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Structured Approach for Floating Roof Integrity Assessment and Preventive Measures

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Abstract: Different tanks have different roof types, and each roof requires specific design considerations to insure safe operation and extended service life. Also, each type needs continuous integrity assessments along with corrective maintenance. However, some operational upsets lead to unaccepted damages, that if left unassessed, and not repaired will lead to catastrophic failures. The paper will shed lights on the common failures of the floating roof, and their common causes during operation of the tank, or even during incorrect practices for cleaning. Then the paper will discuss integrity assessment approaches to assess damages, and the proper methodology for repair. Finally, the paper will share guidelines on the preventive measures that operators need to consider to avoid damages and ensure safe floating roof operation.

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I. GENERAL INTRODUCTION ABOUT TANK ROOFS

In the oil and gas industry, aboveground storage tanks play a crucial role in storing crude oil, refined products, and various hydrocarbons. The design of the tank roof is a key aspect of overall tank engineering, directly influencing operational efficiency, safety, vapor control, and environmental compliance. Depending on the nature of the stored product and operational requirements, tanks may be equipped with different roof types, including fixed cone roofs, dome roofs, external floating roofs, and internal floating roofs.

The American Petroleum Institute (API) provides widely adopted standards governing the design, fabrication, inspection, and maintenance of storage tank roofs. API Standard 650 covers welded tanks for oil storage and provides detailed requirements for various roof designs, while API Standard 620 addresses low-pressure storage tanks, including those with domed or spherical roofs. API Standard 653 outlines inspection and repair practices to ensure long-term tank integrity. Each roof type offers unique advantages: fixed roofs are typically used for low-volatility liquids; external floating roofs minimize vapor emissions and product loss for volatile products; internal floating roofs, often combined with fixed roofs, provide enhanced vapor control; and domed roofs can handle slight internal pressures and are suitable for certain product and climatic conditions. Understanding the characteristics, selection criteria, and design considerations of tank roofs in accordance with API standards is essential for optimizing storage system performance and ensuring regulatory compliance in oil and gas facilities.

II. ROOF MAIN TYPES

➢ *Fixed Roofs*

Fixed roofs are non-movable structures commonly used in storage tanks and industrial facilities. They come in several types, each with specific structural characteristics and applications. Fixed roof main types used in Saudi Arabia are:

- *Fixed Cone Roof:*

Cone roof is one of the most widely used fixed roofs, which is illustrated in Fig. 1, especially for atmospheric storage tanks. It features a simple conical shape that slopes outward from the center, making it easy to construct and cost effective. It is straightforward design and functionality make it a popular choice in many industrial settings and services such as, water, fuel oil, petroleum products, chemical storage and firewater.

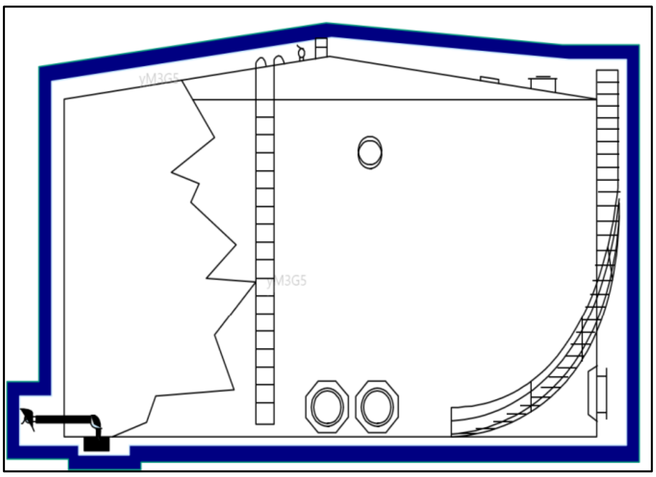

Fig 1 Fixed Cone Roof Tank

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- *Fixed Dome Roof:*

Dome roof has a rounded or hemispherical shape and is often used for tanks that store liquids under low pressure, which is illustrated in Fig. 2. It offers better pressure resistance than cone roofs due to its curved form, making it suitable for certain chemical or oil storage applications such as, low pressure, liquefied petroleum gas, and industrial water treatment.

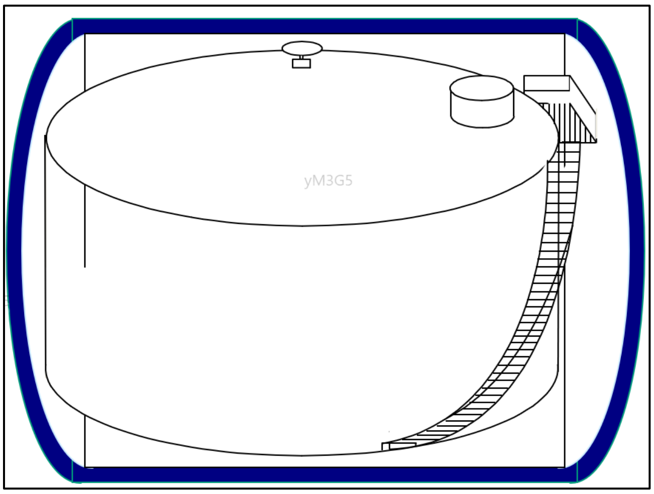

Fig 2 Fixed Dome Roof Tank

➢ *External Floating Roof*

An External Floating Roof is a type of roof that floats directly on the surface of the stored liquid and is exposed to the atmosphere, which is illustrated in Fig. 3. It is widely used for storing crude oil and other volatile petroleum products, mainly to reduce evaporative losses. These roofs are primarily governed by API 650 Appendix C. Among the advantages of EFRs are their effectiveness in significantly reducing volatile emissions and their cost-efficiency, especially for large storage tanks. However, since they are exposed to environmental elements like rain and snow, they require proper drainage systems and generally demand higher maintenance due to external weather exposure.

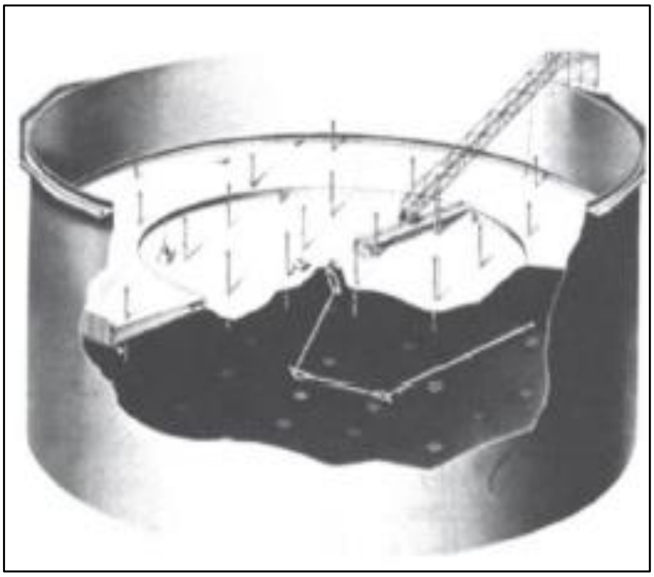

Fig 3 External Floating Roof [1]

➢ *Internal Floating Roof*

An Internal Floating Roof is a floating deck that sits on the liquid surface inside a fixed-roof tank, which is illustrated in Fig. 4. It is typically used for more volatile substances or where environmental regulations demand additional vapor control. The design and construction of IFRs are guided by API 650 Appendix H. IFRs offer enhanced protection from external elements and provide superior vapor containment when used in combination with a fixed roof. On the downside, they usually involve a higher initial cost compared to EFRs and can be more complex to maintain due to their enclosed structure.

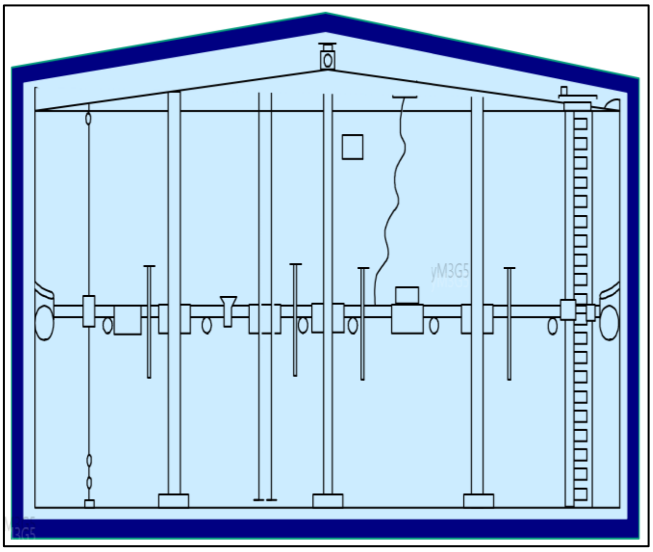

Fig 4 Internal Floating Roof

III. API REQUIREMENTS

➢ *External Floating Roof*

The External Floating Roof is regulated under API 650 – Appendix C, which outlines specific design and safety requirements. The roof must be either a pontoon-type or a double-deck structure. Materials used in its construction must be compatible with both the stored product and the external atmospheric conditions. To control vapor emissions, the system must include a primary sealing system and may also incorporate a secondary seal for additional containment. A drainage system is mandatory to remove rainwater from the roof surface, typically using a flexible hose or an articulated drain pipe.

The roof must allow for free vertical movement as the liquid level changes, and its deck must be structurally capable of bearing loads such as maintenance personnel and equipment. Additionally, ladders and access platforms are required to ensure safe inspection and maintenance, in accordance with API safety provisions.

➢ *Internal Floating Roof*

Internal Floating Roofs fall under API 650 – Appendix H, which governs their design within tanks that also have a fixed roof either cone or dome shaped. IFRs can be of various types, including pan, pontoon, or full-contact designs, and may be constructed from aluminum, steel, or composite

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materials depending on the application. These roofs must have a primary seal between the roof edge and the tank shell to control vapor loss, and in many cases, a secondary seal is recommended or required by environmental regulations.

Ventilation of the tank is critical to prevent pressure or vacuum buildup. The roof must include adjustable support legs that allow it to rest at a set height when the tank is not full. Structurally, the IFR must meet deck loading requirements to safely support personnel. As with EFRs, all materials must be chosen for compatibility with both the stored liquid and the vapor environment inside the tank.

IV. TYPICAL FAILURES AND CAUSES

Failures can be quite catastrophic for the tanks, but the focus of this article will be primarily on the floating roof failures and causes. Like any other component, the types of failures can be experienced in different forms and due to different reasons. The failures can be related to failure of the material used, incorrect design, improper operation or lack or inadequate maintenance. Moreover, following failures are the most common failures in the floating roofs:

- *Seal System Failures:*

Seal system failures are typically caused by aging materials (UV degradation), chemical degradation, mechanical damage, or improper installation. When seals fail, they compromise vapor control, leading to increased emissions and the potential for product contamination. Warning signs include visible gaps between the seal and the tank shell, rising emission levels, or odor complaints from surrounding areas.

- *Roof Pontoon Leakage or Sinking:*

Roof pontoons can leak or sink due to corrosion, manufacturing defects such as poor welding, fatigue cracking or physical impact. These issues can destabilize the roof, causing it to become partially submerged and undermining both flotation and structural integrity. Signs of pontoon failure include a tilted or sunken roof and irregular or sluggish roof movement.

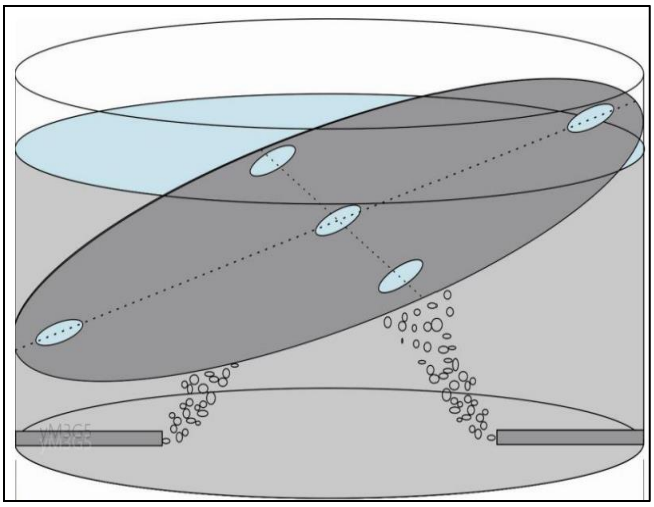

Fig 5 Pontoon Leakage and Sinking Floating Roof [6]

- *Corrosion (General or Localized):*

Corrosion results from prolonged exposure to weather in external floating roofs (EFRs), inadequate coating systems, standing water caused by poor drainage, chemical vapors in internal floating roofs (IFRs). This degradation due to corrosion weakens structural components and can eventually lead to deck collapse. Inspectors often find rust, pitting, or soft spots on the deck surface as early indicators.

- *Drainage System Blockage or Failure:*

In EFRs, drainage system problems are commonly caused by sludge buildup, debris, ice formation, or mechanical issues in the drain lines due to lack of maintenance or inspection. Blocked or failed systems allow rainwater to accumulate on the roof, adding weight and increasing the risk of sinking or damaging the seals. Telltale signs include standing water and sluggish or uneven roof movement.

- *Guide Pole or Roof Movement Problems:*

Guide pole or roof movement issues often stem from misalignment, mechanical jams, or obstructions along the tank shell. These problems restrict the roof's vertical travel, potentially leading to torn seals or tank wall damage. Signs include irregular roof height, unexpected resistance during movement, or unusual noises.

- *Internal Floating Roof Collapse:*

An IFR collapse may occur due to overpressure, improper positioning of support legs, or excessive loading beyond the deck's capacity. This leads to the roof suddenly dropping into the product, posing a significant operational and safety hazard. Indicators of such a failure include a sudden drop in liquid level, structural vibrations, or triggered alarms if monitoring equipment is present.

- *Fire and Explosion Risk:*

Fire and explosion hazards arise from lightning strikes, vapor accumulation due to failed seals, or the presence of ignition sources near the tank. These scenarios can result in catastrophic failures with severe environmental and safety consequences. Warning signs include flammable vapor detection alerts or a recurring history of seal failures.

- *Vapor Venting or Overpressure:*

Inadequate venting or malfunctioning vapor control systems in fixed-roof tanks with IFRs can lead to excessive internal pressure. This condition risks structural damage to the roof or the tank itself. Typical signs include activation of pressure relief valves or visible deformation of the roof structure.

V. ASSESSMENT APPROACH

Assessment practices often vary widely among operators, depending heavily on individual experience, historical data and internal best practices. This lack of uniformity can result in inconsistent evaluations and missed early warning signs of degradation or malfunction. To overcome these challenges, it is essential to adapt a structured assessment approach tailored to the specific design and

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service conditions of each tank. This structured methodology allows for a comprehensive and proactive evaluation that identifies potential damages/failure early, ensures thorough inspection and helps maintain operational safety and compliance. The methodology should account for variations such as:

A. Type of floating roof (external vs. internal)
B. Services environment (crude oil, refined products, chemical, etc)
C. Age and material of construction
D. Operational history and frequency of maintenance.

➤ *The following Key Aspects are Recommended for a Robust Assessment:*

- *Operation Trends Review*

The first step of assessment shall focus on review of the operational trends to evaluate if there have been any operational upsets, or operational concerns. This will determine if there has been more attention given to specific components or so.

- *Maintenance History Review*

Another important element of the assessment is to review the past failures, and maintenance activities. Also, it is imperative to be aware of the repairs to pay more attention during the assessment, and evaluate if the repairs were completed successfully

- *External Visual Inspection*

The tank overall condition and installation should be assessed to evaluate if there are any concerns with the settlements or if there are any excessive piping stresses, affecting the tank. One important element of the roof assessment, is to conduct a visual and external assessment during the tank operation. The objective is to assess, the floating roof operation, and check if there is any abnormal sound, or obstructed movement, or uneven level of the roof. Also, the approach includes careful checks of any signs of leak, or to conduct also emission test, in cases of gas services or trapped gaseous levels. Also, the same visual assessment should be performed during the T&I, while the tank is not in operation, and this should be performed on the as-is condition, before cleaning or removal of the roof. This is to have more detailed inspection of the seals conditions, traces of leaks, coating and painting conductions, any signs coating damages, or rust.

- *Internal Visual inspection*

Tank internals should be visually assessed, before cleaning to check if there is any area of concerns such as dents, burns, and marks. Also, accumulation of sludge or other debris should be checked. Also, after cleaning, it should be visually assessed, to identify any potential risk such as pinhole or materials issues.

- *Materials Evaluation*

The materials evaluation includes comparing the roof materials data by conducting random material tests such as hardness, or replica to evaluate if there is any degradation or issues with the welds. This is performed, when the tank has experienced any abnormal operations that may lead to operational issues.

VI. REPAIR METHODS

The repair of any type of tank roofs is going to be according to API-653 standard, and this must follow specific guidelines to ensure the tank's integrity, safety, and continued service ability.

According to API-653, the repair of floating roof storage tanks must be carried out in manner that restores the tank's structural integrity and ensures continued safe operation. Repairs should be performed by a qualified contractor that comply with API-650, the construction standard for welded oil storage tanks, unless otherwise specified. All repairs must be properly documented, including engineering evaluations, inspection records, and welding certifications. Additionally, any repair work conducted on tanks containing flammable products must strictly follow hot work safety permission and confined space entry requirements. Following are the common floating roof repairs:

➤ *Pontoon Repair or Replacement*

One of the most common repair tasks involves pontoon repair. If pontoons are found to be leaking or corroded, they must undergo thorough inspection to detect the leaks. If localized damage is identified, patch welding may be permitted, but if the corrosion or damage is extensive, entire pontoon section may require replacement. Repaired or replaced pontoons must pass non-destructive testing (NDT), including ultrasonic testing (UT) or radiographic testing (RT), to ensure they meet the required standard of buoyancy and structural integrity.

➤ *Deck Plate Repair*

Deck plate repairs are necessary when floating roof decks are experiencing buckling, corrosion, or pitting. Damaged sections of the deck are typically cut out and replaced with new material that is at least equal in thickness and quality to the original. All new welds must be performed according to API-650 to avoid misalignment that could affect the roof's ability to float and seal properly.

➤ *Seal System Replacement*

Seal system which prevents vapor emissions between the roof and shell, also require regular inspection and repair. When primary or secondary seals become misaligned, they must be removed and replaced with seals that are compatible with both the stored product and the roof configuration (internal or external).

➤ *Drainage System Repair*

The roof drain system that removes rainwater from the floating roof, must be free of leaks and obstructions to ensure proper functioning. The inspection and repair of drainage system will be involving the hoses and piping, and replacing the damaged sections. Also, proper slope must be maintained to allow for efficient drainage without back flow to the roof.

➢ *Support Leg Repair*

Support legs are one of the most common repair tasks which control the roof resting height during product or maintenance. Roof legs sleeves mechanisms shall be checked to ensure the free movement and they are set to the appropriate height.

VII. PREVENTIVE MEASURES

➢ *Proper Design with Allowances for Corrosion and Deflection*

To ensure the roof structure maintains integrity over time and under operational loads.

- *Design Considerations:*

✓ Corrosion Allowance: Add 1.6–3.2 mm (or as per API 650) to the nominal thickness of steel components.
✓ Deflection Limits: Design for maximum deflection under water/snow load (typically <1/240 of span).

➢ *Regular NDT Inspection (UT, VT) of Pontoons and Welds*

To detect early signs of wall thinning, cracks, and other structural defects before they lead to leakage or sinking. The recommended NDT methods are:

- Visual Testing (VT): Identifies visible cracks, corrosion, pitting, weld defects, or deformation.
- Magnetic Particle Testing (MT) and Dye Penetrant Testing (PT) can also be used for weld seam crack detection.
- Ultrasonic Testing (UT): Measures wall thickness and detects corrosion or lamination in pontoons and deck plates.
- These NDT methods could be conducted annually or as part of a scheduled tank inspection (e.g., API 653). More frequently for older or heavily used tanks.

➢ *Seal Gap Monitoring and Emissions Testing*

To ensure seals remain effective in minimizing product vapor losses and environmental emissions.

- Seal Gap Measurement: Use feeler gauges or gap rulers at set intervals around the tank perimeter.
- Seal Shoe Contact Check: Confirm proper contact with shell via visual access.
- Gas/VOC Emissions Testing: Use flame ionization detectors (FID) or infrared cameras to detect fugitive emissions.

➢ *Drainage System Testing and Cleaning*

To ensure rainwater does not accumulate on the roof, which could cause overloading or roof tilt. The following components are recommended to be checked frequently:

- Flexible Hose/Swivel Joint: Check for blockages, pinholes, and mechanical failures.
- Drain Valves: Ensure open/close operation and no leakage.
- Strainers: Clean to prevent debris from clogging the line.

➢ *Routine Roof Alignment and Tilt Checks*

To detect abnormal roof tilt, which could lead to RSC (roof shell contact) or even sinking. The following could be considered for checking the roof alignment:

- Survey with Total Station or Laser: Measure elevations at multiple points along the roof perimeter.
- Tilt Tolerance: Typically, ±75 mm max for large tanks, per EEMUA and operator standards.
- Visual Inspection: Note uneven seal wear or water ponding areas.

VIII. CONCLUSION

It is evident that continuous monitoring and inspection will dictate the level of maintenance which in turn will directly preserve the tanks overall integrity. Therefore, it is imperative to continuously review tanks operational performance and assess the need for in depth inspection based on preliminary evaluations. Various levels of inspections at different stages of tanks life, i.e., during startup, operation and during scheduled Turnaround & Inspection are essential for identifying early signs of degradation and preventing potential failures. The integration of modern technologies such as monitoring sensors, ultrasonic testing, and drones can also enhance inspection effectiveness and reduce human exposure to hazardous environment. A proactive maintenance and inspection do not only extend the service life of the tank but also ensures compliance with safety standards and operational efficiency.

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