Black Square Engineering

DESIGN VERIFICATION REPORT

OZ-TAC ENGINEERING

0167-A000-PANEL TANKS

28TH APRIL 2022

DOCUMENT CONTROL SHEET

Document reference:	OZT0181
Title:	Design Verification Report – Oz-Tac Engineering 0167-A000 Panel Tanks
Project Manager:	Joseph Norris
Author:	James Bailie Email: James.bailie@blacksquareengineering.com.au
Client:	Oz-Tac Engineering
Client Contact:	Luke Edwards luke@oztacengineering.com.au
Client reference:	0167-A000 Panel Tanks

REVISION & CHECKING HISTORY

Revision No.:	Date:	Reviewed by:	Issued by:
0	28th April 2021	Joseph Norris	James Bailie

DISTRIBUTION HISTORY

Destination	Revision					
	0	1	2	3	4	5
Oz-Tac Engineering – Luke Edwards	X					

APPROVED BY:

OZT0181-R220421-PANEL TANK VERIFICATION REPORT-REV0.docx
4:33 PM
28/04/2022

Joseph Norris – Director
BEng (Mech), Dip PM, MIEAust, CPEng, NER, RPEQ

EXECUTIVE SUMMARY

Engineering analysis and verification of the Oz-Tac Enigneering Panel Tank family, reference 0167-A000, was undertaken by Black Square Engineering.

Following the conclusion of works, the 18-panel tank was verified against the required wind and hydrostatic loading requirements. The design was assessed against a 25-year life and for use in Australia.

Further to this, the design was verified against the relevant sections of the listed International and Australian Standards.

TABLE OF CONTENTS

1. SCOPE

The scope of works is defined as the engineering verification of the Oz-Tac Engineering panel tanks against operational load requirements and relevant Australian and International standards. The assessment was limited to the following elements:

- The 0167-A000 panel tank family, defined by the following specification limits:
  - Minimum Tank Size: 13 Top and Bottom Panel Sections, 48.9 *m* Outside Diameter
  - Maximum Tank Size: 18 Top and Bottom Panel Sections, 67.7 *m* Outside Diameter

- The panel tank structure, compromising of the steel shell, retaining plates, structural PFC and SHS and mounting hardware as suitable for the required operating conditions resulting from the carried fluid and defined wind loading.

- Wind loads to be derived in accordance with AS/NZS 1170.2.

- The tank has been assessed for a 25-year operating life.

2. LIMITATIONS

The verification of the structural design of the panel tank family was limited to the scope outlined in Section 1 of this report and the relevant standards listed under Section 3. The following are excluded from the certification:

- Engineering verification of the functional capacity of any system that may be connected or mounting to the panel tank. Verification regards structural assessment of the tank only.

- Engineering verification of OEM fitted components not listed under the Scope of Section 1 (Pipes, control units, lifting beams, strapping lugs, chains/cables, etc.) – Their ability to satisfy operational requirements and verification is covered by the client and OEM respectively.

- Engineering verification of the structure on to which the tank will be anchored. The analysis assumes the tank structure will be positioned and anchored to a suitably rated and reasonably flat surface.

- Analysis has been performed to the level of detail provided, it does not consider additional detail that has been omitted from the supplied engineering data listed under Section 6.

3. RELEVANT STANDARDS & CODES

The relevant sections of the following standards were used as a basis for the analysis of the panel tank family:

Australian Standard(s)

- AS/NZS 1170.0-2002: Structural design actions – General Principles
- AS/NZS 1170.2-2011: Structural design actions – Part 2: Wind actions
- AS/NZS 3678-2011: Structural steel – Hot-rolled plates, floorplates and slabs
- AS/NZS 1163-2016: Cold-formed structural steel hollow sections
- AS 3990-1993: Mechanical equipment - Steelwork

American Petroleum Institute Standard(s)

- API STD 620-12th Edition: Design and Construction of Large, Welded, Low-Pressure Storage Tanks

4. CONSIDERATION OF SAFETY IN DESIGN

The client (Oz-Tac Engineering) and end user are to ensure that the requirements of the engineering certificate issued under this verification are included in the safe work instructions for this equipment and operators are trained accordingly in its installation and use.

No consideration has been made by BSQE in regard to Safety In Design (SID), only structural verification of the design presented has been completed.

5. STRUCTURE VERIFICATION & EVALUATION

The panel tank family was verified through assessing the largest configurations' ability to satisfy strength requirements as defined by the relevant Australian and International Standards against the following load cases. Specifically, the 18 top and bottom panel tank with an outside diameter of 67.7 *m*.

- Design Loads:
  - Permanent loads
  - Live loads
  - Combination of loads

6. REFERENCE DOCUMENTATION

The following engineering data was used for the analysis and verification against the required operating conditions and relevant standards outlined in Section 3:

- Panel Tank Drawing: 0167-A000-Panel Tanks.pdf

- 3D Model of SWRO Tank: 0167-A000-Panel Tanks.step

7. ENGINEERING ANALYSIS

7.1 MATERIAL PROPERTIES

The following calculations define the material properties of the tank structure that formed the basis of the tank analysis.

7.1.1 Open and Closed Sections

The following material properties define the 100x5 SHS and 100 PFC component specifications used in the analysis of the tank structure.

- Material Grade: AS/NZS 1163-C350 Steel
- Yield Strength (σ_Y): 350 *MPa*
- Allowable Yield Strength – AS 3990 (σ_{Y1}): 234.5 *MPa*
- Allowable Yield Strength – API 620 (σ_{Y2}): 210 *MPa*
- Tensile Strength (σ_T): 430 *MPa*
- Poisson's Ratio (v): 0.25
- Elastic Modulus (E): 200×10^3 *MPa*
- Shear Modulus (G): 80×10^3 *MPa*
- Density (ρ): $7850\ kg.m^{-3}$
- Coefficient of Thermal Expansion (α_T): 11.7×10^{-6} per ^oC

7.1.2 Shell and Structural Plate

The following material properties define the plate component specifications used in the analysis of the tank structure.

- Material Grade: AS/NZS 3678-300 Steel
- Yield Strength (σ_Y): 310 *MPa*
- Allowable Yield Strength – AS 3990 (σ_Y): 207.7 *MPa*
- Allowable Yield Strength – API 620 (S_{ts}): 186 *MPa*
- Corrosion Allowance: 0.25 *mm*
- Tensile Strength (σ_T): 430 *MPa*
- Poisson's Ratio (v): 0.25
- Elastic Modulus (E): 200×10^3 *MPa*
- Shear Modulus (G): 80×10^3 *MPa*
- Density (ρ): $7850\ kg.m^{-3}$
- Coefficient of Thermal Expansion (α_T): 11.7×10^{-6} per ^oC

7.2 DESIGN LOADS

The following calculated loads define values used in the analysis and verification of the tank strength:

7.2.1 Permanent Loads

- Empty Tank Weight (Approx. from CAD): 66.45 *Tonnes* x g_{acc}
  = 651.9 *kN*

7.2.2 Live Loads

- Wind Loading (AS 1170.2-2011):
  - Installation Location: Australia
  - Design Working Life: 25 Years
  - Importance Level: 2
  - Wind Region: C
  - Wind Direction Multiplier (M_d): 1
  - Terrain Category: 1
  - Height of Target (z): 3.75 *metres*
  - Height Multiplier (M_{zcat}): 0.99
  - Shielding Multiplier (M_s): 1
  - Topographic Multiplier (M_t): 1
  - Wind Velocity ($V_{sit,BETA}$): 66.184 $m.s^{-1}$
  - External Windward Wall Pressure: 1145 *Pa*
  - Internal Tank Cover Pressure: 1244 *Pa*

- Maximum Hydrostatic Pressure: 1050 $kg.m^{-3}$ x g_{acc} x 3.75 *m* = 0.0386 *MPa*

7.2.3 Combination of Loads

As per AS 1170.0-2002, the combined loading for each analysis case was calculated as follows:

7.2.3.1 Hydrostatic and Permanent Action

$$E_d = [1.2G, 1.2F_{lp}]$$

where *G* is the permanent actions and *Q* is the imposed actions. Therefore,

$$E_d = [(1.2 \times 651.9\ kN) / (1.2 \times 9810\ mm.s^{-2}), (1.2 \times 1050\ kg.m^{-3})]$$
$$= \mathbf{[782.2\ kN / 11772\ mm.s^{-2}, 1260\ kg.m^{-3}]}$$

7.2.3.2 Wind and Permanent Action

$$E_d = [0.9G, W_u]$$

where *G* is the permanent actions and W_u is the wind action. Therefore,

$$E_d = [(0.9 \times 651.9\ kN) / (0.9 \times 9810\ mm.s^{-2}), (1 \times 1145\ Pa) \ \&\ (1 \times 1244\ Pa)]$$
$$= \mathbf{[586.7\ kN / 8829\ mm.s^{-2}, 1145\ Pa\ \&\ 1244\ Pa]}$$

7.3 TANK STRUCTURE VERIFICATION: API STD 620

The following values have been calculated in accordance with API 620, Section 5, to assess the degree to which the panel tank design satisfies the requirements of this standard.

The standard provides guidance on the design of low-pressure storage tanks by defining size limitations of the tank shell, girder and external structure components based on allowable stress values. These were calculated against the required operating conditions, design specifications and material design strength (Section 7.1). This is a conservative approach for the tank design and allows for top level verification of a given tank configuration.

This verification was made up of two main areas of evaluation. Specifically, shell permissible thickness and intermediate wind girders.

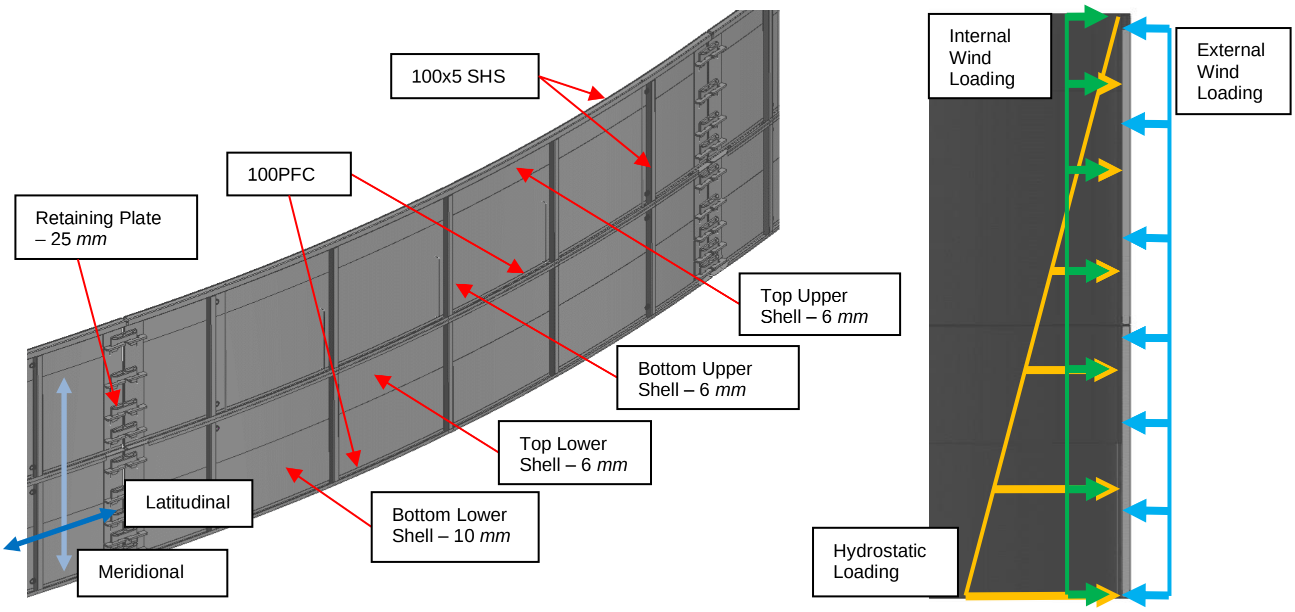

Figure 1: Tank Structure and Loading Overview

7.3.1 Tank Wall Thickness

For the bottom lower shell, the maximum hydrostatic pressure was used for the minimum wall thickness calculation (Figure 1) in accordance with Section 5.10.4 of API 620:

<u>Required Thickness</u>

- Mass Carried by Bottom Panel (W): (Approx. from CAD) — 63.65 *tonnes*
- Vertical Live Load (F): — *No vertical live loads*
- Total Pressure (P): — $P_l + P_g =$ 0.0386 *MPa* + 0.0013 *MPa* = 0.0399 *MPa*

- Minimum Joint Factor (E): 0.85 *(API 620, Table 5-2)*
- Tank Cross Sectional Area (A_t): 2126544.07 mm^2
- Radius of Curvature, Meridional Plane (R1): *Infinity – API 620, Section 5.10.2.5 c)*
- Tank Wall Normal (R_c): 33850 *mm*
- Meridional Unit Force (T_1): $$\mathrm{T1} = \left(\frac{33850}{2}\right)\left(0.0399 + \frac{63650.85+0}{2126544.07}\right) = 1181.40\ N/mm$$
- Latitudinal Unit Force (T_2): $$\mathrm{T2} = 0.0399 * 33850 = 1349.61\ N/mm$$
- Minimum Required Thickness (t): $$\mathrm{t} = \left(\frac{1349.61}{186*0.85}\right) + 0.25 = \mathbf{8.79\ mm}$$

<u>Least Permissible Thickness</u>

- Minimum Allowable Thickness (t): 9.53 *mm (API 620, Table 5-6)*

The minimum required wall thickness calculated above was seen to be less than the design wall thickness of 10 *mm.*

7.3.2 Intermediate Wind Girders for Cylindrical Sidewalls

The maximum pressure resulting from the wind load case was used calculate required specifications for the tank wind girders. This was completed in accordance with Section 5.10.6 of API 620.

- Thickness of Top Shell (t): 6 *mm*
- Nominal Tank Diameter (D): 67690 *mm*
- Maximum height of unstiffened sidewall, unadjusted (H_1): $$H_1 = 6(100 * 6)\sqrt{\left(\frac{100*6}{67690}\right)^3} = 1498.63\ mm$$
- Total Dynamic Pressure (P_d): 0.001144 *MPa*
- API 620 Derivation Pressure (P_{der}): 0.001484 *MPa*
- Girder Modification Factor: $$Factor = \frac{0.001484}{0.001144} = 1.30$$

- Maximum height of unstiffened sidewall, adjusted (H_{1_Adj}): $H_{1\_Adj} = 1.3 * 1498.63$ $= 1943.90\ mm$

First Shell Course (Bottom Lower and Top Lower Shell):

- Thickness of top Shell ($t_{uniform}$): 6 *mm*
- Thickness of bottom Shell (t_{actual}): 10 *mm*
- Course Width (W): 2118.35 *mm*
- Transposed Width (W_{tr}): $W_{tr} = 2118.35\sqrt{(\frac{6}{10})^5}$ $= 590.71\ mm$

First Shell Course (Bottom Lower and Top Lower Shell):

- Thickness of top Shell ($t_{uniform}$): 6 *mm*
- Thickness of bottom Shell (t_{actual}): 6 *mm*
- Course Width (W): 2118.35 *mm*
- Transposed Width (W_{tr}): $W_{tr} = 2118.35\sqrt{(\frac{6}{6})^5}$ $= 2118.35\ mm$
- Transposed height (H_{tr}): $H_{tr} = 2118.35 + 590.71$ $= 2709.09\ mm$

As H_{tr} is larger than H_1, an intermediate wind girder is required. The placement of this needs to be less than H1 however, not greater than half the transposed height in accordance with API 620, Section 5.10.6.3.

Additionally, the girders shall not be placed within 152.4 *mm* of a join and have a section modulus greater than the value calculated below:

- Minimum Section Modulus (Z): $Z = 0.0001 * 67690^2 * 1943.90$ $= 306353.83\ mm^3$
- Actual Section Modulus (100PFC): $363743.456\ mm^3$

Noting the above calculations, the proposed tank design was found to satisfy the requirements of the relevant Sections of API 620.

7.4 TANK STRUCTURE VERIFICATION: ENGINEERING ANALYSIS

In addition to API 620 design requirements, the panel tank structure was evaluated against the required operating requirements and performance specifications using engineering first principal calculations. Findings of this analysis have been summarised below.

7.4.1 Global Stability and Overturning

The tank structure was evaluated against the wind loading defined under Section 7.2.2 of this report. The evaluation criteria concerned the tank structures resistance to sliding and overturing when subjected to wind loading.

- Overturning Moment (Wind): = **786108875.1 *Nmm***
- Restoring Moment (Dead Load): = **18387938774 *Nmm***

- Wind Load: = **209629.03 *N***
- Friction (Dead Load): = **217287.31 *N***

The above calculations assumed the tank to be positioned on reasonably flat ground with a static coefficient of friction of 0.40.

7.4.2 Structural Strength – Vertical 100x5 SHS

The following maximum stresses were calculated from the analysis of the 100x5 SHS external structure of the tank:

- Bending Stress: = **142.4 *MPa***
- Shear Stress: = **24.2 *MPa***
- Von Mises Stress: = **148.4 *MPa***

7.4.3 Structural Strength – Horizontal 100PFC

The following maximum stresses were calculated from the analysis of the 100PFC external structure of the tank:

- Bending Stress: = **199.2 *MPa***
- Shear Stress: = **36.2 *MPa***
- Von Mises Stress: = **208.9 *MPa***

7.4.4 Structural Strength – Tank Shell

The following maximum stress and critical bucking pressure was calculated from the analysis of the tank wall.

- Base Hoop Stress: = **156.9 *MPa***
- Theoretical Critical Buckling Pressure: = **-0.17804 *MPa (Negative Denotes external pressure)***

7.4.5 Structural Strength – 25 *mm* Retaining Plate

The following maximum stresses were calculated from the analysis of the 25 *mm* retaining plate (9x per edge) against the required loading:

- Bending Stress: = **120.7 *MPa***
- Shear Stress: = **44.8 *MPa***
- Von Mises Stress: = **143.5 *MPa***

7.4.6 Structural Strength – Welds

The following maximum stresses were calculated for the resepective welded connection:

<u>100x5 SHS</u>

- Joint Stress: = **99.1 *MPa***

<u>Tank Wall – Shell Connection</u>

- Joint Stress: = **160.1 *MPa***

<u>Retaining Plate Connection</u>

- Joint Stress: = **39.2 *MPa***

7.4.7 Structural Strength – Mounting Hardware

The following maximum loads were calculated for the M24 8.8 mounting location:

- Shear Load per Bolt: = **79.82 *kN***
- Bearing Stress – PFC Hole: = **163.02 *MPa***
- Tear Out Stress – PFC Hole: = **63.11 *MPa***

7.5 TANK STRUCTURE VERIFICATION: FINITE ELEMENT ANALYSIS (FEA)

For the assessment of the tank strength against the hydrostatic and wind loading, a finite element model was created in Autodesk Inventor Nastran. From this, locations of peak stress were evaluated against corresponding values defined under section 7.1.

The FEA model assumes no structural capacity is provided by the internal bladder and has therefore been excluded from the analysis.

The construction of the FEA model can be defined as follows:

<u>Mesh Parameters:</u>

- Tank Wall Shell: 50 *mm* Quadrilateral Shell Elements
- 100x5 SHS: 50 *mm* Quadrilateral Shell Elements
- 100PFC: 50 *mm* Quadrilateral Shell Elements
- Retaining Platework: 50 *mm* Quadrilateral Shell Elements

<u>Constraints:</u>

- Tank Base: Contact constraint – Negative Y-Direction translation restrained.
- Tank Wall Edges: Symmetry constraint for edges, symmetry around vertical connection used for model (Figure 2).

<u>Shell Elements:</u>

- Bottom Lower Shell: 10 *mm* thick, 300 Steel
- Top Lower Shell: 6 *mm* thick, 300 Steel
- Bottom Upper Shell: 6 *mm* thick, 300 Steel
- Top Upper Shell: 6 *mm* thick, 300 Steel
- 100x5 SHS: 5 *mm* thick, C350 Steel
- 100PFC: 4.72 *mm* thick, C350 Steel
- Vertical Retaining Mounting Plate: 16 *mm* thick, 300 Steel
- Retaining Anchor Plate: 25 *mm* thick, 300 Steel
- Retaining Plate: 25 *mm* thick, 300 Steel

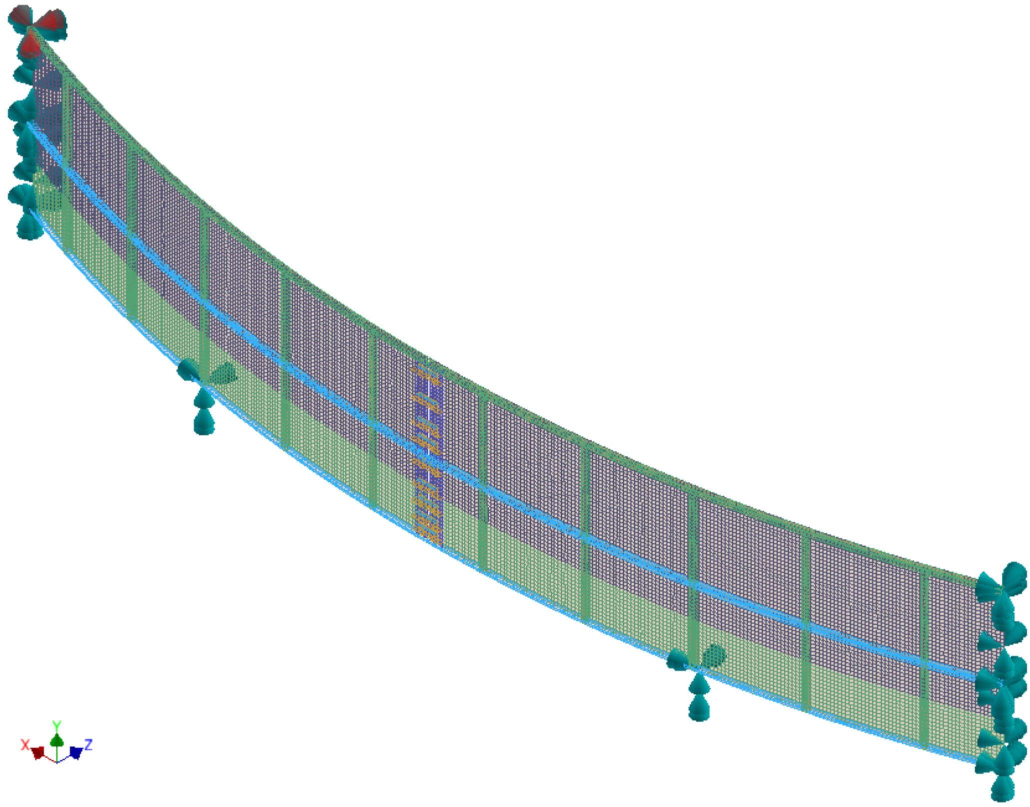

Figure 2: FEA Model

7.5.1 Hydrostatic and Permanent Action

The FEA model was subjected to the load case described under Section 7.2.3.1, specifically hydrostatic loading of the tank:

- Water Density (Live Load): = 1260 $kg.m^{-3}$
- Pressure Head: = 3750 *mm*
- Gravity (Permanent Action): = -11772 $mm.s^{-2}$

Form this analysis, the following peak stresses were noted:

- Tank Wall Stress: = **106.6 *MPa***
- Retaining Plate: = **179.7 *MPa***
- SHS Connection Stress: = **56.3 *MPa***

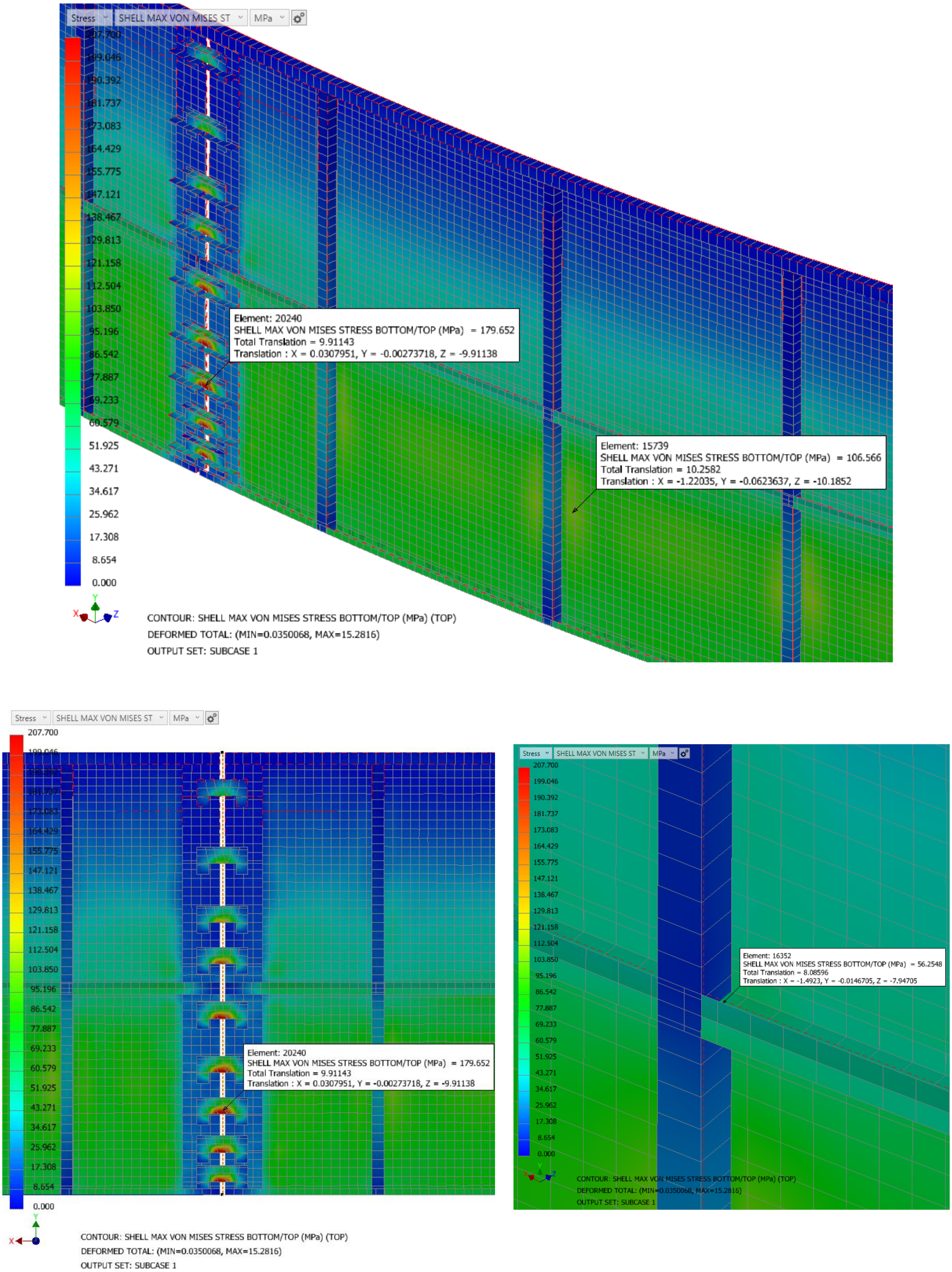

Figure 3: Hydrostatic & Permanent Action Shell Von Mises Stress Plots

7.5.2 Wind and Permanent Action

The FEA model was subjected to the load case described under Section 7.2.3.2, specifically wind loading of the tank when empty:

- Wind Pressure – External (Live Load): = 1145 *Pa*

- Roof Pressure – Internal (Live Load): = 1244 *Pa*

- Gravity (Permanent Action): = -8829 $mm.s^{-2}$

Form this analysis, the following peak stresses were noted:

- Tank Wall Stress: = **4.3 *MPa***
- Retaining Plate: = **9.8 *MPa***
- SHS Connection Stress: = **3.5 *MPa***

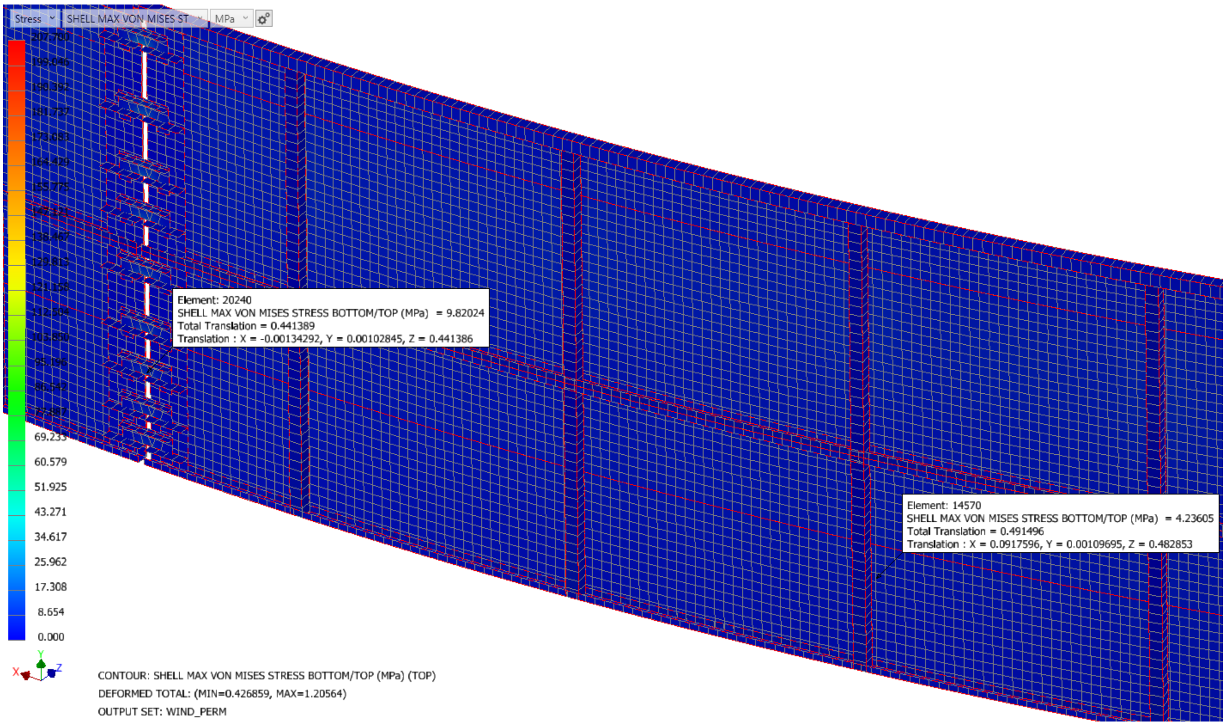

Figure 4: Wind & Permanent Action Shell Von Mises Stress Plot

8. SUMMARY OF RESULTS

The panel tank design was certified as fit for purpose against the requirements of the relevant Sections of API 620 and loading conditions defined in Section 7.2 of this report. The factors of safety from the structural analysis of the design have been listed below:

- Tank Structure – API 620

API 620 Evaluation Criteria	Minimum Calculated Compliance Factor
Tank Wall Thickness	1.05
Unsupported Length	1.37
Wind Girder to Joint Separation Distance	4.63
Wind Girder Section Modulus	1.19

- First Principal Engineering Analysis:
    - Global Stability and Overturning

Evaluation against Section 7.1 Design Stress	Minimum Calculated Compliance Factor
Global Stability – Overturning	23.39
Global Stability – Sliding	1.04

-
    - Structural Strength

Evaluation against Section 7.1 Design Stress	Minimum Calculated Compliance Factor
Vertical 100x5 SHS	1.41
Horizontal 100PFC	1.01
Tank Shell	1.19
Retaining Plate	1.30
Welded Connections	1.05 (Shell to Shell Connection)
Mounting Hardware	1.06

- <u>Finite Element Analysis:</u>
  - Hydrostatic and Permanent Action:

Evaluation against Section 7.1 Design Stress	Minimum Calculated Factor of Safety
Retaining Plate Strength	1.04
Tank Wall Strength	1.74
External Structure Strength	2.45

  - Wind and Permanent Action:

Evaluation against Section 7.1.1: PE100 Short-Term Design Strength	Minimum Calculated Factor of Safety
Retaining Plate Strength	18.98
Tank Wall Strength	43.26
External Structure Strength	39.40

9. CONDITIONS OF CERTIFICATION

Through the engineering analysis covered under this report, the 0167-A000 panel tank family is verified against the required loading conditions and relevant Standards. However, the explicit conditions of this certification are covered under the BSQE issued engineering certificate *OZT0181-C220421-PANEL TANK CERTIFICATE-REV0*.

The verification works conducted by BSQE are only valid through compliance with the loads and parameters analysed in this report and the conditions stipulated on the BSQE issued engineering certificate.