ER-87496

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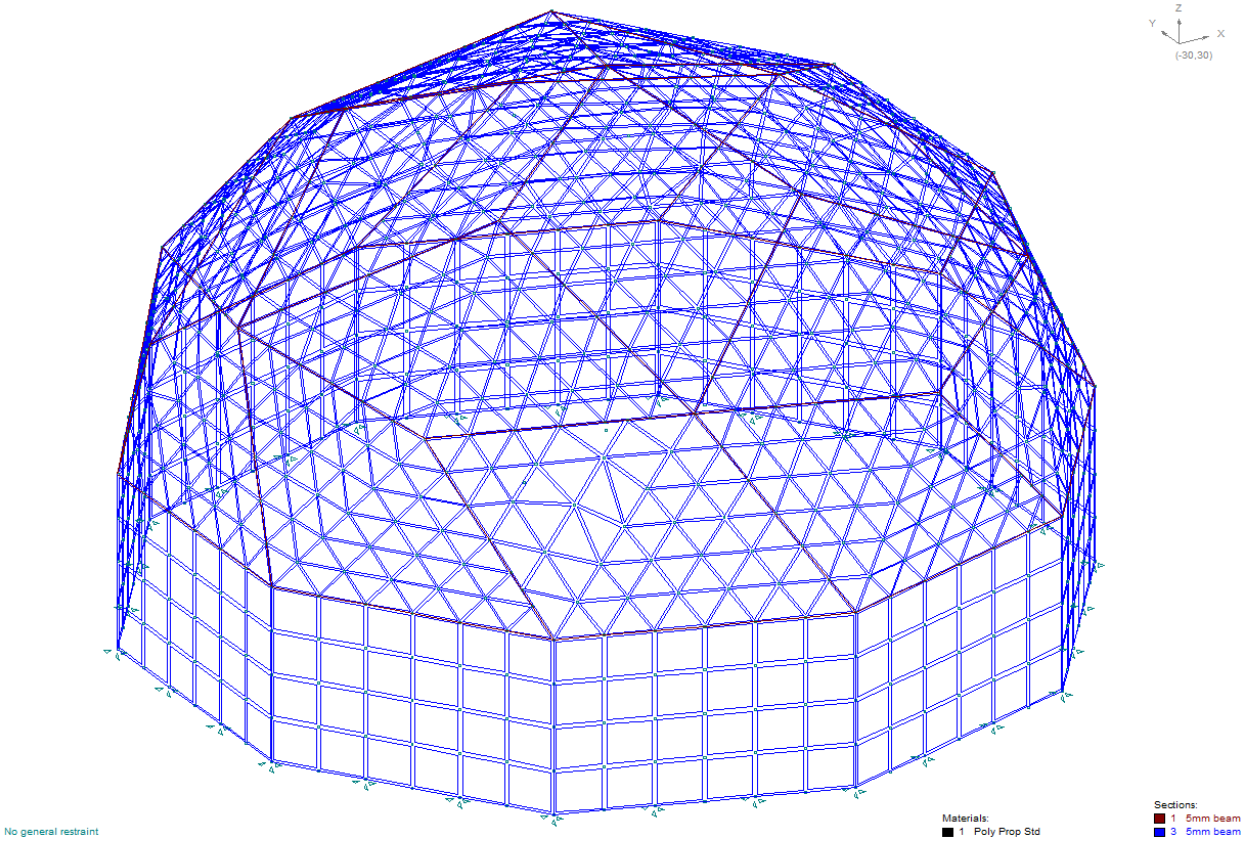
U-Dome 200

Dome Shelter

Engineering Report:

Dome Structure

30 October 2009



engineering review

i n t e r n a t i o n a l

1.0 Introduction

This report summarizes analysis results of a 16 ft (4.8 m) diameter x 11 ft 10 inch (3.6 m) tall dome. The lower wall is nearly 3 ft 10 inches (1.17 m) tall and the upper dome is a 2 frequency icosahedron. The enclosed area in plan is some 200 ft^2 (18 m^2).

The dome material is made of flame retardant 5 mm thick corrugated polypropylene panels connected with nylon fasteners. Checking of the actual foundation and fasteners is beyond the scope of this report but a minimum fastener load capacity is provided for the design capacity loads.

2.0 Summary

The materials used for construction of the dome are not defined in the 2006 International Building Code (2006 IBC) so testing of panel strength and deflection has been performed to use in the analysis. The limiting environmental loads have been determined to provide a 1.9 safety factor against panel buckling. Individual panel segments may deflect to the interior side up to 6" during capacity loading but still maintain significant load capability during high wind loading.

Resulting capacities of the system are:

Roof Live /Snow load: 12 psf.

Wind load:
- Exposure B locations 90 mph (145 km/hr) 3 second gust
(Urban and suburban areas, wooded areas or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger – within 1,500 ft (457 m) upwind).

-Exposure C locations 74 mph (119 km/hr) 3 second gust
(Open terrain with scattered obstructions having heights generally less than 30 feet (9.1 m). This category includes flat open country, grasslands, and all water surfaces in hurricane-prone regions).

The foundation attachment at each corner (10 total locations) must be able to withstand 167 lbs (76 kg) uplift and 95 lbs (43 kg) lateral.

3.0 Input Data

Documentation provided by World Shelters to conduct the structure analysis includes:

1. Panel construction of 5mm Polypropylene co-polymer with a density of 90 g/cc, tensile strength at yield of 4000 psi and elongation at yield of 10%.

Assumptions made by Engineering Review International include:

1. U-domes are not placed adjacent to the top of escarpments, hills or ridges that could result in increased wind loading.
2. A safety factor of 1.9 against panel buckling has been used to determine dome loading capacities of live/snow and wind.

3. With a total self weight of structure less than 200 lbs, earthquake loads will not govern.

4.0 Loading

Using methods from the 2006 IBC, the structure is checked for a 90 mph 3 second gust wind speed for wind exposure B. Wind loading on the dome surface is approximated using ASCE Standard 7-05 and specifically figure 6-7 for domed roofs. A roof live/snow load capacity of 12 psf is determined.

The loading conditions modeled for the steel structure include:

10.	D	Dead
11.	D + Lr/S	Dead + Roof Live/Roof Snow load of 12 psf
12.	D + W	Dead + Wind for 90 mph exp B

5.0 System Analysis

The analysis is completed using the program Spacegass which is described in Appendix B. A summary of the analysis model is included in Appendix C. The dome is modeled with panel elements connected to the folded beam elements made of the same material as the panels. The beam element moments are released at the ends. In this finite element model, non linear affects of large displacements are accounted for. Global buckling values exceed 12 so local plate buckling controls.

Appendix A

Calculations:

- Loads
- Material Property Test
- Panel Stress Plots

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subject LOADS

1. ROOF LIVE / SNOW — IBC 2006

Typical structures require a 20psf live load reducible to 12psf for larger areas.

As personnel access is not required for the dome, use 12psf

2. WIND LOAD — ASCE 7-05

THE TARGET DESIGN WIND LOAD = 90mph 3 second gust
WIND exposure B

MAX. HEIGHT ≤ 12 FT.

EXTERNAL PRESSURE coef. C_p for Domed Roofs is CONTAINED IN FIGURE 6-7.

$f = 96"$ $\quad f/D = 0.5$

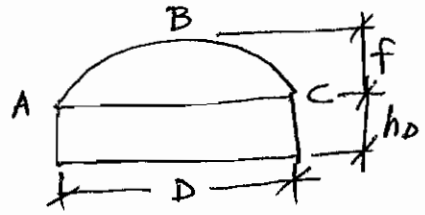
$D = 192"$

$h_D = 46"$ $\quad h_D/D = 0.24$

C_p at A = +0.80

C_p at B = −1.35

C_p at C = −0.25



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2. CONT. (WIND)

MWFRS - METHOD 2

$$q_z = 0.00256 K_z K_{zt} K_d V^2 I$$
$$= 0.00256(0.57)1.0(0.85)90^2(1.0)$$
$$= 10.05 \text{ psf}$$

$$p = qGC_p - q_i(GC_{pi}) \qquad 6\text{-}17$$

where for an enclosed structure, $GC_{pi} = \pm 0.18$
use $-0.18(10.05) = -1.81$ psf for max. uplift

@A $p = 10.05(0.85)0.80 - 1.81 =$ +5.0 psf windward

@B $p = 10.05(0.85) - 1.35 - 1.81 =$ -13.3 psf top

@C $p = 10.05(0.85) - 0.25 - 1.81 =$ -3.9 psf leeward

INTERPOLATION IS used between A & B and B & C.

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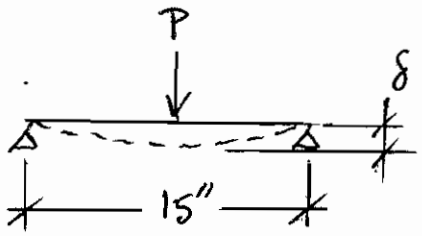
subject MATERIAL PROPERTY TEST

1. TEST DESCRIPTION



6.8125" wide

TEST WITH FLUTES ⊥ SPAN

P	δ	f_b effective
3.0 lbs	−0.83"	239 psi
6.2 lbs	−1.79"	488 psi
10.4 lbs	− failure	814 psi

TEST WITH FLUTES // SPAN

P	δ	f_b effective
3.0 lbs	−0.78"	239 psi
6.2 lbs	−1.60"	488 psi
10.4 lbs.	−2.66"	814 psi

2. MATERIAL PROPERTIES

USE MODULUS OF ELASTICITY = 69,000 psi

MAX. PANEL VM STRESS = $\frac{814}{1.9}$ = 428 psi

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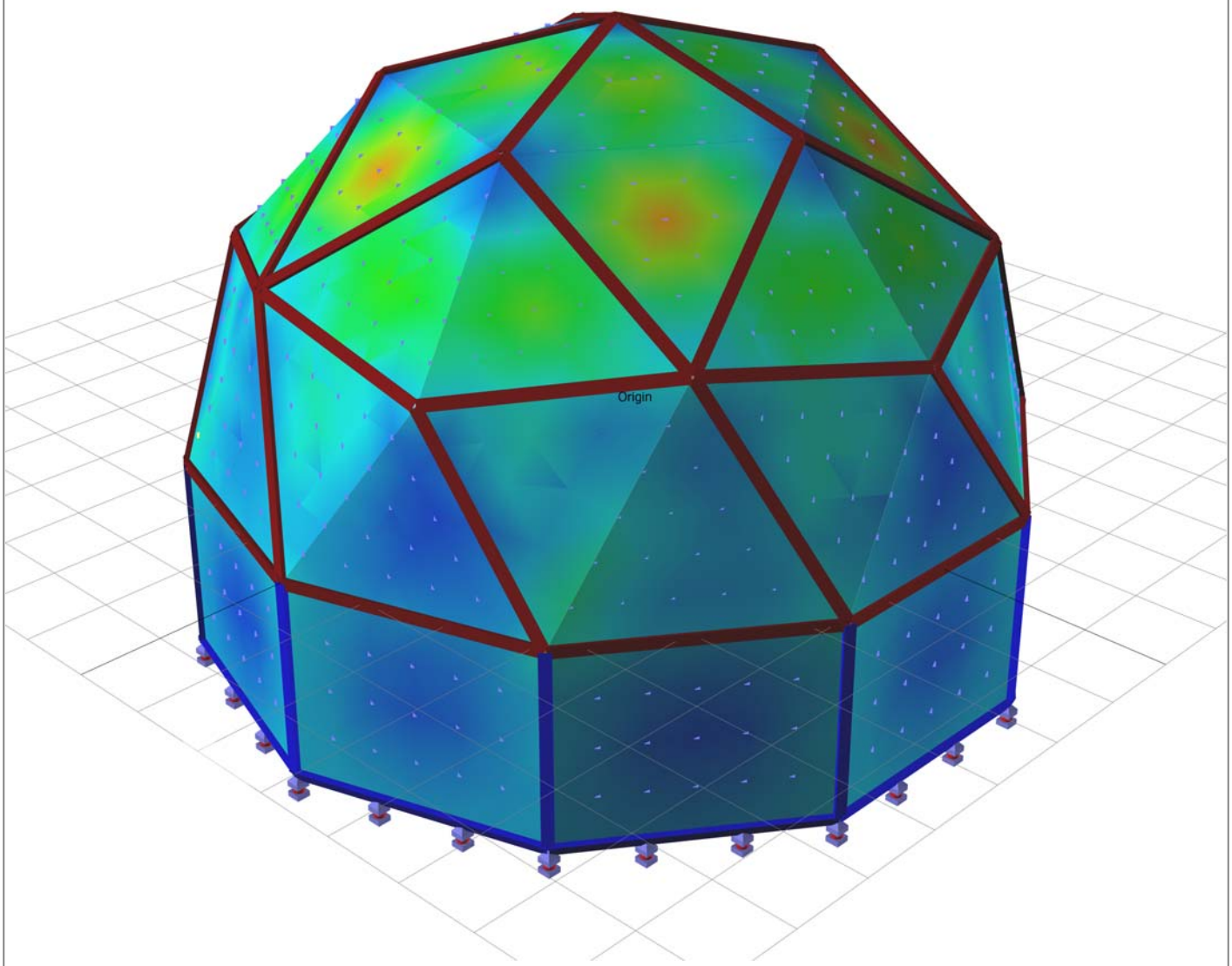
Load case 10 - D

Von Mises Stress:

- 5.26Psi
- 4.63Psi
- 4.00Psi
- 3.37Psi
- 2.74Psi
- 2.11Psi
- 1.48Psi
- 0.86Psi
- 0.23Psi



Materials:

- 1 Poly Prop Std

Sections:

- 1 5mm beam
- 3 5mm beam

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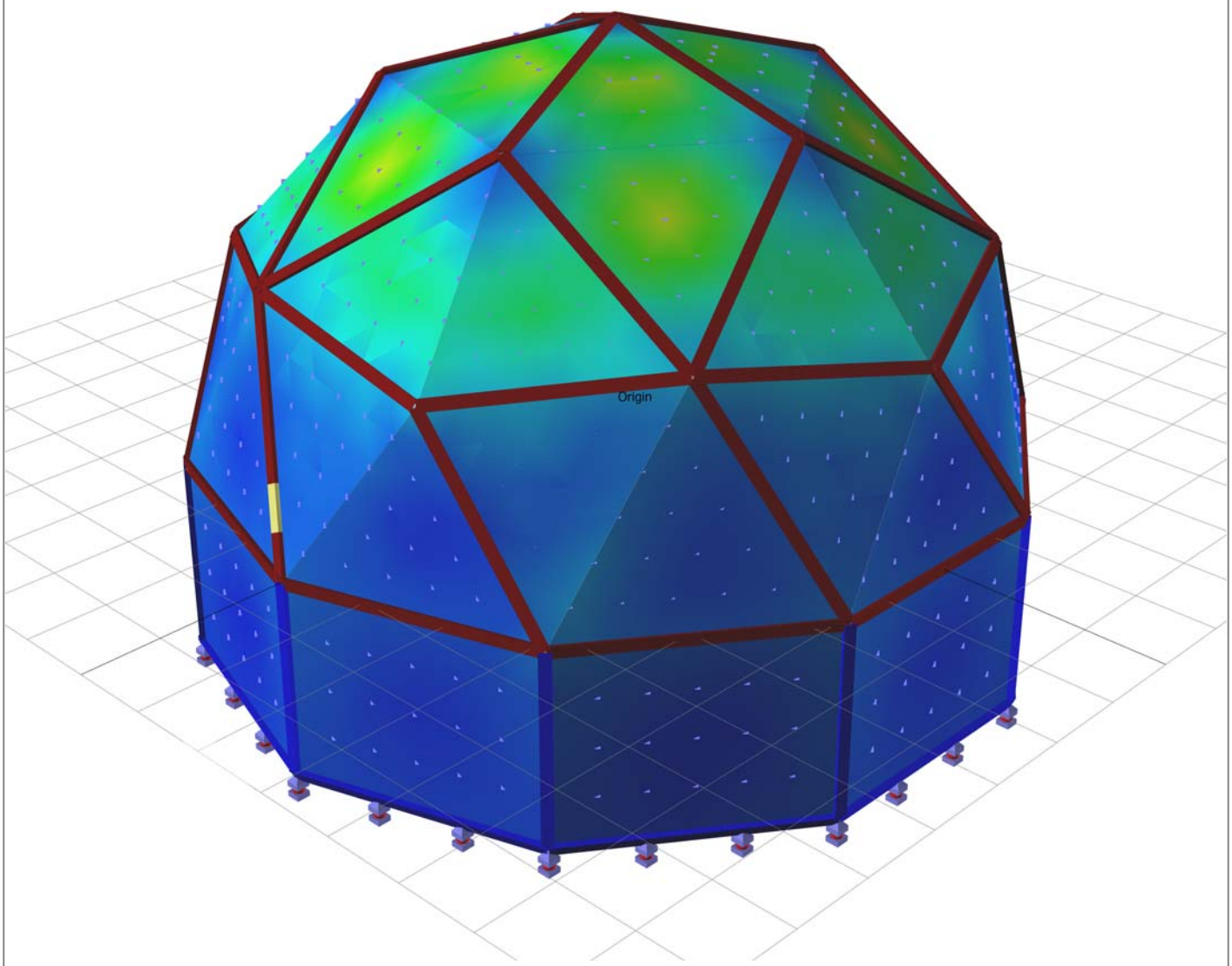
Load case 11 - D+Lr

Von Mises Stress:

- 295.73Psi
- 259.08Psi
- 222.44Psi
- 185.80Psi
- 149.15Psi
- 112.51Psi
- 75.86Psi
- 39.22Psi
- 2.58Psi



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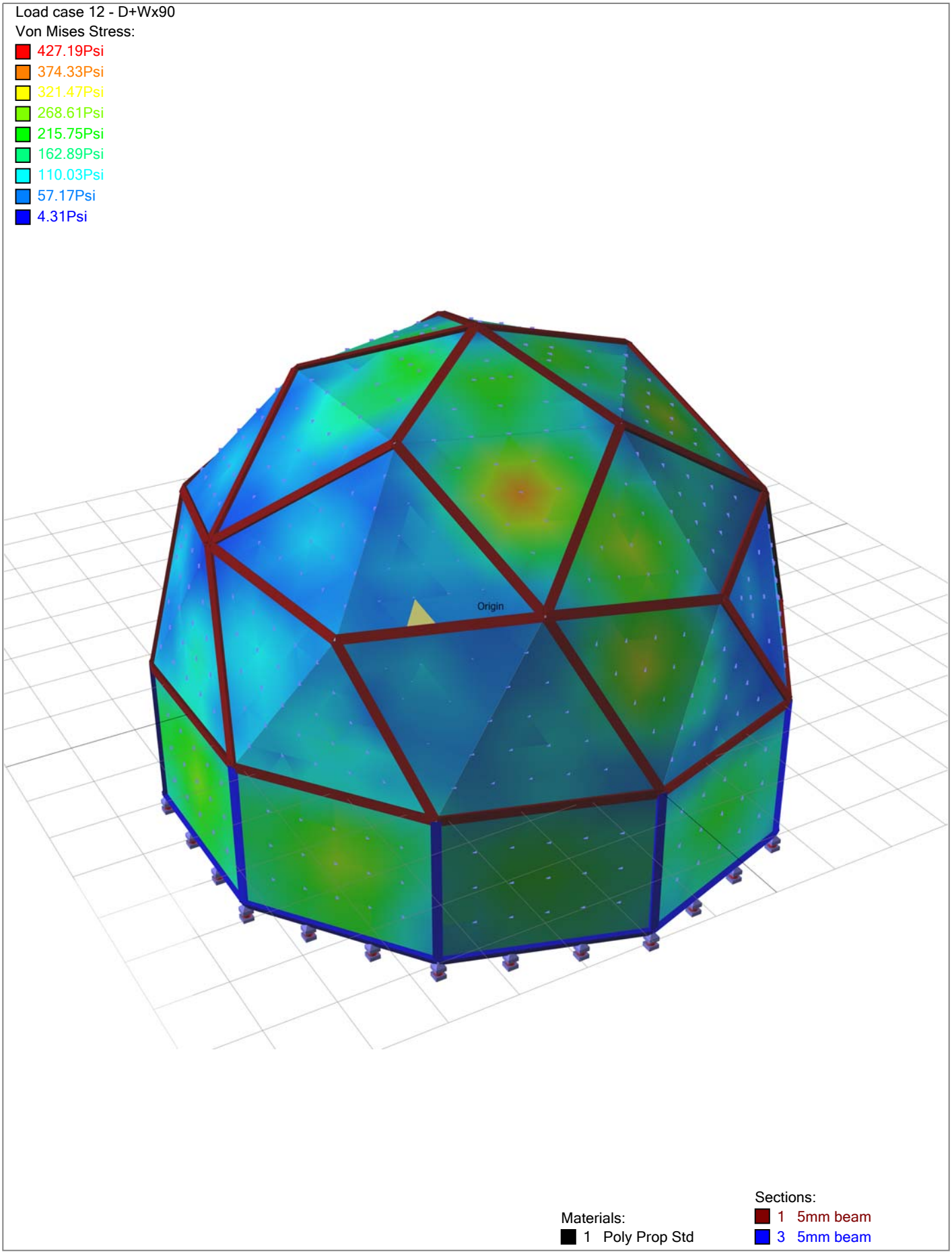

Appendix B

Analysis Program description - SPACEGASS

TITLE: 3D or 2D general frame analysis and steel design. ACCESSIBILITY: Any computer running Windows 95, 98, NT, 2000 or ME.

MAINTENANCE: Integrated Technical Software

CAPABILITY: Analyses 3 dimensional frames with straight prismatic members. Capacity is theoretically unlimited but depends on the available memory in the computer. Units may be any consistent set. Input methods include graphical input, datasheet input, free format text file input, standard structure input and CAD input.

Features include linear and non-linear static analysis, dynamic frequency analysis, dynamic response analysis, buckling analysis, master-slave constraints, tension-only members, compression-only members, cable members, 3D member offsets, extensive data generation facilities, non-sequential numbering, automatic re-numbering, elastic supports, complete or partial member end fixity, comprehensive data checking for inconsistencies and instabilities and wavefront analysis method with wavefront optimizer.

Permissible loading conditions include any combination of concentrated and distributed forces and moments on nodes and members, thermal loads, self weight, and prescribed node displacements. Numerous primary and combination load cases can be analyzed in a single run. Frames or sub-frames can be moved, rotated, copied or mirrored. Section and material properties can be input manually or can be read directly from a library. Data can be transferred into or from a CAD program such as AutoCAD via DXF files.

Integrated steel member design modules for the latest codes including AISC-LRFD (17), AISC-ASD (16), EUROCODE 3 (18), AS1250 (3), AS4100 (4), SABS0162 (5), BS5950 (6), NZS3404 (7), AS3990 (11) and AS/NZS4600 (13). Selected members or the entire frame can be designed or checked in accordance with the appropriate code.

Integrated steel connection design and drafting module for AS4100 (4). Connections can be designed and connection drawings can be viewed, printed or exported to DXF files.

Integrated concrete design module for AS3600 (14). Selected members or the entire frame can be designed or checked in accordance with the code.

INPUT:Node coordinates, member connectivity and fixity, node restraints, section and material properties, master-slave constraints, member offsets, node loads, prescribed displacements, member concentrated and distributed loads, self weight, combination load cases, load case titles, lumped masses, dynamic response spectra, steel member design data, steel connection design data and concrete design data.

OUTPUT: Printout of all input data plus displacements, forces, moments, reactions, stresses, equilibrium summary, bill of materials, centre of gravity coordinates, dynamic

natural frequencies and mode shapes, buckling load factors and member effective lengths, steel member design results, steel connection design results and concrete design results. Output can be chosen selectively and can be limited to user defined nodes, members, load cases, member design groups and connections. Results envelopes can be produced. Deflections, forces and moments can be output at numerous points along members (not just at the end nodes). Graphical output on screen, printer or plotter includes the frame geometry, loading diagrams, deformed geometry, bending moment diagrams, shear force diagrams, axial force diagrams, stress diagrams, dynamic mode shapes, buckling mode shapes, 3D full member geometry with hidden line removal, steel connection drawings, concrete column interaction diagrams.

METHOD: Stiffness analysis method using wavefront equation solver with optimization.

LANGUAGE: Fortran and C.

AUTHORS: Integrated Technical Software

DOCUMENTATION: Comprehensive user manual with worked examples.

INFORMATION: www.spacegass.com

ABSTRACT BY: Integrated Technical Software

Appendix C

Spacegass Models, UD200-01.sg

- Model images with property and support node number locations
- Model deflected shape for Wind
- Input/Output Summary of Model

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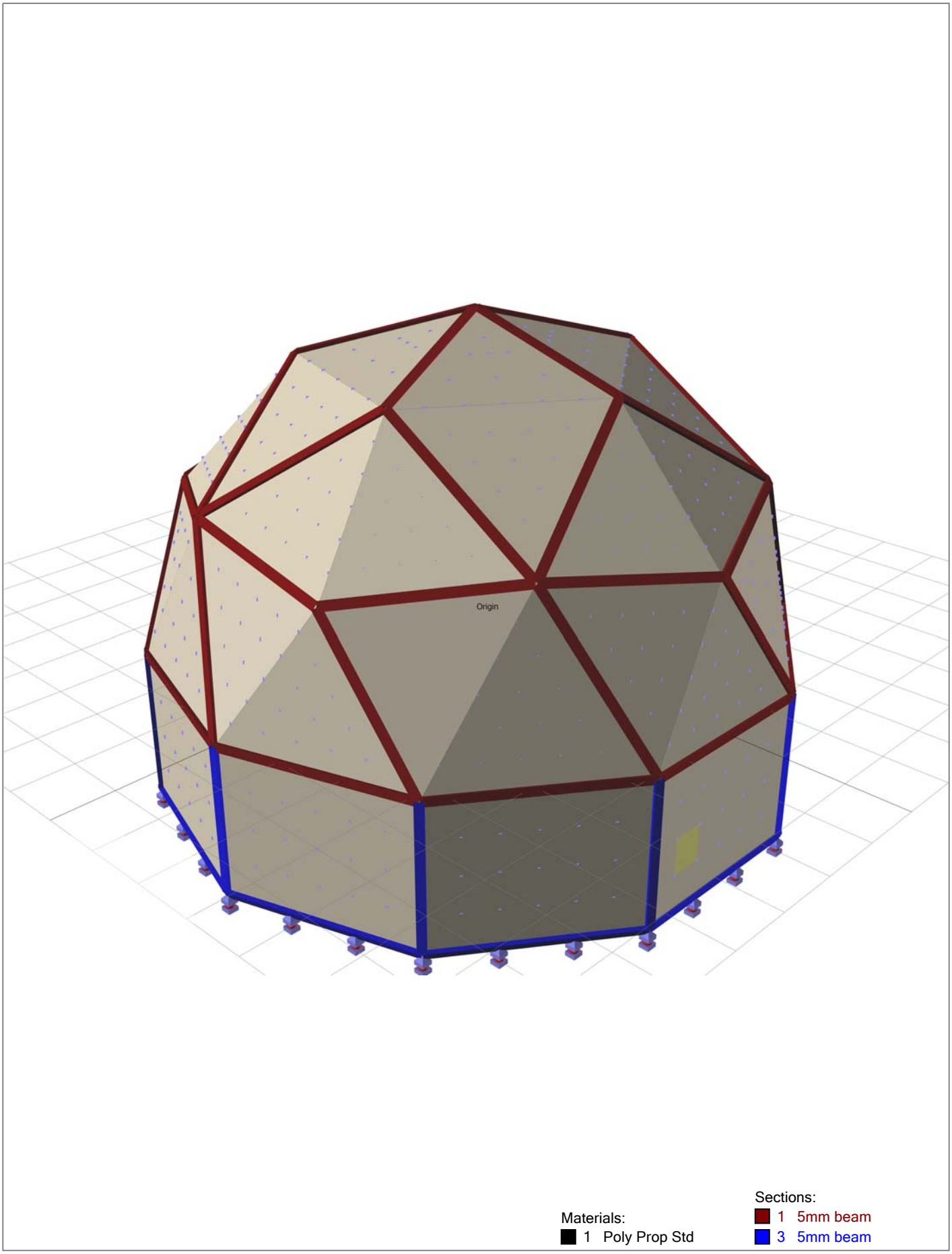

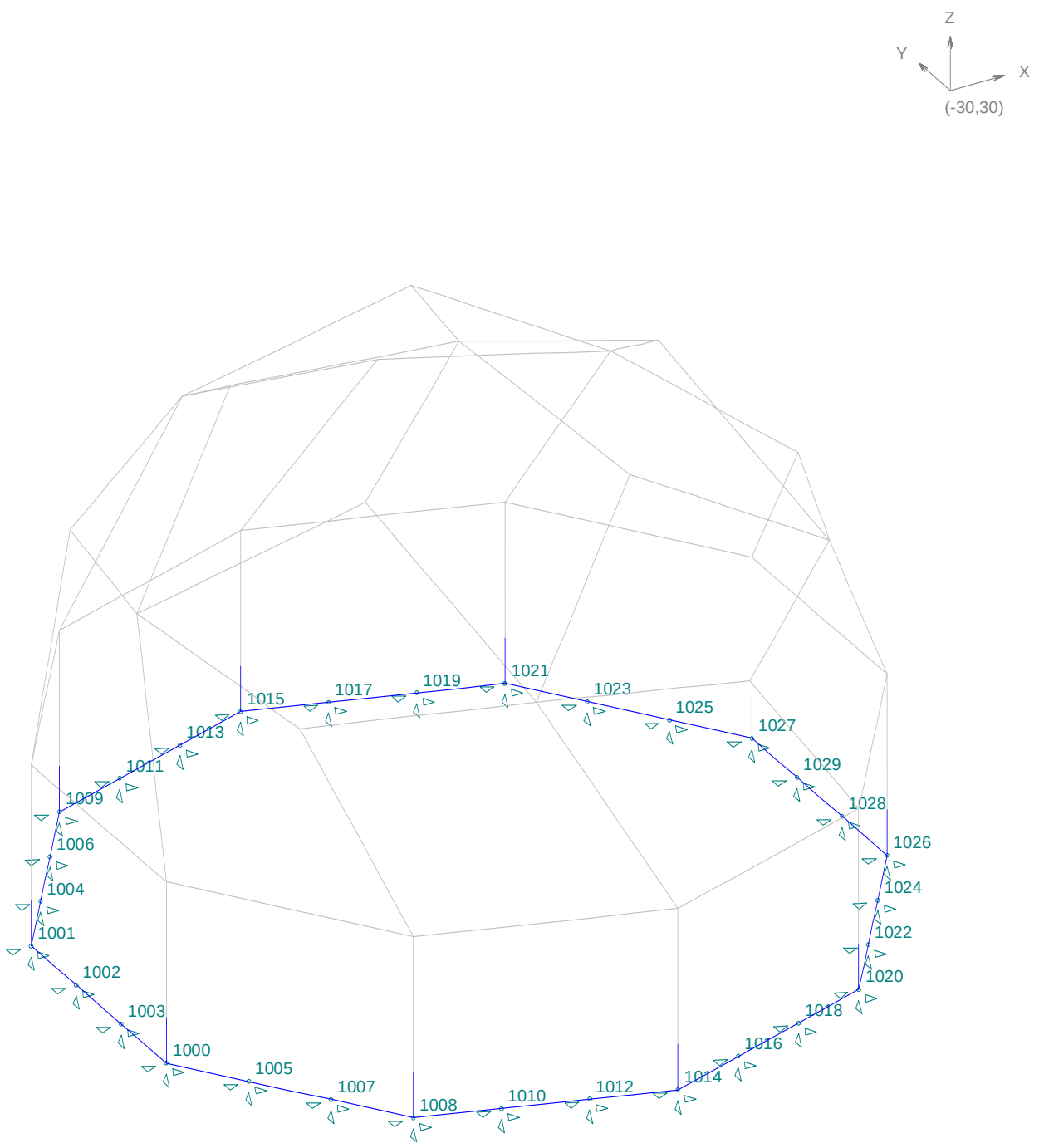

Support Node Numbers
No general restraint

Materials:
1 Poly Prop Std

Sections:
3 5mm beam