Agenda Item: 620-1034

Title: **The Exception to Anchorage Design Rules for API 625 Tanks**

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Contact: Name : Yasunari Watanabe
Company : IHI Plant Service Corporation
Phone : +81-3-6204-8311
E-mail : watanabe3854@ihi-g.com

Purpose: To propose adding an alternative rule for anchor straps design to exempt the slope requirement for API 625 tanks.

Source: N/A

Revision: 0

Impact: Provide alternative approach to API 625 Tanks

Rationale: Background and Objective

In the 2018 revision, provisions related to anchor straps were added, and the requirement specified in 5.11.2.4 e) stipulates that the design slope of the anchor strap from vertical must be kept within 5° (hereafter referred to as the "slope rule").
For API 625 (Refrigerated Liquefied Gas Storage) tanks, due to characteristics such as the thickness of the bottom insulation and the thermal contraction of the primary container and/or secondary container, it is often necessary to significantly extend the anchor straps (resulting in a higher installation point) or partially cut the bottom insulation to comply with the slope rule.
As a result, there are numerous constraints in the design and construction process compared to conventional structures.

Therefore, this agenda proposes adding an alternative rule for anchor straps design to exempt API 625 Tanks from the slope requirement.

Alternative rules for anchor strap design

It is assumed that the slope rule was specified to simplify the design of anchor straps, by minimizing the out-of-plane force acting on the anchor strap and allowing the anchor strap to be subjected to pure tensile forces.
Therefore, when a detailed structural design is properly conducted through analysis or other methods, and structural soundness of the anchor strap and related component is assured, it is considered that the slope rule requirement may be exempted.

A detailed analysis allows the slope to exceed 5 degrees, provided that the new requirements described in the proposal (proposed sections Q.3.7.1.10 and R.3.7.1.9 below) are met.

API 620 does not specify the methodology for detail analysis such as FEA. Therefore, "Design by Analysis" in ASME BPVC Section VIII Division 2 (2023 edition) is used as the basis for this type of analysis, as it is the most widely recognized and adopted standard worldwide. However, to incorporate this method, difference in design condition between ASME BPVC VIII.2 and API 620 must be appropriately considered as stated below.

- If an elastic analysis is performed, the safety factor shall be adjusted to comply with Sections Q.3.3.3, R.3.3.1 and L.3.3.1 of API 620 for Primary Containers and Sections Q.3.3.4, R 3.3.2 and L.3.3.1 for Secondary Containers (Factor of safety 2.4 in ASME BPVC VIII.2 is lower than API 620).
- If an elastic-plastic analysis is performed, the load combinations shall be taken from sources other than API 620. Specifically, Table 2D.4 in Annex 2D of API 579-1/ASME FFS-1 (2026) shall be used, as it is specifically designated for evaluating Protection Against Plastic Collapse, Local Failure, and Buckling. Note that ASME BPVC Section

VIII Division 2 does not provide a dedicated table for load combinations applicable to aboveground storage tanks. Further, this method is applicable only to SSE design and shall not be used for OBE design. For OBE, in accordance with the design philosophy, an elastic seismic analysis approach shall be adopted.

Proposal: **Q.3.7.1.7**

Anchor straps shall provide sufficient flexibility, without being overstressed, to accommodate thermal contraction and deformation caused by liquid level changes of the container structures storing cryogenic product.

The container thermal contraction shall be considered when meeting the anchor strap slope requirements of 5.11.2.4. The anchor strap design and maximum allowable slope shall use an eccentricity equivalent to the sum of the following:

- strap offset from the outside surface of the shell;
- liquid container shell radius tolerance specified in Table Q-6;
- half the strap thickness; and
- thermal contraction of the shell at the attachment.

The design slope may exceed 5 degrees provided the design requirement from Q.3.7.1.10 are met.

R.3.7.1.6

Anchor straps shall provide sufficient flexibility, to accommodate thermal contraction and deformation caused by liquid level changes of the container structures storing cryogenic product without being overstressed. The container thermal contraction shall be considered when meeting the anchor strap slope requirements of 5.11.2.4. The anchor strap design and maximum allowable slope shall use an eccentricity equivalent to the sum of the following:

- strap offset from the outside surface of the shell;
- liquid container shell radius tolerance specified in Table 6-1;
- half the strap thickness; and
- thermal contraction of the shell at the attachment.

The design slope may exceed 5 degrees provided the design requirement from R.3.7.1.9 are met.

(New)

Q.3.7.1.10 The design slope requirements of the anchor strap per Section 5.11.2.4 can be exempted if the following requirements are met, and subject to the approval of the purchaser:

a) A stress analysis is performed on the structure, including the anchor strap as well as the secondary bottom plate, thermal protection system, and thermal corner protection, if applicable.

b) The stress analysis shall be conducted in accordance with ASME BPVC Section VIII Division 2, Design by Analysis Requirements. The following conditions shall be evaluated,
- Protection Against Plastic Collapse
- Protection Against Local Failure
- Protection Against Collapse From Buckling
- Protection Against Failure From Cyclic Loading

The selection of the analysis methodology, such as elastic or elastic-plastic analysis as specified therein, shall be determined by the tank system contractor. However, elastic-plastic analysis shall be applicable only to SSE conditions, whereas elastic analysis shall be applicable to Normal operating, OBE and SSE conditions.

c) The anchor strap membrane stress generated in the analysis shall not exceed the allowable stress specified in Q.3.3 and L.3.3.1.

d) Locations of structural discontinuities at anchor strap welds, or where constrained to the shell plates for primary and secondary liquid containers, bottom plates for secondary liquid container, thermal protection system, base slab, etc., shall be designed to withstand the repeated cyclic loads, including thermal loads assumed during the service life. The surface stress/strain shall be in accordance with ASME BPVC Section VIII Division 2.

e) Load conditions such as leakage from the primary liquid container, OBE, SSE and ALE during the service life, shall be considered in the evaluation.

f) When performing an elastic analysis, allowable stress for appropriate container type, S shall be based on API 620 Sections Q.3.3.3, Q.3.3.4 and L.3.3.1. The surface stress/strain shall be in accordance with ASME BPVC Section VIII Division 2. The load affecting the anchor strap shall be appropriately selected and combined in accordance with API 625 Section 6.

g) When elastic-plastic analysis is used, factored load combinations and design margin, M for Protection Against Plastic Collapse, Local Failure, and Buckling shall be determined in accordance with API 579-1/ASME FFS-1 using RSFa = 1 for new design. Force Reduction Factor for SSE analysis, R shall be 1.0. This analysis is restricted to SSE load combinations.

h) When nonlinear analysis is performed, the stress analysis shall be peer reviewed for technical adequacy by an independent party/engineer knowledgeable in the design and behavior of tanks built to annexure Q.

(New)
R.3.7.1.9 The design slope requirements of the anchor strap per Section 5.11.2.4 can be exempted if the following requirements are met, and subject to the approval of the purchaser:

a) A stress analysis is performed on the structure, including the anchor strap as well as the secondary bottom plate, thermal protection system, and thermal corner protection, if applicable.

b) The stress analysis shall be conducted in accordance with ASME BPVC Section VIII Division 2, Design by Analysis Requirements. The following conditions shall be evaluated,
- Protection Against Plastic Collapse
- Protection Against Local Failure
- Protection Against Collapse From Buckling
- Protection Against Failure From Cyclic Loading

The selection of the analysis methodology, such as elastic or elastic-plastic analysis as specified therein, shall be determined by the tank system contractor. However, elastic-plastic analysis shall be applicable only to SSE conditions, whereas elastic analysis shall be applicable to Normal operating, OBE and SSE conditions.

c) The anchor strap membrane stress generated in the analysis shall not exceed the allowable stress specified in R.3.3 and L.3.3.1.

d) Locations of structural discontinuities at anchor strap welds, or where constrained to the shell plates for primary and secondary liquid containers, bottom plates for secondary liquid container, thermal protection system, base slab, etc., shall be designed to withstand the repeated cyclic loads, including thermal loads assumed during the service life. The surface stress/strain shall be in accordance with ASME BPVC Section VIII Division 2.

e) Load conditions such as leakage from the primary liquid container, OBE, SSE and ALE during the service life, shall be considered in the evaluation.

f) When performing an elastic analysis, allowable stress for appropriate container type, S shall be based on API 620 Sections R.3.3.1, R.3.3.2 and L.3.3.1. The surface stress/strain shall be in accordance with ASME BPVC Section VIII Division 2. The load affecting the anchor strap shall be appropriately selected and combined in accordance with API 625 Section 6.

g) When elastic-plastic analysis is used, factored load combinations and design margin, M for Protection Against Plastic Collapse, Local Failure, and Buckling shall be determined in accordance with API 579-1/ASME FFS-1 using RSFa = 1 for new design. Force Reduction Factor for SSE analysis, R shall be 1.0. This analysis is restricted to SSE load combinations.

h) When nonlinear analysis is performed, the stress analysis shall be peer reviewed for technical adequacy by an independent party/engineer knowledgeable in the design and behavior of tanks built to annexure R.

Reference

1. API 620 5.11.2.4 Anchor Strap Design

e) The design slope of the anchor strap from vertical shall not exceed 5 degrees.

2. Allowable stress in Annex L of API620

L.3.3 Resistance to Design Loads

L.3.3.1 Allowable Stresses

For Annex R tanks, design allowable stresses shall be per API 620, Section R.3.3, increased by 33 % for load combinations, including earthquake loads. The load combination in 5.4.2 f) is applicable.

For Annex Q tanks, design allowable stresses shall be per API 620, Section Q.3.3, increased by 33 % for load combinations, including earthquake loads. The load combination in 5.4.2 f) is applicable.

3. Load case combination and load factor for an Elastic-Plastic Analysis of Aboveground Storage Tank in API 579 Part 2D.

API 579-1/ASME FFS-1 ~~2021~~ 2026 Fitness-For-Service

Table 2D.4– Load Case Combinations and Load Factors for an Elastic-Plastic Analysis of Aboveground Storage Tanks

Design Conditions		
Criteria	**Required Factored Load Combinations**	
Global Criteria	Load Case	Load Combination
	1	$\beta(P_i + P_s + D)$
	2	$0.86\beta(D + F_p P_i \text{ or } F_{pe} P_e) + 0.71\beta W$
	3	$0.86\beta(D + P_s + F_p P_i) + 0.71\beta E_v + 0.71\beta E_h + 0.11\beta S_s$
Buckling Criteria	1	$0.86\beta_b(D + P_e) + (0.36\beta_b L_r \text{ or } 0.21\beta_b S_s)$
	2	$0.86\beta_b(D + F_{pe} P_e) + (1.1\beta_b L_r \text{ or } 0.71\beta_b S_s)$
	3	$0.86\beta_b(D + (F_p P_i \text{ or } F_{pe} P_e)) + 0.71\beta_b W$
	4	$0.86\beta_b(D + P_s + F_p P_i) + 0.71\beta_b E_v + 0.71\beta_b E_h + 0.11\beta_b S_s$
Local Criteria	$1.7(P + P_s + D) \cdot RSF_a$	
Serviceability Criteria	Per Tank Design Basis	
Hydrostatic or Hydrostatic-pneumatic Test Conditions		
Global and Local Criteria	$\frac{\beta}{1.5}(P_t + P_h + D)$	
Serviceability Criteria	Per Tank Design Basis	

Notes:
1. The parameters used in the Required Factored Load Combination column are defined in Table 2D.1.
2. Loads listed herein shall be considered to act in the combinations described above; whichever produces the most unfavorable effect in the component being considered. Effects of one or more loads not acting shall be considered.
3. In the assessment of fixed roof tanks with suspended internal floating roofs, the internal floating roof uniform live load, internal floating roof point load, or the internal floating roof design external pressure, shall be added to Load Case 2 and Load Case 3. A factor of 0.4 may be applied to the internal floating roof loads in Load Case 2 and the external roof loads in Load Case 3.
4. The magnitude and direction of any external loads or restraint applied to the tank shell or shell connections should be included in the defined load cases.

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Table 2D.~~4~~ 5 – Values of M and β for an FFS Assessment Based on Elastic-Plastic Analysis

Construction Code	Design Margin, M (1)	β (2)
PD 5500	2.35	$M \cdot RSF_a$
EN ~~13346~~ 13445	2.4	$M \cdot RSF_a$
~~ASME Section VIII, Division 2, 2017 Edition and later, Class 1 Vessel~~	~~3.0~~	~~$M \cdot RSF_a$~~
~~ASME Section VIII, Division 2, 2017 Edition and later, Class 2 Vessel~~	~~2.4~~	~~$M \cdot RSF_a$~~
~~ASME Section VIII, Division 2, 2007 up to the 2017 Edition~~	~~2.4~~	~~$M \cdot RSF_a$~~
ASME Section VIII, Division 2, 2007 through 2017 Edition and ASME Section VIII, Division 2, 2025 Edition and later	2.4	$M \cdot RSF_a$
ASME Section VIII, Division 2, 2017 Edition through 2023 Edition, Class 2 Vessel	2.4	$M \cdot RSF_a$
ASME Section VIII, Division 2, 2017 Edition through 2023 Edition, Class 1 Vessel	3.0	$M \cdot RSF_a$
ASME Section VIII, Division 2, prior to the 2007 Edition	3.0	$M \cdot RSF_a$
ASME Section VIII, Division 1, 1999 Addenda of the 1998 Edition and later	3.5	$M \cdot RSF_a$
ASME Section VIII, Division 1, 1968 Edition up to the 1999 Addenda of the 1998 Edition	4.0	$M \cdot RSF_a$
ASME Section VIII, 1950 Edition up to the 1968 Edition	4.0	$M \cdot RSF_a$
ASME Section VIII, prior to the 1950 Edition (3)	5.0	$M \cdot RSF_a$
API-ASME Code 1934-1954 (3)	4.0	$M \cdot RSF_a$
API 650	2.5	$M \cdot RSF_a$
API 620	3.3	$M \cdot RSF_a$
ASME B31.1 2007 Edition and later	3.5	$M \cdot RSF_a$

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calculation should be the minimum thickness less any future corrosion allowance unless another thickness can be justified.

2D.5 Supplemental Requirements for Stress Classification in Nozzle Necks

Classification of stresses for nozzle necks shall be in accordance with VIII-2, Part 5, paragraph 5.6.

2D.6 Nomenclature

β	load multiplier used in an elastic-plastic analysis that is based on a design margin in a construction code.
β_b	load multiplier used in an analysis for collapse from buckling.
β_T	hydrostatic test load factor (0.95) or pneumatic test load factor (0.8).
F	design factor used in the ASME B31.4, B31.8 and B31.12 Piping Codes.
F_p	internal pressure combination factor from API 650 or API 620 aboveground storage tank Standards.
F_{pe}	external pressure combination factor from API 650 or API 620 aboveground storage tank Standards.
H_f	materials performance factor for pipelines used in the ASME B31.12 Piping Code.
M	a design margin of the construction code.
M_f	materials performance factor for industrial piping used in the ASME B31.12 Piping Code.
m_2	curve fitting exponent for the stress-strain curve equal to the true strain at the true ultimate stress from Table 2E.7.
RSF_a	allowable remaining strength factor (see Part 2).
S	allowable stress based on the material of construction, design temperature, and construction code.
S_y	yield strength based on the material of construction, design temperature, and construction code.
S_t	allowable test stress based on the material of construction, pressure-test temperature, and construction code.
S_{PL}	allowable limit on the local primary membrane and local primary membrane plus bending stress categories (see VIII-2, Part 5).
σ_{ys}	yield strength to be used in a limit-load analysis.
T	design load parameter to represent the self-restraining load case or the temperature derating factor used in the ASME B31.8 and B31.12 Piping Codes.

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Commented [BM5]: 2021 edition is Table 2E.8, but with updates to Annex 2E it will be Table 2E.7.