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1.0 SCOPE AND APPLICATION

This guideline is intended to be used as supplementary document to NBCC2005 for the seismic design of petrochemical facilities in Canada, with particular focus on Northern Alberta Fort McMurray area. This document only covers Equivalent Static Force Procedure (ESFP), which is the easiest and most applicable way to implement seismic design in low seismic zone like Fort McMurray area. There is no provision on seismic design of Nonbuilding Structure in NBCC2005. ASCE 7-05 Chapter 15 Seismic Design Requirements for Nonbuilding Structures is referenced for Nonbuilding Structure seismic design in Canadian location. When ASCE 7-05 is referenced, NBCC2005 version of ground motion parameters is used to interpret the ASCE 7-05 formula. This is what NBCC2005 recommends in Commentary J page J-61, Para. 226.

2.0 GENERAL

2.1 Spectral Acceleration \( S_a(T) \) and \( S(T) \)

\( S_a(T) \)
- 5% Damped Spectral Response Acceleration
- Based on Site Class C as per NBCC Table 4.1.8.4.A
- For most cities in Canada, \( S_a(T) \) value can be found in NBCC Appendix C Table C-2

\( S(T) \)
- Design Spectral Acceleration
- Modified from \( S_a(T) \) by applying \( F_a \) and \( F_v \) factors relating to Site Class \( \text{NBCC 4.1.8.4 (6)} \)
- \( S(T) = S_a(T) \) when specific project site class is Class C

2.2 Methods to Determine Site Class

Two methods are available to determine Site Class if it’s not provided by Geotechnical consultant

1. Average shear wave velocity \( V_s \) \( \text{NBCC Table 4.1.8.4A} \)
   - Preferable way to classify Site Class \( \text{NBCC 4.1.8.4 (2)} \)
   - Shear wave velocity \( V_s \) is normally available in soil report under dynamic machine foundation section
   - Use \( V_s = \sqrt{G/\rho} = \sqrt{Gg/\gamma} \) to get shear wave velocity if only shear modulus is provided

2. SPT \( N_{60} \), for sand site. Undrained shear strength, \( s_u \), for clay site \( \text{NBCC Table 4.1.8.4A} \)

2.3 Determine If Seismic Design Is Required for Project

From NBCC 4.1.8.1 … requirements in this Subsection need not be considered in design if \( S(0.2) \), as defined in Sentence 4.1.8.4.(6), is less than or equal to 0.12
Please note it's $S(0.2) = 0.12$, not $S_a(0.2) = 0.12$

For Fort McMurray, $S_a(0.2) = 0.12$
For Site Class C or better, $S(0.2) <= S_a(0.2) = 0.12 \rightarrow$ seismic design is not required
For Site Class D or worst, $S(0.2) > S_a(0.2) = 0.12 \rightarrow$ seismic design is required
For most projects in Fort McMurray, average shear wave velocity is 200~300 m/s, and the Site Class is Class D.

### 3.0 METHOD OF ANALYSIS

1. **Equivalent Static Force Procedure (ESFP)  **   
   **NBCC 4.1.8.11**
   ESFP may be used for structures that meet any of the following criteria
   a) in cases where $I_E F_a S_a(0.2)$ is less than 0.35,
   b) regular structures that are less than 60 m in height and have a fundamental period $T_a < 2s$
   c) irregular structures, other than those that are torsionally sensitive, that are less than 20 m in height and have $T_a < 0.5s$

   In Fort McMurray, for the highest importance category Post disaster structure, Site Class D, $I_E F_a S_a(0.2) = 1.5 \times 1.3 \times 0.12 = 0.234 < 0.35$
   $\rightarrow$ For Site Class D or better, ESFP can be used as the seismic analysis method for all structures in Fort McMurray area.

2. **Modal Response Spectrum Method**  
   **NBCC 4.1.8.12**
   Not covered in this guideline.

3. **Time History Method**  
   **NBCC 4.1.8.12**
   Not covered in this guideline.

**Notes on Equivalent Static Force Procedure (ESFP)**

1. **NBCC2005 4.1.8.11 (3)** allow the use of estimated period for seismic calculation.
   Computed structure period via computer model is not absolutely required.
2. Most of the time, the computed period is much longer than estimated one. This is due to the fact that formula for estimation given by code always leans to the conservative side.
   Using computed period instead of estimated one gives us the advantage to reduce the seismic base shear.

   Below is a comparison of $S(T)$ value based on estimated $T_a$ and computed $T_a$, from Example 01.
3. **NBCC2005 4.1.8.11 (3)(d)** sets the upper limit on using longer computed period, considering that the actual structure may be stiffer than the model in STAAD. For example, mechanical equipments, pipings, cable trays etc are conventionally not modeled in STAAD while they may actually contribute to the stiffness of SFRS system.

NBCC2005 focuses mainly on residential/commercial buildings, for industrial facilities there are mostly open structures and less partition wall cases. In high seismic zone, should there be a demand for reducing seismic force to achieve a economical design for industrial structures, engineering judgment is required to identify if this upper limit is applicable, when the engineer is confident that the computer model can reflect the actual SFRS stiffness and give an accurate period.

4. **Seismic serviceability check** NBCC 4.1.8.13
   - Storey drift weighs more important than lateral deflection at top of structure  
     NBCC Commentary J Para 195
   - NBCC 4.1.8.13 (3) specifies storey drift limit 0.025h for normal buildings. 0.025h is an allowable limit for inelastic storey drift, which is applicable when seismic force is not reduced by dividing $R_d \times R_o$ factor.
     Use $R_d \times R_o \times I_e$ to scale up the drift for comparison with 0.025h when the drift value is obtained from a model with seismic load scaled down by $I_e/(R_d \times R_o)$.
4.0 DUCTILITY AND OVERSTRENGTH FACTOR

NBCC Table 4.1.8.9

Ductility-Related Seismic Force Reduction Factor \( R_d \)

Overstrength-Related Seismic Force Reduction Factor \( R_o \)

In high seismic zone, the total seismic load can be more than 20 times of total wind load.

Refer to attached example 01, exchanger structure, site location: Vancouver

Base shear by seismic =8270 kN, base shear by wind =341 kN \[ \frac{8270}{341} = 24.3 \]

It’s almost impractical to design a structure deforming elastically with seismic lateral load 24 times of wind load.

\( R_d \times R_o \) factor is used to reduce the seismic forces in recognition of the fact that a ductile structure designed based on the reduced forces is able to dissipate the earthquake energy through inelastic deformation without collapsing.

Higher Ductility of SFRS for High Seismic Zone

In high seismic zone, higher ductility of SFRS is more desirable.

Refer to attached example 01, exchanger structure, site location: Vancouver

If Ductile SFRS is used, \( R_d \times R_o = 5.0 \times 1.5 \) for moment frame and \( R_d \times R_o = 4.0 \times 1.5 \) for eccentrically braced frame, the seismic force for design can be reduced to \[ \frac{8270}{4.0 \times 1.5} = 1378 \text{ kN} \], which is more comparable to wind load, 341 kN.

Higher Ductility Causes Rigorous Design Requirements for Connection Detailing

The tradeoff of higher ductility for SFRS, is the steel member and connection design requirements.

CSA S16-09 Clause 27 specifies the requirements for design of members and connections for all steel SFRS with \( R_d > 1.5 \), with the exception of Conventional Construction, \( R_d = 1.5 \), \( R_o = 1.3 \) in S16-09 27.11

Some direct impacts to structural design, if the SFRS is under Clause 27 coverage

1. Limitation on beam and column size, mainly only Class 1 & 2 section are allowed
2. For energy dissipating elements, not the min yield strength \( \text{Fy} \), but the probable yield strength \( \text{RyFy} = 1.1 \text{Fy} \) shall be used, and \( \text{RyFy} \) shall not be less than 460MPa for HSS or 385MPa for others sections S16-09 27.1.7
3. S16-09 requires that all bracing connections in SFRS be detailed such that they are significantly stronger than the probable tensile capacity of bracing members. S16-09 27.5.4.2
   Brace connection design to meet such high capacity is very difficult, considering probable capacity using \( \text{RyFy} = 1.1 \text{Fy} \), and for HSS \( \text{RyFy} \) shall not be less than 460MPa. S16-09 27.1.7
4. The amplification factor \( U_2 \), to account the P-delta effects for structural element in SFRS, is calculated differently compared to conventional design S16-09 27.1.8.2
5. Ductile moment resisting connections for seismic application must satisfy more rigorous design and detail requirements. Moment Connection shall be pre-qualified connections and designed as per CISC publication Moment Connections for Seismic Applications-2008, which contains design procedure of three types of pre-qualified moment resisting connections.
Conventional Construction for Low and Moderate Seismic Zone

From above we can see that, once SFRS is covered by S16-09 Clause 27, the increased complexity of SFRS frame member sizing, frame analysis, connection design and detailing, steel fabrication and erection is tremendous.

In low and moderate seismic zone, Conventional Construction is an advantageous design option to waive all provisions in S16-09 Clause 27, except clause 27.11.

In low seismic zone like Fort McMurray, the low ductility of Conventional Construction SFRS will not cause significant increase to member size, as the seismic load is normally lower or comparable to wind load, even using the lower reduction factor $R_d \times R_o$ value of Conventional Construction.

Refer to attached example 01, exchanger structure, location: Fort McMurray
The seismic base shear before applying $/ (R_d \times R_o)$ is 823 kN, wind load base shear is 341 kN
With Conventional Construction, design seismic load reduced to $823 / (R_d \times R_o) = 823 / (1.5 \times 1.3) = 422$ kN, which is already close to wind load 341 kN $\rightarrow$ use of higher ductility SFRS is not necessary.

In Fort McMurray, always use Conventional Construction, $R_d \times R_o = 1.5 \times 1.3$, for all SFRS systems.

5.0 STRUCTURE CLASSIFICATION

Most of petrochemical facilities can be classified as the following categories:

1. Building Structure
2. Nonbuilding Structure Similar to Building
3. Nonbuilding Structure Not Similar to Building
4. Nonbuilding Structure (Less Than 25% Comb Wt) Supported by Other Structure
5. Nonbuilding Structure (More Than 25% Comb Wt) Supported by Other Structure

<table>
<thead>
<tr>
<th>Classification</th>
<th>Structure Type</th>
<th>Case No</th>
<th>Seismic Force Calc</th>
<th>RdxRo Factor</th>
<th>Structure Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Structure</td>
<td></td>
<td></td>
<td>NBCC 4.1.8.11</td>
<td></td>
<td>Industrial Building, Pump House</td>
</tr>
<tr>
<td>Nonbuilding Structure Similar to Building</td>
<td></td>
<td>Case 02</td>
<td>NBCC 4.1.8.11</td>
<td></td>
<td>Piperack, Exchanger Structure, Process Module</td>
</tr>
<tr>
<td>Nonbuilding Structure Not Similar to Building</td>
<td>Skirt-Supported Ver Vessel</td>
<td>Case 03</td>
<td>ASCE 7-05 Table 15.4-2</td>
<td></td>
<td>Skirt-Supported Ver Vessel on Conc Foundation</td>
</tr>
<tr>
<td></td>
<td>Braced Leg-Supported Ver Vessel</td>
<td>Case 04</td>
<td>ASCE 7-05 Table 15.4-2</td>
<td></td>
<td>Braced Leg-Supported Ver Vessel on Conc Foundation</td>
</tr>
<tr>
<td></td>
<td>Self-Supported Hor Vessel</td>
<td>Case 05</td>
<td>ASCE 7-05 Table 15.4-2</td>
<td></td>
<td>Self-Supported Hor Vessel on Conc/Steel Pier</td>
</tr>
<tr>
<td></td>
<td>Nonbuilding Structure Rigid Structure</td>
<td>Case 06</td>
<td>ASCE 7-05 15.4.2</td>
<td>No RdxRo Value Required</td>
<td>Conc Mounted Pump and Compressor</td>
</tr>
<tr>
<td>Nonbuilding Structure (Less Than 25% Comb Wt) Supported by Other Structure</td>
<td>Overall Structure</td>
<td>Case 07</td>
<td>NBCC 4.1.8.11</td>
<td></td>
<td>Exchanger Structure, Process Module</td>
</tr>
<tr>
<td></td>
<td>Equipment Support</td>
<td></td>
<td>NBCC 4.1.8.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonbuilding Structure (More Than 25% Comb Wt) Supported by Other Structure</td>
<td>Rigid Nonbuilding Structure</td>
<td>Case 08</td>
<td>NBCC 4.1.8.11</td>
<td></td>
<td>Hor Vessel Mounted on Conc/Steel Structure</td>
</tr>
<tr>
<td></td>
<td>Nonrigid Nonbuilding Structure</td>
<td>Case 09</td>
<td>NBCC 4.1.8.11</td>
<td></td>
<td>Ver Vessel Mounted on Conc/Steel Structure</td>
</tr>
</tbody>
</table>

Seismic provision in NBCC2005 is written predominantly to address residential and commercial building structures. It covers the seismic requirements for Building Structure (clause 4.1.8.11 and table 4.1.8.9) and Nonstructural Component (clause 4.1.8.17 and table 4.1.8.9), but there is no provision for Nonbuilding Structure.

Nonbuilding Structure includes many popular petrochemical facilities, such as all free-standing vertical vessels, flare stacks, all horizontal vessels, piperacks, exchanger structures, process/equipment modules etc.

In this guideline, ASCE 7-05 Chapter 15 is referenced for seismic design of Nonbuilding Structure. When ASCE 7-05 is referenced for seismic design in Canadian location, Canadian version of ground motion parameters in NBCC2005 are used to interpret formulas in ASCE 7-05. This is exactly what NBCC2005 suggests in its Commentary J page J-61 Para. 226.

Some of the equipments, such as hor vessel, can be treated as either Nonstructural Component or Nonbuilding Structure. When a hor vessel is supported on a steel structure and it's weight is less than 25% of the combined weight, it's a Nonstructural Component and NBCC2005 4.1.8.17 is used to calculate the base shear, for equipment local support design only. For the overall structure, NBCC2005 4.1.8.11 is used to calculate the base shear. The hor vessel weight is considered as part of effective seismic weight in the base shear calculation and seismic force distribution.
Case 01 Building Structures

Building structure seismic force shall be designed as per NBCC 4.1.8.11, with the weight of nonstructural components (Process, HVAC equipment and Bridge Crane etc) considered as effective seismic weight for base shear calculation and base shear distribution along vertical direction.

- 25% of roof snow load shall be counted as effective seismic weight for base shear calculation as per NBCC Commentary J page J-46 note 168
- All process equipments (piping, tank, vessel, exchanger, pump, crusher etc) content weight under normal operating condition shall be counted as effective seismic weight for base shear calculation as per NBCC Commentary J page J-46 note 168
- For building with crane, only crane empty weight (bridge+trolley/hoist), excluding lifting weight, shall be counted as effective seismic weight for base shear calculation as per AISC Design Guide 7: Industrial Buildings--Roofs to Anchor Rods 2nd Edition 13.6 on page 50

Case 01 Building Structure
Case 02 Nonbuilding Structures Similar to Building

Nonbuilding Structures Similar to Building seismic force shall be designed as per NBCC 4.1.8.11, with the weight of nonstructural components (Process, Mechanical equipments etc) considered as effective seismic weight for base shear calculation and base shear distribution along vertical direction.

- 25% of snow load, if there is any, shall be counted as effective seismic weight for base shear calculation as per NBCC Commentary J page J-46 note 168
- All process equipments (piping, tank, vessel, exchanger, pump, crusher etc) content weight under normal operating condition shall be counted as effective seismic weight for base shear calculation as per NBCC Commentary J page J-46 note 168
- All Process, Mechanical equipments supported on a steel/conc structure with its weight less than 25% of the combined weight, shall be designed as Nonstructural Component and NBCC2005 4.1.8.17, for equipment local support design only. For the overall structure, NBCC2005 4.1.8.11 is used to calculate the base shear. The equipment weight is considered as part of effective seismic weight in the base shear calculation and seismic force distribution.
6.0 DESIGN EXAMPLES

Design Example 01: Nonbuilding Structure Similar to Building - Exchanger Structure
Structure Classification: Case 02 & Case 07

Calculate the seismic force for an exchanger structure supporting stacked heat exchangers as shown on next page. Frames along GL1,2,3 are moment frame. Frames along GLA, C are braced frame. Frame along GLB is unbraced. Single exchanger shell operating weight 500 kN, each floor equipment effective seismic weight = 4 x 500 = 2000 kN. Assume each floor has 20m long 20" dia pipes to be counted for effective seismic weight. Structure importance category = High as the exchanger contains flammable hydrocarbon content. Calculate seismic force for the following scenarios:

1. Site in Fort McMurray, Site D, Use SFRS $R_xR_o$ of Conventional Construction (CC)
   Use Equivalent Static Force Procedure
   • Seismic force calc for overall structure steel design
   • Seismic force calc for local structure steel support design (exchanger support)
   • Compare wind and seismic force, with the $R_xR_o$ value of Conventional Construction and Moderately Ductility

2. Site in Vancouver, Site D, Use SFRS $R_xR_o$ of Ductile (D) and Moderately Ductility (MD)
   Use Equivalent Static Force Procedure

From STAAD output, braced frame in N-S direction $T_a=0.66s$, moment frame in E-W direction $T_a=2.43s$
Example 01 Exchanger Structure

**Notes:**
- All column: W310X202
- All floor beam: W310X107
- All MBR brace: W125X22.5
- Secondary beam not shown for clarity.
- Use secondary beam + crating with 1.014 kPa
- All VBR brace: W150X30
Wind Load Calc for Overall Structure
To simplify the calc and for comparison purpose only, use the wind load on enclosed structure for a quick check
Wind load pressure 1/50 yr q=0.35 kPa, C_f=1.3, C_e=1.10, C_g=2.0, I_w=1.15
Wind load base shear = I_w x C_f x q x C_g x C_e x A =1.15 x 1.3 x 0.35 x 2.0 x 1.1 x 12.6 x 23.5 = 341 kN

Seismic Base Shear for Overall Structure Design

Location: Fort McMurray

<table>
<thead>
<tr>
<th>SFRS</th>
<th>Base Shear Ve before Ve / (R_d x R_o)</th>
<th>Base Shear SFRS CC Ve / (1.5x1.3)</th>
<th>Base Shear SFRS MD Ve / (3.0x1.3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moment Frame</td>
<td>328</td>
<td>168</td>
<td>84</td>
</tr>
<tr>
<td>Braced Frame</td>
<td>823</td>
<td>422</td>
<td>211</td>
</tr>
</tbody>
</table>

From above seismic base shear calc, we can find that, in low seismic zone such as Fort McMurray area, using Conventiona Construction (CC) is good enough to bring the lateral seismic force down to a magnitude comparable to wind load, 341 kN.
From CSA S16-09 clause 27.11.1 Conventional construction R_d=1.5 , R_o=1.3
... the requirement of clauses 27.1 to 27.10 and 27.1 2 shall not apply to these systems.
In low or moderate seismic zone, using a higher R_d x R_o modification factor is not necessary as it will trade the convenience of non-seismic connection design for nothing. With the use of response reduction factor R_d x R_o under Conventional Construction, the seismic load is already comparable to wind load, and in many cases, seismic load is actually lower than wind load.

NOTES

It’s incorrect to conceive that in Fort McMurray area the wind load will govern structural design and the seismic load is neglegible compared to wind load. In this case the seismic load for braced frame, 422 kN, is bigger than the wind load, 341 kN. One may argue that the wind load still govern when it goes to the load combination considering wind load factor of 1.4, and seismic load factor of 1.0, but actually in many cases the seismic load will gorven in the design of petrochemical structures in Fort McMurray area.
Location: Vancouver

<table>
<thead>
<tr>
<th>SFRS</th>
<th>Base Shear Ve before Ve / (Rd x Ro)</th>
<th>Base Shear SFRS CC Ve / (1.5x1.3)</th>
<th>Base Shear SFRS MD Ve / (3.0x1.3)</th>
<th>Base Shear SFRS D Ve / (4.0x1.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moment Frame</td>
<td>4185</td>
<td>2146</td>
<td>1073</td>
<td>698</td>
</tr>
<tr>
<td>Braced Frame</td>
<td>8270</td>
<td>4241</td>
<td>2121</td>
<td>1378</td>
</tr>
</tbody>
</table>

From above seismic base shear calc, we can find that, in high seismic zone such as Vancouver, using higher modification factor of Rd x Ro is absolutely necessary, otherwise the huge seismic lateral load, 8270 / 341 = 24 times of wind load in this case, will create an impractical structural design.
LOAD DEVELOPMENT

LOAD DATA INPUT

Structure importance category

Wind Load Data

<table>
<thead>
<tr>
<th>Wind pressure q 1/50</th>
<th>q</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.35 [kPa]</td>
</tr>
</tbody>
</table>

Snow Load Data

<table>
<thead>
<tr>
<th>Ground snow load 1/50</th>
<th>S_s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.50 [kPa]</td>
</tr>
<tr>
<td>Rain load 1/50</td>
<td>S_r</td>
</tr>
<tr>
<td></td>
<td>0.10 [kPa]</td>
</tr>
</tbody>
</table>

Seismic Data

<table>
<thead>
<tr>
<th>Site location</th>
<th>Avg. soil shear wave V_s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fort McMurray</td>
<td>232 [m/s]</td>
</tr>
</tbody>
</table>

Load Data

| Grating+secondary beams area wt. | = 1.00 [kPa] |
| Handrail linear wt. | = 0.30 [kN/m] |
| Ladder with cage linear wt. | = 0.50 [kN/m] |
| Stair+handrail linear wt. | = 1.50 [kN/m] |

Steel Frame Period

If there is no STAAD output, key in 0 as value for periods below

<table>
<thead>
<tr>
<th>STAAD output Trans. direction moment frame period</th>
<th>T_T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.43 [s]</td>
</tr>
<tr>
<td>STAAD output Long. direction braced frame period</td>
<td>T_L</td>
</tr>
<tr>
<td></td>
<td>0.66 [s]</td>
</tr>
</tbody>
</table>

Structure Plan Summary

<table>
<thead>
<tr>
<th>Plan Description</th>
<th>Elevation</th>
<th>w_i (kN)</th>
<th>Δ h (m)</th>
<th>Status</th>
<th>h_i (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U/S column base EL.100</td>
<td>EL_0 = 100.000 [m]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plan TOS EL.101</td>
<td>EL_1 = 101.000 [m]</td>
<td>2400.7</td>
<td>1.000</td>
<td>Active</td>
<td>1.000</td>
</tr>
<tr>
<td>Plan TOS EL.108.5</td>
<td>EL_2 = 108.500 [m]</td>
<td>2518.9</td>
<td>7.500</td>
<td>Active</td>
<td>8.500</td>
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<tr>
<td>Plan TOS EL.116</td>
<td>EL_3 = 116.000 [m]</td>
<td>2518.9</td>
<td>7.500</td>
<td>Active</td>
<td>16.000</td>
</tr>
<tr>
<td>Plan TOS EL.123.5</td>
<td>EL_4 = 123.500 [m]</td>
<td>2518.9</td>
<td>7.500</td>
<td>Active</td>
<td>23.500</td>
</tr>
<tr>
<td>Plan TOS EL.0</td>
<td>EL_5 = 0.000 [m]</td>
<td>0.0</td>
<td>0.000</td>
<td>Inactive</td>
<td>0.000</td>
</tr>
<tr>
<td>Plan TOS EL.0</td>
<td>EL_6 = 0.000 [m]</td>
<td>0.0</td>
<td>0.000</td>
<td>Inactive</td>
<td>0.000</td>
</tr>
<tr>
<td>Plan TOS EL.0</td>
<td>EL_7 = 0.000 [m]</td>
<td>0.0</td>
<td>0.000</td>
<td>Inactive</td>
<td>0.000</td>
</tr>
<tr>
<td>Plan TOS EL.0</td>
<td>EL_8 = 0.000 [m]</td>
<td>0.0</td>
<td>0.000</td>
<td>Inactive</td>
<td>0.000</td>
</tr>
<tr>
<td>Plan TOS EL.0</td>
<td>EL_9 = 0.000 [m]</td>
<td>0.0</td>
<td>0.000</td>
<td>Inactive</td>
<td>0.000</td>
</tr>
<tr>
<td>Plan TOS EL.0</td>
<td>EL_10 = 0.000 [m]</td>
<td>0.0</td>
<td>0.000</td>
<td>Inactive</td>
<td>0.000</td>
</tr>
</tbody>
</table>
Seismic Base Shear for Exchanger Support Design
In this part the equipment is taken as a Nonstructural Component and its seismic force is calculated as per NBCC 4.1.8.17. This seismic force is used for the design of local equipment support only (steel support for exchangers). The exchangers sitting on top of structure (EL23.500) get the biggest seismic response as the acceleration increases with the height of structure. This effect is captured by the height factor, newly introduced in NBCC2005, $A_x = 1 + \frac{2h_x}{h_n}$.
For equipments at foundation level $A_x = 1.0$, and $A_x = 3.0$ for equipments sitting at roof level.

<table>
<thead>
<tr>
<th>Lateral Load Type</th>
<th>Transverse Direction</th>
<th>Longitudinal Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kN</td>
<td>kN</td>
</tr>
<tr>
<td>Wind</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>Seismic</td>
<td>122</td>
<td>243</td>
</tr>
</tbody>
</table>

From above we find that, for local equipment support design, the seismic load is much bigger than the wind load if the equipment is located on a higher elevation above grade. This is mainly due to the dynamic amplifying effect ($A_r = 2.5$) for big mass sitting on a flexible supporting structure.

NOTES

It’s incorrect to conceive that in Fort McMurray area the wind load will govern structural design and the seismic load is negligible compared to wind load. In this case the seismic load can be $243/4 = 61$ times bigger than the wind load.
SEISMIC LOAD CALC - EXCHANGER SUPPORT

Exchanger support design based on

<table>
<thead>
<tr>
<th>Code Abbreviation</th>
<th>NBCC 2005 Division B 4.1.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASCE Wind Loads and Anchor Bolt Design for Petrochemical Facilities</td>
<td>ASCE Wind Loads</td>
</tr>
<tr>
<td>PIP STE03360 Heat Exchanger and Horizontal Vessel Foundation Design Guide-2007</td>
<td>PIP STE03360</td>
</tr>
</tbody>
</table>

Exchanger Data

<table>
<thead>
<tr>
<th>Input</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>D (Shell OD)</td>
<td>1470 [mm]</td>
</tr>
<tr>
<td>Insul. Thickness</td>
<td>38 [mm]</td>
</tr>
<tr>
<td>OD (Overall OD)</td>
<td>1546 [mm]</td>
</tr>
<tr>
<td>H₁ (Exchanger length)</td>
<td>1200 [mm]</td>
</tr>
<tr>
<td>L₁ (Saddle distance)</td>
<td>11092 [mm]</td>
</tr>
<tr>
<td>H₂ (Steel support width)</td>
<td>4900 [mm]</td>
</tr>
<tr>
<td>H₃ (Steel support width)</td>
<td>1400 [mm]</td>
</tr>
<tr>
<td>H₄ (Steel support width)</td>
<td>1200 [mm]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Single Shell Weight</th>
<th>Estimated Wei</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty weight Wₑ</td>
<td>350 [kN]</td>
</tr>
<tr>
<td>Operating weight Wₒ</td>
<td>500 [kN]</td>
</tr>
<tr>
<td>Hydro test weight Wᵢ</td>
<td>500 [kN]</td>
</tr>
<tr>
<td>Bundle weight Wᵇᵢ</td>
<td>144 [kN]</td>
</tr>
<tr>
<td>Number of stacked shells n</td>
<td>2</td>
</tr>
</tbody>
</table>

Wind Data

| Wind pressure q 1/50 | q = 0.35 [kPa] |
### Seismic Data

<table>
<thead>
<tr>
<th>Site location</th>
<th>Fort McMurray</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg soil shear wave velocity ( V_s )</td>
<td>200 [m/s] Site D</td>
</tr>
<tr>
<td>Structure importance category</td>
<td>High</td>
</tr>
<tr>
<td>Importance factor seismic load ( I_e )</td>
<td>1.30 For importance category High structure</td>
</tr>
<tr>
<td>Importance factor wind load ( I_w )</td>
<td>1.15 For importance category High structure</td>
</tr>
<tr>
<td>Exchanger contains toxic or flammable liquid</td>
<td>Yes ( C_p = 1.5 )</td>
</tr>
<tr>
<td>Support floor base height ( h_x )</td>
<td>23.500 [m]</td>
</tr>
<tr>
<td>Total structure height ( h_n )</td>
<td>23.500 [m]</td>
</tr>
</tbody>
</table>

### Steel Support Data

<table>
<thead>
<tr>
<th>Steel support beam size</th>
<th>W250x73</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel support column size</td>
<td>W250x73</td>
</tr>
<tr>
<td>Steel support bracing size</td>
<td>DAngle_LLV 2L102x76x7.9LLBB</td>
</tr>
</tbody>
</table>

**Code Reference**

- NBC 05
- Table 4.1.8.4.A
- Table 4.1.8.5
- Table 4.1.7.1
- Table 4.1.8.17
GRAVITY LOAD

Stacked Shells

Total Weight

Add 20% of single shell weight to account for attached misc. piping & insulation weight.

\[(n+0.2)xW_e = 770 \text{ [kN]}\]
\[(n+0.2)xW_o = 1100 \text{ [kN]}\]
\[(n+0.2)xW_t = 1100 \text{ [kN]}\]

Gravity load distributed 60% at channel end, 40% at shell end. Use 60% for design of both ends.

Empty case: \(D_0 = 462 \text{ [kN]}\)
Operating case: \(D_0 = 660 \text{ [kN]}\)
Hydro test case: \(D_t = 660 \text{ [kN]}\)

Trans. Moment from Piping Eccentricity

Ecc = 0.5OD + 1.5ft
\(e = 1230 \text{ [mm]}\)

Apply 0.6 x 10% of single shell weight with eccentricity \(e\) as trans. moment for both ends.

Empty case: \(M_{T0} = 26 \text{ [kNm]}\)
Operating case: \(M_{T0} = 37 \text{ [kNm]}\)
Hydro test case: \(M_{T1} = 37 \text{ [kNm]}\)

WIND LOAD

Transverse Wind

\(C_g = 2.00\)
\(C_f = 0.80\) Rough surface

Exchanger height above grade

\(H = EL + (H_1 + H_2 + H_3) = 27.9 \text{ [m]}\)

Add 1.5ft (0.46m) to OD to account for piping attached to exchanger

\(A = L x (D + 0.46) = 22.2 \text{ [m}^2\]

Wind force on single shell

\(F_{T1} = I_w x C_t x q x C_g x C_e x A = 17.6 \text{ [kN]}\)

Trans. Wind on Steel Support

Trans. base shear

\(F_T = F_{T1} x n \text{ (shell)} / 2 \text{ (end)} = 17.6 \text{ [kN]}\)

Trans. OTM to support base

\(M_{TW} = \left[ F_{T1}(H_2+H_3+H_4) + F_{T1}(H_2+H_3) \right] / 2 \text{ (end)} = 36.9 \text{ [kNm]}\)

Longitudinal Wind

\(C_t = 1.20\) Assume flat head to be conservative

Add 1.5ft (0.46m) to OD to account for piping attached to exchanger

\(A = \pi (D + 0.46)^2 / 4 = 3.2 \text{ [m}^2\]

Wind force on single shell

\(F_{L1} = I_w x C_t x q x C_g x C_o x A = 3.7 \text{ [kN]}\)

Long. Wind on Steel Support

Long. base shear

\(F_L = F_{L1} x n \text{ (shell)} / 2 \text{ (end)} = 3.7 \text{ [kN]}\)

Couple on supp caused by wind

\(N_w = \left[ F_{L1}(H_2+H_3+H_4) + F_{L1}(H_2+H_3) \right] / S = 3.2 \text{ [kN]}\)
Design Example 02: Skirt-Supported Vertical Vessel
Structure Classification: Case 03

Calculate the seismic force for a skirt-supported vertical vessel

Vessel diameter = 7.189 m
Vessel height = 12.400 m
Vessel shell thickness = 0.25 in

Vessel empty weight = 221 kN
Vessel operating weight = 3793 kN
Vessel hydrotest weight = 5055 kN
Site location : Fort McMurray
Site class : Class D
Structure importance category : Normal

NOTES

It’s incorrect to conceive that in Fort McMurray area the wind load will govern structural design and the seismic load is negligible compared to wind load. In this case
seismic base shear is 131.5 kN vs wind base shear 71.9 kN
seismic overturn moment is 1087.0 kNm vs wind overturn moment 499.9 kNm

In this case, the overturn moment caused by seismic is 2 times of the overturn moment caused by wind. This is mainly due to the reverse triangle distribution of seismic load.
DESCRIPTION
Vertical vessel foundation design based on

<table>
<thead>
<tr>
<th>Code Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBCC 2005 Division B 4.1.8</td>
<td>NBCC05</td>
</tr>
<tr>
<td>ASCE Wind Loads and Anchor Bolt Design for Petrochemical Facilities</td>
<td>ASCE Wind Loads</td>
</tr>
<tr>
<td>PIP STE03350 Vertical Vessel Foundation Design Guide-2007</td>
<td>PIP STE03350</td>
</tr>
<tr>
<td>PIP STE05121 Anchor Bolt Design Guide-2006</td>
<td>PIP STE05121</td>
</tr>
</tbody>
</table>

INPUT

Vessel Data
Structure importance category Normal
- Vessel diameter \( D = 7.189 \) [m]
- Vessel height \( H = 12.400 \) [m]
- Vessel content height \( H_1 = 12.400 \) [m]
- Mat thickness \( H_2 = 0.650 \) [m]
- Vessel shell thickness \( t = 0.250 \) [in]

Vessel Weight Estimated
- Vessel surface area \( = 361.2 \) [m²]
- Vessel volume \( = 503.3 \) [m³]
- Vessel content weight \( = 5033 \) [kN] water 10kN/m²
- Vessel empty weight \( = 867 \) [kN] shell 50lb/ft²
- Vessel operating weight \( = 5900 \) [kN]

Vessel Weight from Vendor Estimated Weight
- Vessel empty weight \( = 221 \) [kN] 867
- Vessel operating weight \( = 3793 \) [kN] 5900
- Vessel hydro test weight \( = 5055 \) [kN]

Vessel Weight for Design
- Vessel empty weight \( W_e = 265 \) [kN] Increase empty we 20% to account for insulation/piping wei
- Vessel operating weight \( W_o = 4016 \) [kN] Increase content wei 5% to account for pipe content wei
- Vessel hydro test weight \( W_h = 5341 \) [kN] These increase doesn't apply to uplift load comb cases

Overturn Moment Due to Piping Eccentricity
Take 10% of vessel empty weight as eccentric piping/nozzle weight
- Pipe eccentricity= \( D/2 + 0.5m = 4.095 \) [m]
- Piping/nozzle eccentric weight \( = 22.1 \) [kN]
- Overturn Moment by Pipe Ecc \( M_{pp} = 90.5 \) [kNm]

Vessel top platform width \( W_p = 1.200 \) [m]
Vessel top platform length \( L_p = 8.000 \) [m]
Wind pressure \( q = 0.35 \) [kPa]
Top platform live load \( LL = 4.80 \) [kPa]
Top platform dead load \( DL = 2.00 \) [kPa] including framing and grating
Snow load \( SL = 1.50 \) [kPa]
## WIND LOAD

Wind load calc based on

- **NBCC 2005 Division B 4.1.7**
- **NBCC 2005 Commentary I**
- **ASCE Wind Loads and Anchor Bolt Design for Petrochemical Facilities**
- **ASME STS-1-2006 Steel Stacks**

### Code Abbreviation

- **NBCC 2005**
- **NBC05 Comment I**
- **ASCE Wind Loads**
- **ASME Steel Stacks**

### Code Reference

- **NBC05 Table 4.1.7.1**
- **ASME Steel Stacks**

#### Structure importance category

- Normal

#### Importance factor

- \( I_w = 1.00 \)
  - For importance category Normal structure

#### Vessel diameter

- \( D = 7.189 \) [m]

#### Vessel height

- \( H = 12.400 \) [m]

#### Mat thickness

- \( H_2 = 0.650 \) [m]

#### Wind pressure q 1/50

- \( q = 0.35 \) [kPa]
- \( C_a = 1.04 \)
- \( C_g = 2.00 \)
- \( D \times \sqrt{qC_a} = 4.346 > 0.167 \)
- \( H/D = 1.7 \)

#### Vortex Shedding Check

- Strouhal Number
  - \( S = 0.20 \)
  - For large-diameter structures
- Vessel 1st mode frequency
  - \( f_n = 1/T_a = 8.87 \) [Hz]
  - Get period \( T_a \) from seismic analysis
- Critical mean wind speed at top
  - \( V_{HC} = f_n \times D / S \)
  - \( = 318.8 \) [m/s]
  - page I-33 (16)

#### Dynamic Exposure Factor

- \( C_{ah} = 1.06 \)
  - Exposure A

#### Wind on Attached Piping and Ladder

Use simplified method in **ASCE Wind Loads and Anchor Bolt Design for Petrochemical Facilities**

- Add 5ft (1.52m) to vessel diameter to account for ladder & piping attached below top tangent line
  - \( \text{Wid} = D + 1.52 = 8.71 \) [m]
- Add 5ft (1.52m) to vessel height to account for piping attached above top tangent line
  - \( \text{Hei} = H + 1.52 = 13.92 \) [m]
  - \( A = \text{Wid} \times \text{Hei} = 121.23 \) [m²]

#### Wind on Vessel

- Wind force on vessel
  - \( F_1 = I_w \times C_t \times q \times C_g \times C_a \times A \)
  - \( = 63.1 \) [kN]

---

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Design Example 03: Braced Leg Supported Vertical Vessel
Structure Classification: Case 04

Calculate the seismic force for a braced-leg supported PSC vessel. The PSC vessel is supported by 10 x OD=1450mm wall thk =27mm steel column equally spaced at 22.5m diameter circle. The 3D support frame is braced by 25 dia steel tension only rod. Vessel empty weight = 13810 kN, operating weight = 183710 kN
Site location: Fort McMurray       Site class: Class D      Structure importance category: Normal

The PSC vessel is a cone shape, diameter varies from 0m to 32m along the 30m vessel height. To simplify the wind load calculation, assume it's a dia=16m H=30m cylinder vessel, which gives the same projection area for wind load calc.
Use Master/Slave to define the top support plane as a rigid diaphragm. Use the central node as a master node, the central node needs not to be physically connecting to the surrounding nodes.

STAAD Model : Rigid Diaphragm and Tension Only Brace
Two approaches are used to get the fundamental period of vessel support

1. Use STAAD CALCULATE RAYLEIGH FREQUENCY command to get Rayleigh frequency
   STAAD returns Rayleigh frequency 0.26558 CPS \( \rightarrow T_a = 1/0.26558 = 3.765 \text{ s} \)

2. Apply vessel operating weight as lateral load at mass center, get the hor deflection \( \Delta \) in inch, \( T_a = 0.32 \sqrt{\Delta} \)
   STAAD returns hor deflection \( \Delta = 3522 \text{mm} = 138.66 \text{ in} \) \( \rightarrow T_a = 0.32 \sqrt{138.66} = 3.768 \text{ s} \)

These two approaches are actually the same way of estimating structure period. Here is just a proof that the estimating formula \( T_a = 0.32 \sqrt{\Delta} \), which is used in hor vessel case, is good for practical use.

Use \( T_a = 3.765 \text{ s} \) to calculate seismic force for PSC vessel.
NOTES

It's incorrect to conceive that in Fort McMurray area the wind load will govern structural design and the seismic load is negligible compared to wind load. In this case
seismic base shear is 771.6 kN vs wind base shear 319.0 kN
seismic overturn moment is 10416.4 kNm vs wind overturn moment 5335.9 kNm

In this case, the overturn moment caused by seismic is 2.0 times of the overturn moment caused by wind. This is mainly due to

- \( T_a > 0.7 \text{s causing } F_i > 0 \)
- Vessel mass center is located at a higher elevation
**DESCRIPTION**

Vertical vessel foundation design based on

<table>
<thead>
<tr>
<th>Code Abbreviation</th>
<th>Code Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBCC 2005 Division B 4.1.8</td>
<td>NBCC05</td>
</tr>
<tr>
<td>ASCE Wind Loads and Anchor Bolt Design for Petrochemical Facilities</td>
<td>ASCE Wind Loads</td>
</tr>
<tr>
<td>PIP STE03350 Vertical Vessel Foundation Design Guide-2007</td>
<td>PIP STE03350</td>
</tr>
<tr>
<td>PIP STE05121 Anchor Bolt Design Guide-2006</td>
<td>PIP STE05121</td>
</tr>
</tbody>
</table>

**INPUT**

### Vessel Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel diameter</td>
<td>D = 16.000 [m]</td>
</tr>
<tr>
<td>Vessel height above pedestal</td>
<td>H = 30.000 [m]</td>
</tr>
<tr>
<td>Vessel content height</td>
<td>H₁ = 20.000 [m]</td>
</tr>
<tr>
<td>Mat Thickness</td>
<td>H₂ = 1.200 [m]</td>
</tr>
<tr>
<td>Pedestal height</td>
<td>H₃ = 0.650 [m]</td>
</tr>
<tr>
<td>Support leg height</td>
<td>H₄ = 16.500 [m]</td>
</tr>
<tr>
<td>Vessel CG height</td>
<td>H₅ = 26.000 [m]</td>
</tr>
<tr>
<td>Vessel leg number</td>
<td>Nₚ = 10</td>
</tr>
<tr>
<td>Vessel leg circle dia.</td>
<td>Dₚ = 22.500 [m]</td>
</tr>
<tr>
<td>Leg support brace section area</td>
<td>Aₚ = 491 [mm²]</td>
</tr>
<tr>
<td>Vessel type</td>
<td>Sphere</td>
</tr>
<tr>
<td>Structure importance category</td>
<td>Normal</td>
</tr>
<tr>
<td>Support struc period from STAAD</td>
<td>Tₛ = 3.765 [s]</td>
</tr>
</tbody>
</table>

**Vessel Weight Estimated**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel Surface Area</td>
<td>1407.4 [m²]</td>
</tr>
<tr>
<td>Vessel Volume</td>
<td>4021.2 [m³]</td>
</tr>
<tr>
<td>Vessel Content Weight</td>
<td>40212 [kN]</td>
</tr>
<tr>
<td>Vessel Empty Weight</td>
<td>3378 [kN]</td>
</tr>
<tr>
<td>Vessel Operating Weight</td>
<td>43590 [kN]</td>
</tr>
</tbody>
</table>

**Vessel Weight from Vendor Estimated Weight**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel Empty Weight</td>
<td>Wₑ = 13810 [kN]</td>
</tr>
<tr>
<td>Vessel Operating Weight</td>
<td>Wₒ = 183710 [kN]</td>
</tr>
<tr>
<td>Vessel Hydro Test Weight</td>
<td>Wₕ = 183710 [kN]</td>
</tr>
</tbody>
</table>

**Vessel Weight for Design**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel Empty Weight</td>
<td>Wₑ = 16572 [kN]</td>
</tr>
<tr>
<td>Vessel Operating Weight</td>
<td>Wₒ = 194967 [kN]</td>
</tr>
<tr>
<td>Vessel Hydro Test Weight</td>
<td>Wₕ = 194967 [kN]</td>
</tr>
</tbody>
</table>

*Increase empty wei 20% to account for insulation/piping wei*

*Increase content wei 5% to account for pipe content wei*

*These increase doesn't apply to uplift load comb cases*

**Vessel top platform width**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel top platform width</td>
<td>Wₚ = 3.000 [m]</td>
</tr>
<tr>
<td>Vessel top platform length</td>
<td>Lₚ = 3.000 [m]</td>
</tr>
<tr>
<td>Wind pressure q 1/50</td>
<td>q = 0.35 [kPa]</td>
</tr>
<tr>
<td>Top platform live load</td>
<td>LL = 4.80 [kPa]</td>
</tr>
<tr>
<td>Top platform dead load</td>
<td>DL = 2.00 [kPa]</td>
</tr>
<tr>
<td>Snow load</td>
<td>SL = 1.50 [kPa]</td>
</tr>
</tbody>
</table>

*including framing and grating*
Design Example 04: Self-Supported Horizontal Vessel
Structure Classification: Case 05

Calculate the seismic force for a self-supported horizontal vessel

Vessel diameter OD= 3.683 m  Insulation thk = 50mm
Vessel length = 20.700 m  Vessel saddle distance = 16.535 m
Vessel empty weight = 533 kN
Vessel operating weight = 2317 kN

Site location : Fort McMurray
Site class : Class D
Structure importance category : Normal

NOTES

It’s incorrect to conceive that in Fort McMurray area the wind load will govern structural design and the seismic load is negligible compared to wind load. In this case
For lateral load on vessel longitudinal direction
seismic base shear is 80.3 kN  vs wind base shear 13.1 kN
seismic overturn moment is 157.4 kNm  vs wind overturn moment 20.1 kNm
DESCRIPTION

Horizontal vessel foundation design based on

**NBCC 2005 Division B 4.1.8**

**ASCE Wind Loads and Anchor Bolt Design for Petrochemical Facilities**

**PIP STE03360 Heat Exchanger and Horizontal Vessel Foundation Design Guide-2007**

**PIP STE05121 Anchor Bolt Design Guide-2006**

**INPUT**

- **Structure importance category**: Normal
- **Vessel diameter**: OD = 3.683 [m]
- **Insulation thickness**: T_{ins} = 50 [mm]
- **Vessel diameter for design**: D = 3.783 [m]
- **Vessel length**: L = 20.700 [m]
- **Saddle distance**: S = 16.535 [m]
- **Vessel center hei above footing**: H = 4.159 [m]
- **Back fill soil height**: H_5 = 0.500 [m]
- **Platform width**: W_1 = 2.000 [m]
- **Platform length**: L_1 = 17.000 [m]
- **Saddle base plate width**: W_3 = 0.660 [m]
- **Saddle base plate length**: L_3 = 3.277 [m]
- **Saddle height**: H_3 = 2.150 [m]
- **Anchor bolt spacing in width**: W_0 = 0.305 [m]
- **Anchor bolt spacing in length**: L_0 = 2.895 [m]
- **Pier height**: H_3 = 1.960 [m]
- **Pier width**: W_2 = 1.000 [m]
- **Pier length**: L_2 = 3.600 [m]

**Code Abbreviation**

- **NBCC05**
- **ASCE Wind Loads**
- **PIP STE03360**
- **PIP STE05121**
Design Example 05: Building Structure
Structure Classification: Case 01

Calculate the seismic force for a pump house building

Building span = 11.1 m  Building total length = 33.37m  Roof slope = 1:12
Building eave height = 7.94m  Crane runway height = 5.32m
Building has a 18 tonne overhead crane
Crane bridge wt = 8600kg  Trolley + hoist wt = 1365kg
Site location: Fort McMurray
Site class: Class D
Structure importance category: Normal
For comparison purpose only, wind load on building, in transverse direction, can be estimated as

Total wind base shear = \( I_w \times C_f \times C_e \times q \times A = 1.0 \times 1.3 \times 1.0 \times 2.0 \times 0.35 \times 33.37 \times 11.1 = 337 \) kN

Total seismic base shear in transverse direction = 15.3 \times 5 \text{ (5 internal frames)} + 14.4 \times 2 \text{ (2 external frames)} = 106 \) kN

In this building structure, wind base shear 337 kN, is much bigger than seismic base shear, 106 kN.

For industrial facilities in low seismic zone, the following two factors are the essential condition when the seismic load may surpass wind load and become a governing load case

- Heavy equipments attached to the structure
- Heavy equipments located at high elevation above grade

In this building structure case, there is not many heavy equipments attached to the building, even after considering the crane selfweight and 25% snow load on roof, the lateral wind load is still bigger than the lateral seismic load.
**SEISMIC LOAD CALC FOR BUILDING STRUCTURE**

<table>
<thead>
<tr>
<th>Building Data</th>
<th>Number of bay</th>
<th>Crane Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building importance category</td>
<td>W = 11.100 [m]</td>
<td>Number of bay</td>
</tr>
<tr>
<td>Building width</td>
<td>L₁ = 3.370 [m]</td>
<td>n₁ = 1</td>
</tr>
<tr>
<td>Bay spacing</td>
<td>L₂ = 6.000 [m]</td>
<td>n₂ = 1</td>
</tr>
<tr>
<td></td>
<td>L₃ = 6.000 [m]</td>
<td>n₃ = 1</td>
</tr>
<tr>
<td></td>
<td>L₄ = 6.000 [m]</td>
<td>n₄ = 1</td>
</tr>
<tr>
<td></td>
<td>L₅ = 6.000 [m]</td>
<td>n₅ = 1</td>
</tr>
<tr>
<td></td>
<td>L₆ = 6.000 [m]</td>
<td>n₆ = 1</td>
</tr>
<tr>
<td>Wind column tributary length</td>
<td>C₁ = 2.000 [m]</td>
<td>D₁ = 2.000 [m]</td>
</tr>
<tr>
<td></td>
<td>C₂ = 3.550 [m]</td>
<td>D₂ = 3.550 [m]</td>
</tr>
<tr>
<td></td>
<td>C₃ = 3.550 [m]</td>
<td>D₃ = 3.550 [m]</td>
</tr>
<tr>
<td>Bay spacing used for transverse frame</td>
<td>B = 6.000 [m]</td>
<td></td>
</tr>
<tr>
<td>seismic &amp; foundation load calc.</td>
<td>H = 7.940 [m]</td>
<td></td>
</tr>
<tr>
<td>Building eave height</td>
<td>1 : 12.00</td>
<td></td>
</tr>
<tr>
<td>Roof slope</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Wind Load Data**

- Wind pressure q 1/50: q = 0.35 [kPa]
- Building category - internal pressure: Category 2
Design Example 06: Nonbuilding Structure (> 25% Comb Wt) Supported by Other Structure
Structure Classification: Case 09

Calculate the seismic force for a vertical surge drum supported by a steel frame table top.

Vessel diameter \( D = 7.550 \, \text{m} = 24.770 \, \text{ft} \)
Vessel height \( H = 33.150 \, \text{m} = 108.760 \, \text{ft} \)
Vessel shell thickness \( t = 25.4 \, \text{mm} = 1 \, \text{in} \)

Vessel empty weight = 2243 kN = 504675 lb
Vessel operating weight=20081kN = 4518225 lb
Vessel hydrotest weight=15938 kN= 3586050 lb
Site location : Fort McMurray
Site class : Class D
Vessel content is flammable hydrocarbon
Structure importance category : High

Determine If Vessel Is Rigid Nonbuilding Structure
Vessel linear weight \( W = \frac{4518225 \, \text{lb}}{108.760 \, \text{ft}} = 41543.1 \, \text{lb/ft} \)

Vessel fundamental period \( T_s = \frac{7.78 \, H}{D} \sqrt{\frac{12 \, W}{D} \, t} = 0.527 \, \text{s} >> 0.06 \, \text{s} \) → the vessel is a flexible Nonbuilding Structure
Determine If Nonbuilding Structure Wt Is More Than 25% of Comb Wt

Steel supporting frame selfweight = 588 kN,
Support structure + Vessel operating combined total weight = 588 + 20081 = 20669 kN
Vessel operating Wt / Combined Wt = 20081 / 20669 = 97% >> 25% → vessel and supporting structure shall be modeled together in a combined model with appropriate stiffness and effective seismic weight distribution

Vessel Support Steel Frame

Determine $R_d \times R_o$ Value

$R_d \times R_o$ value of combined system shall be taken as the lesser $R_d \times R_o$ value of the nonbuilding structure or the supporting structure → Use $R_d \times R_o = 1.5 \times 1.3$ as Conventional Construction

Modeling Techniques In STAAD

1. Model the vertical vessel as seven segments of beam element, break the 33.15m into 6x5m + 1x3.15m =33.15m
   Breaking the vertical vessel into segments is critical as it will distribute the mass evenly along the height and capture the high modes of vibration.
2. Use Master/Slave to define the vessel base as a rigid diaphragm. The central node is a master node and all surrounding nodes on support plan are slave nodes. The master node is not necessary to be physically connecting to the slave nodes.
Seismic load distribution and overturn moment to vessel base

<table>
<thead>
<tr>
<th>Elevation (m)</th>
<th>Weight (kN)</th>
<th>Weight x Height (kN)</th>
<th>Friction (kN)</th>
<th>Overturning Moment (kNm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.300</td>
<td>2102.4</td>
<td>11142.7</td>
<td>18.3</td>
<td>0.0</td>
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<tr>
<td>10.300</td>
<td>3028.8</td>
<td>31196.6</td>
<td>51.2</td>
<td>255.9</td>
</tr>
<tr>
<td>15.300</td>
<td>3028.8</td>
<td>46340.6</td>
<td>76.0</td>
<td>760.3</td>
</tr>
<tr>
<td>20.300</td>
<td>3028.8</td>
<td>61484.6</td>
<td>100.9</td>
<td>1513.1</td>
</tr>
<tr>
<td>25.300</td>
<td>3028.8</td>
<td>76628.6</td>
<td>125.7</td>
<td>2514.4</td>
</tr>
<tr>
<td>30.300</td>
<td>3028.8</td>
<td>91772.6</td>
<td>150.6</td>
<td>3764.1</td>
</tr>
<tr>
<td>35.300</td>
<td>2468.5</td>
<td>87138.1</td>
<td>143.0</td>
<td>4288.9</td>
</tr>
<tr>
<td>38.450</td>
<td>954.1</td>
<td>36685.1</td>
<td>100.2</td>
<td>3321.2</td>
</tr>
<tr>
<td>Sum</td>
<td>20669.0</td>
<td>442389.1</td>
<td>765.8</td>
<td>16417.9</td>
</tr>
</tbody>
</table>

Calculate Overturning Reduction Factor J

\[ S_a(0.2) / S_a(2.0) = 0.120 / 0.006 = 20.0 \quad T_a = 0.747 \quad \text{Braced Frame} \Rightarrow J = 0.918 \quad \text{NBC05 Table 4.1.8.11} \]

OTM by seismic = 16417.9 x 0.918 = 15071.6 kNm

For comparison purpose only, the wind load on vessel can be estimated as

\[ F = I_w \times C_f \times q \times C_g \times C_e \times A = 1.15 \times 0.77 \times 0.35 \times 2.2 \times 1.3 \times (7.55+1.52) \times (33.15+1.52) = 278.7 \text{ kN} \]

Overturn moment to vessel base can be roughly estimated as

OTM by wind = 278.7 x 33.15 / 2 = 4619.5 kNm

NOTES

It’s incorrect to conceive that in Fort McMurray area the wind load will govern structural design and the seismic load is negligible compared to wind load. In this case

- seismic base shear is 766 kN vs wind base shear 279 kN \[ 766 / 279 = 2.7 \text{ times} \]
- seismic overturn moment is 15072 kNm vs wind overturn moment 4620 kNm \[ 15072 / 4620 = 3.3 \text{ times} \]

It’s also risky to assume that the vendors’ calculation will take care of the seismic design. The vendor’s seismic calculation always assumes the vessel base is fixed, as the vendor never has intention to get the boundary condition of support structure. In this case, when vessel weight exceeds 25% of combined weight, the vessel and supporting structure shall be modeled together in a combined model to get the accurate response of seismic load.
Reference
2. ASCE 7-05 Minimum Design Loads for Buildings and Other Structures
5. CISC Moment Connections for Seismic Applications
6. CSA S16-09 Limit States Design of Steel Structures