Introduction:

Aluminum geodesic dome roofs that meet the design requirements of API-650, Appendix G are increasingly specified for new tank construction projects and as a retrofit option on existing tanks. These domes utilize aluminum’s lightweight inherent strength, corrosion resistance with low maintenance to span unsupported diameters of up to 60 meters. This growing trend is based on numerous factors.

While more than 10,000 aluminum domes have been installed on petrochemical storage tanks in the United States, only a fraction of that number have been installed in the rest of the world. Although aluminum domes have been in service on petrochemical storage tanks in the United States since the 1970’s, they only began to be used in the rest of the world in the 1990’s. One possible reason for this is that the largest suppliers of aluminum domes US-based and selling internationally is not something a company does until it reaches...
Material & Components:

The primary factors in choosing materials for aluminum geodesic dome manufacturing are as follows:

- Climate / exposure to elements
- Structural strength
- Corrosion resistance
- Compatible with the product to be stored and the surrounding environment
- Cost considerations

Material Costs

<table>
<thead>
<tr>
<th>Diameter (m)</th>
<th>Material</th>
<th>Cost (€)</th>
<th>Weight (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Steel</td>
<td>500,000</td>
<td>500</td>
</tr>
<tr>
<td>20</td>
<td>Steel</td>
<td>300,000</td>
<td>300</td>
</tr>
<tr>
<td>30</td>
<td>Steel</td>
<td>200,000</td>
<td>200</td>
</tr>
<tr>
<td>40</td>
<td>Steel</td>
<td>100,000</td>
<td>100</td>
</tr>
<tr>
<td>50</td>
<td>Steel</td>
<td>50,000</td>
<td>50</td>
</tr>
<tr>
<td>60</td>
<td>Steel</td>
<td>10,000</td>
<td>10</td>
</tr>
</tbody>
</table>

- Being one-third the weight. Aluminum is a light, trivalent, ductile and malleable metal. It is non-sparking, non-magnetic and corrosion resistant. Therefore, attitudes are starting to change. Certain tank builders recognize the benefits of aluminum domes and are an advocate for them and more projects for petroleum plants and chemical facilities, domes are being specified by the customer.
Beams
The structural components and connections of the aluminum geodesic dome roof are lightweight extrusions fabricated from 6061-T6 or other recognized alloy like 6005A-T6 aluminum alloy. 6061-T6 and 6005A-T6 have the same minimum strength properties. 6005A-T6 is a relatively new alloy that has some advantages over 6061-T6. The main advantages are a better finish, less sensitive timeframe to quench after extruding, and its ability to be air quenched instead of water quenched for most extrusion sizes. Finally, it costs a little less, mainly due to the easier quenching process for the extruder. This aluminum dome beam extrusion is typical. Note the protrusions on the top. The protrusions are the attachments for the dome panels and batten bar. The batten bar holds the dome panels in place and is attached by a ¼" tri-lobe screw in the slot at the center of the beam. The flange stiffeners at the end of each flange are typical for a thin-wall beam extrusion. The flange stiffeners increase the allowable compression and bending in a thin-wall shape by about 20-25%. They also increase the weak-axis moment of inertia, section modulus and radius of gyration without increasing the width of the beam. They are not needed on thicker shapes. The protrusion on the top of the beam must be milled or cut back to allow the beam to bolt to the connection hub. The triangular non-structural panels are cut to size, formed from series 3000 or 5000 aluminum sheet with a minimum nominal thickness of 1.20mm (0.050 in.).

Hubs
The hubs are the connections where the beams are joined. The hub is a circular dish with a center hole punched for placing on the forming die to coin the angle needed from the dish. The center hole is tapped on the top hub for attaching the hub cover. There are four possible common Aluminum materials that can be used for the hubs: 6061-T6 extruded flat bar, 6061-T6 extruded flat bar, 6061-T6 hot rolled plate, and 5052-H34 hot rolled plate.

API-650, Appendix G Design Requirements:
This appendix of the American Petroleum Institute’s (API) aboveground storage tank design code, API-650 establishes the minimum criteria for the design, fabrication and erection of structurally supported aluminum dome roofs. API’s definition of a structurally supported dome roof is that the 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. Further minimum design criteria include:

- Unless otherwise specified by the purchaser, the internal design pressure shall not exceed the weight of the roof.
- Structural supports for the roof shall be bolted or welded to the tank.
- 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.
- The maximum dome radius shall be 1.7 times the tank diameter. The minimum dome radius shall be 0.7 times the tank diameter unless otherwise specified by the purchaser.
- If skylights are specified by the purchaser, each skylight shall be furnished with a curb of 4” or higher (to prevent ingress) and shall be designed for live and wind loads.

Reasons for Choosing Aluminum Geodesic Dome Roofs:

With some tanks more than others, there are issues where having an aluminum geodesic dome roof would be advantageous. For instance, it can help with odor control and other emission control issues. Some typical categories of products that might be stored under a floating deck and aluminum geodesic dome would include:

- Petroleum
- Water
- Wastewater
- Chemical

The main benefit of an aluminum geodesic dome roof would be the long term maintenance cost savings. Usually a cone roof is less expensive than an aluminum geodesic dome but a cost saving can be realized over the life of the aluminum geodesic dome roof due to lower maintenance costs. Increasing construction costs and rising steel prices for traditional storage tank roofs have further enhanced the desirability of aluminum geodesic dome roofs. In the long run the aluminum dome roof is proven more cost effective.

Aluminum geodesic dome roofs are often specified when vapor space corrosion is expected to be a concern. Vapor space corrosion occurs in the vapor space of tanks, above the product on the underside of the roof and the top of the internal surfaces of the tank shell. Vapor space corrosion is accelerated by the presence of moisture condensing on the walls and roof as the temperature varies throughout the day and the night. In the alternating wet and dry conditions, the concentrations of corrosive compounds are often increased. The rate of corrosion is often most severe at the interface between the vapor and the liquid.
External Floating Roofs (EFR) Versus Internal Floating Roofs (IFR) With Aluminium Geodesic Dome Roof

The design and construction of EFR’s, especially the larger diameter double deck type is complex and costly requiring a lot of steel plate material. A tank fitted with an aluminium geodesic dome roof with an Internal Floating Roof (IFR) either aluminum or glass reinforced plastic design or construction is less complex with all the components being field assembled. Exposed to the elements. In high humidity areas the inner surface of the tank shell quickly becomes corroded and will cause the seal envelope to fail prematurely. EFR’s require roof drainage which in the advent of sustained heavy rain or snow can become overwhelmed resulting in the roof sinking, normally destroying the roof. External floating roofs (EFR) have a seal that goes all the way around the perimeter of the floating deck.

Operational Restrictions of Aluminum in Methanol:

One of the drawbacks of methanol is its corrosivity to some metals, including aluminum. Methanol, although a weak acid, attacks the oxide coating that normally protects the aluminum from corrosion:

$$6\text{CH}_3\text{OH} + \text{Al}_2\text{O}_3 \rightarrow 2\text{Al(OCH}_3)_3 + 3\text{H}_2\text{O}$$

The resulting methoxide salts are soluble in methanol, resulting in clean aluminum surface, which is readily oxidized by some dissolved oxygen. Also the methanol can act as an oxidizer:

$$6\text{CH}_3\text{OH} + 2\text{Al} \rightarrow 2\text{Al(OCH}_3)_3 + 3\text{H}_2$$

This reciprocal process effectively fuels corrosion until either the metal is eaten away or the concentration of CH\text{3OH} is negligible.
Retrofitting Existing Tanks:

Why fit an aluminum geodesic dome over an existing external floating roof? This is a logical question and there are many legitimate reasons. Take a military situation, for instance. Satellite technology could possibly determine how much product is left in military supply tanks based upon the level of the EFR. An aluminum geodesic dome over the EFR would prevent detection of empty or low supply.

- Keeps rain and snow from entering the tank and contaminating product.
- No chance of roof sinking in extreme weather
- Prevents corrosion of the steel roof by eliminating standing water.
- Protects existing tank internal coating and seals from UV and environmental damages
- Environmental Regulations. Emissions are further reduced. Product is preserved. Odors are controlled.
- One of the least expensive alternatives to cover an existing tank.
- Minimal weight has insignificant effect on foundation design making retrofit easier.
- Future parts replacements are less expensive.

Structural Analysis

An aluminum dome roof is a 3-dimensional space frame. The reactions in a small space frame can be solved with simple statics. However, an aluminum dome roof is usually not a small space frame. The solution of the reactions could easily be system of linear equations with several thousand equations and several thousand unknowns. Therefore, the use of a finite element model is a necessity.

The FEA Model

FEA is an approximate solution method for a beam element very similar to numeric integration. The FEA model is constructed from the calculated geometry of the dome. The pier connection is also modeled using a series of beam elements. The dome is usually cantilevered toward the inside of the tank from the tank shell. The pier induces significant bending moments into the dome. Therefore, a design consideration is to keep the pier as short as possible. All connections between all beam elements are modeled as 100% moment resisting in both axis.
Dome Stress Analysis

The method used for determining allowable stress is Part I-A Specification for Aluminum Structures Allowable Stress Design, The Aluminum Design Manual. Allowable Stress Design with aluminum is in many ways similar to Allowable Stress Design with steel. The 6061-T6/6005A-T6 alloys used in this dome design have a minimum yield stress of 35ksi. A36 steel is only 1 ksi higher. A common grade of aircraft aluminum alloy 2024-T4 has a minimum yield of 59 ksi. Some more exotic grades of aluminum have even higher minimum yield stress.

Aluminum is a strong material. The alloys used in this dome are not the 5-10 ksi yield beer cans alloys most people are familiar with. These alloys are high strength structural alloys. There are two primary differences between aluminum and steel that leads to several additional factors to check in aluminum design:

1. Aluminum can be easily extruded. Metal can be placed at exact locations in a structural member. Thin wall sections are easily made. Stiffeners can be easily added to a structural member. All of the structural members in this dome are extruded. These members cannot be rolled and they would be impossible to economically manufacture in steel.

2. The modulus of elasticity of aluminum is only 10100 ksi. Aluminum is about 3 times more flexible than steel.