Seismic Hazard (Design Spectrum)

The design spectrum represents the seismic hazard based on the buildings soil condition and location (location to faults etc.). This building is assumed ot be located in downtown Vancouver BC, site class C.

$$S_{a0.1} := 0.686 \quad S_{a0.2} := 0.848 \quad S_{a0.3} := 0.852 \quad S_{a0.5} := 0.751 \quad S_{pga} := 0.369$$

$$S_{a1.0} := 0.425 \quad S_{a2.0} := 0.257 \quad S_{a5.0} := 0.0804 \quad S_{a10.0} := 0.0285 \quad S_{pgv} := 0.553$$

According to the NBCC, the response spectrum values are adjusted to account for site class conditions, for site class C use the following conditions:

$$F_{0.2} := 1.0 \quad F_{0.5} := 1.0 \quad F_{1.0} := 1.0 \quad F_{2.0} := 1.0 \quad F_{5.0} := 1.0 \quad F_{10.0} := 1.0 \quad F_a := F_{0.2} \quad F_v := F_{1.0}$$

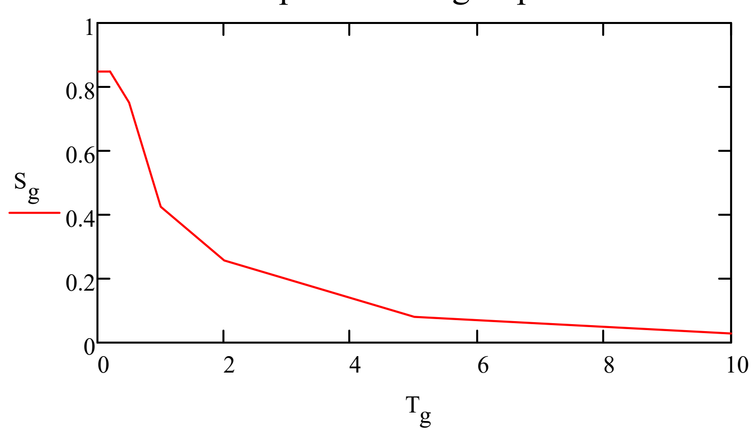
Importance Factor for a Normal importance category: $I_E := 1.0$

Using the equations from NBCC 4.1.8.4 the values are adjusted:

$$T_g := \begin{pmatrix} 0 \\ 0.2 \\ 0.5 \\ 1 \\ 2 \\ 5 \\ 10 \end{pmatrix} s \qquad S_g := \begin{pmatrix} \max(F_{0.2} \cdot S_{a0.2}, F_{0.5} \cdot S_{a0.5}) \\ \max(F_{0.2} \cdot S_{a0.2}, F_{0.5} \cdot S_{a0.5}) \\ F_{0.5} \cdot S_{a0.5} \\ F_{1.0} \cdot S_{a1.0} \\ F_{2.0} \cdot S_{a2.0} \\ F_{5.0} \cdot S_{a5.0} \\ F_{10.0} \cdot S_{a10.0} \end{pmatrix} = \begin{pmatrix} 0.848 \\ 0.848 \\ 0.751 \\ 0.425 \\ 0.257 \\ 0.08 \\ 0.029 \end{pmatrix}$$

$$S_{0.2} := S_{g_1} \quad S_{0.5} := S_{g_2} \quad S_{1.0} := S_{g_3} \quad S_{2.0} := S_{g_4} \quad S_{5.0} := S_{g_5} \quad S_{10.0} := S_{g_6}$$

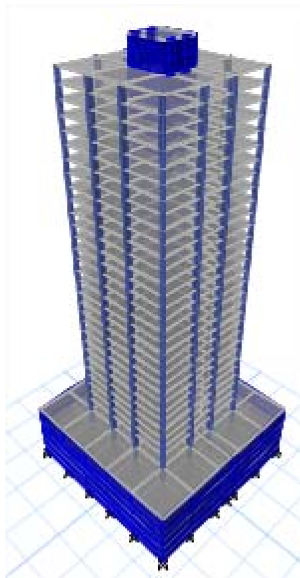
Site-Specific Design Spectrum



4.1.8.7 Methods of Analysis
According to NBCC 4.1.8.7 buildings with a height greater than 60m or a fundmental period greater than 2s require dynamic anlysis. Therefore, a elastic cracked model was buult in ETABS.

ETABS MODEL

Model was created in etabs. Podium floor uses a semi-rigid diaphragm constraint. The grade and below grade slabs are 250mm thick, elastic membranes with a semi-rigid diaphragm constraint. The above grade slabs are 190mm with a rigid diaphragm constraint. Column elements are assumed to not contributed to the lateral stiffness and therefore have moment relesases at every story.



Cracking properties:

For diagonally reinforced coupling beams: $I_{crCB} := 0.25 \cdot I_{CB}$ $A_{crCB} := 0.45 \cdot A_{CB}$

For walls, the area is cracked the same as the moment of inertia, therefore adjust the modulus of elasticity

$$I_{crWall} := \alpha_w \cdot I_{wall} \qquad A_{crWall} := \alpha_w \cdot A_{wall}$$

Where:

$$\alpha_w := \min\left[\max\left[1 - 0.35 \cdot \left(\frac{R_d \cdot R_o}{\gamma_w} - 1\right), 0.5\right], 1\right]$$

Where γw is the overstrength and can be taken as Ro

For East-West Direction Overstrength and ductility are (Assuming DOC > 0.66 - > check this):

$R_{dx} := 4$ and $R_{ox} := 1.7$

Cracked value is: $\alpha_{wx} := \min\left[\max\left[1 - 0.35 \cdot \left(R_{dx} - 1\right), 0.5\right], 1\right] = 0.5$

For North-South Direction Overstrength and ductility are: $R_{dy} := 3.5$ and $R_{oy} := 1.6$

Cracked value is: $\alpha_{wy} := \min\left[\max\left[1 - 0.35 \cdot \left(R_{dy} - 1\right), 0.5\right], 1\right] = 0.5$

Natural frequencies:

Modal analysis showed: $T_{ETABSx} := 5.864s$ $T_{ETABSy} := 4.567s$

The NBCC gives an emperical formula to estimate the period of the structure. NBCC period is estimated as:

NBCC emperical formula for period: $T_a := 0.05s \cdot \left(\frac{H_n}{m}\right)^{\frac{3}{4}} = 1.463\ s$ 4.1.8.11 3) c

where Hn was taken as $H_n = 90.15\ m$ which does not include the basement levels

. If the dynamic period is > than 2xNBCC use the NBCC estimate (4.1.8.11 3.d.iii):

$T_x := \min\left(T_{ETABSx}, 2T_a\right) = 2.926\ s$ $T_y := \min\left(T_{ETABSy}, 2T_a\right) = 2.926\ s$

Using response spectrum analysis in Etabs, gives the following base shears:

$V_{etabsx} := 16322kN$ $V_{etabsy} := 22410kN$

NBCC 2015 Base Shear

Seismic weight: $W_{seismic} := 153193\text{kN}$

Spectral acceleration

$S_{Tax} := \text{linterp}(T_g, S_g, T_x) = 0.203 \qquad S_{Tay} := \text{linterp}(T_g, S_g, T_y) = 0.203$

Factors from the NBCC

Table 4.1.8.11: Higher mode factors

X Direction: $T_x = 2.926\,\text{s}$

$$M_{v2.0x} := \text{linterp}\left[\begin{pmatrix} 5 \\ 20 \end{pmatrix}, \begin{pmatrix} 1 \\ 1 \end{pmatrix}, \frac{S_{0.2}}{S_{5.0}}\right] = 1 \qquad M_{v5.0x} := \text{linterp}\left[\begin{pmatrix} 5 \\ 20 \end{pmatrix}, \begin{pmatrix} 1 \\ 1.08 \end{pmatrix}, \frac{S_{0.2}}{S_{5.0}}\right] = 1.03$$

$$M_{vx} := \frac{\text{linterp}\left[\begin{pmatrix} 2\text{s} \\ 5\text{s} \end{pmatrix}, \begin{pmatrix} S_{2.0} \cdot M_{v2.0x} \\ S_{5.0} \cdot M_{v5.0x} \end{pmatrix}, T_x\right]}{S_{Tax}} = 1.004$$

Y Direction: $T_y = 2.926\,\text{s}$

$$M_{v2.0y} := \text{linterp}\left[\begin{pmatrix} 5 \\ 20 \end{pmatrix}, \begin{pmatrix} 1 \\ 1.18 \end{pmatrix}, \frac{S_{0.2}}{S_{5.0}}\right] = 1.067 \qquad M_{v5.0y} := \text{linterp}\left[\begin{pmatrix} 5 \\ 20 \end{pmatrix}, \begin{pmatrix} 1.25 \\ 2.3 \end{pmatrix}, \frac{S_{0.2}}{S_{5.0}}\right] = 1.638$$

$$M_{vy} := \frac{\text{linterp}\left[\begin{pmatrix} 2\text{s} \\ 5\text{s} \end{pmatrix}, \begin{pmatrix} S_{2.0} \cdot M_{v2.0y} \\ S_{5.0} \cdot M_{v5.0y} \end{pmatrix}, T_y\right]}{S_{Tay}} = 1.137$$

Base shear from the NBCC

$$V_{ax} := \frac{S_{Tax} \cdot M_{vx} \cdot I_E \cdot W_{seismic}}{R_{ox} \cdot R_{dx}} = 4.579 \times 10^3 \cdot \text{kN} \qquad V_{ay} := \frac{S_{Tay} \cdot M_{vy} \cdot I_E \cdot W_{seismic}}{R_{oy} \cdot R_{dy}} = 6.297 \times 10^3 \cdot \text{kN}$$

$$V_{maxx} := \frac{M_{vx} \cdot I_E \cdot W_{seismic}}{(R_{ox} \cdot R_{dx})} \cdot \max\left(\frac{2}{3} S_{0.2}, S_{0.5}\right) \qquad V_{maxy} := \frac{M_{vy} \cdot I_E \cdot W_{seismic}}{(R_{oy} \cdot R_{dy})} \cdot \max\left(\frac{2}{3} S_{0.2}, S_{0.5}\right)$$

$S_{4.0} := \text{linterp}(T_g, S_g, 4\text{s}) = 0.139$

$$V_{minx} := \frac{M_{vx} \cdot S_{4.0} \cdot I_E \cdot W_{seismic}}{R_{ox} \cdot R_{dx}} = 3.149 \times 10^3 \cdot \text{kN} \qquad V_{miny} := \frac{M_{vy} \cdot S_{4.0} \cdot I_E \cdot W_{seismic}}{R_{oy} \cdot R_{dy}} = 4.33 \times 10^3 \cdot \text{kN}$$

$V_x := \min\left(\max\left(V_{ax}, V_{minx}\right), V_{maxx}\right) = 4.579 \times 10^3 \cdot kN$ $\quad V_y := \min\left(\max\left(V_{ay}, V_{miny}\right), V_{maxy}\right) = 6.297 \times 10^3 \cdot kN$

Determine Scaling factor

$$Fact_{Vex} := \min\left(1, \max\left(\frac{2}{3} \cdot S_{0.2}, S_{0.5}\right) \cdot \frac{1}{\text{linterp}\left(T_g, S_g, T_x\right)}\right) = 1$$

$$Fact_{Vey} := \min\left(1, \max\left(\frac{2}{3} \cdot S_{0.2}, S_{0.5}\right) \cdot \frac{1}{\text{linterp}\left(T_g, S_g, T_x\right)}\right) = 1$$

$$V_{dx} := \max\left(\frac{Fact_{Vex} \cdot V_{etabsx} \cdot I_E}{R_{ox} \cdot R_{dx}}, 0.8 \cdot V_x\right) = 3.663 \times 10^3 \cdot kN$$

$$V_{dy} := \max\left(\frac{Fact_{Vey} \cdot V_{etabsy} \cdot I_E}{R_{oy} \cdot R_{dy}}, 0.8 \cdot V_y\right) = 5.037 \times 10^3 \cdot kN$$

Scaling factor:

$$SF_x := \frac{V_{dx}}{V_{etabsx}} = 0.224 \qquad SF_y := \frac{V_{dy}}{V_{etabsy}} = 0.225$$