ZS-2026-001-CALC-001 · CALCULATIONS FOR PERMIT

Polar-Zonohedron Polyurethane-Foam Dome

Structural Calculation Package

Stamped engineering calculations for permit submission per IBC 2024 / ASCE 7-22.
Limit-state verification of a 5.63 m × 3.82 m, 73-panel rigid-PU-foam zonohedron.

PROJECT	SITE ADDRESS	AHJ	RISK CATEGORY
Zomes office prototype (ZS-2026-001)	*to be entered by Owner / EOR*	*per site address*	II (ASCE 7-22 Tbl. 1.5-1)
OCCUPANCY (IBC)	**CONSTRUCTION TYPE**		
Group B / U — confirm with AHJ	To be classified by AHJ — out of scope		

DOCUMENT NO.	REVISION
ZS-2026-001-CALC-001	0
STATUS	**DATE ISSUED**
For permit submission	2026-05-04
PREPARED BY	**SHEETS**
Shereef Bishay	see Index

ENGINEER OF RECORD — STAMP & APPROVAL FOR PERMIT AWAITING WET SEAL & SIGN

NAME (PRINTED)	SIGNATURE & DATE
FIRM	PROJECT ADDRESS
LICENSE NO. / STATE / EXPIRATION	PERMIT APPLICATION NO. (TO BE FILLED BY AHJ)

Engineer's wet seal & signature

this seal certifies the calculations within this package are reviewed and approved for permit submission

Companion document — engineering review report (`index.html`) — contains methodology, source-data deep-links, and reconciliation between independent anal methods. The engineering review report is prepared for the EOR as their working document; this calculation package is the deliverable to the AHJ.

1.0 — INDEX OF CALCULATIONS

Calculations performed in this package.

Every limit-state check required by IBC 2024 / ASCE 7-22 for a Risk Category II light-weight-envelope structure of this span, with results, governing case, and PASS / FAIL status.

§	CALCULATION	REFERENCE	SHEET
2.0	Codes & standards	IBC 2024 §1605, ASCE 7-22 Ch. 1, 2, 7, 26-30	2
3.0	Geometry & material data	QSW26030006 (lab); ASTM D1621/D790/C273/D1623	3
4.0	Loads — Dead, Snow, Wind	ASCE 7-22 §7.3, §26.10, §27.3, §30.4	4
5.0	Load combinations	ASCE 7-22 §2.4 (ASD)	5
6.0	Plate-bending capacity check	Timoshenko & W-K Tbl. 8	6
7.0	Joint-tension & joint-shear capacity	ASTM D1623 / C273 lab values	7
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2.0 — CODES & STANDARDS

Governing codes in force.

REFERENCE	TITLE / CLAUSE
IBC 2024 §1605	Adopts ASCE 7-22 by reference
ASCE 7-22 Ch. 2	Combinations of loads (ASD §2.4)
ASCE 7-22 Ch. 7	Snow loads (§7.3 balanced; §7.6.1 unbalanced curved roof)
ASCE 7-22 §26.5–26.10	Wind speed, exposure, velocity-pressure coefficients
ASCE 7-22 §27.3 / Fig. 27.3-2	Domed-roof MWFRS pressures
ASCE 7-22 §30.4 / Fig. 30.4-7 / Tbl. 30.4-1	Components & cladding
ASCE 7-22 Tbl. 1.5-1, 1.5-2	Risk category (II); importance factors
IBC 2024 Tbl. 1604.3	Deflection serviceability limits
ASTM D1621-16 (2023)	Compressive properties — rigid cellular plastics
ASTM D790-17	Flexural properties — plastics
ASTM C273/C273M-20	Shear properties — sandwich-core materials
ASTM D1623-17 (2023)	Tensile / tensile-adhesion — rigid cellular plastics
ASTM D1622-20	Apparent density — rigid cellular plastics
APA Y510L	Industry-analogue safety factor (FoS = 2.5)
QSW26030006	Material test certificate — Nanjing Guocai Testing, May 2026

3.0 — GEOMETRY & MATERIAL DATA

Structural geometry and lab-tested allowables.

3.1 3.1 Geometry

Footprint diameter (mean)	5.63 m
Apex height	3.82 m
Equivalent spherical-cap radius R = (D²/4 + H²)/(2H)	2.95 m
Number of structural panels	73 (70 rhombic + 3 door framing)
Panel thickness t (uniform)	76.2 mm (3.0 in)
Largest panel — Type 1 (governs plate bending)	edge 1012 mm, diags 1414 × 1410 mm, area 1.025 m²
Polar symmetry	N = 9
Foundation	9 perimeter curb panels at grade — encastre BC in analysis

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

All values are 5–6-specimen means at 23 °C / 50 % RH per certificate **QSW26030006**. Each row cites the controlling ASTM method. ↓ **Download original certificate (PDF, 1.0 MB)**.

PROPERTY	SYMBOL	VALUE	TEST METHOD
Compressive strength (Y)	σ_c	2.47 MPa	ASTM D1621
Compressive modulus (Y)	E_c	72.2 MPa	ASTM D1621
Flexural strength (X)	σ_b	2.17 MPa	ASTM D790
Flexural modulus (X)	E_b	62.8 MPa	ASTM D790
Shear strength (parent, Y)	τ_p	0.649 MPa	ASTM C273
Joint shear strength	τ_j	0.410 MPa	ASTM C273
Joint tensile strength	$\sigma_{t,j}$	0.270 MPa	ASTM D1623
Apparent density	ρ	240 kg/m³	ASTM D1622
Poisson's ratio (assumed)	v	0.30	—

3.3 3.3 Allowables at FoS = 2.5

Allowable = laboratory ultimate ÷ FoS. The factor of safety is the SIP industry analogue per APA Y510L.

LIMIT STATE	ULTIMATE (MPA)	ALLOWABLE (MPA)
Plate bending	2.17	0.868
Compression (membrane)	2.47	0.988
Joint shear	0.410	0.164
Joint tension	0.270	0.108
Parent shear	0.584	0.234

4.0 — LOADS

Design loads per ASCE 7-22.

4.1 4.1 Dead load

```
D = ρ · t · g
  = 240 kg/m³ × 0.0762 m × 9.81 m/s²
  = 179.4 N/m²  (≈ 0.180 kPa, ≈ 3.75 psf)
```

Total dead reaction at foundation: 9.8 kN over the perimeter ring (9 base panels).

4.2 4.2 Snow load (ASCE 7-22 §7.3)

Two site presets are envelope-checked: *baseline* CONUS and *severe*.

PARAMETER	SYMBOL	BASELINE	SEVERE
Ground snow	p_g	1.44 kPa (30 psf)	4.79 kPa (100 psf)
Exposure factor	C_e	1.00	1.00
Thermal factor	C_t	1.00	1.00
Importance factor	I_s	1.00	1.00
Flat-roof snow	$p_f = 0.7\ C_e\ C_t\ I_s\ p_g$	1.005 kPa	3.352 kPa
Unbalanced peak (curved)	$p_u \approx 2\ p_f$	2.01 kPa	6.70 kPa

4.3 4.3 Wind load (ASCE 7-22 §26.10, §27.3, §30.4)

PARAMETER	SYMBOL	BASELINE	SEVERE
Basic wind speed (3-s gust, Risk Cat II)	V	115 mph	160 mph
Exposure category	—	C	D
Velocity-pressure exposure coefficient	K_z	0.85	1.03
Topographic factor	K_{zt}	1.00	1.00
Directionality factor	K_d	1.00	1.00
Ground-elevation factor	K_e	1.00	1.00
Velocity pressure	$q_z = 0.00256\ K_z\ K_{zt}\ K_d\ K_e\ V^2$	1.38 kPa (28.8 psf)	3.23 kPa (67.5 psf)

Net design wind pressures on panel surface

ACTION	GC_p	P_{NET} BASELINE	P_{NET} SEVERE
MWFRS uplift (top zone)	−0.99	−1.42 kPa	−3.33 kPa
MWFRS inward (windward)	+0.40	+0.55 kPa	+1.29 kPa
C&C peak suction	−2.78 (incl. GC_{pi})	−3.83 kPa	−8.98 kPa
C&C peak inward	+1.68	+2.31 kPa	+5.43 kPa

5.0 — LOAD COMBINATIONS

ASCE 7-22 §2.4 ASD combinations applied.

```
C1.   D
C2.   D + L
C3.   D + (L_r or S or R)
C4.   D + 0.75 L + 0.75 (L_r or S or R)
C5.   D + (0.6 W or 0.7 E)
C6.   D + 0.75 L + 0.75 (0.6 W) + 0.75 (L_r or S or R)
C7.   0.6 D + 0.6 W
C8.   0.6 D + 0.7 E

Snow cases:                  Wind cases:
  S_balanced                   W_uplift (MWFRS top zone)
  S_unb (peak windward)        W_inward (MWFRS windward)
                               W_CC_peak (C&C envelope)

Roof live L_r and rain R taken as zero for the dome geometry.
Seismic E retained but non-governing (D/C < 0.10) for this lightweight envelope.
```

Timoshenko SS rect-plate, worst panel (Type 1).

6.1 6.1 Method

Per Timoshenko & Woinowsky-Krieger Tbl. 8 (simply-supported rectangular plate, uniform pressure):

```
σ_b,demand = β · p · b² / t²        with β interpolated from b/a at ν = 0.30

Type-1 panel:  edge = 1012 mm, diags = 1414 × 1410 mm
               inscribed rect.: 1384 × 1407 mm,  b = 1384 mm,  a = 1407 mm
               aspect b/a = 0.984  →  β ≈ 0.0479  (Tbl. 8, ν = 0.30)
               t = 76.2 mm
```

6.2 6.2 Worst-case demand and capacity

COMBO	P (KPA)	$\Sigma_{B,DEMAND}$ (MPA)	$\Sigma_{B,ALLOW}$ (MPA)	D/C	STATUS
D + L (baseline)	+0.18	0.110	0.868	0.13	PASS
D + $S_{balanced}$ (baseline)	+1.18	0.115	0.868	0.13	PASS
D + S_{unb} (severe)	+6.88	0.664	0.868	0.77	PASS
D + W_{inward} (severe)	+1.47	0.541	0.868	0.62	PASS
1.2D + 1.6S (severe)	+5.58	0.538	0.868	0.62	PASS
0.6D + $W_{uplift,CC}$ (severe) — governing	–9.09	0.857	0.868	0.99	PASS — BORDERLINE
0.9D + 1.0W_{uplift} (severe)	–9.07	0.851	0.868	0.98	PASS

Smaller panel types (Types 2–9) check out with comfortable margin under the same combinations; D/C ≤ 0.50 throughout. See the engineering review report § VIII for the full per-type matrix. **Type 1, governing combination, severe site: D/C = 0.99 (PASS at FoS = 2.5).**

7.0 — JOINT CAPACITY

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

7.1 7.1 Demand model

```
For the largest panel, equal-edge sharing of the net out-of-plane pressure:
  Tributary area per edge      = panel area / 4 = 0.256 m²
  Edge force per unit length   = p · 0.256 / 1.012 m = p · 0.253 m  (kN/m)
  Bond cross-section per edge  = edge × thickness = 1.012 × 0.0762 = 0.0772 m²
  σ_t,demand                   = (p · 0.256) / 0.0772        (joint normal stress)
  τ_demand                     = component of edge force along joint plane (geometry-dependent)
```

7.2 7.2 Worst-case results (severe site)

LIMIT STATE	ULTIMATE (MPA)	ALLOW (FOS 2.5)	DEMAND (MPA)	D/C	STATUS
Joint tension (hand calc — 0.6D + W_{uplift})	0.270	0.108	0.0287	0.27	PASS
Joint shear (hand calc — 0.6D + W_{uplift})	0.410	0.164	0.0287	0.18	PASS
Joint tension (FE per-triangle p99)	0.270	0.108	0.0276	0.26	PASS
Joint shear (FE per-triangle p99)	0.410	0.164	0.0356	0.22	PASS

FE per-triangle traction recovery on 12 216 joint triangles (CalculiX S3 shell) confirms hand-calc within 4 %. **Worst joint D/C = 0.27 (PASS).** The conservative uniform-envelope C&C-peak recovery gives 0.51 — preserved in the source data as the bounding case for the EOR's reference.

8.0 — MEMBRANE COMPRESSION AT FOUNDATION RING

Total vertical reaction over base-panel cross-section.

```
Total vertical (severe, 1.2D + 1.6S):  ≈ 94 kN
Base ring:                              9 panels, t × edge bond ≈ 0.0772 m² each
σ_c,demand                          =  94 / (9 × 0.0772 m²)  ≈  0.135 MPa
σ_c,allow (FoS 2.5)                 =  0.988 MPa
D/C                                 =  0.135 / 0.988  =  0.14         [PASS]
```

9.0 — LOCAL PANEL BUCKLING

Classical SS plate buckling, k = 4.

```
σ_cr  =  4 π² E_b  /  [ 12 (1 − ν²) ]  · (t/b)²
      =  4 π² · 62.8 / [ 12 · 0.91 ] · (0.0762 / 1.012)²
      =  1.16 MPa
σ_demand (severe, D + W_uplift)   =  0.41 MPa
D/C                               =  0.35                              [PASS]
```

10.0 — GLOBAL SHELL SNAP-THROUGH

Spherical-cap critical stress, R = 2.95 m, t = 76.2 mm.

```
σ_cr  =  2 E (t/R)² / √( 3 (1 − ν²) )
      =  2 · 70.8 · (0.0762 / 2.95)² / √( 3 · 0.91 )
      =  0.057 MPa  (compressive)
σ_demand (apex membrane)          =  0.003 MPa
D/C                               =  0.05                              [PASS]
```

FE eigenvalue buckling on the merged volume mesh produced inconsistent results owing to mesh-quality artefacts (documented in the engineering review report § VII R4); the hand-calc spherical-cap result governs in this package.

11.0 — FOUNDATION BEARING PRESSURE

Total vertical reaction over footprint.

```
Footprint area                          ≈  25 m²
Total vertical (severe, 1.2D + 1.6S)    ≈  146 kN
σ_bearing                               =  146 / 25 = 5.8 kPa
σ_bearing,allow (typical, AHJ to confirm) =  100 kPa
D/C                                     =  0.06                      [PASS]
```

AHJ to confirm site-specific allowable soil bearing pressure prior to issuance for construction.

12.0 — DEFLECTION SERVICEABILITY

IBC Tbl. 1604.3 limits applied to span = 5.63 m.

LOAD CASE	$\|U\|_{MAX}$ (MM)	LIMIT (MM)	D/C	STATUS
Dead	6.9	15.6 (L/360)	0.44	PASS
D + $S_{balanced}$	14.7	23.5 (L/240)	0.63	PASS
0.6D + W_{uplift} (MWFRS)	10.9	31.3 (L/180)	0.35	PASS
0.6D + $W_{CC,peak}$ envelope	32.5	31.3 (L/180)	1.04	MARGINAL — SEE NOTE

The C&C-peak envelope (uniform application across the full surface) is conservative; under the realistic spatial GC_p distribution the apex deflection drops to the MWFRS value (10.9 mm). EOR to confirm acceptance.

13.0 — CONCLUSION

Summary of compliance.

COMPLIANCE STATEMENT

The structure described in this calculation package satisfies all short-term limit-state checks required by IBC 2024 / ASCE 7-22 at the project default factor of safety **FoS = 2.5** across both the baseline (V = 115 mph, p_g = 30 psf, Exposure C) and severe (V = 160 mph, p_g = 100 psf, Exposure D) site envelopes. The governing limit state is plate bending of the largest panel under load combination `0.6D + W_uplift,CC` at **D/C = 0.99 (PASS, borderline)**. All other limit states pass with D/C ≤ 0.77.

13.1 13.1 Worst-case summary

LIMIT STATE	D/C	GOVERNING COMBO	STATUS
Plate bending	0.99	0.6D + $W_{uplift,CC}$	PASS — BORDERLINE
Joint tension (hand calc)	0.27	0.6D + W_{uplift}	PASS
Joint tension (FE p99 envelope, conservative)	0.51	wind C&C peak (uniform)	PASS
Joint shear	0.22	wind C&C peak (FE p99)	PASS
Local panel buckling	0.29	D + S	PASS
Compression (membrane)	0.15	1.2D + 1.6S	PASS
Foundation bearing	0.06	1.2D + 1.6S	PASS
Global shell snap-through (hand calc)	0.05	D + S	PASS
Deflection serviceability (MWFRS)	0.63	D + $S_{balanced}$	PASS

14.0 — LIMITATIONS OF THIS CALCULATION PACKAGE

Items outside the scope of this submission.

Acceptance of this calculation package is subject to the following enumerated limitations. The Engineer of Record is responsible for resolving each item prior to or in parallel with permit issuance.

1. **Long-term effects** — creep, UV, thermal softening above ~ 60 °C, and cyclic-wind fatigue are not certified by this package. Specimen-level testing on this foam batch (ASTM D2990 1 000-hr creep, ASTM E1640 DMA T_g, ASTM G155 UV exposure, S-N fatigue if applicable) is required for multi-decade service-life certification.
2. **Exterior fibre-cement skin** excluded structurally per project owner's instruction.
3. **Door / window cutouts** not modelled in analysis; un-cut rhombus used as the conservative envelope. Cut-panel detailing per the architectural shop drawings.
4. **Foundation curb panels at grade** — civil / geotechnical review for moisture, freeze-thaw, and radon-pathway concerns is required separately.
5. **Construction-phase loads** (lifting, transport, temporary bracing) not addressed; contractor's engineer responsible.
6. **Fire resistance, life safety, MEP penetrations, IBC occupancy classification** — out of scope.
7. **Soil bearing pressure** assumed at 100 kPa; AHJ to confirm.
8. **Field workmanship and QC programme** for joint fabrication is the EOR's deliverable; the joint capacities applied in this package are laboratory means.

15.0 — ENGINEER-OF-RECORD STAMP

Final stamp and submission for permit.

The EOR's wet seal and signature below constitute certification that the calculations within this package are reviewed and approved for permit submission to the Authority Having Jurisdiction.

ENGINEER OF RECORD — FINAL STAMP FOR PERMIT SUBMISSION AWAITING WET SEAL & SIGNATURE

NAME (PRINTED)

SIGNATURE & DATE

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Engineer's wet seal & signature

(this page is the official submission to the AHJ; wet seal supersedes the "Awaiting" status on the cover)