Annex G
(normative)

Structurally-Supported Aluminum Dome Roofs

G.1 General

G.1.1 Purpose

This Annex establishes minimum criteria for the design, fabrication, and erection of structurally-supported aluminum dome roofs. When this Annex is applicable, the requirements of 5.10 and the paragraphs in Annex F that deal with roof design are superseded. All other requirements of API Standard 650 shall apply, except that the maximum design temperature shall not exceed 90 °C (200 °F).

G.1.2 Definition

A structurally-supported aluminum dome roof is a fully triangulated aluminum space truss with the struts joined at points arrayed on the surface of a sphere. Aluminum closure panels are firmly attached to the frame members. The roof is attached to and supported by the tank at mounting points equally spaced around the perimeter of the tank.

G.1.3 General Application

G.1.3.1 New Tanks

When this Annex is specified for a new tank, the tank shall be designed to support the aluminum dome roof. The roof Manufacturer shall supply the magnitude and direction of all the forces acting on the tank as a result of the roof loads, together with details of the roof-to-shell attachment. The tank shall be designed as an open-top tank, and its wind girder shall meet the requirements of 5.9. The top of the tank shell shall be structurally suitable for attachment of the dome roof structure. The tank Manufacturer and the foundation designer shall be responsible for designing the tank and foundation, respectively, for the loads and moments transmitted from the roof, as provided by the roof manufacturer. If the Purchaser specifies a roof with fixed supports, the supports shall be rigidly attached directly to the tank and the top of the tank shall be designed to sustain the horizontal thrust transferred from the roof (see G.5.2). The as-built minimum and maximum diameter at the top of the tank shall be reported to the roof manufacturer by the Purchaser or the tank Manufacturer.

- #### G.1.3.2 Existing Tanks

When this Annex is specified for an aluminum dome roof to be added to an existing tank (with or without an existing roof), the roof Manufacturer shall verify that the tank has sufficient strength to support a new roof and meet the applicable requirements of Section 5.11. Information on the existing tank shall be provided by the Purchaser including minimum tank shell course thicknesses, tank shell course heights, design corrosion allowance, and existing anchorage details. The Purchaser shall specify the existing or new appurtenances to be accommodated by the roof Manufacturer. The roof Manufacturer shall supply the values of the forces acting on the tank as a result of the roof loads. The Purchaser shall verify the adequacy of the foundations. Unless otherwise specified, any reinforcement required to enable the tank to support the roof shall be the responsibility of the Purchaser. The design and erection of the roof shall accommodate the actual tank shape. The responsibility for determining the tank shape shall be specified by the Purchaser. The existing tank shall be equipped with a wind girder that meets the requirements of 5.9 for an open-top tank.

- #### G.1.3.3 Existing Tank Data Sheet

When an aluminum dome is ordered for an existing tank, a data sheet shall be completed by the Purchaser (see Figure G.1).

DATA SHEET FOR A STRUCTURALLY-SUPPORTED ALUMINUM DOME ADDED TO AN EXISTING TANK

JOB NO. _____ ITEM NO. _____
PURCHASE ORDER NO. _____
REQUISITION NO. _____
INQUIRY NO. _____
PAGE 1 OF 1 BY _____

(INFORMATION TO BE COMPLETED BY THE PURCHASER)

1. PURCHASER/AGENT _____
   ADDRESS _____
   CITY _____ STATE _____ ZIP _____
   PHONE _____ FAX _____
2. USER _____
3. ERECTION SITE:NAME OF PLANT _____
   LOCATION _____
4. TANK NO. _____
5. PUMPING RATES: IN _____ m^3/h (bbl/h) OUT _____ m^3/h (bbl/h)
6. MAXIMUM DESIGN TEMPERATURE _____ (NOT TO EXCEED 90 °C [200 °F])
7. DESIGN PRESSURE: ◯ ATMOSPHERIC OR _____ kPa (in.) OF WATER (INDICATE WHETHER POSITIVE OR NEGATIVE)
8. ROOF LOADS: UNIFORM LIVE _____ kPa (lbf/ft^2)
   SPECIAL (PROVIDE SKETCH) _____ kPa (lbf/ft^2)
9. SEISMIC DESIGN: ◯ YES ◯ NO ◯ ANNEX E ◯ OR ALTERNATE SEISMIC CRITERIA _____
   IF ANNEX E, CONTINUE HERE SEISMIC USE GROUP _____ MBE SITE CLASS _____
   BASIS OF LATERAL ACCELERATIONS (SELECT ONE):
   ◯ MAPPED SEISMIC PARAMETERS, %g (E.4.1) S_S_____ S_1_____ S_0_____
   ◯ SITE-SPECIFIC SPECTRAL RESPONSE ACCELERATIONS (E.4.2); MCE DESIGN REQUIRED ◯ YES ◯ NO
   ◯ OTHER (NON-ASCE) METHODS _____
   VERTICAL SEISMIC DESIGN? ◯ YES ◯ NO; VERTICAL EARTHQUAKE ACCELERATION COEFFICIENT A_v, %*g*: _____
   GROUND SNOW LOAD (IF NOT FROM ASCE 7): _____ kPa (lbf/ft^2)
10. DESIGN WIND SPEED: (SELECT ONE) ◯ 190 Km/h (120 mph)
    ◯ PURCHASER SPECIFIED WIND SPEED (50-YHR MIN. 3-SEC GUST) _____Km/h (mph)
    ◯ 3-SEC GUST FROM ASCE 7, FIGURE 6-1 _____Km/h (mph)
    IMPORTANCE FACTOR (IF OTHER THAN 1.0) _____
    EXPOSURE CATEGORY PER ASCE 7 _____
    _____ Km/h (mph)
11. MAXIMUM HEIGHT FROM TOP OF SHELL TO TOP OF DOME _____m (ft)
12. TANK SHELL THICKNESS (ACTUAL)

COURSE NUMBER	MINIMUM THICKNESS	TYPICAL THICKNESS	PLATE WIDTH

13. ACTUAL TANK STIFFENER DETAILS, POSITION AND DIMENSIONS (PROVIDE SKETCH)
14. GASES EXPECTED IN THE VAPOR SPACE _____
15. REQUIRED FREEBOARD ABOVE TOP OF TANK _____ mm (in.)
16. ACTUAL MINIMUM TANK DIAMETER AT THE TOP OF THE TANK _____m (ft)
    ACTUAL MAXIMUM TANK DIAMETER AT THE TOP OF THE TANK _____m (ft)
17. ELEVATION OF TOP OF TANK: MAXIMUM _____MINIMUM
18. BOTTOM THICKNESS AT THE TANK SHELL _____ mm (in.)
19. MAXIMUM THICKNESS LEVEL _____m (ft)
20. EXISTING ANCHORAGE DETAILS IF ANY: _____
21. LIST ALL APPURTENANCES, OTHER THAN THOSE TO BE REMOVED BY THE PURCHASER, AND INDICATE ACTION REQUIRED OF CONTRACTOR

APPURTENANCE	CONTRACTOR ACTION: REMOVE	CONTRACTOR ACTION: ACCOMMODATE
_____	◯	◯
_____	◯	◯
_____	◯	◯
_____	◯	◯
_____	◯	◯
_____	◯	◯
_____	◯	◯

Figure G.1—Data Sheet for a Structurally-Supported Aluminum Dome Added to an Existing Tank

G.1.4 Special Features

G.1.4.1 Self-Supporting Structure

The aluminum dome roof shall be supported only from the rim of the tank. The design of the connection between the roof and the tank rim shall allow for thermal expansion. A minimum temperature range of ±70 °C (120 °F) shall be used for design unless a wider range is specified by the Purchaser.

G.1.4.2 Finish

Unless otherwise specified, the aluminum dome roof materials shall have a mill finish.

G.1.4.3 Maintenance and Inspection

The roof Manufacturer shall provide a maintenance and inspection manual for roof items that may require maintenance, periodic inspection, or both.

G.1.4.4 Jurisdictional Requirements

The Purchaser is required to provide all applicable jurisdictional requirements that apply to the aluminum dome roof (see 1.3).

G.2 Materials

G.2.1 General

Materials furnished to meet the requirements of this Annex shall be new. A complete material specification shall be submitted by the roof Manufacturer for approval by the Purchaser. The materials shall be compatible with the product specified to be stored in the tank and the surrounding environment. No aluminum alloy with a magnesium content greater than 3 % shall be used when the maximum design temperature exceeds 65 °C (150 °F). Properties and tolerances of aluminum alloys shall conform to *Aluminum Standards and Data*, as published by the Aluminum Association (Washington, D.C.).

G.2.2 Structural Frame

Structural frame members shall be fabricated from 6061-T6 or a recognized alloy with properties established by the Aluminum Association, Inc.

G.2.3 Roof Panels

Roof panels shall be fabricated from Series 3000 or 5000 aluminum with a minimum nominal thickness of 1.20 mm (0.050 in.).

G.2.4 Bolts and Fasteners

Fasteners shall be of 7075-T73 aluminum, 2024-T4 aluminum, austenitic stainless steel, or other materials as agreed to by the Purchaser. Only stainless steel fasteners shall be used to attach aluminum to steel.

G.2.5 Sealant and Gasket Material

G.2.5.1 Sealants shall be silicone or urea urethane compounds that conform to Federal Spec TT-S-00230C unless another material is required for compatibility with stored materials. Sealants shall remain flexible over a temperature

range of –60 °C to +90 °C (–80 °F to +200 °F) without tearing, cracking, or becoming brittle. Elongation, tensile strength, hardness, and adhesion shall not change significantly with aging or exposure to ozone, ultraviolet light, or vapors from the product stored in the tank.

G.2.5.2 Preformed gasket material shall be Neoprene, silicone, Buna-N, urea urethane, or EPDM elastomer meeting ASTM C509 or Federal Spec A-A-59588B, unless another material is required for compatibility with stored materials.

G.2.6 Skylight Panels

Skylight panels shall be clear acrylic or polycarbonate with a minimum nominal thickness of 6 mm (0.25 in.).

G.3 Allowable Stresses

G.3.1 Aluminum Structural Members

Aluminum structural members and connections shall be designed in accordance with the *Aluminum Design Manual*, as published by the Aluminum Association, Inc. (Washington, D.C.), except as modified by this Annex.

G.3.2 Aluminum Panels

Aluminum panels shall be designed in accordance with S*pecifications for Aluminum Sheet Metal Work in Building Construction*, as published by the Aluminum Association, Inc. (Washington, D.C.) and this Annex. Attachment fasteners shall not penetrate both the panel and the flange of the structural member.

G.3.3 Bolts and Fasteners

G.3.3.1 Allowable stresses for aluminum fasteners shall be determined in accordance with the *Aluminum Design Manual*. Allowable stresses for stainless steel fasteners shall be determined in accordance with AISC *Design Guide 27: Structural Stainless Steel*. For seismic loads, these values may be increased by one-third.

G.3.3.2 The hole diameter for a fastener shall not exceed the diameter of the fastener plus 1.5 mm ($^1/_{16}$ in.).

G.4 Design

G.4.1 Design Principles

G.4.1.1 The roof framing system shall be designed as a three-dimensional space frame or truss with membrane covering (roof panels) providing loads along the length of the individual members. The design must consider the increased compression induced in the framing members due to the tension in the roof panels.

G.4.1.2 The actual stresses in the framing members and panels under all design load conditions shall be less than or equal to the allowable stresses per the *Aluminum Design Manual*, as published by the Aluminum Association, Inc. (Washington, D.C.).

G.4.1.3 The allowable general buckling pressure p_a shall equal or exceed the maximum pressure given in 5.2.2 (e).

$$p_a = \frac{1.6E\sqrt{I_x A}}{LR^2(SF)} \qquad \text{(G.4.1.3-1)}$$

where

E is the modulus of elasticity of the dome frame members;

I_x is the moment of inertia of frame members for bending in a plane normal to the dome surface;

A is the cross-sectional area of frame members;

R is the spherical radius of the dome;

L is the average length of the frame members;

SF is the safety factor = 1.65.

Alternatively, p_a shall be determined by a non-linear finite element analysis with a safety factor of 1.65.

G.4.1.4 The net tension ring area (exclusive of bolt holes and top flange protrusions) shall not be less than:

$$A_n = \frac{D^2\ p}{8F_t\ \tan\theta} \qquad \text{(G.4.1.4-1)}$$

where

A_n is the net area of tension ring;

D is the nominal tank diameter;

p is the maximum pressure given in 5.2.2 (e);

θ is 1/2 the central angle of the dome or roof slope at the tank shell;

F_t is the least allowable stress for components of the tension ring.

NOTE This formula does not include bending stresses due to loads from the panel attached to the beam. These stresses must also be considered in the tension ring design per G.3.1.

G.4.2 Design Loads

G.4.2.1 Loads on Dome Roofs

Dome roofs shall be designed for:

a) the loads in 5.2.1;

b) the load combinations in 5.2.2 (a), (b), (c), (e), and (f).

G.4.2.2 Seismic Load

If the tank is designed for seismic loads, the roof shall be designed for:

a) a horizontal seismic force $F_h = A_i W_r$

b) a vertical seismic force $F_v = \pm A_v W_r$

where A_i, A_v, and W_r are as defined in Annex E. Forces shall be uniformly applied over the surface of the roof. Horizontal and vertical forces need not be applied simultaneously.

G.4.2.3 Panel Loads

G.4.2.3.1 Roof panels shall be of one-piece aluminum sheet (except for skylights as allowed by G.8.3). The roof panel shall be designed to support the greater of a uniform load of 3 kPa (60 lbf/ft^2), or loads specified in G.4.2.1 a), applied over the full area of the panel.

G.4.2.3.2 The roof shall be designed to support two concentrated loads 1100 N (250 lbf), each distributed over two separate 0.1 m^2 (1 ft^2) areas of any panel.

G.4.2.3.3 The loads specified in G.4.2.3.1 and G.4.2.3.2 shall not be applied simultaneously or in combination with any other loads.

• G.4.3 Internal Pressure

Unless otherwise specified by the Purchaser, the internal design pressure shall not exceed the weight of the roof. In no case shall the internal design pressure exceed 2.2 kPa (9 in. of water). When the design pressure, $P_{\max}$, for a tank with an aluminum dome roof is being calculated, the weight of the roof, including structure, shall be used for the D_{LR} term in F.4.2.

G.5 Roof Attachment

G.5.1 Load Transfer

Structural supports for the roof shall be bolted or welded to the tank. To preclude overloading of the shell, the number of attachment points shall be determined by the roof Manufacturer in consultation with the tank Manufacturer. The attachment detail shall be suitable to transfer all roof loads to the tank shell and keep local stresses within allowable limits.

G.5.2 Roof Supports

G.5.2.1 Sliding Supports

The roof attachment points may incorporate a slide bearing with low-friction bearing pads to minimize the horizontal radial forces transferred to the tank. The primary horizontal thrust transferred from the dome shall be resisted by an integral tension ring.

G.5.2.2 Fixed Supports

The roof may have fixed supports attached directly to the tank, and the top of the tank shall be analyzed and designed to sustain the horizontal thrust transferred from the roof, including that from differential thermal expansion and contraction. For roofs with fixed supports on a new tank, the maximum acceptable radial tank deflections at the top of the tank shall be coordinated between the tank Manufacturer and roof manufacturer. For roofs with fixed supports on an existing tank, the maximum acceptable radial tank deflections at the top of the tank shall be coordinated between the Purchaser and roof manufacturer.

• G.5.3 Separation of Carbon Steel and Aluminum

Unless another method is specified by the Purchaser, aluminum shall be isolated from carbon steel by an austenitic stainless steel spacer or an elastomeric isolator bearing pad.

G.5.4 Electrical Grounding

The aluminum dome roof shall be electrically interconnected with and bonded to the steel tank shell or rim. As a minimum, stainless steel cable conductors 3 mm ($^1/_8$ in.) in diameter shall be installed at every third support point. The choice of cable shall take into account strength, corrosion resistance, conductivity, joint reliability, flexibility, and service life.

G.6 Physical Characteristics

G.6.1 Sizes

An aluminum dome roof may be used on any size tank erected in accordance with this standard.

• G.6.2 Dome Radius

The maximum dome radius shall be 1.2 times the diameter of the tank. The minimum dome radius shall be 0.7 times the diameter of the tank unless otherwise specified by the Purchaser.

• G.7 Platforms, Walkways, and Handrails

Platforms, walkways, and handrails shall conform to 5.8.10 except that the maximum concentrated load on walkways or stairways supported by the roof structure shall be 4450 N (1000 lbf). When walkways are specified to go across the exterior of the roof (to the apex, for example), stairways shall be provided on portions of walkways whose slope is greater than 20 degrees. Walkways and stairways may be curved or straight segments.

G.8 Appurtenances

G.8.1 Roof Hatches

If roof hatches are required, each hatch shall be furnished with a curb 100 mm (4 in.) or higher and a positive latching device to hold the hatch in the open position. The minimum size of opening shall not be less than 600 mm (24 in.). The axis of the opening may be perpendicular to the slope of the roof, but the minimum clearance projected on a horizontal plane shall be 500 mm (20 in.).

G.8.2 Roof Nozzles and Gauge Hatches

Roof nozzles and gauge hatches shall be flanged at the base and bolted to the roof panels with an aluminum reinforcing plate on the underside of the panels. The axis of a nozzle or gauge hatch shall be vertical. If the nozzle is used for venting purposes, it shall not project below the underside of the roof panel. Aluminum or stainless steel flanges may be bolted directly to the roof panel, with the joint caulked with sealant. Steel flanges shall be separated from the aluminum panel by a gasket (see Figure G.2 for a typical nozzle detail).

• G.8.3 Skylights

G.8.3.1 If skylights are specified by the Purchaser, each skylight shall be furnished with a curb 100 mm (4 in.) or higher and shall be designed for the live and wind loads specified in G.4.2.1. The Purchaser shall specify the total skylight area to be provided. 14

G.8.3.2 When skylights are specified for tanks without floating roofs or for floating roof tanks which are sealed and gas-blanketed (not provided with circulation venting per H.5.2.2.1 and H.5.2.2.2), the Purchaser shall consider skylight material compatibility with exposure to elevated concentrations of the stored product.

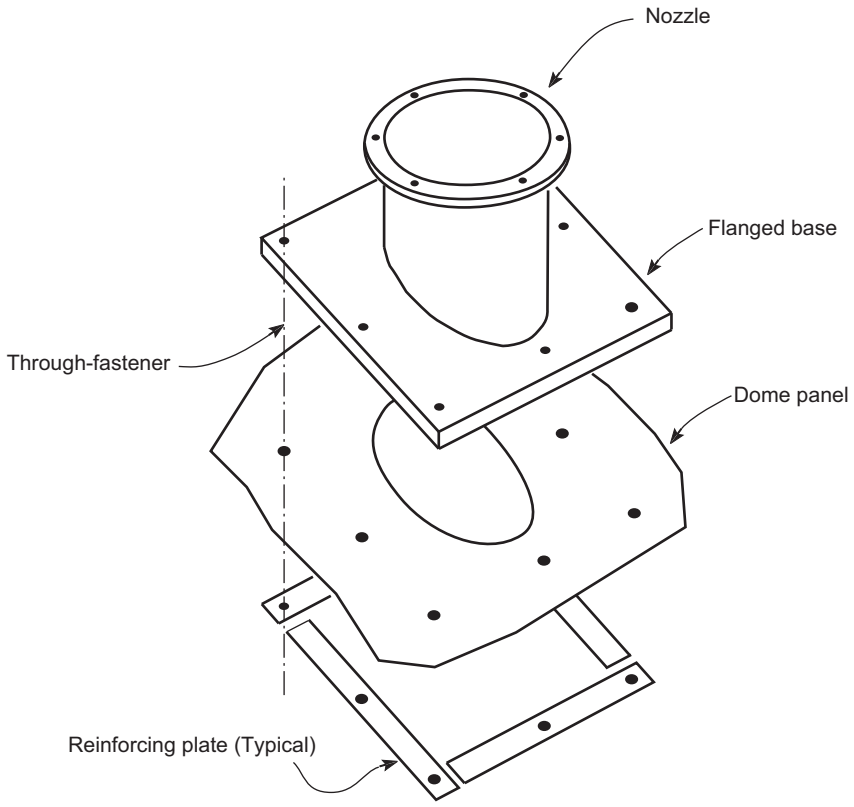

Figure G.2—Typical Roof Nozzle

G.9 Sealing at the Shell

The roof need not be sealed to the tank shell unless specified by the Purchaser or required to contain internal pressure. The bottom of the flashing shall extend at least 50 mm (2 in.) below the top of the tank. Corrosion-resistant coarse-mesh screen (13 mm [1/2 in.] openings) shall be provided to prevent the entrance of birds. The net open area of peripheral screened venting (if provided) shall be considered to serve as an open vent/emergency pressure relief device and contribute to the emergency vent area in accordance with 5.8.5.3.

G.10 Testing

G.10.1 Leak Testing

G.10.1.1 After completion, the roof seams shall be leak tested by spraying the outside of the seams with water from a hose with a minimum static head pressure 350 kPa (50 lbf/in.^{2}) gauge at the nozzle. Because of possible corrosive effects, consideration shall be given to the quality of the water used and the duration of the test. Potable water shall be used unless otherwise specified. The water shall not be sprayed directly on roof vents. Any water on the inside of the roof shall constitute evidence of leakage.

15 **G.10.1.2** Where gas-tight roofs are required, leak testing may be accomplished in accordance with F.4.4 or F.8.3 or by another means acceptable to the roof Manufacturer and the Purchaser.

G.10.1.3 Any leaks discovered during testing shall be sealed, and the roof shall be retested until all leaks are sealed.

G.11 Fabrication and Erection

G.11.1 General

The dome contractor shall perform the work described in this Annex using qualified supervisors who are skilled and experienced in the fabrication and erection of aluminum structures.

G.11.2 Fabrication

All roof parts shall be prefabricated for field assembly. Fabrication procedures shall be in accordance with Section 6 of the *Aluminum Design Manual*. All structural shapes used to make the roof shall be punched or drilled before any shop coating is applied.

• G.11.3 Welding

The design and fabrication of welded aluminum parts shall be in accordance with the A*luminum Design Manual: Specifications for Aluminum Structures* and AWS D1.2. All aluminum structural welds and components joined by welding shall be visually examined by dye-penetrant method in accordance with Section 5, Part D, of AWS D1.2. All structural welding of aluminum shall be performed before the dome is erected in the field. A full set of satisfactory examination records shall be delivered to the owner before field erection.

G.11.4 Shipping and Handling

Materials shall be handled, shipped, and stored in a manner that does not damage the surface of aluminum or the surface coating of steel.

G.11.5 Erection

The erection supervisor shall be experienced in the construction of aluminum dome roofs and shall follow the Manufacturer’s instructions and drawings furnished for that purpose.

G.11.6 Workmanship

To minimize internal stresses on the structure when fasteners are tightened, the roof shall be installed on supports that are in good horizontal alignment. The components of the structure shall be erected with precise fit and alignment. Field cutting and trimming, relocation of holes, or the application of force to the parts to achieve fit-up is not acceptable.