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ProtaStructure Design Guide

Equivalent Lateral Force Analysis According to UBC 97

Version 2.0 30 December 2019

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Model Description

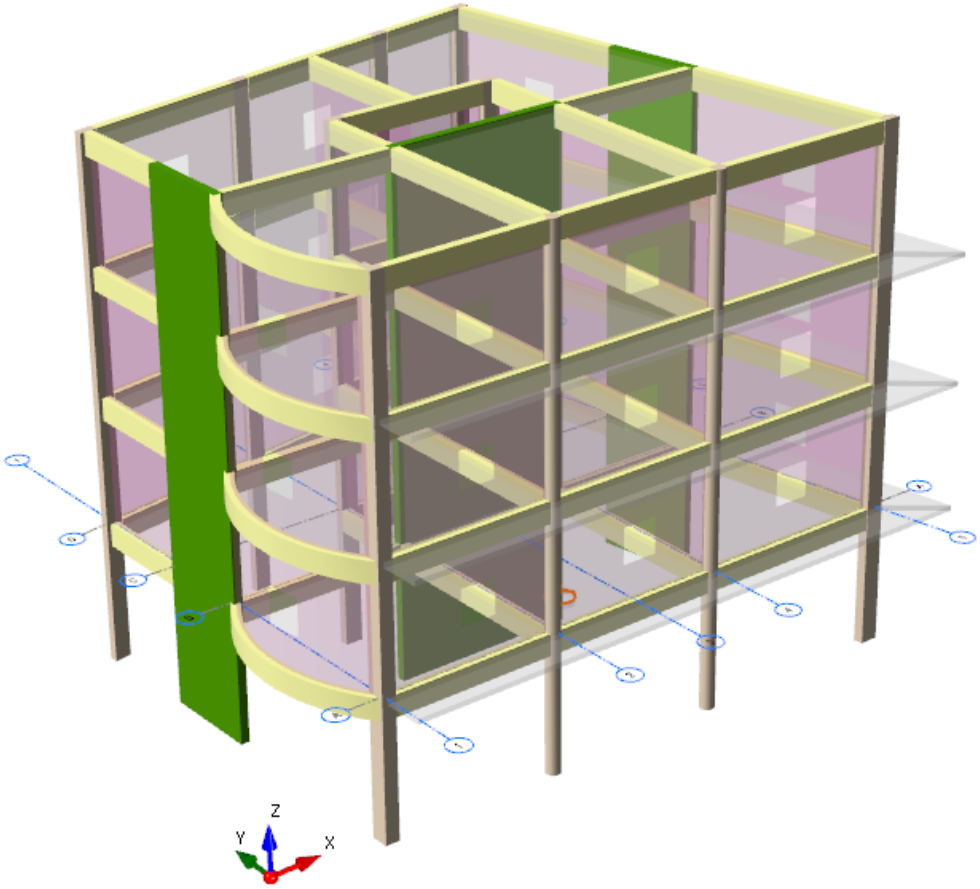
In this case study, the equivalent lateral forces acting on a 4 story residential reinforced concrete building is determined using the procedures described in the **1997 Uniform Building Code (UBC 97).**

The case study building is composed of 4 stories. All of the floor heights are 3.5 m. As a result, the total structural height is h_n=14.0 m.

All stories are to be designed as reinforced concrete slabs with beams. There are shearwalls along both directions.

The creation of the building model and the completion of the building analysis using the modeling tools in ProtaStructure are out of the scope of this study.

A 3-D view of the structure is shown below.



3-D Model of the Building

Determination of the Seismic Parameters

» The seismic zone for the structure is 3. Therefore, **Seismic Zone Factor Z** is **0.3** [UBC 97, Table 16-I].

TABLE 16-I—SEISMIC ZONE FACTOR *Z*

ZONE	1	2A	2B	3	4
Z	0.075	0.15	0.20	0.30	0.40

NOTE: The zone shall be determined from the seismic zone map in Figure 16-2.

» Soil Profile Type is **S_C** for the structure [UBC 97, Table 16-J].

» Occupancy Category for the structure is **IV**. Therefore, **the Seismic Importance Factor** is **I=1.00** for standard occupancy structures [UBC 97, Table 16-K].

» According to UBC 97, Table 16-N;

4. Dual systems	1. Shear walls			
	a. Concrete with SMRF	8.5	2.8	N.L.
	b. Concrete with steel OMRF	4.2	2.8	160
	c. Concrete with concrete IMRF[5]	6.5	2.8	160
	d. Masonry with SMRF	5.5	2.8	160
	e. Masonry with steel OMRF	4.2	2.8	160
	f. Masonry with concrete IMRF[3]	4.2	2.8	—
	g. Masonry with masonry MMRWF	6.0	2.8	160
	2. Steel EBF			
	a. With steel SMRF	8.5	2.8	N.L.
	b. With steel OMRF	4.2	2.8	160
	3. Ordinary braced frames			
	a. Steel with steel SMRF	6.5	2.8	N.L.
	b. Steel with steel OMRF	4.2	2.8	160
	c. Concrete with concrete SMRF[3]	6.5	2.8	—
	d. Concrete with concrete IMRF[3]	4.2	2.8	—
	4. Special concentrically braced frames			
	a. Steel with steel SMRF	7.5	2.8	N.L.
	b. Steel with steel OMRF	4.2	2.8	160

The "**Basic Structural System**" is selected from "**Dual Systems**" as "**D1**", and the corresponding "**Response Modification Factor**" is **R=8.5**.

Overstrength Factor, Ω_0 is **2.50** .

It can be seen from the table that the structural height is not limited for this type of structural system and Seismic Zone 3.

» Soil Profile Type is S_C and Seismic Zone Factor Z is 0.3. Using these values, the acceleration-dependent seismic coefficient, **C_a** is **0.33** [UBC 97, Table 16-Q].

» Soil Profile Type is S_C and Seismic Zone Factor Z is 0.3. Using these values, velocity-dependent seismic coefficient, **C_v** is **0.45** [UBC 97, Table 16-R].

» **Spectrum Characteristic Periods, T_0** and **T_s** are determined using the equations given at Figure 16-3 in UBC 97 :

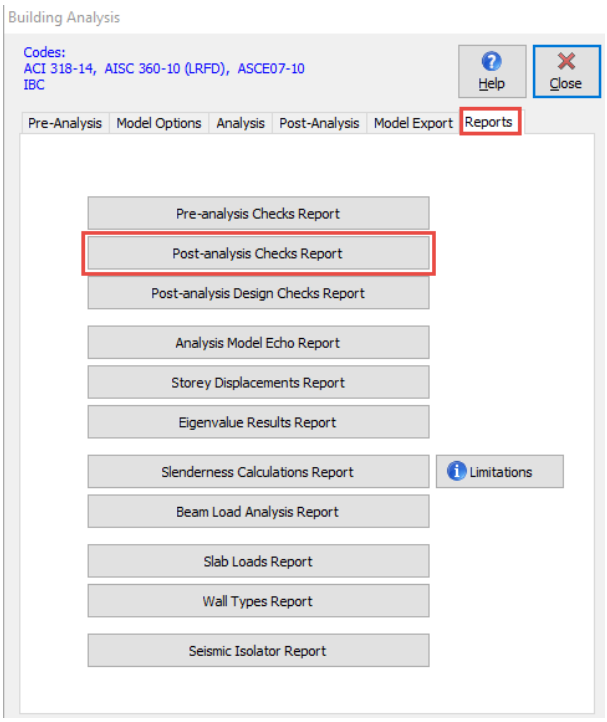
T_s = C_v / (2.5 C_a) = 0.45 / (2.5 x 0.33) = **0.545 sec.**

T_0 = 0.2 T_s = 0.2 x 0.545= **0.109 sec.**

Building Analysis and Selection Analysis Procedure

After carrying out the building analysis process without any error, it is necessary to check Equivalent Lateral Force Analysis is suitable for the structure under consideration.

Parameters such as horizontal and vertical irregularities, earthquake forces, mass and weight of the structure. can be viewed using "**Post-Analysis Checks Report**" in the Reports tab.



For instance, Torsion Irregularity Check in this report for the structure under consideration is as follows;

TORSION IRREGULARITY CHECK:

δ_{Min} : Min. Absolute Storey Drift
δ_{Max} : Max. Absolute Storey Drift
Δ : Relative Storey Drift ($\delta_{column,top} - \delta_{column,bot}$)
η_C : $\Delta_{Max} / \Delta_{ave}$

EARTHQUAKE DIRECTION: 1 (Angle From X 0.00 Deg)

Load Case: **Ex+** (ES Earthquake X (E+))

Storey	δ_{Min} (m)	δ_{Max} (m)	Δ_{Min} (m)	Δ_{Max} (m)	Δ_{ave} (m)	η_C	Additional Eccentricity
Storey: 4	0.003418	0.003742	0.000991	0.001091	0.001041	1.048 ≤ 1.20	---
Storey: 3	0.002428	0.002650	0.001033	0.001134	0.001083	1.047 ≤ 1.20	---
Storey: 2	0.001395	0.001516	0.000901	0.000987	0.000944	1.046 ≤ 1.20	---
Storey: 1	0.000495	0.000529	0.000495	0.000529	0.000512	1.033 ≤ 1.20	---

Load Case: **Ex-** (ES Earthquake X (E-))

Storey	δ_{Min} (m)	δ_{Max} (m)	Δ_{Min} (m)	Δ_{Max} (m)	Δ_{ave} (m)	η_C	Additional Eccentricity
Storey: 4	0.002346	0.004599	0.000716	0.001310	0.001013	1.293 > 1.20	5.8
Storey: 3	0.001630	0.003289	0.000713	0.001389	0.001051	1.322 > 1.20	6.1
Storey: 2	0.000917	0.001900	0.000593	0.001232	0.000913	1.350 > 1.20	6.3
Storey: 1	0.000324	0.000667	0.000324	0.000667	0.000496	1.346 > 1.20	6.3

Warning: Dir 1... Torsion Irregularity Exist in the structure.
Max. Torsion Irregularity Coefficient = 1.350 > 1.2

Building Analysis is repeated using additional eccentricities. ✓

EARTHQUAKE DIRECTION: 2 (Angle From X 90.00 Deg)

Load Case: **Ey+** (ES Deprem Y (E+))

Storey	δ_{Min} (m)	δ_{Max} (m)	Δ_{Min} (m)	Δ_{Max} (m)	Δ_{ave} (m)	η_C	Additional Eccentricity
Storey: 4	0.007707	0.010098	0.002233	0.002868	0.002550	1.124 ≤ 1.20	---
Storey: 3	0.005474	0.007231	0.002361	0.003084	0.002723	1.133 ≤ 1.20	---
Storey: 2	0.003113	0.004147	0.002088	0.002768	0.002428	1.140 ≤ 1.20	---
Storey: 1	0.001025	0.001378	0.001025	0.001378	0.001202	1.147 ≤ 1.20	---

Load Case: **Ey-** (ES Earthquake Y (E-))

Storey	δ_{Min} (m)	δ_{Max} (m)	Δ_{Min} (m)	Δ_{Max} (m)	Δ_{ave} (m)	η_C	Additional Eccentricity
Storey: 4	0.008356	0.009179	0.002398	0.002629	0.002513	1.046 ≤ 1.20	---
Storey: 3	0.005958	0.006549	0.002558	0.002805	0.002682	1.046 ≤ 1.20	---
Storey: 2	0.003401	0.003744	0.002277	0.002503	0.002390	1.047 ≤ 1.20	---
Storey: 1	0.001124	0.001241	0.001124	0.001241	0.001182	1.049 ≤ 1.20	---

Dir 2: Torsion Irregularity does not Exist. √

The torsional irregularity doesn't exist for the Earthquake Direction 2 (Y direction); on the other hand, it exists for the Earthquake Direction 1 (X direction).

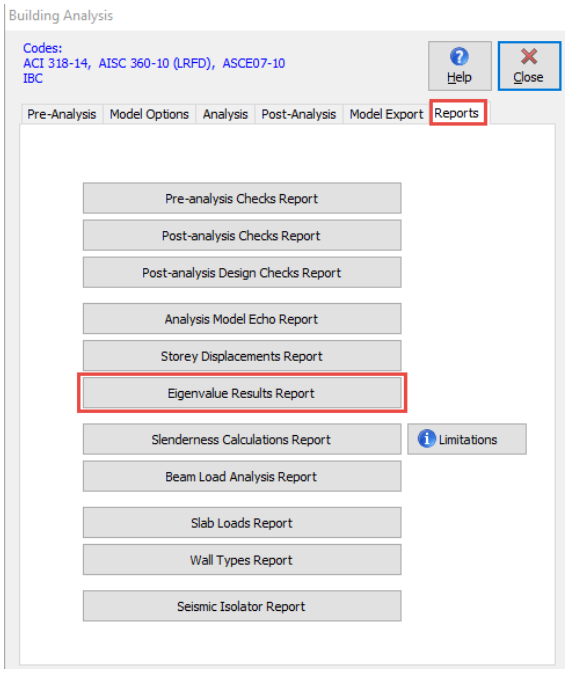
» The total structural height, h_n=14.0 m., is less than 19.812 m. Also, the total number of stories is 4 and less than 5. So, the structure can be analyzed by using "**Static Force Procedure**" [UBC 97, Section 1629.8.3].

Calculation of Equivalent Lateral Loads

» Eigenvalue analysis provides dynamic properties of a structure by solving the characteristic equation composed of mass matrix and stiffness matrix.

ProtaStructure calculates the dynamic properties of the structure such as natural modes (or mode shapes), natural periods (or frequencies) and modal participation factors by a 3-Dimensional Eigenvalue Analysis.

These results can be viewed using "**Eigenvalue Results Report**" in the Reports tab :



Eigenvalue/EQ Analysis Results

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========================================================================
                        P S - S O L V E R
               Three-Dimensional Finite Element Program
                        for ProtaStructure

                     Version 7.23 (November 2019)
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E I G E N S Y S T E M M O D A L C A S E : MODALALL

Number of Equations : 1020
Number of Masses : 12
Number of Eigenvalues : 6

E I G E N V A L U E S A N D F R E Q U E N C I E S

Mode Number	Period (Sec)	Frequency (Cycles/Sec)	Circular Fre (Rad/Sec)	Eigenvalue (Rad/Sec)**2
1	0.456076	2.192616	13.776611	189.795016
2	0.369653	2.705241	16.997529	288.915998
3	0.286790	3.486876	21.908690	479.990685
4	0.110771	9.027661	56.722465	3217.438068
5	0.095681	10.451397	65.668067	4312.294990
6	0.071247	14.035609	88.188331	7777.181678

M O D A L P A R T I C I P A T I N G F A C T O R S

Mode	Period	X-dir	Y-dir	Z-dir	X-rot	Y-rot	Z-rot
1	0.456076	0.855357	24.960419	0.000000	-7.692185	89.323606	18.839525
2	0.369653	-5.141177	2.742120	0.000000	975.271276	-68.072669	-164.373462
3	0.286790	24.639296	-0.197871	0.000000	31.131770	751.155083	-32.743932
4	0.110771	-0.796756	-12.268996	0.000000	-13.966789	175.886412	-11.815475
5	0.095681	-2.421929	2.385035	0.000000	-.117252E+04	-182.689300	-77.043120
6	0.071247	12.832540	-0.351551	0.000000	-35.886043	-499.392374	-19.421717

P A R T I C I P A T I N G M A S S - (%)

Mode	Period	X-dir	Y-dir	Z-dir	X-rot	Y-rot	Z-rot
1	0.456076	0.005600	72.899680	0.000000	0.524219E-03	0.070688	0.938844
2	0.369653	3.092766	0.879822	0.000000	3.493286	0.017019	71.468874
3	0.286790	71.035991	0.004581	0.000000	0.056032	32.620213	2.836059
4	0.110771	0.074280	17.613266	0.000000	0.216462E-03	0.034328	0.369280
5	0.095681	0.686348	0.665597	0.000000	0.431257	0.010469	15.700781
6	0.071247	19.268465	0.014461	0.000000	0.011801	2.285321	0.997766

By using the "**Participating Mass**" values in this report, the fundamental periods of the structure are calculated as follows;

Fundamental Period of the Structure in X Direction	**T (X) = 0.287 sec.**
Fundamental Period of the Structure in Y Direction	**T (Y) = 0.456 sec.**

» These calculated periods can not exceed the approximate fundamental period times 1.40 for Seismic Zone 3 [UBC 97, Section 1630.2.2 - Method B].

T_a = 0.0488 x $14^{0.75}$ = **0.353 sec.** [UBC 97 Equation 30-8]

T_{max} = 1.4 x 0.353 = **0.495 sec.**

T(X) = 0.287 sec. < T_{max} = 0.495 sec. then **T (X) = 0.287 sec.**

T(Y) = 0.456 sec. < T_{max} = 0.495 sec. then **T (Y) = 0.456 sec.**

» Seismic Base Shear, V is determined with the following equation [UBC 97 Equation 30-4] :

$$V = \frac{C_v I}{RT} W$$

Here;

W: Effective Seismic Weight

C_v: Velocity-dependent seismic coefficient

R: Response Modification Factor

T: Elastic fundamental period of vibration

I: Seismic Importance Factor

C_a: Acceleration dependent seismic coefficient

The weight of the structure can be viewed using the "Post-Analysis Checks Report" in the Reports tab.

STOREY MASSES, WEIGHTS AND DIAPHRAGM DEFINITIONS:

h : Storey Height
m, mr² : Storey Mass and Mass Moment of Inertia
G, Q : Sum of Dead and Live Loads in Storey
W : Storey Seismic Weight (W = G + nQ)

Storey	h (m)	m (t)	mr² (t.m2)	G (kN)	Q (kN)	W (kN)	Storey Diaphragm	Floor FE Mesh	Slab Stiffnesses In/Out-of-Plane
4	3.500	166.695	6742.539	1531.317	346.547	1635.281	Rigid	None	
3	3.500	229.302	10345.444	2106.516	476.450	2249.451	Rigid	None	
2	3.500	228.799	10316.251	2101.586	476.450	2244.521	Rigid	None	
1	3.500	229.834	10362.906	2111.737	476.450	2254.672	Rigid	None	
Total				7851.156	1775.897	8383.926			

» Remembering that the seismic parameters of the structure under consideration are :
I=1.00 / R=8.5 / C_v = 0.45 / C_a =**0.33** / **T(X) = 0.287 sec.** / **T(Y) = 0.456 sec.** ;

$\mathbf{V_X}$ = (0.45 x 1.00) / (8.5 x 0.287) = 0.1845 x 8383.926 = **1546.53 kN**

$\mathbf{V_Y}$ = (0.45 x 1.00) / (8.5 x 0.456) x 8383.926 = 0.1160 x 8383.926 = **973.37 kN**

» But, V can not exceed the value obtained by the following formula [UBC 97 Equation 30-4]:

$$V = \frac{2.5 C_a I}{R} W$$

$\mathbf{V_X\ max = V_Y\ max}$ = (2.5 x 0.33 x 1.00 / 8.5) x 8383.926 = 0.097 x 8383.926 = **813.73 kN**

» Also, V shall not be less than the following base shear value obtained by the following formula [UBC 97 Equation 30-6]:

$$V = 0.11 C_a I W$$

V_X min= V_Y min = 0.11 x 0.33 x 1.00 x 8383.926 = **304.34 kN**

∴ **V_X = 813.73 kN** **V_Y = 813.73 kN**

» Vertical Distribution of Base Shear in X Direction

Seismic base shear is distributed over the height of the building according to the following formulas: to the floor levels by the following formulas [UBC 97 Equation 30-13]:

$$F_x = \frac{(V - F_t)(w_x h_x)}{\sum_{i=1}^{n} w_i h_i}$$

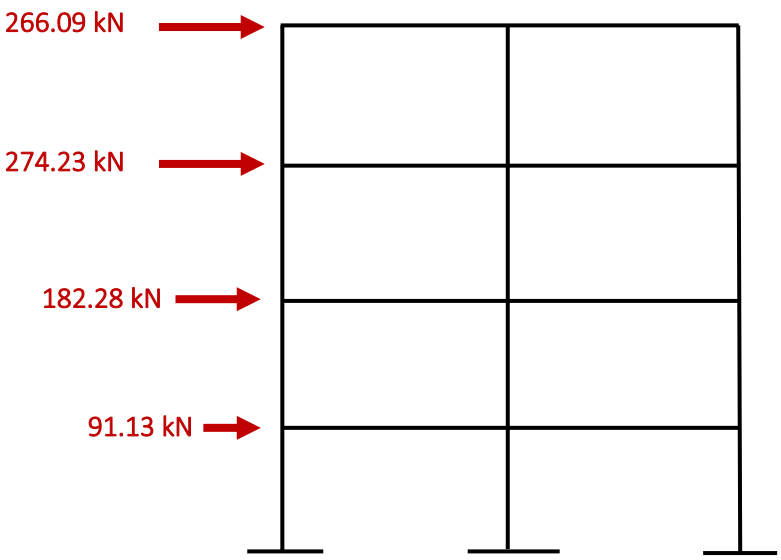
T (X) =0.287 sec. < 0.7 ⇒ **F_t=0** (The Concentrated Force at the Top)

V_X = 813.73 kN

$\Sigma W_i h_i$ = 1635.281 x (14.00) + 2249.451 x (10.5) + 2244.521 x (7.0) + 2254.672 x (3.5)

= **70116.169 kNm**.

Floor	Weight, W_i (kN)	Floor Height, h_i (m)	$W_i h_i$	Vertical Distribution Factor $W_i h_i^k / \Sigma W_i h_i^k$	F (kN)
4th	1635.281	14.00	22893.934	0.327	266.09
3rd	2249.451	10.50	23619.236	0.337	274.23
2nd	2244.521	7.00	15711.647	0.224	182.28
1st	2254.672	3.50	7891.352	0.112	91.13
Σ	**8383.926**		**70116.169**	**1.000**	**813.73**



» Vertical Distribution of Base Shear in Y Direction

Seismic base shear is distributed over the height of the building according to the following formulas: to the floor levels by the following formulas [UBC 97 Equation 30-13]:

$$F_x = \frac{(V - F_t)(w_x h_x)}{\sum_{i=1}^{n} w_i h_i}$$

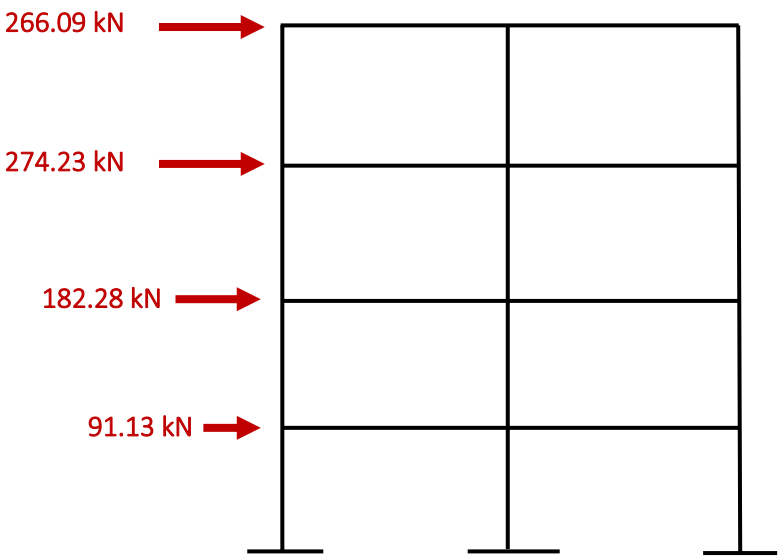
T (Y) =0.456 sec. < 0.7 ⇒ F_t=0 (The Concentrated Force at the Top)

V_Y = 813.73 kN

$\Sigma W_i h_i$ = 1635.281 x (14.00) + 2249.451 x (10.5) + 2244.521 x (7.0) + 2254.672 x (3.5)

= **70116.169 kNm**.

Floor	Weight, W_i (kN)	Floor Height, h_i (m)	$W_i h_i$	Vertical Distribution Factor $W_i h_i^k / \Sigma W_i h_i^k$	F (kN)
4th	1635.281	14.00	22893.934	0.327	266.09
3rd	2249.451	10.50	23619.236	0.337	274.23
2nd	2244.521	7.00	15711.647	0.224	182.28
1st	2254.672	3.50	7891.352	0.112	91.13
Σ	**8383.926**		**70116.169**	**1.000**	**813.73**


266.09 kN
274.23 kN
182.28 kN
91.13 kN

Comparison of the Results

Results can be viewed using the “Post-Analysis Checks Report” in the Reports tab.

As can be seen from the report, ProtaStructure results are close to the ones obtained by hand calculations.

EARTHQUAKE FORCES:

Earthquake forces are calculated using R(1)= 8.5.

EARTHQUAKE DIRECTION: 1 (Angle From X 0.00 Degrees)

Dir	Periyod (sn)	Max. Period (sn)	Effective PGA (g)	Total Base Shear (kN)	Min. BaseShear (kN)	Added Roof Load (kN)
X	0.287	0.497	0.097	813.743	304.336	0.000
Y	0.456	0.000	0.000	0.000	0.000	0.000

Storey	Fx (kN)	Fy (kN)	Fz (kN)	Mz (kN.m)
4	265.699	0.000	0.000	-185.04
3	274.117	0.000	0.000	-190.90
2	182.344	0.000	0.000	-126.99
1	91.584	0.000	0.000	-63.78
Total	813.743	0.000	0.000	-566.70

Earthquake forces are calculated using R(2)= 8.5.

EARTHQUAKE DIRECTION: 2 (Angle From X 90.00 Degrees)

Dir	Periyod (sn)	Max. Period (sn)	Effective PGA (g)	Total Base Shear (kN)	Min. BaseShear (kN)	Added Roof Load (kN)
X	0.287	0.000	0.000	0.000	0.000	0.000
Y	0.456	0.497	0.097	813.743	304.336	0.000

Storey	Fx (kN)	Fy (kN)	Fz (kN)	Mz (kN.m)
4	0.000	265.699	0.000	206.69
3	0.000	274.117	0.000	213.24
2	0.000	182.344	0.000	141.85
1	0.000	91.584	0.000	71.24
Total	0.000	813.743	0.000	633.01

Thank You

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