PIONEER
WATER TANKS

# ASSESSMENT OF PIONEER TANK BODY

# STRUCTURE

# AGAINST NFPA 22 - 2013 REQUIREMENTS

# 1 INTRODUCTION

1.1 Pioneer Water Tanks manufactures a factory-coated, bolted steel water tank which is utilised extensively in Australia and internationally. The tank body differs in some respects from the specifications nominated in the United States standard, "NFPA 22 – Standard for Water Tanks for Private Fire Protection – 2013 Edition."

1.2 From a structural perspective, notable differences exist firstly in that the Pioneer tank body employs a reinforced liner to provide water retaining capacity while all hydrostatic and structural strength is provided by the steel shell and strengthened vertical bolt seams. Secondly, the thickness of the steel body, while complying with structural standards, does not equate directly to the steel thicknesses nominated in NFPA 22.

1.3 The purpose of this report is to review the tank body structural requirements of NFPA 22, the typical structural requirements of a tank body, the actual structural capacities of the Pioneer tank body, and to demonstrate structural equivalence.

1.4 Specifically, a Pioneer XL50/04 tank model has been chosen as the representative tank in order to illustrate the arguments.

# 2 STRUCTURAL REQUIREMENTS OF NFPA 22 WITH RESPECT TO TANK BODY

2.1 For the purposes of this report, the relevant clause in NFPA 22 is 6.4 – Design Details.

2.2 It is noted that the Pioneer tank does not require a steel floor, since the liner provides water tightness at the base of the tank.

2.3 The relevant sub clauses are shown in the following pages. The quantities have been evaluated for the top ring (or strake) of the representative tank, which has a thickness of 0.0315" (0.80mm). The parameter relating to the height of liquid under the calculations of shell thickness has been conservatively taken as the height to the top of the tank, rather than to the overflow level. Conclusions are drawn about compliance with the minimum requirements based on the equations.

2.4 It is recognised that this is a first step, and that Clause 6.4.1.4.1 nominates 0.105" (2.4mm) as the minimum thickness even if the provisions of 6.4.1.3.1 are satisfied.

2.5 It is clear from the calculations on the following pages that the 0.315" minimum thickness provided is sufficient to withstand the hydrostatic stresses. It is respectfully submitted that the NFPA minimum thickness rules are in place in order to ensure that the tank body -

2.6 Is sufficiently rigid to withstand its own weight and the weight of the roof and any incidental loads.

2.7 Can successfully withstand wind loads while empty, which might otherwise cause wall buckling.

2.8 Has some allowance for potential corrosion to be identified during maintenance, and controlled prior to a failure event

2.9 The first two aspects are considered in the next section of this report.

2.10 The corrosion aspect is thought to be inapplicable to the Pioneer tank, as a liner is utilised, so there is no direct contact of the contents with the steel tank body.

## 6.4.1.3.1 (1)
## Tension on the Net Section

**Top ring, XL50/04 tank**

| | | | | | |
|---|---|---|---|---|---|
| $f_t$ = | allowable tensile stress = Lesser of:<br>0.5 Fy (1.0 - 0.9 r + 3 r dbolt / s) <= 0.5Fy<br>or<br>0.33 Fu | | | | |
| Fy = | published yield of the sheet material (psi) | 44,962 | psi | 310 | MPa |
| Fu = | ultimate strength of the sheet material (psi) | 49,313 | psi | 340 | MPa |
| r = | ratio of force transmitted by bolt or bolts at section considered, to<br>tensile force in member at that section. If r less than 0.2, then taken as zero. | | | | |
| = | 1 / No of columns of bolts at each end | 0.5 | | | |
| dbolt = | diameter of bolt (in) | 0.3937 | in | 10 | mm |
| s = | bolt spacing perpendicular to line of stress (in) | 3.1496 | in | 80 | mm |

| | | |
|---|---|---|
| $f_{t1}$ = | 16,580 | psi |
| 0.5 Fy | 22,481 | psi |
| $f_{t2}$ = | 16,273 | psi |
| Hence, $f_t$ = | 16,273 | psi |

$F_t$ = Unfactored tensile stress on net section

| | | | | | |
|---|---|---|---|---|---|
| $F_t$ = | 0.5*D*(unit height)*Hydrostatic pressure at base/Wall thickness | | | | |
| D = | Tank diameter | 473.70 | ft | 12.03 | m |
| Hydro p = | Ht x G = | 1.48 | psi | 10.2 | kPa |
| t = | Wall thickness | 0.0315 | in | 0.80 | mm |

| | | |
|---|---|---|
| Hence, $F_t$ = | 11,128 | psi |

11128 < 16273

Hence, $F_t < f_t$

**∴ Tension on Net Section OK**

PIONEER WATER TANKS

## 6.4.1.3.1 (2)
## Shell Thickness

**Top ring, XL50/04 tank**

| | | | | | | |
|---|---|---|---|---|---|---|
| $t_{req}$ = | 2.6 H D S G / $f_t$ (S- $d_{hole}$) | | | | | |
| $t_{req}$ = | required shell plate thickness (in) | | | | | |
| H = | height of liquid from the top capacity line at the point of overflow to the bottom of the shell course being designed (ft) | 3.412 | ft | 1.04 | m | |
| D = | tank diameter (ft) | 39.475 | ft | 12.03 | m | |
| S = | bolt spacing perpendicular to line of stress (in) | 3.1496 | in | 80 | mm | |
| G = | specific gravity of liquid (1.0 for water) | | | | | |
| ft = | allowable tensile stress (psi) | 16,273 | psi | | | |
| d = | bolt-hole diameter (in) | 0.4724 | in | 12 | mm | |
| Hence, $t_{req}$ = | | 0.025 | in | 0.64 | mm | |
| t = | actual thickness | | | | | |
| t = | | 0.031 | in | 0.80 | mm | |

Hence, $t > t_{req}$

**∴ Shell Thickness OK**

## 3 STRUCTURAL CAPACITY OF PIONEER TANK BODY

3.1 To introduce this section, it is noted that the approximate equivalent in Australia of NFPA 22 is the Australian standard "AS 2304 – 2100 Water storage tanks for fire protection systems." While it breaches copyright laws to copy the entire standard, it is permitted to copy limited portions of it in communications.

3.2 Appendix 1 of this report comprises scans of some relevant pages from AS 2304, including cover, scope, table of contents and structural clauses relevant to the subject of this report.

3.3 AS 2304 is about to be revised. The revisions will not affect the subject matter included in Appendix 1. The writer is a member of the Standards Australia subcommittee which wrote the standard and the current revision-in-consideration.

3.4 The Pioneer tank panel is ribbed with a profile which provides greater stiffness and strength to withstand out-of-plane loads than a flat panel of the same thickness. AS 2304 recognises the extra strength of a profiled panel and nominates 0.8mm as the minimum thickness of such a panel (Appendix 1, clause 5.2.2.) The Pioneer tank satisfies this clause.

3.5 With respect to the requirement for a tank body to be sufficiently rigid to withstand its own weight and the weight of the roof and any incidental loads – Pioneer tanks with the 0.8mm thick panel have been installed and are in successful service in literally tens of thousands of locations across the Australian continent and in many diverse parts of the world. Structural analysis demonstrates the profiled design to be capable of withstanding the loads nominated, and the empirical evidence of numerous locations confirms that demonstration.

3.6 The requirement that the wall panels be capable of withstanding wind buckling is addressed at AS2304 clause 5.3.2 (Appendix 1). The standard incorporates a method for calculating the wind pressure capacity of a tank body. Consideration is given to varying thickness up the tank wall and to profiled and plane panels, as well as to panel thickness and tank height and diameter.

3.7 The method is an iterative one that requires an initial estimate to be made of the number of buckling wavelengths around the tank circumference. This parameter is iterated in order to discover the minimum or limiting wind pressure that applies to the portion of the tank under consideration. A limiting minimum value (and therefore the design capacity) is established for the whole tank.

3.8 Pioneer Water Tanks has automated the procedure for undertaking this iterative calculation. The summary of the calculations is presented below. The calculations confirm that while the design pressure is calculated as 1.00 kPa (20.9 psf), corresponding to a Basic regional wind velocity of 51.8 $ms^{-1}$ (116mph), the tank has sufficient wind buckling capacity of 1.09 kPa, and it therefore passes the test.

# Specification Data Sheet

Return to Index

| | | | |
|---|---|---|---|
| PROJECT No.: | E03008 | | |
| PROJECT : | NFPA 22 structural assessment | | |
| DATE: | Fri, 13 Jan 2017 | | |
| **TANK DATA** | Design by = | LM | |
| | Tank Model = | XL50 | |
| | Rings = | 4 | |
| | Build = | Commercial | |
| | Material = | Zincalume | |
| | No. Panels = | 18 | |
| | Diameter = | 12.032 | m |
| | Height = | 4.275 | m |
| | Gross Volume = | 486.1 | $m^3$ |
| | Circumference = | 37.8 | m |
| | Panel coverage (Arc Length) = | 2.1 | m |
| | Horizontal spacing of end bolts = | 34 | mm |
| | Edge distance of end bolts = | 33 | mm |
| | Vertical spacing of end bolts = | 80 | mm |
| | Bottom edge distance = | 65 | mm |
| | Lap bolts used ? = | Yes | |
| | Lap Bolt spacing = | 420 | mm |
| | Lap Bolt Size = | 10 | mm |
| | Edge distance of Lap bolts = | 210 | mm |
| | Vertical sheet width for Lap bolts = | 50 | mm |
| | Wind Girt Design Type = | Type 2 | Okay |
| | Wind Girt Thickness = | 2 | mm |
| | Wind Girt Width = | 100 | mm |
| | Edge distance = | 38 | mm |
| | Hold Down Bracket Type = | 200/85 | Okay |
| | Hilti Anchor Bolts = | M16 | Okay |
| | No. Hold Down Bolts = | 1 | **One bolt** |
| | Clamp system = | No Clamps | **Okay** |
| | No. Clamps per panel = | 0 | **Okay** |
| | Max No. of hold-down bolts permitted = | 1 | |
| | Test for hold down bolts - | **Valid Combination** | |
| | Hold Down Index No. = | 2 | |
| | Steel platform beam spacing = | 0 | mm |

| Ring No. | Std Galaxy Panel | Actual Panel Sizes | Ring Height (m) | No. Plies | Ply Thickness (mm) | Bolt Size (mm) | Rows Bolts | No. Column Bolts | Ring C of G Height (m) | C of G Calculation |
|---|---|---|---|---|---|---|---|---|---|---|
| R1 (Top) | 0.8 | 0.8 | 1.090 | 1 | 0.8 | 10 | 13 | 2 | 3.73 | 2.98 |
| R2 | 1.2 | 1.2 | 1.040 | 1 | 1.2 | 10 | 13 | 2 | 2.67 | 3.20 |
| R3 | 2.0 | 2.0 | 1.040 | 2 | 1.0 | 12 | 13 | 2 | 1.63 | 3.25 |
| R4 | 2.0 | 2.0 | 1.105 | 2 | 1.0 | 12 | 14 | 2 | 0.55 | 1.11 |
| R5 | | | 0.000 | 0 | 0.0 | 0 | 0 | 0 | 0.00 | 0.00 |
| R6 | | | 0.000 | 0 | 0.0 | 0 | 0 | 0 | 0.00 | 0.00 |
| R7 | | | 0.000 | 0 | 0.0 | 0 | 0 | 0 | 0.00 | 0.00 |
| R8 (Bottor | | | 0.000 | 0 | 0.0 | 0 | 0 | 0 | 0.00 | 0.00 |
| | 6.0 | 6.0 | **4.275** | 6 | | | | | | 10.537 |
| Multiple = | **1.00** | 1.5 | is average panel thickness | | | | | | C of G = | **1.756** |

G Prem = 1.35 Total weight tank walls = 2220 kg Total Tank Height with Roof = 4.676 m

**STD GALAXY TANK DESIGN** No. Wind Girders = 0

Girders as % of tank weight = 0.0%

Summary Table

| Ring No. | Actual Panel Sizes | Panel Combined Tension | HT Bolts Combined SR | Lap Bolts SR | Wind Buckling SR | Pf (kPa) |
|---|---|---|---|---|---|---|
| R1 (Top) | 0.8 | 0.00 | 0.00 | 0.06 | 0.64 | 1.56 |
| R2 | 1.2 | 0.00 | 0.00 | 0.08 | 0.74 | 1.36 |
| R3 | 2.0 | 0.15 | 0.23 | 0.14 | 0.70 | 1.43 |
| R4 | 2.0 | 0.33 | 0.48 | | 0.92 | 1.09 |
| R5 | 0.0 | | | | | |
| R6 | 0.0 | | | | | |
| R7 | 0.0 | | | | | |
| R8 (Bottor | 0.0 | | | | | |

**Tank Wind Buckling Capacity =** 1.09 kPa

Tank design wind pressure = 1.00 kPa **PASSED**

Wind buckling pressure = 1.09 kPa

Hold Down rolled angle bolt spacing <= 1219 mm before 23% increase in buckling pressure permitted

Actual hold down bolt spacing = 300 mm therefore allowance is permitted

## 4 CONCLUSION

4.1 It is respectfully submitted that the subject matter and calculations above demonstrate that the Pioneer tank, even though it does not equate directly to the steel thicknesses nominated in NFPA 22, nevertheless has sufficient strength, stiffness and serviceability capacity to qualify as an equivalent tank under the provisions of clause 1.4 of NFPA 22.

Yours faithfully,

L A Mitchell

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Fri 13 Jan 2017

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# APPENDIX 1

# EXTRACT FROM

# AS 2304 – 2011 – Water storage tanks for fire protection systems

AS 2304—2011

Australian Standard®

# Water storage tanks for fire protection systems

# PREFACE

This Australian Standard was prepared by Standards Australia Committee FP-008, Fire Pumpsets and Fire Tanks.

Technical Sub-committee FP-008-02, Fire Tanks, provided invaluable assistance in the development of this Standard, especially in the sections relating to design action (loads), tank design and tank foundations.

This Standard was developed taking into consideration local and international Standards.

Maintenance of water storage tanks for fire protection purposes is covered in Section 11 of this Standard, but will be removed by amendment when the same requirements are published in Australian Standard titled, *Routine servicing of fire protection systems and equipment*, currently under development (see Note to Clause 1.1).

The term 'informative' has been used in this Standard to define the application of the appendix to which it applies. An 'informative' appendix is only for information and guidance.

*This Standard incorporates commentary on some of the clauses. The commentary directly follows the relevant Clause shown in italic font-type and enclosed in a panel. The commentary is for information only and does not need to be followed for compliance with the Standard. Commentaries explain the purpose of a Clause and give, in some cases, background information.*

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# FOREWORD

This Standard has been developed to provide reliable water storage for fire protection purposes. Water storage tanks that are not designed correctly nor adequately maintained are prone to failure.

Design provisions for bolted steel tanks are covered in this Standard. Design provisions for tanks made from other materials are not covered by this Standard and may be included in future editions.

This Standard applies to suction tanks for sprinkler, hydrant and hose reel systems as well as for break tanks and dual-use fire protection storage tanks.

Steel tanks consist of a floor (either steel, concrete or liner), cylindrical or rectangular shell fabricated from steel plates joined together, and a roof, all of which rest upon a foundation. Tanks are filled with water from an outside source. Water is withdrawn in emergency situations through piping connected to a pump. Accessory items are provided to fill and drain the tank, monitor the water level, gain access for inspection and repair, provide means for accessing the water and to prevent positive or negative pressures, etc.

For tanks manufactured from materials other than bolted steel and bolted cast iron, the accessories and maintenance provisions of this Standard apply.

# SECTION 5 TANK DESIGN

## 5.1 GENERAL

This Section provides options for tank design for the minimum steel thickness. For unlined tanks, the minimum steel thickness is specified for corrosion degradation over the design life of the tank and takes precedence. For lined tanks, the designer has the option of using the default steel thickness of 2 mm or using lesser thicknesses with profiles and or laminations with a minimum of 0.8 mm, to safely withstand the design actions calculated in Section 4.

The design of the tank body, its roof, accessories and foundation shall be performed by a competent person.

The tank shall be located to allow for installation and maintenance purposes, and a minimum clear space of 600 mm shall be provided around the tank perimeter, tank accessories and the roof line.

## 5.2 MINIMUM STEEL THICKNESS

### 5.2.1 Unlined tanks

The minimum base metal thickness (BMT) for bolted steel tank wall plates shall be 2.0 mm and 3.0 mm for tank floor plates.

**C5.2.1** *The 3 mm thickness for unlined tanks was selected because tank floors are subject to accelerated corrosion and the underside cannot be inspected or maintained.*

### 5.2.2 Tanks with liners

The minimum BMT for flat wall bolted steel tank wall plates shall be 2.0 mm.

The minimum BMT for profiled wall bolted steel tank wall plates shall be 0.8 mm.

## 5.3 BOLTED STEEL CIRCULAR WATER STORAGE TANK DESIGN

### 5.3.1 General

Tank bodies, including connections, shall be designed in accordance with AS 4100 or AS/NZS 4600 as appropriate to safely withstand any design actions calculated in Section 4.

Tank panels may be profiled. Tank bodies may be strengthened by girders attached at the vertical or horizontal seams. Such girders shall be designed in accordance with AS 4100 or AS/NZS 4600 as appropriate.

The required thickness of the tank panels may be achieved by laminations. If laminations are used—

(a) panel properties shall be calculated as the algebraic sum of the lamination properties; and

(b) edges of each layer and all penetrations shall be continuously sealed to prevent water ingress between layers for the life of the tank.

### 5.3.2 Wind buckling

#### 5.3.2.1 *General*

Wall panels shall be designed in accordance with this Section to withstand wind buckling from wind actions determined from Section 4. Irrespective of any requirements for circumferential stiffeners, circularity of the tank shall be ensured at roof and base levels.

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Buckling pressure shall be determined from Equations 5.3.2.2(1) or 5.3.2.3(1).

For uniform isotropic tanks (i.e. flat plate constant thickness for the height of the tank), Equation 5.3.2.2(1) shall be used.

For uniform orthotropic tanks (i.e. profiled constant thickness for the height of the tank), Equation 5.3.2.3(1) shall be used.

For non-uniform tanks (i.e. different ring thicknesses), the procedure in Clause 5.3.2.4 shall be followed using the appropriate equations from Clauses 5.3.2.2 to 5.3.2.3.

NOTE: For examples of wind buckling calculations, see Appendix F.

**5.3.2.2** *Uniform isotropic tanks*

The following equation shall be used to determine the buckling pressure for uniform isotropic tanks:

$$P_c = \frac{Et^3}{12(1-\upsilon^2)R^3}\left(\frac{\pi R}{l}\right)^2\left(\alpha+\frac{1}{\alpha}\right)^2+\frac{Et}{R}\left(\frac{l}{\pi R}\right)^2\left[\frac{\alpha^4}{\left(\alpha+\frac{1}{\alpha}\right)^2}\right] \quad \ldots 5.3.2.2(1)$$

where

$\alpha = \frac{\pi R}{ml}$

$l$ = height of buckle, in metres

$R$ = tank radius, in metres

$t$ = panel thickness, in metres

$E$ = Young's modulus (= 200 GPa for steel), in kilopascals

$\upsilon$ = Poisson's ratio (= 0.3 for steel)

$m$ = number of buckling wavelengths around the tank circumference

The minimum buckling pressure shall be determined by making trials with increasing integer values of $m$ until a minimum value is found.

For tanks with a $\frac{H^2}{Rt}$ ratio greater than 100, Equation 5.3.2.2(1) shall be closely approximated by—

$$P_c = \frac{184000}{\frac{H}{R}\left(\frac{R}{t}\right)^{2.5}} \quad \ldots 5.3.2.2(2)$$

where

$H$ = height of the tank

NOTES:

1 The height of buckle ($l$) is the height from the top of the tank to the level for which the analysis is being carried out. To determine the buckling pressure for the whole tank it will be the tank's height. If analysing the top ring of the tank it will be from the top of the tank to the bottom of the top ring.

2 The number of buckling wavelengths around the tank circumference ($m$) is an integer number that needs to be increased from 1 until the minimum buckling pressure is obtained. '$m$' is the number of buckling waves that can occur around the circumference of the tank (horizontal buckle) the size of the buckle would be $\pi R$/m.

3 More detailed information is given in AWWA D 103 (see Bibliography).


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**5.3.2.3** *Uniform orthotropic tanks*

The following equation shall be used to determine the buckling pressure for uniform orthotropic tanks:

$$P_c = \frac{EI_\theta}{R^3}\left(\frac{\pi R}{l}\right)^2\left[\left(\frac{ml}{\pi R}\right)^2\frac{I_z}{I_\theta}+\frac{I_{\theta z}}{2I_\theta}+\left(\frac{\pi R}{ml}\right)^2\right] + \frac{E}{\frac{R}{t_\theta}}\left(\frac{l}{\pi R}\right)^2\frac{\left(\frac{\pi R}{ml}\right)^4}{\left[\left(\frac{ml}{\pi R}\right)^2\frac{t_\theta}{t_z}+2\frac{t_\theta}{t_{\theta z}}+\left(\frac{\pi R}{ml}\right)^2\right]} \quad \ldots 5.3.2.3(1)$$

where

$R$ = tank radius, in metres

$E$ = Young's modulus (= 200 GPa for steel), in kilopascals

$l$ = height of buckle, in metres

$m$ = number of buckling wavelengths around the tank circumference

$t$ = base metal thickness of the wall sheet joined at a vertical seam, in millimetres (Clause 5.4.2.5) panel thickness, in metres (Clause 5.3.2.2)

and

$t_z$, $t_\theta$ and $t_{\theta z}$ are equivalent membrane properties per unit projected width

$I_z$, $I_\theta$ and $I_{\theta z}$ are equivalent flexural properties per unit projected width

The minimum buckling pressure is determined by making trials with increasing integer values of $m$ until a minimum value is found.

For a profiled sheet, the equivalent membrane and flexural property values shall be determined by the following equations, where $b$, $d$ and $t$ are as per Figure 5.3.2.3.

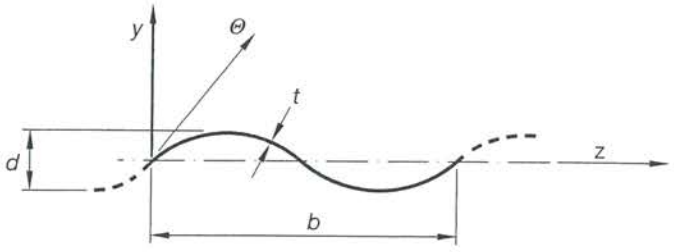


FIGURE 5.3.2.3 EXAMPLE OF PROFILED SHEETING

The equivalent membrane properties shall be determined by the following equations:

$$t_z = \frac{2t^3}{3d^2} \quad \ldots 5.3.2.3(2)$$

$$t_\theta = t\left(1+\frac{\pi^2 d^2}{4b^2}\right) \quad \ldots 5.3.2.3(3)$$

$$t_{\theta z} = \frac{t}{\left(1+\frac{\pi^2 d^2}{4b^2}\right)} \quad \ldots 5.3.2.3(4)$$

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The equivalent flexural properties shall be determined by the following equations:

$$I_z = \left(\frac{d^2 t}{8}\right)\left(1+\frac{\pi^2 d^2}{8b^2}\right) \quad \ldots 5.3.2.3(5)$$

$$I_\theta = \frac{\left(\frac{t^3}{12}\right)}{\left(1+\frac{\pi^2 d^2}{4b^2}\right)} \quad \ldots 5.3.2.3(6)$$

$$I_{\theta z} = \left(\frac{t^3}{3}\right)\left(1+\frac{\pi^2 d^2}{4b^2}\right) \quad \ldots 5.3.2.3(7)$$

### 5.3.2.4 *Non-uniform isotropic or orthotropic tanks*

When tank panels have different thicknesses over the height of the tank (i.e. different ring thicknesses), then the equations in Clauses 5.3.2.2 and 5.3.2.3 shall be used to determine the buckling pressure. The thickness of the tank panels shall be the weighted average thickness for the height of the tank, working from the top of the tank downward, for each change of thickness. Hence the buckling pressure shall be checked progressively down the height of the tank. The weighted average thickness of the wall panels shall be used to determine the panel properties and hence the buckling pressure.

### 5.3.2.5 *Limit state buckling pressure*

The limit state buckling pressure shall be determined by the following equation:

$$P_f = 0.65 \times P_c \quad \ldots 5.3.2.5(1)$$

The value of $P_f$ shall be greater than the wind actions determined in Section 4 of this Standard.

This limit state pressure may be increased by 23%, provided the tank is continuously fixed to a substantial concrete ring beam, and provided that there are at least three times more hold-down brackets than there are full buckling wavelengths around the tank circumference. That is, the number of hold-down brackets shall be greater than $3 \times m$, where $m$ is value found in the determination of the minimum value of $P_c$ in Equation 5.3.2.2(1) or 5.3.2.3(1).

## 5.3.3 Circumferential stiffeners

If increasing the panel thickness or laminating panels does not provide sufficient resistance to wind buckling actions, then circumferential stiffeners (wind girders) may be used to prevent wind buckling.

The required capacity of a circumferential stiffener against the compressive forces induced by the wind actions determined in Section 4 shall be determined from the following:

$$F = p_t R h_s \quad \ldots 5.3.3(1)$$

where

$F$ = compressive force on the circumferential stiffener, in kilonewtons

$P_t$ = wind action from Section 4, in kilopascals

$R$ = tank radius, in metres

$h_s$ = effective height for wind pressure, in metres


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where

$R$ = 4679 mm

$E$ = $200 \times 10^6$ kPa

$l$ = 4275 mm

$m$ = 20 (start of iteration integers)

**Calculating minimum wind buckling pressure**

Use the values in Equation 5.3.2.3(1).

$$P_c = \frac{200\times10^6\times0.274}{4679^3}\left(\frac{\pi\times4679}{4275}\right)^2\left[\left(\frac{20\times4275}{\pi\times4679}\right)^2\frac{12.148}{0.274}+\frac{1.153}{2\times0.274}+\left(\frac{\pi\times4679}{20\times4275}\right)^2\right]$$

$$+\frac{200\times10^6}{\frac{4679}{1.537}}\left(\frac{4275}{\pi\times4679}\right)^2\frac{\left(\frac{\pi\times4679}{20\times4275}\right)^4}{\left[\left(\frac{20\times4275}{\pi\times4679}\right)^2\frac{1.537}{0.035}+2\frac{1.537}{1.464}+\left(\frac{\pi\times4679}{20\times4275}\right)^2\right]} \quad \ldots \text{F3.2}$$

*Iteration*:

Using $m$ = 20 then $P_c$ = 9.5 kPa

Using $m$ = 8 then $P_c$ = 2.33 kPa

Using $m$ = 10 then $P_c$ = 2.59 kPa

Using $m$ = 7 then $P_c$ = 2.94 kPa

Using $m$ = 9 then $P_c$ = 2.33 kPa

Therefore, the minimum value of $P_c$ = 2.33 kPa

The ultimate wind buckling pressure is determined by the following equation:

$P_f = 0.65 \times P_c$

$P_f = 0.65 \times 2.33 = 1.5$ kPa

## F4 EXAMPLE 4—A NON-UNIFORM ORTHOTROPIC TANK

This example shows how the wind buckling pressure is determined for a three-ring tank, 3.0 m high with a tank diameter of 9.2 m.

The ring thicknesses are $t$ = 1.0 mm (top ring), $t$ = 2.0 mm (middle ring), $t$ = 3.0 mm (bottom ring).

The height of the rings are 1000 mm each.

The weighted average thickness for these rings are 1.5 mm for the top two rings and 2.0 mm for the full height.

All profile panel corrugation dimensions are $d$ = 8 mm, $b$ = 80 mm as per the diagram in Example 3).

**Calculating properties of the corrugated sheet for top ring**

The corrugated sheet equivalent membrane and flexural property values are found first.

Where $t$ = 1.0 mm, and $l$ = 1000 mm

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$$t_z = \frac{2t^3}{3d^2} = 0.01 \text{ mm}$$

$$t_\theta = t\left(\frac{1+\pi^2 d^2}{4b^2}\right) = 1.025 \text{ mm}$$

$$t_{\theta z} = \frac{t}{\left(\frac{1+\pi^2 d^2}{4b^2}\right)} = 0.976 \text{ mm}$$

$$I_z = \left(\frac{d^2 t}{8}\right)\left(\frac{1+\pi^2 d^2}{8b^2}\right) = 8.099 \text{ mm}^3$$

$$I_\theta = \frac{\left(\frac{t^3}{12}\right)}{\left(\frac{1+\pi^2 d^2}{4b^2}\right)} = 0.081 \text{ mm}^3$$

$$I_{\theta z} = \left(\frac{t^3}{3}\right)\left(\frac{1+\pi^2 d^2}{4b^2}\right) = 0.342 \text{ mm}^3$$

**Calculating minimum wind buckling pressure for the top ring:**

$$P_c = \frac{EI_\theta}{R^3}\left(\frac{\pi R}{l}\right)^2\left[\left(\frac{ml}{\pi R}\right)^2 \frac{I_z}{I_\theta} + \frac{I_{\theta z}}{2I_\theta} + \left(\frac{\pi R}{ml}\right)^2\right] + \frac{\frac{E}{R}}{t_0}\left(\frac{l}{\pi R}\right)^2 \frac{\left(\frac{\pi R}{ml}\right)^4}{\left[\left(\frac{ml}{\pi R}\right)^2 \frac{t_\theta}{t_z} + 2\frac{t_\theta}{t_{\theta z}} + \left(\frac{\pi R}{ml}\right)^2\right]} \quad \ldots \text{F4.1}$$

where

$R$ = 4600 mm

$E$ = $200 \times 10^6$ kPa

$l$ = 1000 mm

$m$ = 20 (start of iteration integers)

$$P_c = \frac{200\times10^6 \times 0.081}{4600^3}\left(\frac{\pi\times4600}{1000}\right)^2\left\{\left(\frac{20\times1000}{\pi\times4600}\right)^2 \frac{8.099}{0.081} + \frac{0.342}{2\times0.081} + \left(\frac{\pi\times4600}{20\times1000}\right)^2\right\} + \frac{\frac{200\times10^6}{4600}}{1.025}\left(\frac{1000}{\pi\times4600}\right)^2 \frac{\left(\frac{\pi\times4600}{(20\times1000)}\right)^4}{\left[\left(\frac{20\times1000}{\pi\times4600}\right)^2 \frac{1.025}{0.010} + 2\frac{1.025}{0.976} + \left(\frac{\pi\times4600}{20\times1000}\right)^2\right]} \quad \ldots \text{F4.2}$$


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*Iteration*:

Using $m$ = 20 then $P_c$ = 7.05 kPa

Using $m$ = 14 then $P_c$ = 5.91 kPa

Using $m$ = 15 then $P_c$ = 5.54 kPa

Using $m$ = 16 then $P_c$ = 5.51 kPa

Using $m$ = 17 then $P_c$ = 5.71 kPa

Therefore minimum value for the top ring for $P_c$ = 5.51 kPa

**Calculating properties of the corrugated sheet to the middle ring**

Where average $t$ = 1.5 mm, and $l$ = 2000 mm.

$$t_z = \frac{2t^3}{3d^2} = 0.035 \text{ mm}$$

$$t_\theta = t\left(1+\frac{\pi^2 d^2}{4b^2}\right) = 1.537 \text{ mm}$$

$$t_{\theta z} = \frac{t}{\left(1+\frac{\pi^2 d^2}{4b^2}\right)} = 1.464 \text{ mm}$$

$$I_z = \left(\frac{d^2 t}{8}\right)\left(1+\frac{\pi^2 d^2}{8b^2}\right) = 12.148 \text{ mm}^3$$

$$I_\theta = \frac{\left(\frac{t^3}{12}\right)}{\left(1+\frac{\pi^2 d^2}{4b^2}\right)} = 0.274 \text{ mm}^3$$

$$I_{\theta z} = \left(\frac{t^3}{3}\right)\left(1+\frac{\pi^2 d^2}{4b^2}\right) = 1.153 \text{ mm}^3$$

**Calculating minimum wind buckling pressure to the middle ring**

Use Equation 5.3.2.3(1) to determine the lowest buckling pressure.

*Iteration*:

Using $m$ = 20 then $P_c$ = 10.11 kPa

Using $m$ = 10 then $P_c$ = 6.61 kPa

Using $m$ = 11 then $P_c$ = 5.39 kPa

Using $m$ = 12 then $P_c$ = 5.03 kPa

Using $m$ = 13 then $P_c$ = 5.14 kPa

Therefore minimum value for the top two rings for $P_c$ = 5.03 kPa

**Calculating properties of the corrugated sheet to the bottom ring**

Where weighted average $t$ = 2.0 mm, and $l$ = 3000 mm.

$$t_z = \frac{2t^3}{3d^2} = 0.083 \text{ mm}$$

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$$t_\theta = t\left(1+\frac{\pi^2 d^2}{4b^2}\right) = 2.049 \text{ mm}$$

$$t_{\theta z} = \frac{t}{\left(1+\frac{\pi^2 d^2}{4b^2}\right)} = 1.952 \text{ mm}$$

$$I_z \quad \left(\frac{d^2 t}{8}\right)\left(1+\frac{\pi^2 d^2}{8b^2}\right) \quad 16.197 \text{ mm}^3$$

$$I_\theta = \frac{\left(\frac{t^3}{12}\right)}{\left(1+\frac{\pi^2 d^2}{4b^2}\right)} = 0.651 \text{ mm}^3$$

$$I_{\theta z} = \left(\frac{t^3}{3}\right)\left(1+\frac{\pi^2 d^2}{4b^2}\right) = 2.732 \text{ mm}^3$$

**Calculating minimum wind buckling pressure to the bottom ring**

Use Equation 5.3.2.3(1) to determine the lowest buckling pressure.

*Iteration:*

Using $m = 20$ then $P_c = 13.41$ kPa

Using $m = 10$ then $P_c = 5.31$ kPa

Using $m = 12$ then $P_c = 5.51$ kPa

Using $m = 11$ then $P_c = 5.18$ kPa

Using $m = 13$ then $P_c = 6.09$ kPa

Therefore, the minimum value for the full height for $P_c = 5.18$ kPa.

The lowest pressure value over the three calculations is 5.03 kPa, as shown in Table F1.

Therefore, the ultimate wind buckling pressure is determined using the following equations:

$$P_f = 0.65 \times P_c$$

$$P_f = 0.65 \times 5.03 = 3.27 \text{ kPa}$$

**TABLE F1**

**SUMMARY OF RESULTS FOR WIND BUCKLING PRESSURE FOR A NON-UNIFORM ORTHOTROPIC TANK**

| Ring No. | $P_c$ kPa | $P_f$ kPa |
|---|---|---|
| 1 (top) | 5.51 | 3.58 |
| 2 | 5.03 | 3.27 |
| 3 (bottom) | 5.18 | 3.37 |


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