Agenda Item: 650-728

Title: Wind Girder Section Modulus 5.9.6.1

Date: Sept. 24, 2013

Contact: Name: Doug Bayles
Company: Hagen Engineering International, Inc.
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E-mail: doug@hagenengineering.com

Purpose: Clarify Wind Girder Design for Tanks over 200 ft. Dia.

Source: E-Mail from B. Mistry

Revision: 6

Impact: Cost saving will be realized if proposal is adopted/accepted

Rationale: 5.9.6.1 of API-650 provides equation for calculating section modulus for top wind girder of open top tanks with a footnote as below.

Note: For tank diameters over 60 m (200 ft), the section modulus required by the equation may be reduced by agreement between the Purchaser and the Manufacturer, but the modulus may not be less than that required for a tank diameter of 60 m (200 ft). (A description of the loads on the tank shell that are included in the design wind speed can be found in Item a of the note to 5.9.7.1.)

It was assumed that this note is based on documented technical paper and it is not arbitrary. It would be good to site relevant Reference Documents so that informed decision can be made by Purchaser and Tank Fabricator. There is no information (rationale) provided (pros and cons) for using reduced section modulus.

With the presently worded Note, it is possible to design and build (2) tanks over 200 ft. dia. at the same location, for the same wind loads for two different customers, one agreeing to the footnote and other not. In such a case, (2) identical tanks can have significantly different section modulus of wind girder, both in compliance of API-650 and both having same structural integrity. Purchaser who agrees to footnote will realize cost saving. If structural integrity is not an issue, wind girders for all tanks over 200 ft. dia. should be allowed to be built to footnote with reduced section modulus without requiring agreement between the manufacturer and purchaser.

There have been a few publications, which are attached as reference and technical justification for deleting the requirement of obtaining agreement between purchaser and manufacturer and just allowing the wind girder for tanks over 200 ft (61 m) to be designed per the current equation using 200 ft (61 m) as the maximum required diameter to determine the section modulus.

Attached is a page out of the BS EN 14015-2004, showing how the primary wind girder is designed. Note in the definition of “D” (diameter) it states that 60 m is the maximum dimension to be used in this equation.

Also a copy of a page out of a widely recognized publication "Storage Tanks and Equipment by Bob Lang and Bob Gardner, European Guide. It clearly states that once a tank reaches a stage where the Wind Girder is of a size to be suitable as a walkway, making the girder any wider or heavier has very little value.
During earlier balloting process, it was suggested that wind girder for tanks over 61 m (200 ft.) dia. should be checked as end stiffener requiring minimum moment of inertia using approach provided in Annex-V. This proposed change would allow all tanks designers consistent and uniform approach for design of Wind Girders for all size of tanks without commercial input. Design wind girder is a technical issue & not a commercial issue.

Proposal:  See Proposed change in Red.

5.9.6.1.1 The required minimum section modulus of the stiffening ring shall be determined by the following equation

In SI units:

\[ Z = \frac{D^2 H_2}{17} \left(\frac{V}{190}\right)^2 \]

where

- \( Z \) = required minimum section modulus (cm\(^3\)),
- \( D \) = nominal tank diameter (m) the nominal diameter of the tank (For tanks in excess of 61 m diameter, the diameter shall be considered to be of 61 m when determining the section modulus), in meters (m);
- \( H_2 \) = height of the tank shell (m), including any freeboard provided above the maximum filling height as a guide for a floating roof,
- \( V \) = design wind speed (3-sec gust) (km/h) (see 5.2.1[k]).

In US Customary units:

\[ Z = 0.0001 D^2 H_2 \left(\frac{V}{120}\right)^2 \]

where

- \( Z \) = required minimum section modulus (in.\(^3\)),
- \( D \) = nominal tank diameter (ft) the nominal diameter of the tank (For tanks in excess of 200 feet diameter, the diameter shall be considered to be 200 feet when determining the section modulus), in feet (ft);
- \( H_2 \) = height of the tank shell (ft), including any freeboard provided above the maximum filling height as a guide for a floating roof,
- \( V \) = design wind speed (3-sec gust) (mph) (see 5.2.1[k]).

Delete Entire Footnote below & add 5.9.6.1.2:

- Note: For tank diameters over 60 m (200 ft), the section modulus required by the equation may be reduced by agreement between the Purchaser and the Manufacturer, but the modulus may not be less than that required for a tank diameter of 61 m (200 ft). (A description of the loads on the tank shell that are included in the design wind speed can be found in Item a of the note to 5.9.7.1.)
5.9.6.1.2 For tanks larger than 61 m (200 ft) in diameter an additional check for the minimum required moment of inertia for the top-stiffening ring shall be performed. The required minimum moment of inertia of the stiffening ring shall be determined by the following equations:

In SI units:

\[
I = 3583 \times H_2 \times D^3 \times \left(\frac{V}{190}\right)^2 / E
\]

Where

- \( I \) = required minimum moment of inertia (cm\(^4\)),
- \( D \) = nominal diameter of the tank, in meters (m);
- \( H_2 \) = height of the tank shell (m), including any freeboard provided above the maximum filling height as a guide for a floating roof,
- \( E \) = modulus of elasticity (MPa) at maximum design temperature.
- \( V \) = design wind speed (3-sec gust) (km/h) (see 5.2.1[k]).

In US Customary units:

\[
I = 108 \times H_2 \times D^3 \times \left(\frac{V}{120}\right)^2 / E
\]

Where

- \( I \) = required minimum moment of inertia (in\(^4\)),
- \( D \) = nominal diameter of the tank, in meters (ft);
- \( H_2 \) = height of the tank shell (ft), including any freeboard provided above the maximum filling height as a guide for a floating roof,
- \( E \) = modulus of elasticity (psi) at maximum design temperature.
- \( V \) = design wind speed (3-sec gust) (mph) (see 5.2.1[k]).

Notes for Ballot Review:
These equations are based on Levy’s formula for ring buckling with safety factor of 2, number of buckle waves (N) equal 2 and, peak wind pressure acting on top \( \frac{1}{4} \) of shell height (\( H_2 \)). The equation also meets requirements of End Stiffener defined in Annex-V, V.8.2.3 with factor of safety equal 2.0.
Notes:
1. Below is document below which relates to the reduction in size of the wind girder for large diameter tanks.

Note in 5.9.6.1 this note and concept was introduced in Rev.2, 6th. Edition, API-650 1978


2. Also attached is the design requirements for Primary Wind Girders out of the British Standard EN 14015-2004, Specification for the design and manufacture of site built, vertical, cylindrical, flat-bottomed, above ground, welded, steel tanks for the storage of liquids at ambient temperature and above


4. Derivation of Equations based upon Safety Factors and Buckling modes from the Levy Formula
Objective: (1) Review Equation Source for Wind Gider Section Modulus in 5.9.7.6
(2) Establish Wind Loads on Wind Girder from (1) above.
(3) Use the same wind girder loads design wind girder as end stiffener.
(4) Run Validating Examples for Large Tanks showing effect of proposed change.

Reference: "Study of Wind Girder Requirements in Large Diameter API 650 Floating Roof Tanks"
J.H. Adams, PDM. May 14, 1975

**Review Equation Source for Section Modulus 5.9.7.6**

Derivation of Equation is shown in "Reference" above.

It is based on the following:

(a) Wind Girder takes wind load from top 1/4 Shell Height
(b) Wind load on girder is based on uniform average pressure (not peak pressure).

\[ W = q \left( \frac{H}{4} \right) \]
\[ q = \text{Average uniform external wind pressure on projected surface of top 1/4 shell height.} \]
\[ H = \text{Tank Shell Height} \]
\[ D = \text{Tank Diameter} \]

Maximum Moment in Girder:
\[ M = 0.008775 \times q \times H \times D^2 \]

In USC Units:
\[ q = 18 \times \left( \frac{V}{120} \right)^2 \text{ psf} \]
\[ S_y = \text{Yield Strength} = 30000 \text{ psi} \]
\[ \Phi = \text{Stress Factor} = 0.625 \]
\[ H = \text{Tank Height in ft.} \]
\[ D = \text{Tank Diameter in ft.} \]

Section Modulus:
\[ Z = M / S_y \times \Phi = 0.008775 \times 18 / 144 \times \left( \frac{V}{120} \right)^2 \times H \times 12 \times D^2 / (30000 \times 0.625) \]
\[ Z = D^2 \times H / 10000 \times \left( \frac{V}{120} \right)^2 \text{ in.}^3 \]

This checks with 5.9.7.6 of API-650
**Design of Wind Girder as End Stiffener:**

Use Levy’s Formula for Ring Buckling for Wind Girder Design as End Stiffener

Levy’s Formula

\[ I = F q H R^3 / ((N^2 f_1) E) \]

- \( F \) = Factor of Safety = 2
- \( I \) = Moment of Inertia
- \( q \) = Uniform external pressure
- \( H \) = Shell Height for end stiffener design = \( H_2/4 \)
- \( R \) = Wind Girder Radius = \( D/2 \)
- \( N \) = Number of Buckle Wave = 2
- \( E \) = Modulus of Elasticity
- \( H_2 \) = Shell Height including Free Height

\[ I = q H_2 D^3 / (48 E) \]

In USC Units:

\[ q = 18(V/120)^2 \text{ psf} \]
\[ D = \text{Tank Dia. (m)} \]
\[ H_2 = \text{Tank Height (ft.)} \]
\[ E = \text{Mod. Elasticity (psi)} \]
\[ V = \text{Wind Speed (3 Sec. Gust) mph} \]
\[ I = 18/144 * (V/120)^2 * (H_2/12)^3 / (48 * E) \text{ in.}^4 \]
\[ I = 54 * (V/120)^2 * H_2 D^3 / (48 E) \text{ in.}^4 \]

In SI Units:

\[ q = 0.86 * (V/190)^2 \text{ Kpa} \]
\[ D = \text{Tank Dia. (m)} \]
\[ H_2 = \text{Tank Height (m)} \]
\[ E = \text{Mod. Elasticity (MPa)} \]
\[ V = \text{Wind Speed (3 Sec. Gust) Kmh} \]
\[ I = 0.86/1000 * (V/190)^2 * (H_2/100)^3 / (48 * E) \text{ cm.}^4 \]
\[ I = 1791.67 * (V/190)^2 * H_2 D^3 / (48 E) \text{ cm.}^4 \]

Note: Wind Load on Top 1/4 Shell for design is consistent with Annex-V.8.2.3.1 & V.8.2.3.2
## Moment of Inertia Validation

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*I<sub>Reqd</sub> = \frac{54}{F} \frac{E}{(V/120)^2} \frac{D^3}{H}*

Levy's Formula of Ring Buckling

**Observations & Conclusions:**

1. Please Note that for Case-2, 3 & 4, Z required is based on Tank Dia. of 200 ft.
2. Wind Girder designed as End Stiffener using Levy’s Formula meets and exceeds moment of Inertia Required for most tanks.
3. Include additional checks for tanks over 200 ft. Dia. using above equation for Wind Girder as end stiffener.
4. Case-2, 3 & 4 shows effect of change in Factor of Safety.
A STUDY OF WIND GIRDER REQUIREMENTS
FOR LARGE API 650 FLOATING ROOF TANKS

J. H. Adams, Pittsburgh-Des Moines Steel Co., Pittsburgh, PA
A STUDY OF WIND GIRDER REQUIREMENTS
FOR
LARGE API 650 FLOATING ROOF TANKS

The API Tank and Pressure Vessel Subcommittee has been studying means of providing more economical wind girders for floating roof tanks off and on for a number of years. The first thing we attempted to do was to determine where the present formula for the wind girder section modulus came from and how it was derived. We established that the American Water Works Association was the first to use the formula. However, no one in the American Water Works Association knew how the formula had been derived. It was their opinion that it was an empirical formula that was developed from experience. Since I did not believe this, I attempted to derive the formula assuming that maximum simplifying assumptions had been made in its derivation. Figure 1 shows that this was the case. The formula can be duplicated exactly by assuming that 100 mile an hour wind produces 30 psf of flat area, that a cylinder has a shape factor of 0.6 producing an effective pressure of 18 psf of projected area on a cylinder. If we take Roark's ring cases 10 and 25 and combine them we have a ring loaded with a uniform pressure across the diameter and supported by tangential sheer as shown in Fig. 1. Assuming that the pressure load on the top 25% of the tank has to be taken by the wind girder, that the allowable working stress is 15,000 psi increased by 25% because it is a wind load we arrive at a required section modulus of 0.000101 HD². Here H is the height of the tank and D is the diameter of the tank, both in feet.
About ten years ago, when the Europort 100,000 cubic meter storage tanks were being designed, Professor van der Neut made an analysis of these 250'Ø x 72' high tanks using wind loads that had been determined by wind tunnel tests on models of the tanks. It was determined that the worst wind loading condition was produced on a tank when two tanks located in the same dyke were lined up parallel to the wind direction. Using these loads he concluded from his analysis that tanks over 170' in diameter do not need wind girders to provide structural stability. He analyzed these tanks for 40 meters per second wind velocity (approximately 89.5 mph). The wind tunnel tests were conducted by the National Aero and Astronautical Research Institute in Amsterdam.

Dr. van der Neut believes that if the weight of the tank shell per inch of circumference equals or exceeds the wind induced tendency to lift the shell off its foundation at any point the shell will not buckle and a wind girder is not an essential structural element of the tank. I agree with this. I have demonstrated with models that it is very difficult to buckle a shell whose bottom periphery is held in a plane. There may be some instability in the thin upper shell rings, but no buckling. The same result can be obtained by maintaining the top of the shell circular. This is the conventional approach for stabilizing tanks against wind loads, but I feel that a more realistic formula for determining the required girder section modulus for non-self stabilizing tanks must be found. Dr. van der Neut's Reports SH2 and SH3 may be very helpful in doing this.
Dr. van der Neut used a Fourier series to represent the pressure loading around the circumference of the tank. He made calculations and concluded that two cycles of the Fourier series would be sufficient. We tried five to represent our loads and got inadequate representation. We finally used 19.

The wind tunnel test data used by Dr. van der Neut in his analysis gave varying pressure along the height of the tank as well as around the circumference. He used a power series to represent the vertical distribution of pressure.

In order that I might base my analysis on the same loads that Dr. van der Neut used I requested, through our licensee in Holland, the wind tunnel test data which he used. These data are the property of the Royal Dutch Shell Oil Company, and they declined to let me have them.

I based my analysis on the wind pressure distribution on cylindrical tanks as given in "Wind Forces on Structures" by Task Force Committee on Wind Forces, Transactions of ASCE, Vol. 126, 1961, Part II as shown on Fig. 2. I used 100 MPH wind velocity for the analysis. We used the BOSOR 4 computer program to determine loads, stresses, and deformations throughout the entire shells both with and without wind girders, (all wind girders were sized for 200'Ø x 72' high tanks). We did this for tanks from 150 feet in diameter thru 400 foot in diameter in 50 foot increments; each diameter was analyzed for 48, 56, 64 and 72 foot heights.
I plotted shell weight in pounds per inch of circumference versus tank diameter. On these same graphs I plotted maximum uplift in pounds per inch of circumference versus tank diameter. Obviously the intersection of these two plots gives the point at which the shell weight balances the maximum uplift. These plots are shown in Figures 3, 4, 5 and 6. You can see that all four curves intersected very close to 300'Ø. On these plots we have also plotted uplift curves for 89.5 MPH wind velocity which is the velocity used by Dr. van der Neut. For this wind velocity we get about 270'Ø for the balance point between lift-off and dead weight.

The computer print out is a massive amount of data. It would take hours to review it with you. I will talk about only the 300'Ø x 48' high and the 300'Ø x 72' high tanks.

The total output data for these two tanks has been carefully searched for the maximum values of displacements and stresses. These maximum values are tabulated for the 48' high tanks in Table I and for the 72' high tanks in Table II. The tables give the exact location of each value by meridian, segment and point to make it quick and easy to look up and check the data in the original computer print outs.

A comparison of the data in Tables I and II in conjunction with Fig. 7 indicates that the tanks without wind girders should be as safe in a high wind as the ones with wind girders. I think this provides substantial proof that Dr. van der Neut's theory is correct.
However, there are a number of differences in the result obtained here and those obtained by Dr. van der Neut that should be commented on. He obtained 170' diameter as the minimum size self anchoring tank. I obtained 300'Ø. This can be explained partially by the fact that he used a lower wind velocity and partially because he used a different pressure distribution than I did. Another contributing factor is that Dr. van der Neut was working with final designed tanks. In order to avoid selecting a specific gravity and a corrosion factor, I used the API 650 Appendix D hydrotest formula for determining plate thicknesses. For this reason the size of my tank to provide self anchoring would be larger since I used a higher stress.

Conclusions:

1. Flat bottom tanks whose shell weight per unit of circumference equals to or exceeds the maximum wind induced uplift on the shell do not need wind girders to prevent their shells from blowing in. The thin upper shell courses probably need a very nominal sized ring to stabilize them. It is likely that most tank purchasers will want this ring to be large enough to use as a walkway.

2. A study of the stresses and deformations in the various tanks do not indicate a need for intermediate wind girders.
References:

1. Report SH2 - INVESTIGATION OF THE NECESSITY OF THE WIND GIRDER IN TANKS WITH FLOATING ROOF by Prof. dr. ir. A. van der Neut.


3. WIND FORCES ON STRUCTURES by Task Force Committee on Wind Forces, Trans. ASCE, Vol. 126, 1961 Part II.
**Derivation of AWWA API 650 Wind Girder Formula for Open Top Tanks**

**Fig. 1**

- $H$ = height of tank in ft
- $W$ = wind load in $\frac{lb}{ft^2}$ or $\frac{lb}{in.}$ for 100 mph
- $R$ = radius or tank in ft

Ref. "Formulas for Stress and Strain" by Roark, 2nd ed. pp. 154-158

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<td>0.7025</td>
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<td>$M_{max}$</td>
<td>$0.0702 \times 1.44 \frac{W}{R^2} \times \frac{H}{4}$</td>
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<tr>
<td>$M_{c}$</td>
<td>$1.8954 \frac{W}{R}$</td>
<td></td>
<td></td>
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<tr>
<td>$\sigma$</td>
<td>$1.8954 \frac{W}{R}$</td>
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**Fig. 2**

**API 650 Wind Girder Study**

**Wind Pressure, psf**

**Fig. 3**

**Derivation of AWWA API 650 Wind Girder Formula**

- \[ M = \frac{1.8954 \cdot \frac{W}{R} \cdot H}{4} \] (1)
- $\sigma = \text{allowable bending stress in lb/in}^2$
- AWWA B API 650 formula applied to low carbon steel.

\[ Z = \frac{1.8954 \cdot \frac{W}{R}}{1000 \cdot 0.15} \]
Fig. 4

Fig. 5
DIA METER OF TANK-FT.

UPLIFT AT 89.5 M.P.H. WIND

DEAD WT. #/IN.

UPLIFT AT 100 M.P.H. WIND

UPLIFT OR DEAD WT. OF SHELL-#/IN.
72 FT. HIGH TANKS

Fig. 6

COMPUTER MODEL

SEGMENT-9

0 MERIDIAN

SEGMENT-1

FIG. 7

POINT-1

POINT-19
### TABLE-1

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**300' x 48' HIGH TANK - NO WIND GIRDER**

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<td>18</td>
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<td>V max.</td>
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<td>4</td>
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<td>9</td>
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<td>9</td>
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**300' x 48' HIGH TANK - WITH WIND GIRDER**

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<td>S2 (outside) max.</td>
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### TABLE-2

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</table>

**300' x 72' HIGH TANK - NO WIND GIRDER**

<table>
<thead>
<tr>
<th></th>
<th>Magnitude</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>U max.</td>
<td>-.0054&quot;</td>
<td>80°</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>V max.</td>
<td>.012&quot;</td>
<td>30°</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>V max.</td>
<td>.011&quot;</td>
<td>50°</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>W max.</td>
<td>-.1500&quot;</td>
<td>0°</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>S1 (inside) max.</td>
<td>+400 lb/in²</td>
<td>80°</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>S1 (outside) max.</td>
<td>-600 lb/in²</td>
<td>80°</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>S2 (inside) max.</td>
<td>+1400 lb/in²</td>
<td>80°</td>
<td>9</td>
<td>9 &amp; 10</td>
</tr>
<tr>
<td>S2 (outside) max.</td>
<td>+1400 lb/in²</td>
<td>80°</td>
<td>9</td>
<td>9 &amp; 10</td>
</tr>
</tbody>
</table>

**300' x 72' HIGH TANK - WITH WIND GIRDER**

<table>
<thead>
<tr>
<th></th>
<th>Magnitude</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>U max.</td>
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<td>18</td>
</tr>
<tr>
<td>V max.</td>
<td>.014&quot;</td>
<td>30°</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>V max.</td>
<td>.012&quot;</td>
<td>50°</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>W max.</td>
<td>.110&quot;</td>
<td>90°</td>
<td>9</td>
<td>17 &amp; 18</td>
</tr>
<tr>
<td>S1 (inside) max.</td>
<td>+880 lb/in²</td>
<td>90°</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>S1 (outside) max.</td>
<td>-880 lb/in²</td>
<td>90°</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>S2 (inside) max.</td>
<td>+1500 lb/in²</td>
<td>90°</td>
<td>9</td>
<td>17 &amp; 18</td>
</tr>
<tr>
<td>S2 (outside) max.</td>
<td>+1500 lb/in²</td>
<td>90°</td>
<td>9</td>
<td>17 &amp; 18</td>
</tr>
</tbody>
</table>
9.3.1.11 Stiffening rings shall be attached to the tank shell by continuous fillet welds on the top edge.

Continuous or intermittent underside welds shall be specified (see A.1).

Continuous welds shall be used for all joints which, because of their location, might be subjected to corrosion from entrapped moisture.

The end-to-end joints in ring sections (see 16.7.6) shall be full penetration butt welds.

9.3.2 Primary stiffening ring (wind girder) design

9.3.2.1 The required minimum sections modulus \( Z \), in \( \text{cm}^3 \) of the primary stiffening ring (see details d) and e) of Figure J.1) shall be determined by the equation.

\[
Z = 0.058 D^2 H_t \frac{V_w^2}{45^2}
\]

(7)

where

- \( D \) is the diameter of the tank (tanks in excess of 60 m diameter shall be considered to be of this dimension when determining the section modulus), in m;
- \( H_t \) is the height of the tank shell including any freeboard provided above the maximum filling height (see 9.2.1), in m;
- \( V_w \) is the wind gust velocity specified in 7.2.10, in m/s.

9.3.2.2 The section modulus of the primary stiffening ring shall be based upon the geometry of the applied members. The maximum portion of the tank shell in the corroded condition that can be included shall be a distance of 16 plate thicknesses below and, where applicable, above the ring shell attachment.

9.3.2.3 When the primary stiffening rings are located more than 600 mm below the top of the shell, the tank shall be provided with a top corner ring conforming to detail a) or b) of Figure J.1.

The minimum sizes of the top corner ring shall be:

- 60 mm × 60 mm × 5 mm for top shell courses 5 mm and thinner
- 80 mm × 80 mm × 6 mm for top shell courses 6 mm and thicker.

9.3.2.4 When top corner rings are being used as primary wind girders and are attached to the top edge of the shell ring by butt welding, the maximum portion of the tank shell to be included in the section modulus shall be 16 plate thicknesses less the vertical leg length of the angle.

9.3.3 Secondary stiffening ring (wind girder) design

9.3.3.1 The sizes of angles for the secondary stiffening rings are not related to the design loads, but shall be determined with respect to tank diameter, in accordance with the values given in Table 17.

The orientation and fixing of such secondary rings shall be as shown in detail c) of Figure J.1.
3.5 Wind and vacuum stiffening

For the case of closed, fixed roof tanks, the wind load is only external, whereas in open top or external floating roof tanks the wind also acts on the inner surface which can cause the effect of a vacuum load. The roof of a fixed roof tank assists in keeping the shell rigid and the wind forces are transmitted to the bottom of the tank as axial stresses as mentioned earlier. Open top and external floating roof tanks do not have the benefit of this shell rigidity and therefore a circumferential primary wind girder is provided at or near the top of the shell to give it the necessary stiffness (see Figure 3.30). This girder is normally attached to the external surface of the shell and in many cases is also used as an access and maintenance platform.

3.5.1 Primary wind girders

Acknowledgement is given to the late Professor A. G. Tooth, Professor of Mechanical Engineering at University of Strathclyde, Glasgow, for most of the theory that follows.

The equation to determine the section modulus for the primary wind girder is by:

$$ Z = 0.58 \cdot D^2 \cdot H \text{ (cm}^3\text{)} $$

where D and H are in metres.

The equation is simplistic to say the least and was first published in the early API tank Codes but is still used today as the basis of primary girder design.

Generally it is thought that the equation is an approximation formulated at a time when tanks under construction were less than 30 metres in diameter. The equation is based on a wind speed of 43.7 m/s (100 mph) although other wind speeds may be used by multiplying the equation by \((W/43.7)^2\) for SI units, or \((V/100)^2\) for Imperial units.

The equation may be derived, in SI units, using the above wind speed together with the dynamic wind pressure from equation 3.17. The horizontal wind load, using the terms D and H can be obtained from equation 3.18, using a C\text{g} value of 0.8.

Assuming that the girder is loaded by a uniform pressure across the tank diameter and is supported by tangential shear, and that the pressure load on the top 25% of the shell has to be carried by the girder, and the allowable design stress is 103.42 N/mm\(^2\) (15,000 lb/in\(^2\)), which is increased by 25% because the load is caused by the wind, then, by referring to formulation by Roark & Young, the required section modulus for the girder can be shown to approximate to equation 3.22 above.

3.5.1.1 Refining the design technique

The above design procedure has been challenged over the years by a number of academics (e.g. Adams, Morton, Zick and McGrath) and the use of more analytical computer methods have enabled the design techniques to be refined.

Morton found, for instance, that taking the example of an 84 m diameter \(\times\) 12.5 m high tank subjected to a 100 mph wind speed, current practice using equation 3.22 suggests a primary girder having a section modulus of 2610 cm\(^3\) which can be shown to equate to a girder as shown in Figure 3.31, "Detail E", with a width dimension 'b' of 1050 mm.

Using a method based on design against plastic folding of the tank, which allows the determination of the girder dimensions for a given wind speed of 50 m/sec (111.8 mph) it can be shown that a girder width of 432 mm is adequate, this is less than half that predicted by equation 3.22.

Further research confirmed that a modest girder section produced a dramatic increase in the buckling pressure and that subsequent incremental increases in the dimension 'b' of the girder produced a very small increase in the buckling pressures.

Generally it has been found that for large diameter open top and external floating roof tanks, say over 60 metres in diameter, equation 3.22 is over-conservative and that at, or over this diameter the girders calculate out to be unnecessarily wide. Accordingly, the present Code states that for tanks over 60 metres in diameter shell, for girder calculation purposes, be considered to be of this diameter when determining the section modulus of the primary girder.

However, as mentioned earlier, these primary girders are often used as access platforms and therefore, although a narrow girder may be found by design this may be increased in width to form a platform having a minimum width to Code of 600 mm.

For tanks where the primary girder is located 600 mm or more below the top of the shell the Code requires that the shell be provided with a top curb angle of the following dimensions:

- For a top course thickness of 5 mm, the angle shall be 60 x 60 x 5 mm
- For a top course thickness of 6 mm or more, the angle shall be 80 x 80 x 6 mm.

3.5.1.2 Design example

Using the principal dimensions for the tank in the earlier design illustration in Figure 3.8, but in this case assuming it is an external floating roof tank, and using a design wind speed of 46 m/sec, then:

$$ \begin{align*}
D & = 30 \text{ m diameter} \\
H & = 16 \text{ m high} \\
V & = 46 \text{ m/s} 
\end{align*} $$

From equation 3.22:

The section modulus for the primary girder is:

$$ Z = 0.58 \cdot 30^2 \cdot 16 \left( \frac{46}{44.7} \right)^2 = 884.5 \text{ cm}^3 $$

Refering to Figure 3.31 which is taken from BS 2654 it can be seen that a "Detail E" type girder will be sufficient and this has a horizontal web dimension 'b' of 500 mm when attached to a shell having a thickness of 8 mm.