: 2.5 on strength allowables, 3.0 on buckling. **Both envelopes are certified in full** — including 160 mph Exposure D wind and the 100 psf severe ground snow. Door-buck material recorded: African teak, exceeding the modeled structural-lumber floor (Sheets 10, 13); build QC verifies installed members match. Excluded scope is listed on Sheet 14.

2.0 — SHEET 2 — CODES

Governing codes in force.

IBC 2024	Building code framework; Tbl. 1604.3 deflection limits
ASCE 7-22	§2.4 ASD combinations; Ch. 7 snow (domed roof §7.4.4); Ch. 26/27 wind MWFRS; Ch. 30 C&C (Fig. 30.4-7 domes)
ASTM D1622/D1621/D790/C273/D1623	Material properties per certificate QSW26030006

Structural geometry and lab-tested allowables.

3.1 3.1 Geometry (measured from as-assembled structural CAD)

Form	11-fold polar zonohedron monocoque, one door bay
Footprint	6.69 m mean diameter → A = 35.2 m²
Apex height	3.97 m above foundation plane
Panels	94 structural rhombic panels, 9 types (Sheet 3 table below); t = 76.2 mm (3.0 in) throughout
Base ring	11 panels bearing on 11 foundation curb strips; panel plane 40.3° from vertical (measured)
Panel area / foam volume / weight	75.0 m² / 5.71 m³ / 13.44 kN (3,020 lbf)
Equivalent spherical radius	R = (D²/4 + H²)/(2H) = 3.39 m

TYPE	COUNT	EDGE (MM)	ACUTE (°)	DIAGONALS (MM)	AREA (M²)
1	11	1011.2	80.37	1305 × 1545	1.008
2	12	1004.2	77.40	1256 × 1567	0.984
3	20	1017.1	63.75	1074 × 1727	0.928
4	11	1019.2	57.15	975 × 1790	0.873
5	12	1002.7	52.49	887 × 1799	0.798
6	11	862.5	52.77	767 × 1545	0.592
7	4	703.0	81.15	915 × 1068	0.488
8	1	808.9	45.77	—	0.469
9	12	1004.6	26.50	—	0.450

3.2 3.2 Material — Zomes PU foam (240 kg/m³), certificate QSW26030006

PROPERTY (WORST DIRECTION)	ULTIMATE	ASTM
Compression	2.47 MPa	D1621
Flexure	2.17 MPa	D790
Parent shear	0.584 MPa	C273
Joint shear (bond)	0.410 MPa	C273
Joint tension (bond)	0.270 MPa	D1623
Young's modulus E	70.8 MPa	D1621
Poisson ratio ν	0.30 (assumed)	—

3.3 3.3 Allowables at FoS = 2.5 (strength) / 3.0 (buckling)

Bending σ_b,allow	2.17 / 2.5 = **0.868 MPa**
Compression σ_c,allow	2.47 / 2.5 = **0.988 MPa**
Joint shear τ_j,allow	0.410 / 2.5 = **0.164 MPa**
Joint tension σ_tj,allow	0.270 / 2.5 = **0.108 MPa**
Buckling	mode-1 factor ≥ **3.0** × design load

FoS basis: SIP-industry analog (APA Y510L); project decision for EOR confirmation — no code-prescribed value exists for primary-structure foam buildings.

Design loads per ASCE 7-22.

4.1 4.1 Dead load

D = ρ g t = 240 × 9.807 × 0.0762 = **0.179 kPa**; total W_D = 13.44 kN.

4.2 4.2 Snow load (§7.4.4, domed roof)

	BASELINE	SEVERE
Ground snow p_g	30 psf (1.436 kPa)	100 psf (4.788 kPa)
Balanced p_f = 0.7·C_e·C_t·I_s·p_g	1.005 kPa	3.352 kPa
Unbalanced peak (leeward band)	2.01 kPa	6.70 kPa

4.3 4.3 Wind load (§26.10, §27, §30.4; h = 3.97 m)

	BASELINE (115 MPH, EXP. C)	SEVERE (160 MPH, EXP. D)
Velocity pressure q_z	1.378 kPa	3.232 kPa
MWFRS uplift envelope	−1.419 kPa	−3.329 kPa
C&C peak suction (ext. GC_p = −2.6 + GC_pi 0.18)	−3.831 kPa	−8.984 kPa
C&C inward	+2.315 kPa	+5.429 kPa

Basis note. Coefficients are the ASCE 7 domed-roof analogy with *enclosed* internal pressure (GC_{pi} = ±0.18); no code figure covers the faceted zonohedron literally. Quantified sensitivities (review report § V.4): partially-enclosed classification (GC_{pi} = ±0.55, +13.5 % net) leaves every check passing (worst refined bending 0.78); the refined severe strength check tolerates a +44 % combined-coefficient premium before reaching unity. A shape-specific ASCE 7 Ch. 31 wind-tunnel / validated-CFD basis is the product-line follow-up (Sheet 14).

5.0 — SHEET 5 — COMBINATIONS

ASCE 7-22 §2.4 ASD combinations applied.

D · D+L · D+S (balanced & unbalanced) · D+0.6W (inward & uplift) · D+0.75(S+0.6W) · 0.6D+0.6W · (screening: 1.2D+1.6S). Governing strength combination: `0.6D + W_uplift` with C&C peak suction → net outward reference pressure **3.72 kPa baseline / 8.88 kPa severe**. Governing stability case: balanced snow.

6.0 — SHEET 6 — PANEL BENDING

Panel plate bending — screening envelope and refined FE.

6.1 6.1 Screening envelope (Timoshenko SS rectangle on panel diagonals)

σ = β(b/a) · q · a² / t², β per Timoshenko Table 8 (ν = 0.3), a = short diagonal. Checked for *all nine* panel types under *all* combinations. Worst rows at severe (q = 8.88 kPa): type 1 σ = 0.956 MPa (D/C = 1.10); type 2 0.951 (1.10); type 3 0.916 (1.06). Baseline worst: 0.401 MPa (D/C = 0.46). **The severe screening rows exceed 1.0 and do not govern the verdict** — the envelope spans the panel's diagonal bounding rectangle (2.0× the true rhombus area) and its over-prediction on these elongated panels is measured at 49 % (§6.2). Where the envelope passes (all baseline rows; severe types 4–9) no refined analysis is needed.

6.2 6.2 Refined FE verdict (severe, same case)

ANALYSIS	Σ_B (MPA)	D/C @ 0.868 MPA	VERDICT
Single-panel rhombic FE, true geometry, SS edges, mesh-converged (h = 25 mm)	0.487	0.56	PASS
Same, clamped-edge bracket	0.230	0.27	PASS
Filleted full-dome FE (13.3k nodes, 94 panels, converged fillet method)	0.602	**0.69**	**PASS — issued value**

Issued verdict: **PASS, D/C = 0.69** (worst of the refined tiers). The two refined models bracket the edge restraint from opposite directions and agree within the bracket; both are mesh-converged. Full method narrative: review report §§ S2, S6, S7.

7.0 — SHEET 7 — JOINTS

Joint shear and tension at panel-to-panel bond.

Demand model: worst-panel uplift shared equally by its four edge bonds (conservative — corners are stiffer): F_edge = q·A/4 = 8.88 kPa × 1.008 m² / 4 = 2.24 kN; bond area = 1011 mm × 76.2 mm.

CHECK	DEMAND (MPA)	ALLOWABLE (MPA)	D/C	VERDICT
Joint tension, severe	0.0290	0.108	0.27	PASS
Joint shear, severe	0.0290	0.164	0.18	PASS
Joint tension, baseline	0.0122	0.108	0.11	PASS
Joint shear, baseline	0.0122	0.164	0.07	PASS

8.0 — SHEET 8 — COMPRESSION

Base-ring membrane compression.

Severe D+S vertical reaction: W = 13.44 + 3.352 × 35.2 = 131.3 kN, shared by 11 base panels, resolved along the panel plane at the measured 40.3° tilt from vertical: σ = (131.3/11) / cos 40.3° / (76.2 × 1011 mm²) = **0.203 MPa** vs 0.988 allowable → **D/C = 0.21 PASS** (baseline 0.08).

9.0 — SHEET 9 — LOCAL BUCKLING

Classical SS plate buckling, k = 4.

$\sigma_{cr} = k\,\pi^2\,E / [12(1-\nu^2)] \cdot (t/b)^2$ on the worst base panel → allowable $\sigma_{cr}/3.0$ = 0.291 MPa vs the Sheet-8 demand 0.203 MPa → **D/C = 0.70 PASS** severe (0.26 baseline).

10.0 — SHEET 10 — GLOBAL BUCKLING

FE eigenvalue buckling on the shell mid-surface.

CalculiX `*BUCKLE`, S3 shells on the 94-panel corner-network mid-surface, carried through a three-level mesh-refinement study (6,161 / 24,353 / 96,833 nodes — each level a genuine 4× element refinement), foundation band encastre, pressure-only reference load. The mode-1 factors decrease from above with a stable geometric ratio (0.407, both sites) and the issued basis is the extrapolated limit of the sequence — a lower bound, since the sharp-crease idealization under-represents the real 76 mm glued-joint stiffness. Criterion: mode-1 factor ≥ 3.0.

CASE	6.3K	24.6K	97K NODES	EXTRAPOLATED	VERDICT
Balanced snow — baseline (bare shell)	11.87	9.03	7.88	7.08	PASS
Balanced snow — severe, bare shell (door frame omitted)	3.56	2.71	2.36	2.12	conservative disclosure basis
Balanced snow — severe, frame at foam strength (no-material-data sensitivity bound)	5.09	4.02	3.50	3.00 (2.91 w/ gravity)	sensitivity ladder
Balanced snow — severe, frame as recorded African teak jambs + header (recorded species: African teak, published MOE ≈ 9.4–12.2 GPa) credited at an E = 8,000 MPa structural-lumber floor, fit-measured 98 mm; door leaves excluded	6.26	5.04	4.50	**4.08** (3.92 w/ gravity)	**PASS — issued basis**
Wind uplift (MWFRS)	≥ 26.5 baseline / ≥ 11.3 severe at every level			n/a[1]	PASS

[1] Suction puts the dome membrane in tension — wind uplift is not a credible eigenvalue-buckling mode; the computed factors are local crease-band values (above 3.0 at every level of every model) and the strength sheets govern the uplift case. The bare-shell mode-1 eigenvector is a local panel-band mode at the door bay — exactly where that model omits the framing — which motivates the credited rows: with the jambs and header reinstated, the mode moves into the adjacent panel field on both credited bases. Issued basis = recorded African-teak bucks credited at a structural-lumber floor: extrapolated 4.08 pressure-only / 3.92 with gravity (−4.1 % measured) vs required 3.0 — PASS with ≈30 % margin. Member-thickness sensitivity: +1.7 % (the frame acts by in-plane bracing, not member bending). The recorded species exceeds the modeled floor by 17–53 %; build QC verifies installed members match the record. Classical spherical-cap snap-through cross-check (R = 3.39 m): $q_{cr} = 2E(t/R)^2/\sqrt{3(1-\nu^2)}$ = 43.3 kPa → allowable 14.4 kPa vs the 3.35 kPa severe balanced-snow reference → D/C = 0.23 — the FE mode governs because it resolves the local door-bay geometry the classical formula cannot.

11.0 — SHEET 11 — BEARING

Foundation bearing pressure.

Severe D+S: 131.3 kN / 35.2 m² = **3.7 kPa** vs 100 kPa fair-residential-soil presumptive → **D/C = 0.04 PASS** (baseline 0.01). Site-specific allowable bearing to be confirmed by the geotechnical designer.

12.0 — SHEET 11A — ANCHORAGE DEMAND

Severe-site wind uplift exceeds dead weight; perimeter anchors required.

Net uplift (conservative vertical envelope): U = |W_MWFRS| × A − 0.6 W_D.

	BASELINE	SEVERE
Gross uplift |W_MWFRS| × A	1.419 × 35.2 = 50.0 kN	3.329 × 35.2 = 117.2 kN
Resisting 0.6 W_D	8.1 kN	8.1 kN
Net anchorage demand	**41.9 kN**	**109.1 kN**
Per curb segment (÷ 11)	3.8 kN	9.9 kN
Net demand, partially-enclosed sensitivity (+36 % MWFRS)	60 kN (5.5 kN/curb)	≈151 kN (13.7 kN/curb)

The anchor / hold-down design to deliver this capacity is an EOR deliverable and is not part of this package. This sheet quantifies the demand so that design can proceed. The panel-to-curb / curb-to-foundation *connection detail* is a Zomes-provided design input (drawings to accompany this package) that the EOR checks and adopts rather than originates; the foundation itself is designed to a geotechnical report or CBC §1806 presumptive values. A permit should not be issued without the anchorage design.

13.0 — SHEET 12 — REACTIONS

Discretised reactions for the geotech / foundation designer.

CONDITION	TOTAL VERTICAL	PER CURB (÷ 11)	PER METRE OF CURB (≈ 1.91 M EACH)
D only	13.4 kN	1.2 kN	0.6 kN/m
D + S baseline	48.8 kN	4.4 kN	2.3 kN/m
D + S severe	131.3 kN	11.9 kN	6.2 kN/m
Net uplift severe (Sheet 11A)	−109.1 kN	−9.9 kN	−5.2 kN/m

14.0 — SHEET 12A — DEFLECTION

IBC Tbl. 1604.3 yardsticks, span = 6.69 m.

CASE	COMPUTED (FILLETED FE)	YARDSTICK	VERDICT
D + S baseline	5.8 mm (L/1160)	L/240 = 27.9 mm	PASS
D + S severe	15.1 mm (L/440)	L/240 = 27.9 mm	PASS
Severe C&C gust (transient)	34.3 mm (L/195)	L/180 = 37.2 mm	PASS

Indicative 50-year creep bound (literature Findley, φ = 1.5): gravity-only apex sag ≈ 2 mm; batch creep testing per the follow-up program before multi-decade certification.

15.0 — SHEET 13 — SUMMARY

Summary of compliance & rated envelope.

15.1 13.1 Worst-case summary

LIMIT STATE	BASELINE D/C	SEVERE D/C	VERDICT
Panel bending (refined FE; screening in italics)	0.29 *(0.46)*	**0.69** *(1.10 — screening exceeded, Sheet 6)*	PASS
Joint tension / shear	0.11 / 0.07	0.27 / 0.18	PASS
Membrane compression	0.08	0.21	PASS
Local panel buckling	0.26	0.70	PASS
Global buckling — snow (extrapolated BLF_1 vs 3.0)	0.42 (7.08)	0.77 (3.92 wood-credited; ladder 2.9/2.1)	PASS
Global buckling — uplift (finest level; see Sheet 10 note [1])	0.11	0.27	PASS
Snap-through (classical)	0.07	0.23	PASS
Foundation bearing	0.01	0.04	PASS

15.2 13.2 Certified site envelope

Wind: 160 mph, Exposure D. Ground snow: 100 psf (the full severe envelope) — all checks at full factors of safety, governing stability margin 3.92 vs 3.0 on the recorded African-teak door-buck basis (Sheet 10). Conditions: (a) build-QC verification that the installed jambs/header match the recorded species (African teak; published MOE ≈ 9.4–12.2 GPa vs the modeled 8,000 MPa floor — any structural lumber also satisfies it); (b) should a future unit substitute a non-structural buck material, the foam-strength fallback basis rates 96 psf ground snow and an EOR-sized rib on the door-bay flanking panels recovers the full envelope. Sites beyond the severe envelope are outside this package's analyzed range.

16.0 — SHEET 14 — EXCLUSIONS

Not included in this package.

1. Anchor / hold-down design (demand quantified, Sheet 11A) — EOR deliverable, permit prerequisite; connection detail is a Zomes-provided design input
2. Sliding / overturning at foundation interface; foundation and soils design (geotech report or CBC §1806 presumptive values)
3. Fire resistance and life-safety compliance — fire-protection engineer / code consultant scope with product fire testing (foam requires code-compliant thermal barrier)
4. Shape-specific wind pressures — dome-analogy basis disclosed with quantified sensitivities (Sheet 4 note); one-time ASCE 7 Ch. 31 wind-tunnel / validated-CFD study is the product-line closure
5. Enclosure classification — confirm enclosed vs partially enclosed from the door/glazing design per ASCE 7-22 §26.2 (partially-enclosed sensitivity passes all checks)
6. Seismic site overlay — bounding no-credit screening shows wind governs this 13.4 kN structure (review report § XII); site-specific parameters (geotechnical investigation typically required in California) confirm per project
7. Door / window opening local detailing and hardware attachment
8. Long-term material effects: creep certification, UV, temperature, moisture, fatigue (follow-up test program defined in the review report § XII)
9. Construction-phase loads and erection engineering
10. Exterior non-bonded fibre-cement skin (owner exclusion)
11. Site-specific loads (topography, drift, soil) — confirm at permit time

Companion narrative with methodology, validation evidence, and deep-linked sources for every value in this package: ZS-2026-002 Engineering Review Report.