TABLE OF CONTENTS

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 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 NBCC Table 4.1.8.4A
   - Preferable way to classify Site Class 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/ ρ) = SQRT(Gg / γ) 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 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 → seismic design is not required

For Site Class D or worst, S(0.2) > $S_a(0.2)$=0.12 → 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 <u>any</u> 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 $S_a(0.2)$ = 1.5x1.3x0.12 = 0.234 < 0.35

→ 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

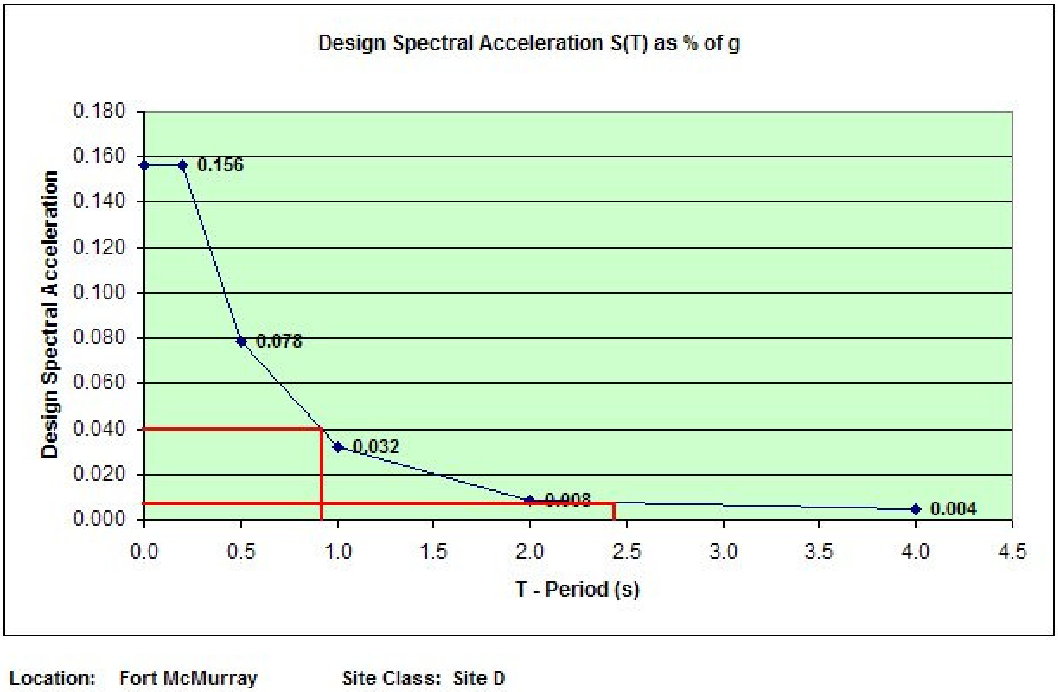
   Not covered in this guideline.

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.



From Example01, Moment Frame direction, estimated period = 0.91 s, STAAD computed period = 2.43 s

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 an 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 <u>inelastic</u> storey drift, which is applicable when seismic force is not reduced by dividing $R_d x R_o$ factor.
     Use $R_d x R_o$ / I_E to <u>scale up</u> the drift for comparison with 0.025h when the drift value is obtained from a model with seismic load scaled down by I_E/($R_d x R_o$).

4.0 DUCTILTY 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 8270/341 = 24.3
It's almost impractical to design a structure deforming elastically with seismic lateral load 24 times of wind load.

R_dxR_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_dxR_o =5.0x1.5 for moment frame and R_dxR_o =4.0x1.5 for eccentrically braced frame, the seismic force for design can be reduced to 8270 / (4.0x1.5) = 1378 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 Fy , but the probable yield strength RyFy = 1.1Fy shall be used, and 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 RyFy = 1.1Fy, and for HSS RyFy shall not be less than 460MPa. S16-09 27.1.7
4. The amplification factor U2, 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 facbrication 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 $R_d x R_o$ value of Conventional Construction.

Refer to attached example 01, exchanger structure, location: For McMurray

The seismic base shear before applying / ($R_d x R_o$) is 823 kN, wind load base shear is 341 kN

With Conventional Construction, design seismic load reduced to 823 / ($R_d x R_o$) = 823 /(1.5x1.3) = 422 kN, which is already close to wind load 341 kN → use of higher ductility SFRS is not necessary.

In Fort McMurray, always use Conventional Construction, $R_d x R_o$ = 1.5x1.3, 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

Classification of Petrochemical Facilities and Applicable Code Provisions

Classification	Structure Type	Case No	Seismic Force Calc	RdxRo Factor	Structure Example
Building Structure		Case 01	NBCC 4.1.8.11	NBCC Table 4.1.8.9	Industrial Building, Pump House
Nonbuilding Structure Similar to Building		Case 02	NBCC 4.1.8.11	NBCC Table 4.1.8.9	Piperack, Exchanger Structure, Process Module
Nonbuilding Structure Not Similar to Building	Skirt-Supported Ver Vessel	Case 03	NBCC 4.1.8.11	ASCE 7-05 Table 15.4-2	Skirt-Supported Ver Vessel on Conc Foundation
	Braced Leg-Supported Ver Vessel	Case 04	NBCC 4.1.8.11	ASCE 7-05 Table 15.4-2	Braced Leg-Supported Ver Vessel on Conc Foundation
	Self-Supported Hor Vessel	Case 05	NBCC 4.1.8.11	ASCE 7-05 Table 15.4-2	Self-Supported Hor Vessel on Conc/Steel Pier
	Nonbuilding Structure Rigid Structure	Case 06	ASCE 7-05 15.4.2	No RdRo Value Required	Conc Mounted Pump and Compressor
Nonbuilding Structure (Less Than 25% Comb Wt) Supported by Other Structure	Overall Structure	Case 07	NBCC 4.1.8.11	NBCC Table 4.1.8.9	Exchanger Structure, Process Module
	Equipment Support		NBCC 4.1.8.17	NBCC Table 4.1.8.17	
Nonbuilding Structure (More Than 25% Comb Wt) Supported by Other Structure	Rigid Nonbuilding Structure	Case 08	NBCC 4.1.8.11	NBCC Table 4.1.8.9	Hor Vessel Mounted on Conc/Steel Structure
	Nonrigid Nonbuilding Structure	Case 09	NBCC 4.1.8.11	NBCC Table 4.1.8.9	Ver Vessel Mounted on Conc/Steel Structure

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 4.1.8.17), 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.

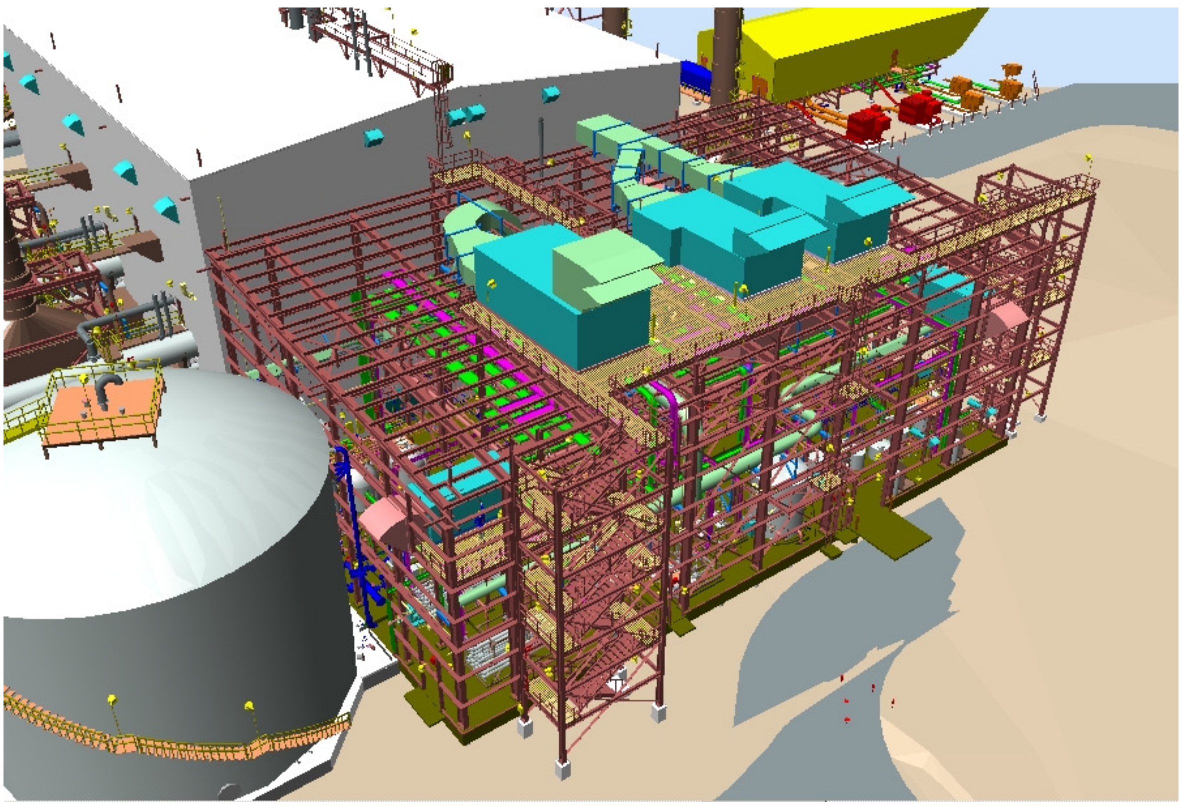
In this guideline, ASCE 7-05 Chapter 15 is referenced for seismic design of Nonbuilding Structure. When ASCE 7-05 is referenced for seismic design in Canadian location, Canadian version of ground motion parameters in NBCC2005 are used to interpret formulas in ASCE 7-05. This is exactly what NBCC2005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

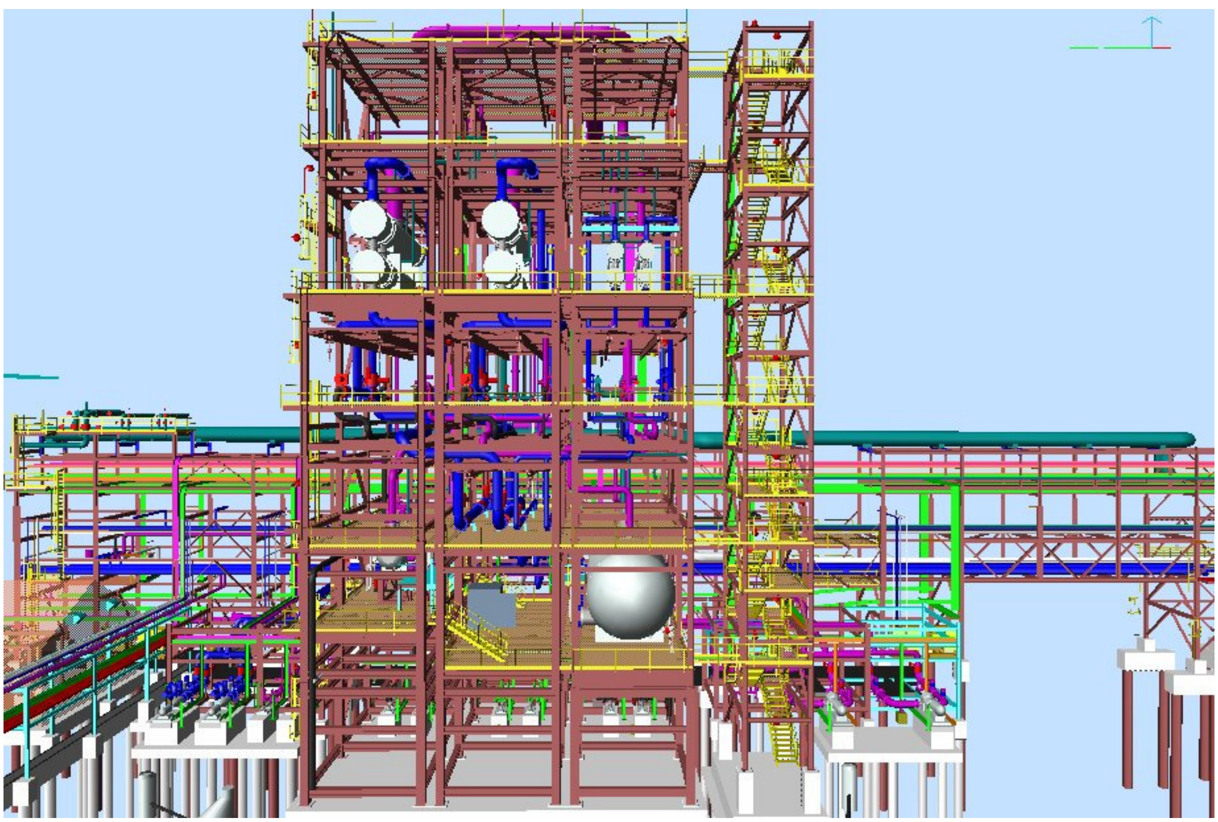


Case 01 Building Structure

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.



Case 02 Nonbuilding Structures Similar to Building

6.0 DESIGN EXAMPLES

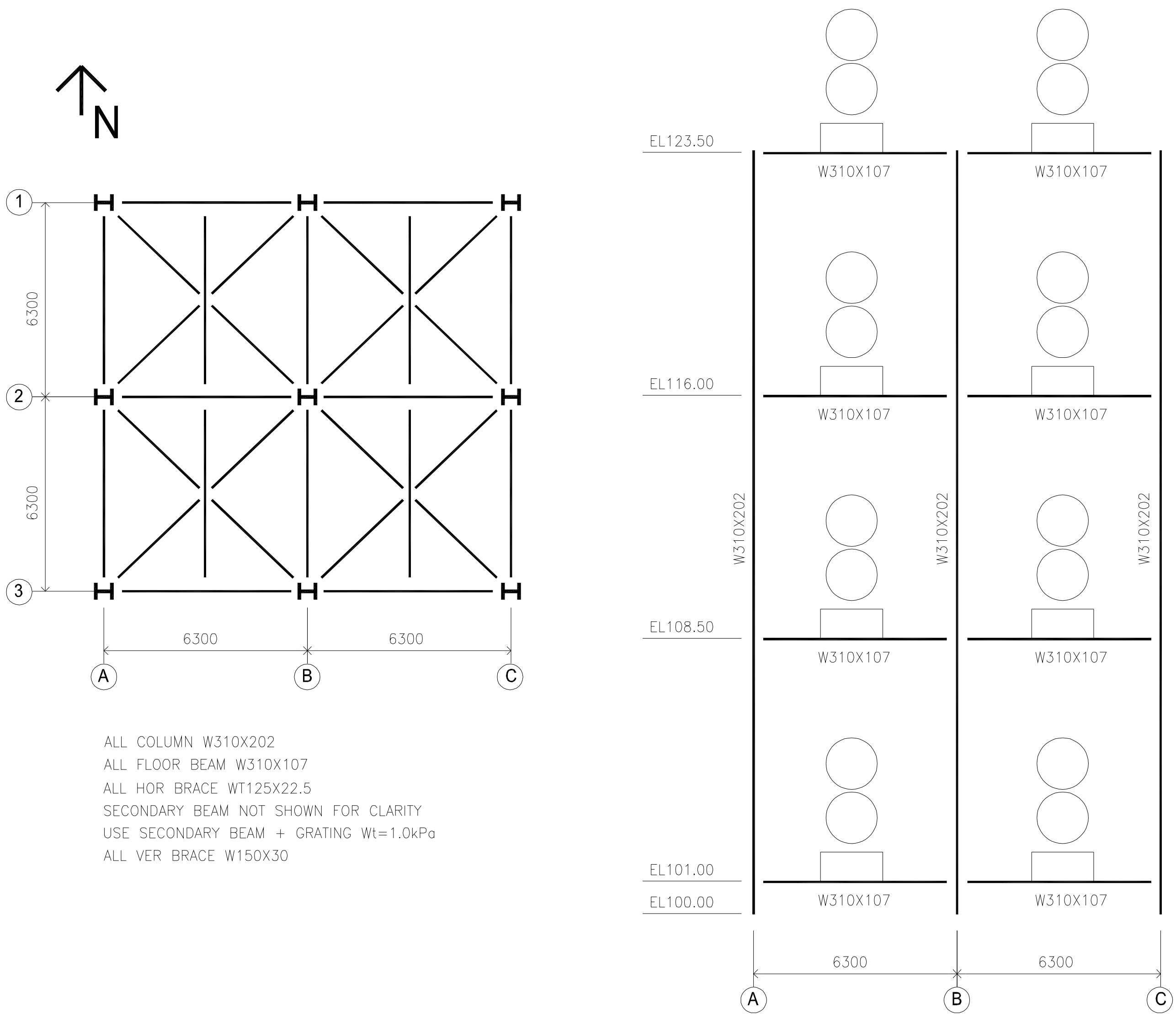
Design Example 01: Nonbuilding Structure Similar to Building - Exchanger Structure
Structure Classification: Case 02 & Case 07

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 flamable hydrocarbon content.
Calculate seismic force for the following scenarios:

1. Site in Fort McMurray, Site D, Use SFRS $R_d x R_o$ 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 $R_d x R_o$ value of Conventional Construction and Moderately Ductility

2. Site in Vancouver, Site D, Use SFRS $R_d x R_o$ 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

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

Location: Fort McMurray Site Class: Site D

SFRS	Base Shear Ve before Ve / (R_dxR_o)	Base Shear SFRS CC Ve / (1.5x1.3)	Base Shear SFRS MD Ve / (3.0x1.3)
	kN	kN	kN
Moment Frame	328	168	84
Braced Frame	823	422	211

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 27.12 shall not apply to these systems.

In low or moderate seismic zone, using a higher R_dxR_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_dxR_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 gorvern 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

Location: Vancouver Site Class: Site D

SFRS	Base Shear Ve before Ve / (R_dxR_o)	Base Shear SFRS CC Ve / (1.5x1.3)	Base Shear SFRS MD Ve / (3.0x1.3)	Base Shear SFRS D Ve / (4.0x1.5)
	kN	kN	kN	kN
Moment Frame	4185	2146	1073	698
Braced Frame	8270	4241	2121	1378

From above seismic base shear calc, we can find that, in high seismic zone such as Vancouver, using higher modification factor of R_dxR_o 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 High

Wind Load Data

Wind pressure q 1/50 q = 0.35 [kPa]

Snow Load Data Fort McMurray

Ground snow load 1/50	S_s =	1.50	[kPa]	1.40
Rain load 1/50	S_r =	0.10	[kPa]	0.10

Seismic Data

Site location Fort McMurray Avg. soil shear wave V_s = 232 [m/s]

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

STAAD output Trans. direction moment frame period	T_T =	2.43	[s]
STAAD output Long. direction braced frame period	T_L =	0.66	[s]

Structure Plan Summary

Plan Description		Elevation		w_i (kN)	Δ h (m)	Status	h_i (m)
U/S column base EL.100	EL_0 =	100.000	[m]				
Plan TOS EL.101	EL_1 =	101.000	[m]	2400.7	1.000	Active	1.000
Plan TOS EL.108.5	EL_2 =	108.500	[m]	2518.9	7.500	Active	8.500
Plan TOS EL.116	EL_3 =	116.000	[m]	2518.9	7.500	Active	16.000
Plan TOS EL.123.5	EL_4 =	123.500	[m]	2518.9	7.500	Active	23.500
Plan TOS EL.0	EL_5 =	0.000	[m]	0.0	0.000	Inactive	0.000
Plan TOS EL.0	EL_6 =	0.000	[m]	0.0	0.000	Inactive	0.000
Plan TOS EL.0	EL_7 =	0.000	[m]	0.0	0.000	Inactive	0.000
Plan TOS EL.0	EL_8 =	0.000	[m]	0.0	0.000	Inactive	0.000
Plan TOS EL.0	EL_9 =	0.000	[m]	0.0	0.000	Inactive	0.000
Plan TOS EL.0	EL_{10} =	0.000	[m]	0.0	0.000	Inactive	0.000

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 caputured by the height factor, newly introduced in NBCC2005, $A_x = 1 + 2h_x / h_n$
For equipments at foundation level $A_x = 1.0$, and $A_x = 3.0$ for equipments sitting at roof level.

Location: Fort McMurray Site Class: Site D

Lateral Load Type	Transverse Direction	Longitudinal Direction
	kN	kN
Wind	18	4
Seismic	122	243

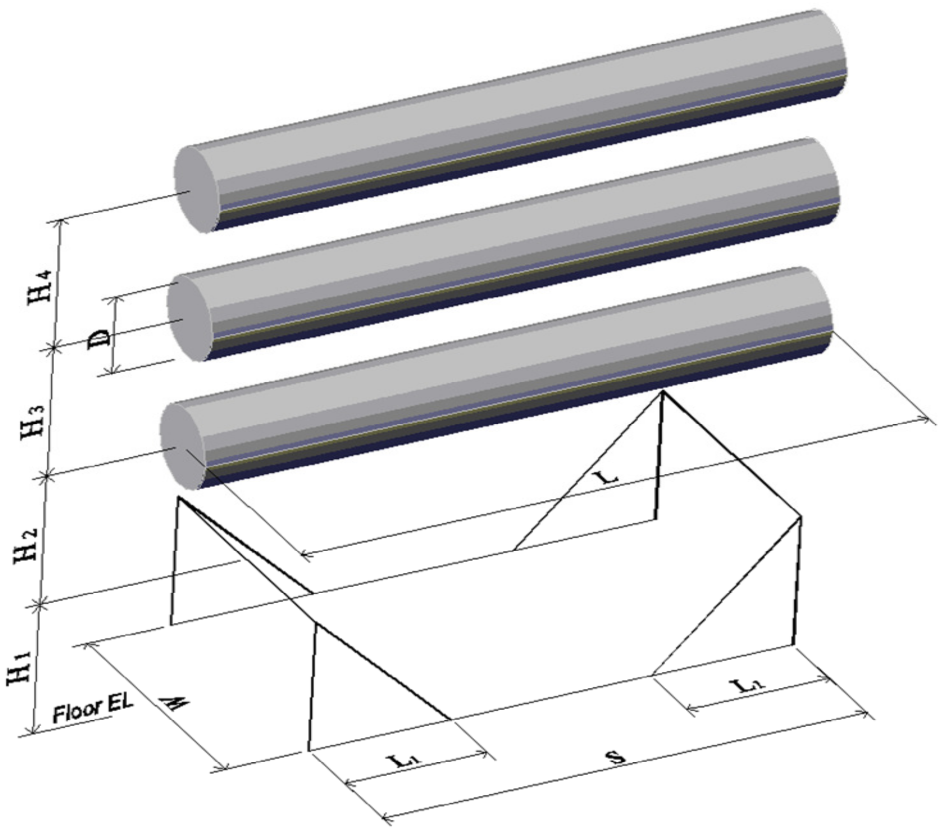
From above we find that, for local equipment support design, the seismic load is much bigger than the wind load if the equipment is located on a higher elevation above grade. This is mainly due to the dynamic amplifying effect (Ar =2.5) for big mass sitting on a flexible supporting structure.

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	**Code Abbreviation**
NBCC 2005 Division B 4.1.8	*NBC05*
ASCE Wind Loads and Anchor Bolt Design for Petrochemical Facilities	*ASCE Wind Loads*
PIP STE03360 Heat Exchanger and Horizontal Vessel Foundation Design Guide-2007	*PIP STE03360*



INPUT

Exchanger Data

Shell OD	D	=	1470	[mm]	Insul. Thickness	=	38	[mm]
Overall OD	OD	=	1546	[mm]	H_1	=	1200	[mm]
Exchanger length	L	=	11092	[mm]	H_2	=	975	[mm]
Saddle distance	S	=	4900	[mm]	H_3	=	2246	[mm]
Steel support width	W	=	1400	[mm]	H_4	=	0	[mm]
					L_1	=	1200	[mm]

Single Shell Weight					Estimated Wei
Empty weight	W_e	=	350	[kN]	300
Operating weight	W_o	=	500	[kN]	489
Hydro test weight	W_t	=	500	[kN]	489
Bundle weight	W_{bp}	=	144	[kN]	226
Number of stacked shells	n	=	2		

Wind Data

Wind pressure q 1/50	q	=	0.35	[kPa]

Seismic Data					**Code Reference**
Site location	Fort McMurray				*NBC 05*
Site Classification					
Avg soil shear wave velocity	V_s =	200	[m/s]	Site D	Table 4.1.8.4.A
Structure importance category		High			
Importance factor seismic load	I_E =	1.30	For importance category High structure		Table 4.1.8.5
Importance factor wind load	I_w =	1.15	For importance category High structure		Table 4.1.7.1
Exchanger contains toxic or flamable liquid		Yes		C_p = 1.5	Table 4.1.8.17
Support floor base height	h_x =	23.500	[m]		
Total structure height	h_n =	23.500	[m]		
Steel Support Data					
Steel support beam size	W250x73				
Steel support column size	W250x73				
Steel support bracing size	DAngle_LLV		2L102x76x7.9LLBB		

GRAVITY LOAD					**Code Reference**
<u>Stacked Shells</u> Total Weight	Add 20% of <u>single</u> shell wei to account for attached misc. piping & insulation wei				
	$(n+0.2)xW_e$ =	770	[kN]		
	$(n+0.2)xW_o$ =	1100	[kN]		
	$(n+0.2)xW_t$ =	1100	[kN]		*PIP STE03360*
Gravity load distributed 60% at channel end, 40% at shell end. Use 60% for design of both ends.					4.2.1.3
Empty case	D_e =	**462**	[kN]		
Operating case	D_o =	**660**	[kN]		
Hydro test case	D_t =	**660**	[kN]		

Trans. Moment from Piping Eccentricity				*PIP STE03360*
Ecc = 0.5OD + 1.5ft	e =	1230	[mm]	4.2.1.2 d.
Apply 0.6 x 10% of <u>single shell</u> weight with eccentricity e as trans. moment for both ends				
Empty case	M_{Te} =	**26**	[kNm]	
Operating case	M_{To} =	**37**	[kNm]	
Hydro test case	M_{Tt} =	**37**	[kNm]	

WIND LOAD

Transverse Wind					*NBC05 Comment I*
	C_g =	2.00	L/D = 7.2		
	C_f =	0.80 Rough surface			Fig. I-24
Exchanger height above grade	H =	$EL + (H_1 + H_2 + H_3)$	= 27.9	[m]	
	C_e =	1.23			*NBC05* 4.1.7.1 (5)
Add 1.5ft (0.46m) to OD to account for piping attached to exchanger					*ASCE Wind Loads*
	A =	L x (D + 0.46)	= 22.2	[m^2]	Section 4.3.2.2
					NBC05 Comment I
Wind force on single shell	F_{T1} =	$I_w \times C_f \times q \times C_g \times C_e \times A$	= 17.6	[kN]	Fig. I-24
Trans. Wind on Steel Support					
Trans. base shear	F_T =	F_{T1} x n (shell) / 2 (end)	= **17.6**	[kN]	
Trans. OTM to support base	M_{TW} =	[$F_{T1}x(H_2+H_3+H_4)+F_{T1}x(H_2+H_3)$ + FT1xH2] /2 (end)	= **36.9**	[kNm]	
Longitudinal Wind					*ASCE Wind Loads*
	C_f =	1.20 Assume flat head to be conservative			Section 4.3.2.4
Add 1.5ft (0.46m) to OD to account for piping attached to exchanger					*ASCE Wind Loads*
	A =	$\pi (D + 0.46)^2 / 4$	= 3.2	[m^2]	Section 4.3.2.2
Wind force on single shell	F_{L1} =	$I_w \times C_f \times q \times C_g \times C_e \times A$	= 3.7	[kN]	
Long. Wind on Steel Support					
Long. base shear	F_L =	F_{L1} x n (shell) / 2 (end)	= **3.7**	[kN]	
Couple on supp caused by wind	N_w =	[$F_{L1}(H_2+H_3+H_4)$ + $FL_1(H_2+H_3)$ + $F_{L1}H_2$] / S	= **3.2**	[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

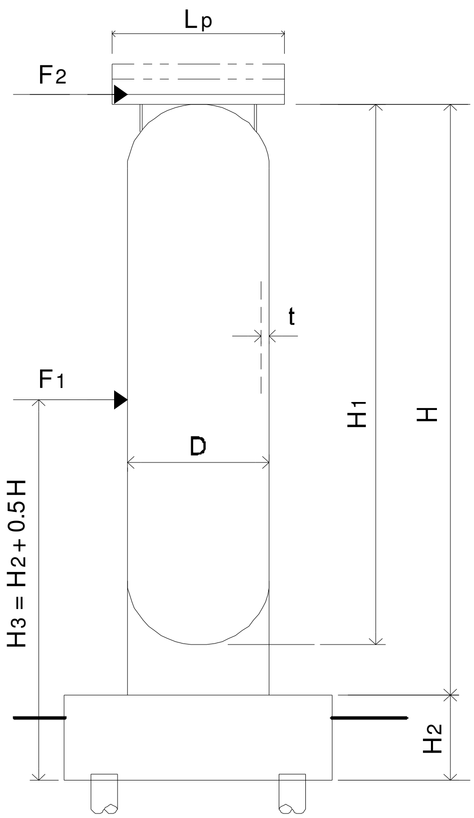
In this case, the overturn moment caused by seismic is 2 times of the overturn moment caused by wind. This is mainly due to the reverse triangle distribution of seismic load.

DESCRIPTION

Vertical vessel foundation design based on	**Code Abbreviation**
NBCC 2005 Division B 4.1.8	*NBC05*
ASCE Wind Loads and Anchor Bolt Design for Petrochemical Facilities	*ASCE Wind Loads*
PIP STE03350 Vertical Vessel Foundation Design Guide-2007	*PIP STE03350*
PIP STE05121 Anchor Bolt Design Guide-2006	*PIP STE05121*

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	[m^2]	
Vessel volume		=	503.3	[m^3]	
Vessel content weight		=	5033	[kN]	water 10kN/m^2
Vessel empty weight		=	867	[kN]	shell 50lb/ft^2
Vessel operating weight		=	5900	[kN]	
Vessel Weight from Vendor					Estimated Wei
Vessel empty weight		=	221	[kN]	867
Vessel operating weight		=	3793	[kN]	5900
Vessel hydro test weight		=	5055	[kN]	5900
Vessel Weight for Design					
Vessel empty weight	W_e	=	**265**	[kN]	Increase empty wei 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]	<u>These increase doesn't apply to uplift load comb cases</u>

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_{pip}	=	**90.5**	[kNm]	
Vessel top platform width	W_p	=	1.200	[m]	
Vessel top platform length	L_p	=	8.000	[m]	
Wind pressure q 1/50	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					**Code Abbreviation**
NBCC 2005 Division B 4.1.7					*NBC05*
NBCC 2005 Commentary I					*NBC05 Comment I*
ASCE Wind Loads and Anchor Bolt Design for Petrochemical Facilities					*ASCE Wind Loads*
ASME STS-1-2006 Steel Stacks					*ASME Steel Stacks*
					Code Reference
Structure importance category		Normal			
Importance factor	I_w =	1.00	For importance category Normal structure		*NBC05* Table 4.1.7.1
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_e =	1.04			*NBC05* 4.1.7.1 (5)
	C_g =	2.00			*NBC05* 4.1.7.1 (6)
	Dxsqrt (qC_e) =	4.346	>0.167	H/D = 1.7	*NBC05 Comment I*
	C_f =	0.71	Rough surface		Fig. I-24

Vortex Shedding Check *NBC05 Comment I*

Strouhal Number	S =	0.20	For large-diameter structures		page I-33
Vessel 1st mode frequency	$f_n=1/T_a$ =	8.87 [Hz]	Get period Ta from seismic analysis		
<u>Critical</u> mean wind speed at top when resonance occurs	V_{HC} =	f_n D / S		= 318.8 [m/s]	page I-33 (16)
<u>Dynamic</u> Exposure Factor	C_{eH} =	1.06	Exposure A		page I-24 (7)
Wind speed at 10m height	V =	39.2 sqrt(q)		= 23.2 [m/s]	page I-29 (14)
Mean wind speed at top	V_H =	V sqrt (C_{eH})		= 23.9 [m/s]	page I-29 (13)

ASME Steel Stacks

Vortex shedding can be ignored if $V_{HC} > 1.2\ V_H$ — $V_{HC} > 1.2V_H$ — clause 5.2.2 (3)

Response of vortex shedding can be ignored

Wind on Attached Piping and Ladder

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

ASCE Wind Loads

Add 5ft (1.52m) to vessel diameter to account for ladder & piping attached <u>below</u> top tangent line — clause C.4.3.1.2

Wid = D + 1.52 = 8.71 [m]

Add 5ft (1.52m) to vessel height to account for piping attached <u>above</u> top tangent line

Hei = H + 1.52 = 13.92 [m]

A = Wid x Hei = 121.23 [m^2]

NBC05 Comment I

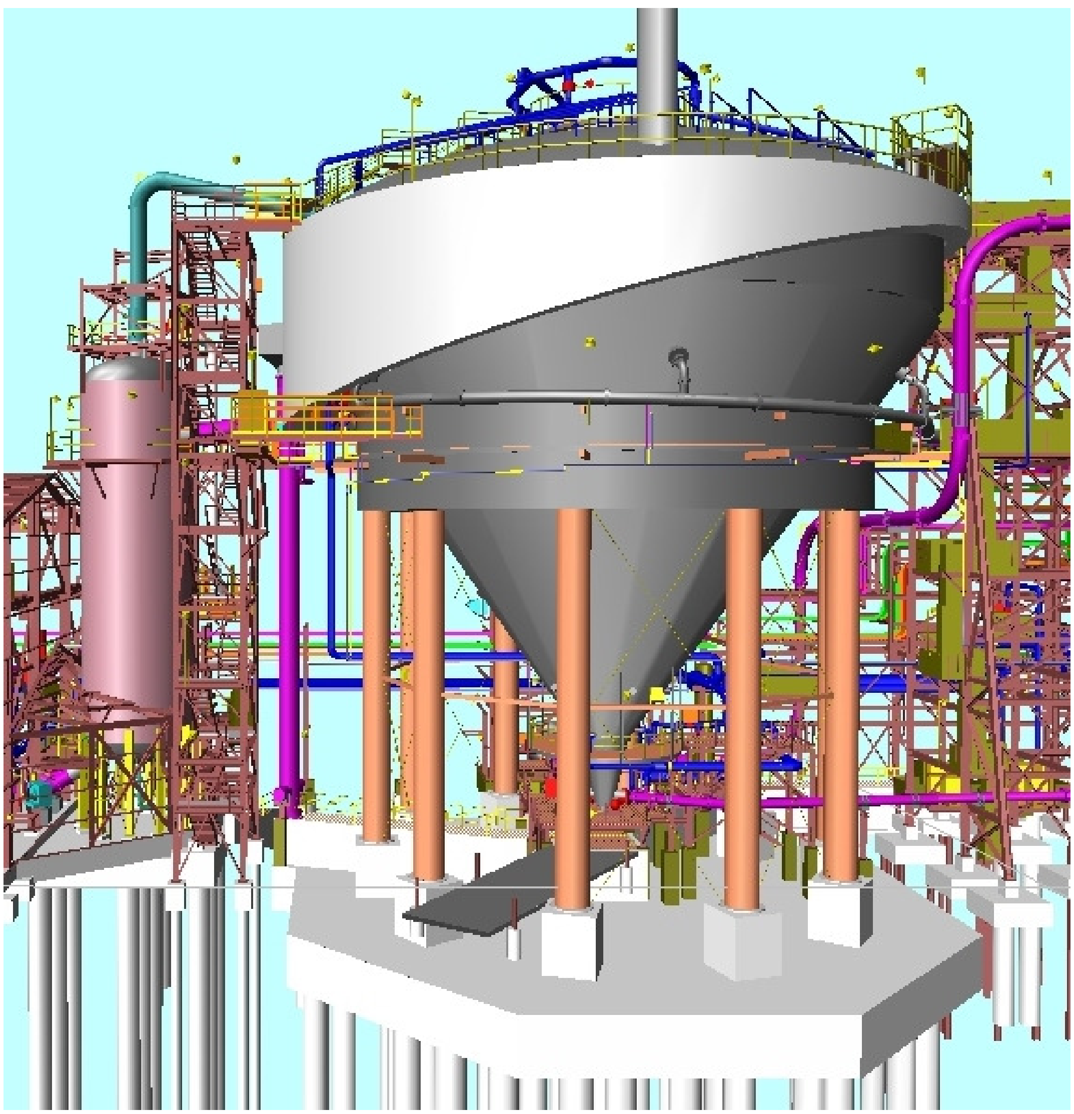
Wind on Vessel

Wind force on vessel $F_1 = I_w \times C_f \times q \times C_g \times C_e \times A$ = 63.1 [kN] — Fig. I-24

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

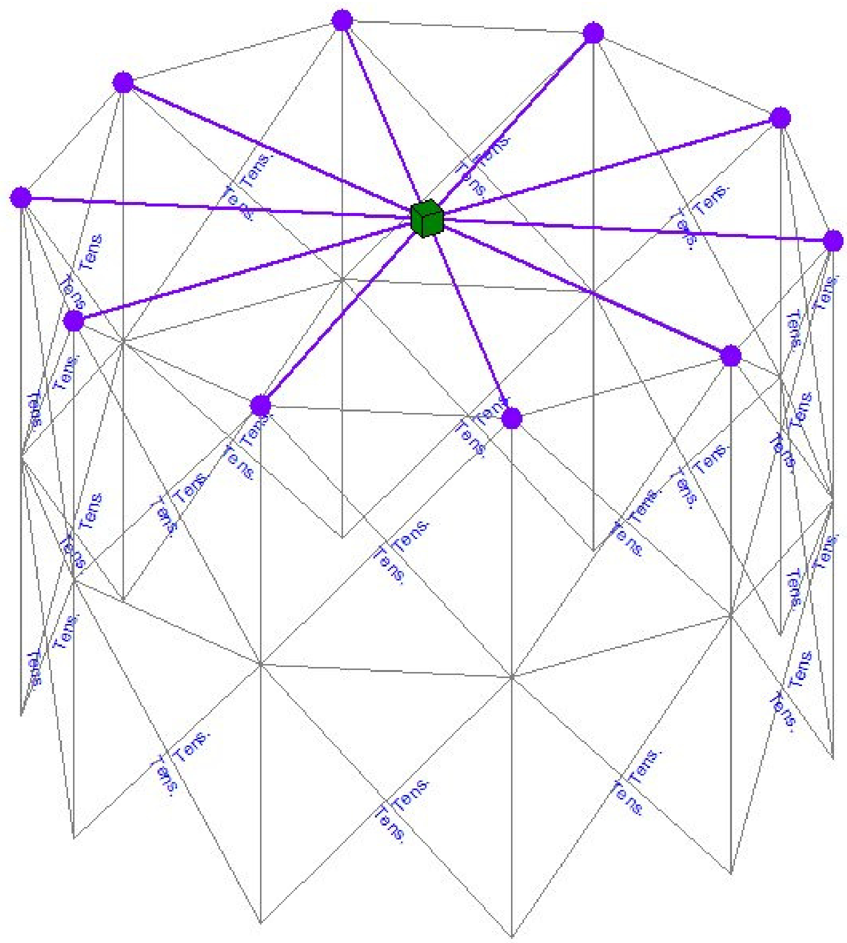
Calculate the seismic force for a braced-leg supported PSC vessel. The PSC vessel is supported by 10 x OD=1450mm wall thk =27mm steel column equally spaced at 22.5m diameter circle. The 3D support frame is braced by 25 dia steel tension only rod. Vessel empty weight = 13810 kN , operating weight = 183710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

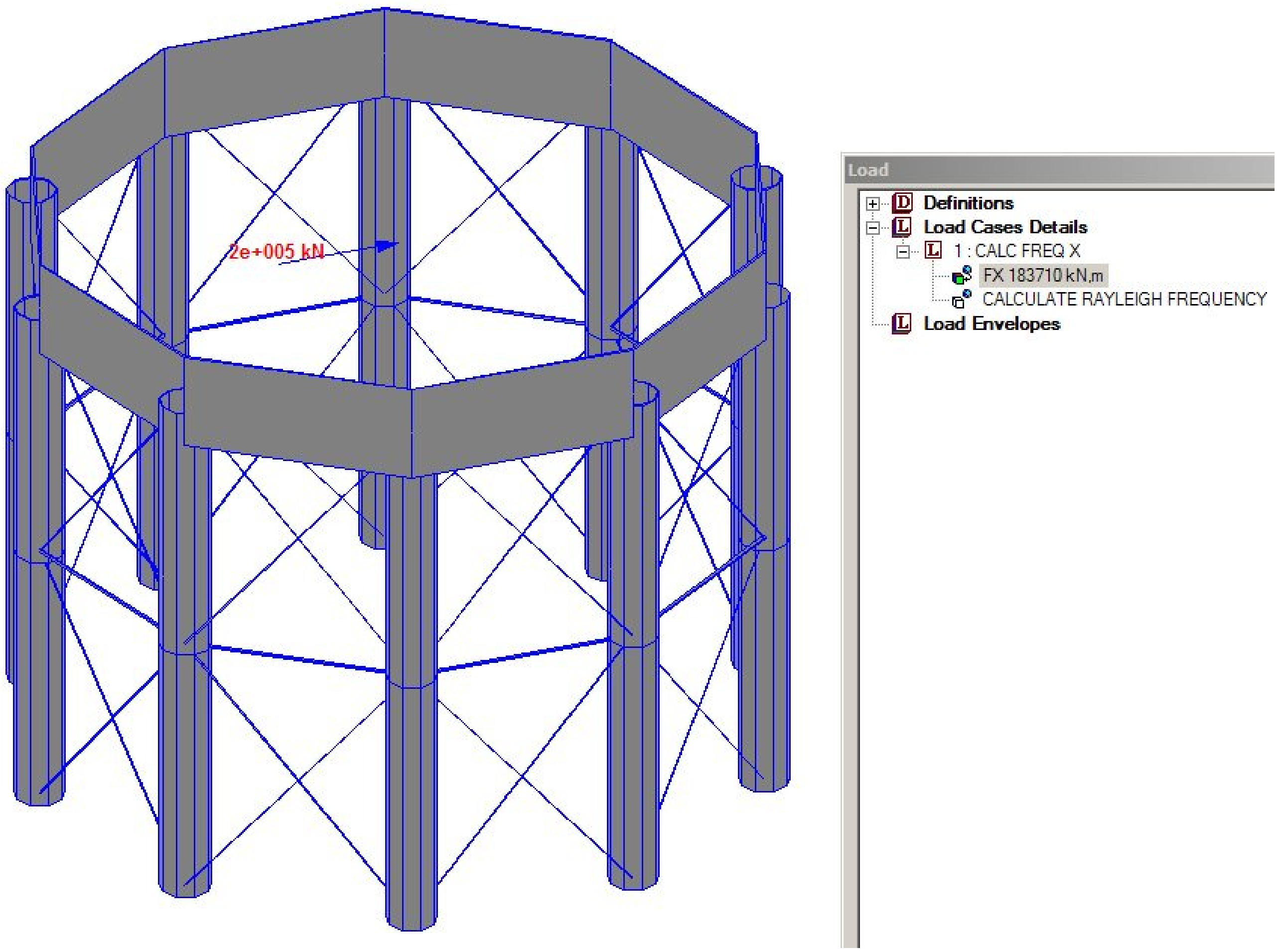


Braced-Leg Supported PSC Vessel

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



STAAD Model : PSC Vertical Vessel Support

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 → T_a = 1/0.26558 = **3.765 s**

2. Apply vessel operating weight as lateral load at mass center, get the hor deflection Δ in inch, T_a = 0.32 sqrt(Δ)
   STAAD returns hor deflection Δ = 3522mm = 138.66 in → T_a = 0.32 sqrt(Δ) = 0.32 sqrt(138.66) = **3.768 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(Δ), which is used in hor vessel case, is good for practical use.

Use T_a = 3.765s 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

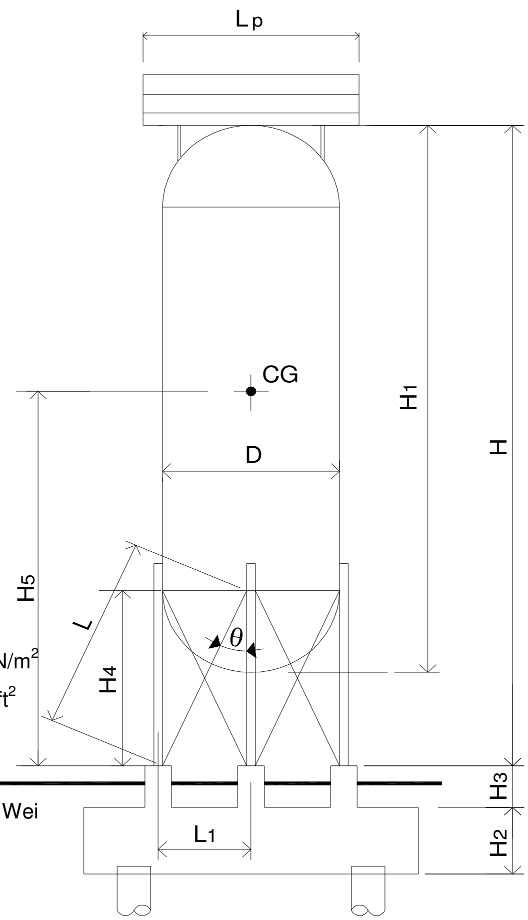
- T_a >0.7s causing F_t >0
- Vessel mass center is located at a higher elevation

DESCRIPTION

Vertical vessel foundation design based on	**Code Abbreviation**
NBCC 2005 Division B 4.1.8	*NBC05*
ASCE Wind Loads and Anchor Bolt Design for Petrochemical Facilities	*ASCE Wind Loads*
PIP STE03350 Vertical Vessel Foundation Design Guide-2007	*PIP STE03350*
PIP STE05121 Anchor Bolt Design Guide-2006	*PIP STE05121*

INPUT

Vessel Data



Vessel diameter	D =	16.000	[m]		
Vessel height above pedestal	H =	30.000	[m]		
Vessel content height	H_1 =	20.000	[m]		
Mat Thickness	H_2 =	1.200	[m]		
Pedestal height	H_3 =	0.650	[m]		
Support leg height	H_4 =	16.500	[m]		
Vessel CG height	H_5 =	26.000	[m]		
Vessel leg number	N_p =	10			
Vessel leg circle dia.	D_{legc} =	22.500	[m]		
Leg support brace section area	A_{br} =	491	[mm^2]		
Vessel type		Sphere			
Structure importance category		Normal			
Support struc period from STAAD	T_a =	3.765	[s]		
Vessel Weight Estimated					
Vessel Surface Area	=	1407.4	[m^2]		
Vessel Volume	=	4021.2	[m^3]		
Vessel Content Weight	=	40212	[kN]	water 10kN/m^2	
Vessel Empty Weight	=	3378	[kN]	shell 50lb/ft^2	
Vessel Operating Weight	=	43590	[kN]		
Vessel Weight from Vendor				Estimated Wei	
Vessel Empty Weight	=	13810	[kN]	3378	
Vessel Operating Weight	=	183710	[kN]	43590	
Vessel Hydro Test Weight	=	183710	[kN]	43590	
Vessel Weight for Design					
Vessel Empty Weight	W_e =	**16572**	[kN]	Increase empty wei 20% to account for insulation/piping wei	
Vessel Operating Weight	W_o =	**194967**	[kN]	Increase content wei 5% to account for pipe content wei	
Vessel Hydro Test Weight	W_h =	**194967**	[kN]	These increase doesn't apply to uplift load comb cases	
Vessel top platform width	W_p =	3.000	[m]		
Vessel top platform length	L_p =	3.000	[m]		
Wind pressure q 1/50	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]		

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

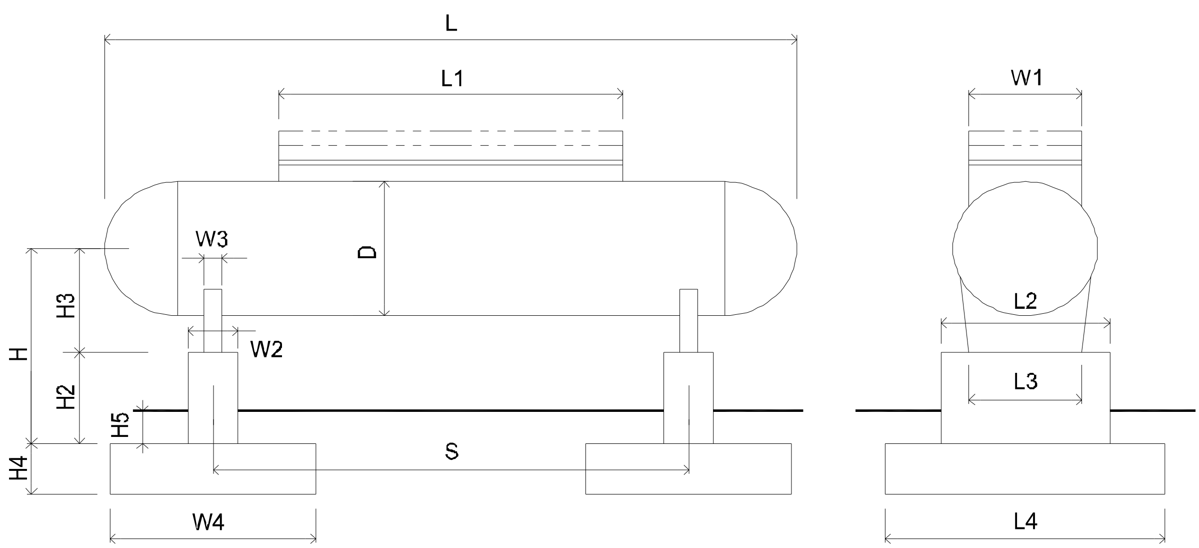
seismic base shear is 80.3 kN vs wind base shear 13.1 kN

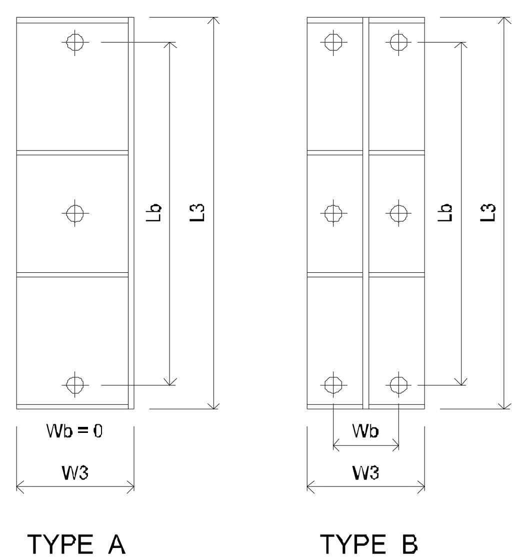
seismic overturn moment is 157.4 kNm vs wind overturn moment 20.1 kNm

DESCRIPTION

Horizontal vessel foundation design based on	**Code Abbreviation**
NBCC 2005 Division B 4.1.8	*NBC05*
ASCE Wind Loads and Anchor Bolt Design for Petrochemical Facilities	*ASCE Wind Loads*
PIP STE03360 Heat Exchanger and Horizontal Vessel Foundation Design Guide-2007	*PIP STE03360*
PIP STE05121 Anchor Bolt Design Guide-2006	*PIP STE05121*

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_b =	0.305	[m]			
Anchor bolt spacing in length	L_b =	2.895	[m]			*PIP STE03360*
				min required		Section 4.7.1
Pier height	H_2 =	1.960	[m]			
Pier width	W_2 =	1.000	[m]	0.762	**OK**	
Pier length	L_2 =	3.600	[m]	3.379	**OK**	

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	

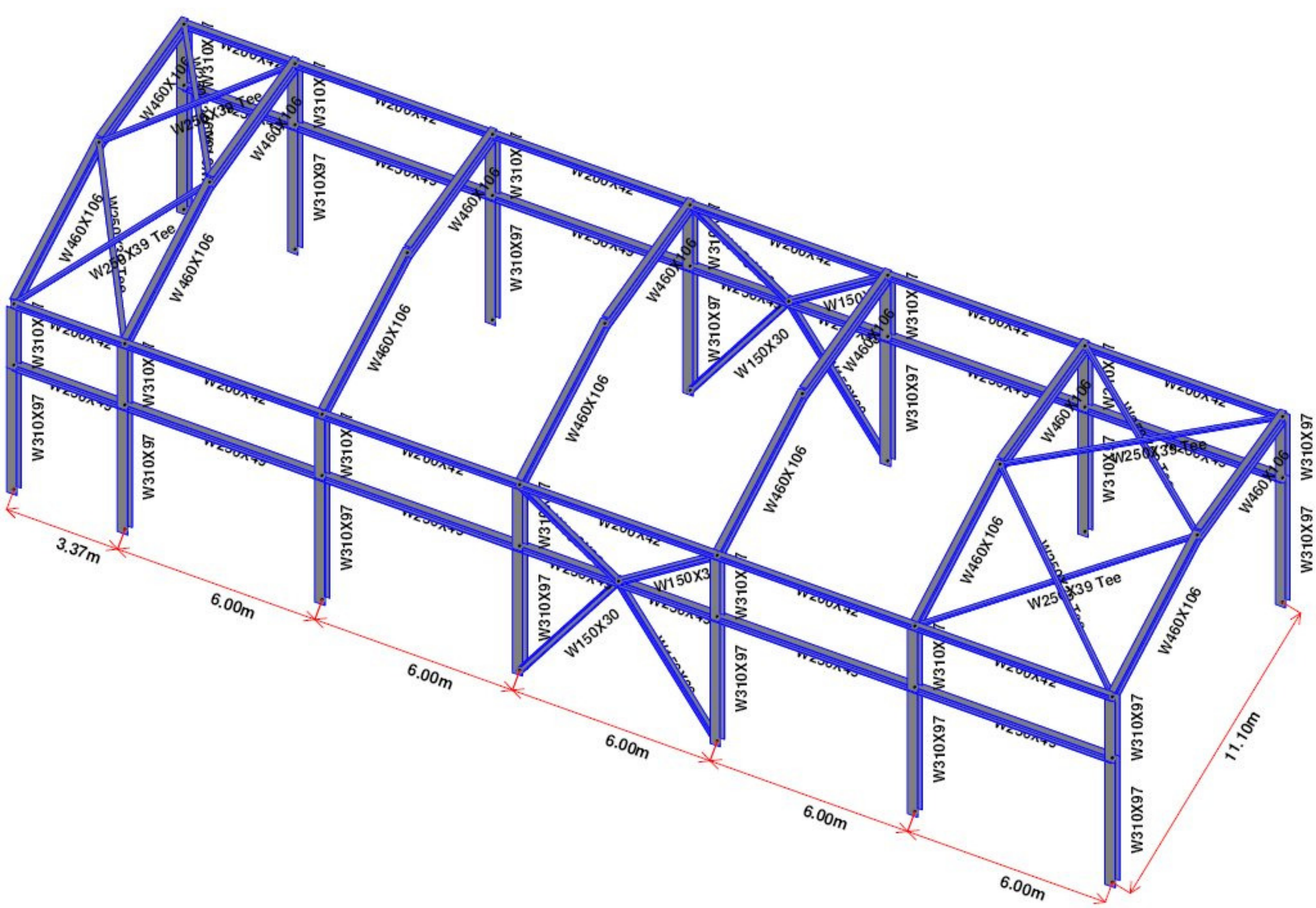
Building has a 18 tonne overhead crane

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 x C_f x C_e x C_g x q x A = 1.0 x 1.3 x 1.0 x 2.0 x 0.35 x 33.37 x 11.1 = **337** kN
Total seismic base shear in transverse direction = 15.3 x 5 (5 internal frames) + 14.4 x 2 (2 external frames) = **106** kN

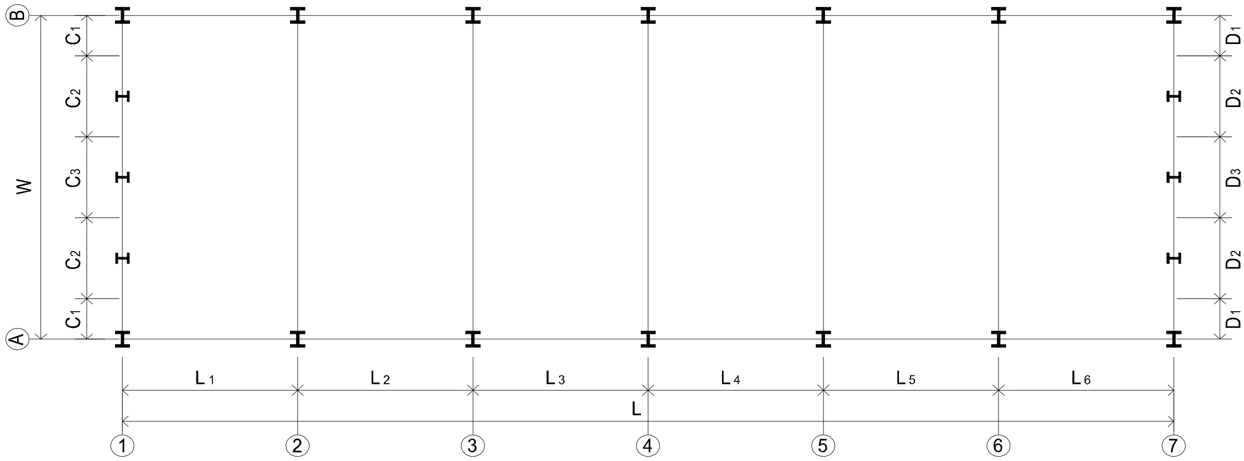
In this building structure, wind base shear 337 kN, is much bigger than seismic base shear, 106 kN.

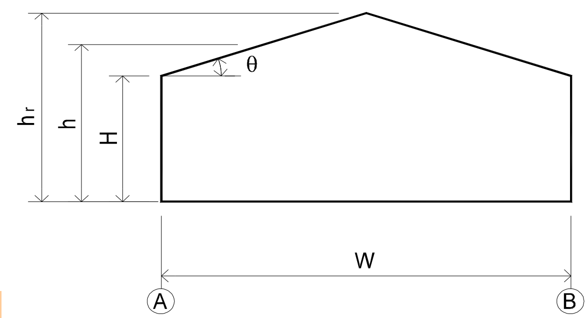
For industrial facilities in low seismic zone, the following two factors are the essential condition when the seismic load may surpass wind load and become a governing load case

- 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 seimic load.

SEISMIC LOAD CALC FOR BUILDING STRUCTURE





Building Data

Building importance category — Normal

Building width	W =	11.100	[m]	Number of bay			Crane Load	
Bay spacing	L_1 =	3.370	[m]	n_1 =	1		Yes	for GL1 Frame
	L_2 =	6.000	[m]	n_2 =	1		Yes	for GL2 Frame
	L_3 =	6.000	[m]	n_3 =	1		Yes	for GL3 Frame
	L_4 =	6.000	[m]	n_4 =	1		Yes	for GL4 Frame
	L_5 =	6.000	[m]	n_5 =	1		Yes	for GL5 Frame
	L_6 =	6.000	[m]	n_6 =	1		Yes	for GL6 Frame
Wind column tributary length							Yes	for GL7 Frame
	C_1 =	2.000	[m]	D_1 =	2.000	[m]		
	C_2 =	3.550	[m]	D_2 =	3.550	[m]		
	C_3 =	3.550	[m]	D_3 =	3.550	[m]		
Bay spacing used for transverse frame								
seimic & foundation load calc.	B =	6.000	[m]					
Building eave height	H =	7.940	[m]					
Roof slope	1 :	12.00		θ =	4.8			

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 m = 24.770 ft

Vessel height H= 33.150 m = 108.760 ft

Vessel shell thickness t = 25.4mm = 1 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 = 4518225 lb / 108.760 ft = 41543.1 lb/ft

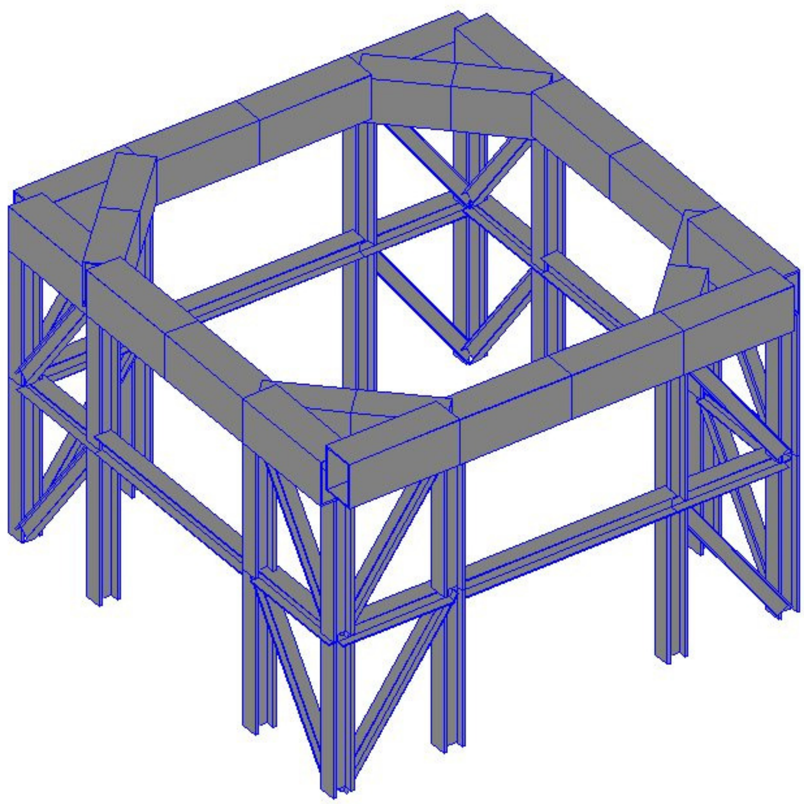
Vessel fundamental period $T_a = \frac{7.78}{10^6}\left(\frac{H}{D}\right)^2\sqrt{\frac{12WD}{t}}$ = 0.527 s >> 0.06 s → the vessel is a flexible Nonbuilding Structure

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 $R_d x R_o$ Value

$R_d x R_o$ value of combined system shall be taken as the lesser $R_d x R_o$ value of the nonbuilding structure or the supporting structure → Use $R_d x R_o$ = 1.5x1.3 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

Elevation	Weight	wixhi	Fi	OTM
hi (m)	wi (kN)	(kNm)	(kN)	(kNm)
5.300	2102.4	11142.7	18.3	0.0
10.300	3028.8	31196.6	51.2	255.9
15.300	3028.8	46340.6	76.0	760.3
20.300	3028.8	61484.6	100.9	1513.1
25.300	3028.8	76628.6	125.7	2514.4
30.300	3028.8	91772.6	150.6	3764.1
35.300	2468.5	87138.1	143.0	4288.9
38.450	954.1	36685.1	100.2	3321.2
Sum	20669.0	442389.1	**765.8**	**16417.9**

Calculate Overturning Reduction Factor J

$S_a(0.2) / S_a(2.0) = 0.120 / 0.006 = 20.0$ $T_a = 0.747$ Braced Frame → J = 0.918 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 x 0.77 x 0.35 x 2.2 x 1.3 x (7.55+1.52) x (33.15+1.52) = **278.7** 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 times

seismic overturn moment is 15072 kNm vs wind overturn moment 4620 kNm   15072 / 4620 = 3.3 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 intension 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

1. National Building Code of Canada 2005 Part 4 and Commentary J
2. ASCE 7-05 Minimum Design Loads for Buildings and Other Structures
3. ASCE Guidelines for Seismic Evaluation and Design of Petrochemical Facilities 1997
4. AISC Design Guide 7: Industrial Buildings -Roofs to Anchor Rods 2nd Edition
5. CISC Moment Connections for Seismic Applications
6. CSA S16-09 Limit States Design of Steel Structures