# EXAMPLE CALCULATIONS – to the Requirements of BC3: 2013

**NOTE**

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**Note: Para* refer to relevant paragraphs in BC3: 2013.**

## 1. Introduction

In this section, a  step- by- step procedure for the elastic analysis of a building is described for Sesimic Actions highlighting the key recommendations of BC3, using Ductility Class DCL.

The example building is a multi-storey reinforced concrete structure. Two floor plans (typical and basement) and the elevation of the building are shown in Figures 1, 2 and 3, respectively. The building properties are listed in Section 2.

## 2. Building Properties

- Building Type: Ordinary (per *Para* 1.2)*
- Importance Factor: 1.0 (per SS EN 1998-1, Clause 4.2.5 (5))
- Ground Type: D (assumed per *Para* 2.3)*
- Number of above ground storys: 25
- Number of below ground storys: 3
- Typical Story Height: 4m
- Typical Floor Area: (50+2) x (30+2) = 1664m$^2$
- Typical Loading:
  - SDL = 2.5 kPa
  - LL  = 3.5 kPa
- Key structural element sizes: Shown on plan.
- Lateral Load Resisting System: Central Core Walls (Coupled along X-Directon, Uncoupled along Y-Direction, per SS EN 1998-1, Clause 5.1.2)
- Behaviour Factor: q = 1.5 (per *Para* 3.3*)
- Typical Office
  - $\Psi_{2i}$ = 0.3 (per *Para* 4.3*)
  - $\Phi$ = 0.8 (storeys with correlated occupancies assumed, per *Para* 4.3*)
  - $\Psi_{Ei}$ = 0.8 x 0.3 = 0.24
- Typical Basement (Traffic Areas assumed)
  - $\Psi_{2i}$ = 0.6 (per *Para* 4.3*)
  - $\Phi$ = 1.0
  - $\Psi_{Ei}$ = 0.6 x 1.0 = 0.6
- Roof
  - $\Psi_{2i}$ = 0.3 (per *Para* 4.3*)
  - $\Phi$ = 1.0
  - $\Psi_{Ei}$ = 0.3 x 1.0 = 0.3

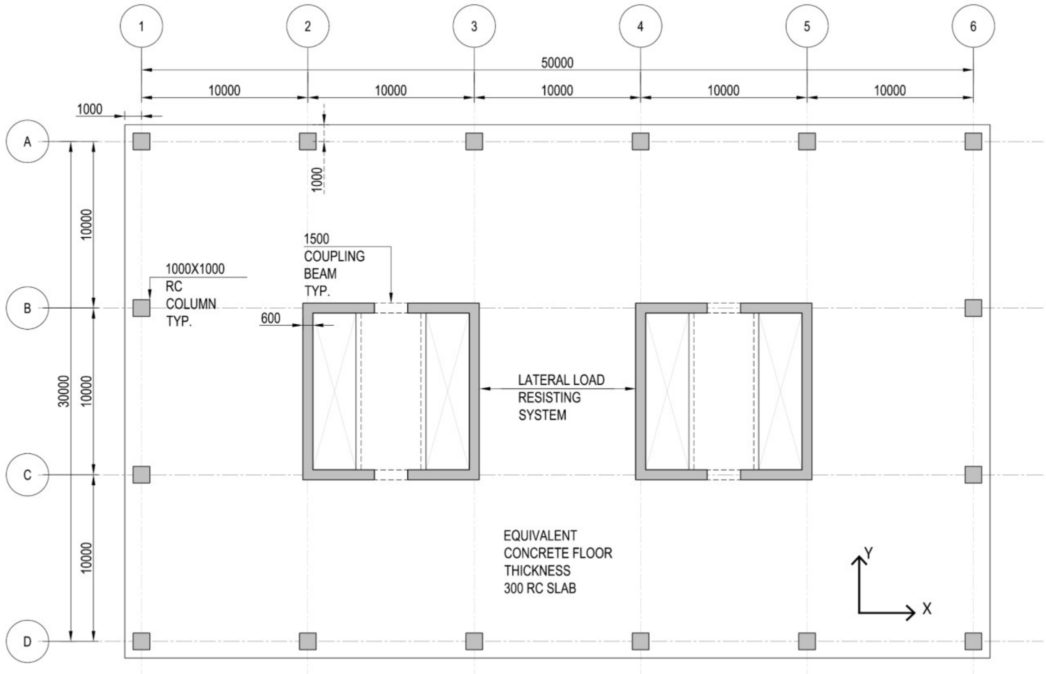


**Figure 1: Example Building Floor Plan**

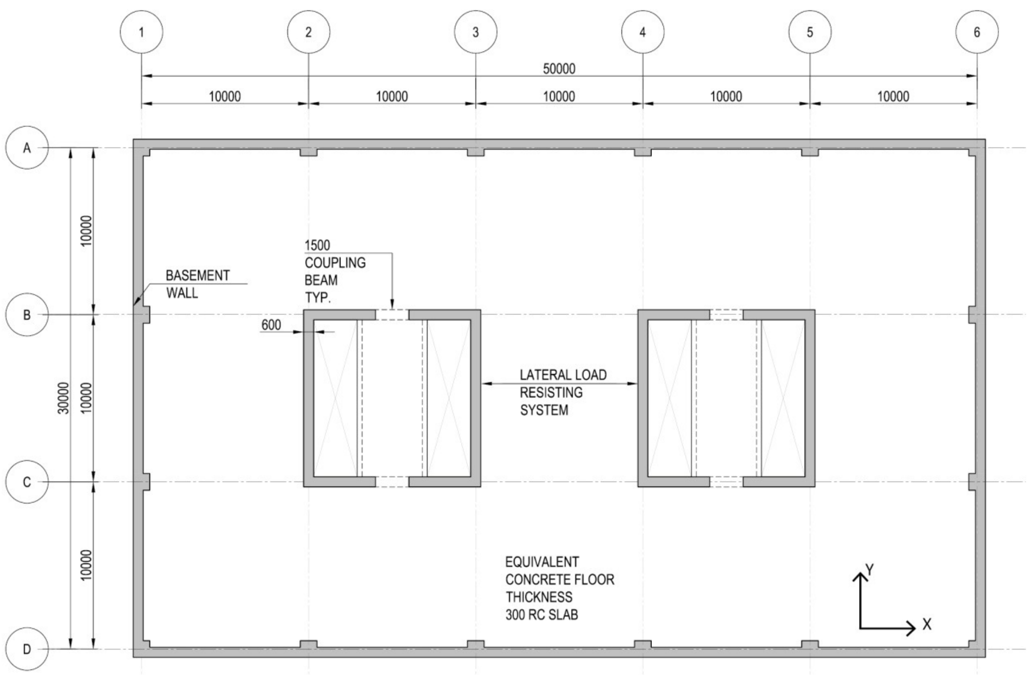


**Figure 2: Example Building Basement Floor Plan**

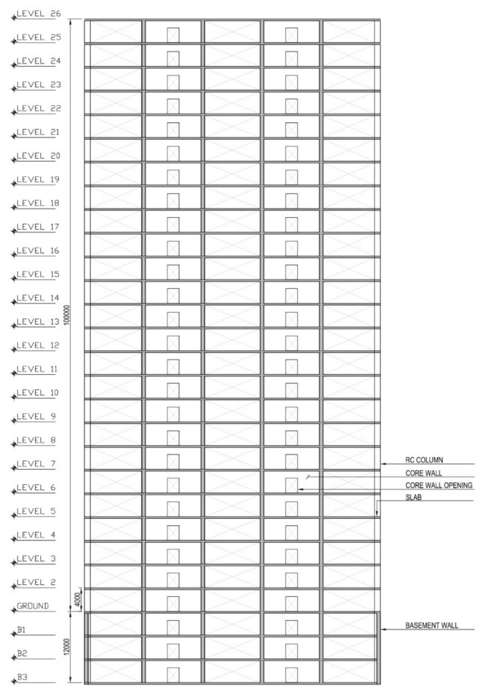


**Figure 3: Example Building Elevation**

A three-dimensional structural model is used for the analysis. The structural model fulfills all the requirements of SS EN 1998-1, Clause 4.3.1, and is shown in Figure 4.

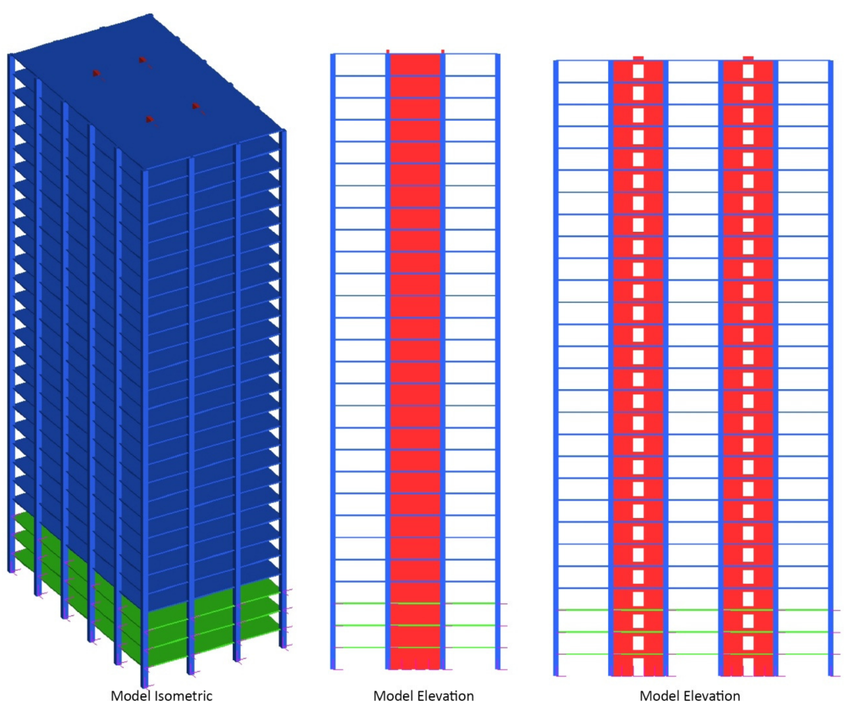


**Figure 4: Analysis Model**

## 3. Evaluation of Structural Regularity *(Para* 3.3.1)*

From inspection, the structure for the design example building can be categorized as being regular in both elevation and in plan. However, for the purpose of explanation, the irregularities are briefly discussed below.

The criteria for irregularity in plan are described in SS EN 1998-1, Clause 4.2.3.2. The key requirements are summarized below.

1. The lateral stiffness and mass distribution of the building structure should be symmetrical in plan with respect to two orthogonal axes. The design example building satisfies the criterion.

2. The plan configuration shall be compact, i.e., each floor shall be delimited by a polygonal convex line. The design example building has no setback and therefore satisfies the criterion.

3. The in-plan stiffness of the floors shall be sufficiently large in comparison with the lateral stiffness of the vertical elements. This may of concern in buildings with outstanding branches from a central part (e.g., L, C, H, I and X shapes in plan). The design example building is of rectangular form and does not fall in this category.

4. The slenderness of the building, λ, ≤ 4. The slenderness of the design example building is 50m/30m = 1.6, and therefore satisfies the criterion.

5. The structural eccentricity shall be smaller than 30% of the torsional radius ($e_{ox} \le 0.3\ r_x$, $e_{oy} \le 0.3\ r_y$) & the torsional radius shall be larger than the radius of gyration of the floor mass in plan ($r_x \ge l_s$, $r_y \ge l_s$). For the design example building, the terms above can be determined as follows.

$$e_{OX,i} = \frac{R_{Z,i}\ (F_{X,i} = 1)}{R_{Z,i}\ (M_i = 1)} \qquad e_{OY,i} = \frac{R_{Z,i}\ (F_{Y,i} = 1)}{R_{Z,i}\ (M_i = 1)}$$

$$r_{X,i} = \sqrt{\frac{K_{M,i}}{K_{FY,i}}} \qquad r_{Y,i} = \sqrt{\frac{K_{M,i}}{K_{FX,i}}}$$

$$K_{M,i} = \frac{1}{R_{Z,i}\ (M_{T,i} = 1)} \qquad K_{FX,i} = \frac{1}{U_{X,i}\ (F_{TX,i} = 1)} \qquad K_{FY,i} = \frac{1}{U_{Y,i}\ (F_{TY,i} = 1)}$$

where

- $e_{OX,i}$, $e_{OY,i}$ are the distances between centre of stiffness and centre of mass along *X* & *Y* directions, respectively, of the storey *i*.
- $R_{z,i}\ (F_{x,i} = 1)$ is the rotation of the storey *i* about the vertical axes due to an unit static load in the *X* direction applied at the centre of mass.
- $R_{z,i}\ (F_{y,i} = 1)$ is the rotation of the storey *i* about the vertical axes due to an unit static load in the *Y* direction applied at the centre of mass.
- $R_{z,i}\ (M_{,i} = 1)$ is the rotation of the storey *i* due to an unit torsional moment about the vertical axis applied at the centre of mass.
- $r_{X,i}$, $r_{Y,i}$ are the torsional radius (square root of the ratio of the torsional stiffness, $K_{M,i}$, to the lateral stiffness, $K_{FY,i}$ and $K_{FX,i}$) in *Y* & *X* directions, respectively, of the storey *i*.

- $R_{z,i}$ ($M_{T,i} = 1$) is the rotation of the storey $i$ about the vertical axis due to a unit moment, $M_T$, applied at the centre of stiffness.
- $U_{X,i}$ ($F_{TX,i} = 1$) is the displacement at storey $i$ in direction $X$ due to a unit force, $F_{TX}$, applied at the centre of stiffness.
- $U_{Y,i}$ ($F_{TY,i} = 1$) is the displacement at storey $i$ in direction $Y$ due to a unit force, $F_{TY}$, applied at the centre of stiffness.
- $l_s$ is the radius of gyration of the floor mass and is defined as the square root of the ratio of the polar moment of inertia of the floor mass in plan to the floor mass. In the case of a rectangular floor area with dimensions $l$ and $b$ and with uniformly distributed mass, $l_s$ is

$$l_s = \sqrt{\frac{(l^2 + b^2)}{12}}$$

For the design example building both the eccentricity and the torsional radius limits are satisfied.

If a structure is classified as irregular in plan, a three-dimensional structural model analysis is necessary, per Clause 4.2.2.1 (3) of SS EN 1998-1. Additionally, for DCM and DCH ductility classes, the calculated seismic force, based on the adopted behavior factor, may increase (depending on the structural system) due to irregularity in plan through a lower over-strength factor, $\alpha_u$ / $\alpha_1$, per Clause 5.2.2.2 (6).

The criteria for irregularity in elevation are described in SS EN 1998-1, Clause 4.2.3.3. The key requirements are summarized below.

1. All lateral load resisting systems shall be continuous from the foundations to the top of the building (or to the top of relevant setbacks, if present).
2. There shall be no abrupt increase to the lateral stiffness and the mass of individual storeys from the base to the top of a building.
3. In framed buildings, the ratio of the actual resistance to the resistance required by analysis should not vary disproportionately between adjacent storeys.
4. When setbacks are present, limiting criteria for the setbacks as defined in Clause 4.2.3.3 (5) shall be complied with.

The design example building satisfies all the requirements for the regularity in elevation.

In the event that a structure is classified as irregular in elevation, the basic value of the behaviour factor, $q_o$, would have to be reduced by 20%, per Clause 5.2.2.2 (3). However, in no case does the upper limit of the behaviour factor, q, need to be reduced below 1.5, per Clause 5.2.2.2 (1), which is the value adopted for the design example building. Elevation irregularity also necessitates a modal response spectrum analysis, per Clause 4.2.3.1 (3). Additionally, if a plan irregularity exists as well, then a three-dimensional structural model analysis is necessary.

In summary, if the behaviour factor, q, is selected as 1.5 (DCL) and a modal response spectrum analysis is carried out on a three dimensional building model, as adopted for the example building design presented below, then plan and elevation irregularities do not require to be evaluated.

## 4. Establishment of Basic Parameters *(Paras* 2 and 4.4.3)*

- Identify the Ground Type for your site per *Paras* 2.1 to 2.4*.
  - For this example building, the ground type is D.
- Determine the height of the building per *Para* 2.1*.
  - For this example, the height is 25x4 = 100m
- Determine the fundamental period of the building, $T_1$, using conventional analysis software or any of the appropriate methods in SS EN 1998-1, Clause 4.3.3.2.2. (Note that if the height of the building is less than 40m, SS EN 1998-1 Clause 4.3.3.2.2 (3) could be used).
  - $T_1$ = 3.3 sec from computer analysis
- Determine the base shear percentage per Para* 4.4.3
  - $F_b = (S_d/g).W.\lambda$ *(where g is the gravitational constant = 9.81 m/s²)*
  - $S_d = S_e.\gamma/q$ = 5.5%g x 1.0 / 1.5 = 3.7%g
  - $\lambda$ = 1.0 (*Para* 4.4.3*, $T_1 > 2T_c$)
  - $F_b$ = 3.7%.W.1.0 = 3.7%W

## 5. Storey Weight *(Para* 4.3)*

Determine the floor by floor weights of the tower. This is shown in Figure 5. Per *Para* 2.1*, basement weights need not be considered. The seismic weight of the building is thus 582,973 kN.

| Storey | Elevation (m) | Flr to Flr (m) | Floor Area ($m^2$) | Cols ($m^3$) | Core ($m^3$) | Slab (kPa) | SDL (kPa) | LL (kPa) | Φ | Ψ | LL Dyn Factor | Slab Weight (kN) | SDL Weight (kN) | LL Weight (kN) | Core + Cols (kN) | Floor Dynamic Weight (Dead + SDL + $LL_{dyn}$) (kN) | Cummulative Weight (kN) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | 100 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 1 | 0.3 | 11,731 | 4,160 | 5,824 | 6,016 | 23,654 | 23,654 |
| 25 | 96 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 46,959 |
| 24 | 92 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 70,264 |
| 23 | 88 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 93,569 |
| 22 | 84 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 116,874 |
| 21 | 80 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 140,179 |
| 20 | 76 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 163,484 |
| 19 | 72 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 186,789 |
| 18 | 68 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 210,094 |
| 17 | 64 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 233,399 |
| 16 | 60 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 256,704 |
| 15 | 56 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 280,009 |
| 14 | 52 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 303,314 |
| 13 | 48 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 326,619 |
| 12 | 44 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 349,924 |
| 11 | 40 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 373,229 |
| 10 | 36 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 396,534 |
| 9 | 32 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 419,839 |
| 8 | 28 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 443,144 |
| 7 | 24 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 466,449 |
| 6 | 20 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 489,754 |
| 5 | 16 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 513,059 |
| 4 | 12 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 536,364 |
| 3 | 8 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | 559,668 |
| 2 | 4 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.3 | 0.8 | 0.24 | 11,731 | 4,160 | 5,824 | 6,016 | 23,305 | **582,973** |
| Ground | 0 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.6 | 1 | 0.6 | 11,731 | 4,160 | 5,824 | 6,016 | 25,402 | 608,375 |
| B1 | -4 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.6 | 1 | 0.6 | 11,731 | 4,160 | 5,824 | 6,016 | 25,402 | 633,777 |
| B2 | -8 | 4 | 1664 | 64 | 192 | 7.05 | 2.5 | 3.5 | 0.6 | 1 | 0.6 | 11,731 | 4,160 | 5,824 | 6,016 | 25,402 | 659,178 |
| B3 | -12 | | | | | | | | | | | | | | | | |
| | | | | 1,792 | 5,376 | | | | | | | 328,474 | 116,480 | 163,072 | | 659,178 | 9,484,178 |

**Figure 5: Floor Weight Tabulation**

## 6. Lateral Force Analysis Method *(Para* 4.4.2)*

Since the fundamental time period of the building is greater than 2.0 sec, per *Para* 4.4.1*, the Lateral Force Analysis method cannot be adopted for this building. However, for an understanding of the steps necessary to carry out this procedure, the Lateral Force Analysis method is explained below for illustration purposes only.

After determining the storey and the total mass/weight of the building, the base shear can be distributed per the formulation in *Para* 4.4.2*. This is repeated in Figure 6 for convenience.

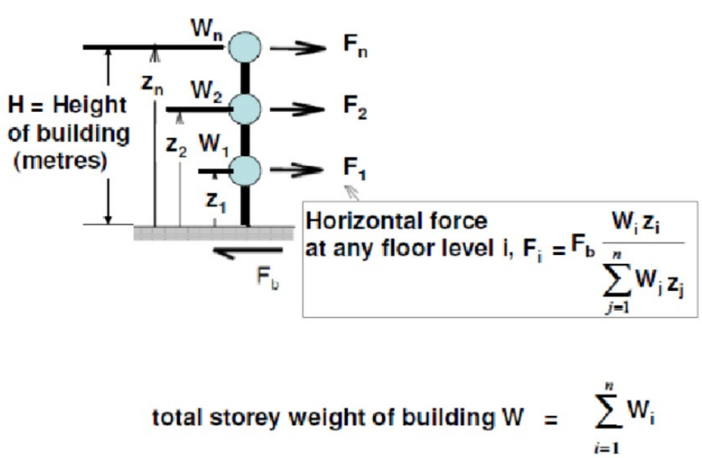


**Figure 6: Extract from *Para* 4.4.2***

The distribution of lateral forces is computed in Figure 7. The base shear percentage has been determined above to be 3.7%. Thus the design base shear is (3.7% x 582,973) = 21,570 kN. It is checked that the sum of the computed lateral force is equal to the initial computation of base shear.

| Storey | Elevation (m) | Flr to Flr (m) | Cummulative Weight (kN) | (Floor Weight) x Elevation | (Weight x Z) / Sum(Weight x Z) | Lateral Force (kN) |
|---|---|---|---|---|---|---|
| 26 | 100 | 4 | 23,654 | 2,365,440 | 0.08 | 1,682 |
| 25 | 96 | 4 | 46,959 | 2,237,276 | 0.07 | 1,591 |
| 24 | 92 | 4 | 70,264 | 2,144,056 | 0.07 | 1,525 |
| 23 | 88 | 4 | 93,569 | 2,050,836 | 0.07 | 1,458 |
| 22 | 84 | 4 | 116,874 | 1,957,617 | 0.06 | 1,392 |
| 21 | 80 | 4 | 140,179 | 1,864,397 | 0.06 | 1,326 |
| 20 | 76 | 4 | 163,484 | 1,771,177 | 0.06 | 1,260 |
| 19 | 72 | 4 | 186,789 | 1,677,957 | 0.06 | 1,193 |
| 18 | 68 | 4 | 210,094 | 1,584,737 | 0.05 | 1,127 |
| 17 | 64 | 4 | 233,399 | 1,491,517 | 0.05 | 1,061 |
| 16 | 60 | 4 | 256,704 | 1,398,298 | 0.05 | 994 |
| 15 | 56 | 4 | 280,009 | 1,305,078 | 0.04 | 928 |
| 14 | 52 | 4 | 303,314 | 1,211,858 | 0.04 | 862 |
| 13 | 48 | 4 | 326,619 | 1,118,638 | 0.04 | 796 |
| 12 | 44 | 4 | 349,924 | 1,025,418 | 0.03 | 729 |
| 11 | 40 | 4 | 373,229 | 932,198 | 0.03 | 663 |
| 10 | 36 | 4 | 396,534 | 838,979 | 0.03 | 597 |
| 9 | 32 | 4 | 419,839 | 745,759 | 0.02 | 530 |
| 8 | 28 | 4 | 443,144 | 652,539 | 0.02 | 464 |
| 7 | 24 | 4 | 466,449 | 559,319 | 0.02 | 398 |
| 6 | 20 | 4 | 489,754 | 466,099 | 0.02 | 331 |
| 5 | 16 | 4 | 513,059 | 372,879 | 0.01 | 265 |
| 4 | 12 | 4 | 536,364 | 279,660 | 0.01 | 199 |
| 3 | 8 | 4 | 559,668 | 186,440 | 0.01 | 133 |
| 2 | 4 | 4 | **582,973** | 93,220 | 0.00 | 66 |
| Ground | 0 | 4 | 608,375 | 0 | 0.00 | 0 |
| B1 | -4 | 4 | 633,777 | | | 0 |
| B2 | -8 | 4 | 659,178 | | | 0 |
| B3 | -12 | | | | | |
| | | | 9,484,178 | 30,331,392 | | 21,570 |

**Figure 7: Lateral Force Analysis Method-Lateral Force Distribution**

The distributions of the storey shears and storey moments are computed in Figure 8.

| Storey | Elevation (m) | Flr to Flr (m) | Lateral Force (kN) | Storey Shear (kN) | Storey Moment (kN-m) |
|---|---|---|---|---|---|
| 26 | 100 | 4 | 1,682 | | |
| 25 | 96 | 4 | 1,591 | 1,682 | 6,729 |
| 24 | 92 | 4 | 1,525 | 3,273 | 19,821 |
| 23 | 88 | 4 | 1,458 | 4,798 | 39,013 |
| 22 | 84 | 4 | 1,392 | 6,256 | 64,039 |
| 21 | 80 | 4 | 1,326 | 7,649 | 94,633 |
| 20 | 76 | 4 | 1,260 | 8,974 | 130,530 |
| 19 | 72 | 4 | 1,193 | 10,234 | 171,466 |
| 18 | 68 | 4 | 1,127 | 11,427 | 217,175 |
| 17 | 64 | 4 | 1,061 | 12,554 | 267,392 |
| 16 | 60 | 4 | 994 | 13,615 | 321,851 |
| 15 | 56 | 4 | 928 | 14,609 | 380,288 |
| 14 | 52 | 4 | 862 | 15,537 | 442,438 |
| 13 | 48 | 4 | 796 | 16,399 | 508,035 |
| 12 | 44 | 4 | 729 | 17,195 | 576,813 |
| 11 | 40 | 4 | 663 | 17,924 | 648,509 |
| 10 | 36 | 4 | 597 | 18,587 | 722,856 |
| 9 | 32 | 4 | 530 | 19,183 | 799,590 |
| 8 | 28 | 4 | 464 | 19,714 | 878,445 |
| 7 | 24 | 4 | 398 | 20,178 | 959,157 |
| 6 | 20 | 4 | 331 | 20,576 | 1,041,459 |
| 5 | 16 | 4 | 265 | 20,907 | 1,125,088 |
| 4 | 12 | 4 | 199 | 21,172 | 1,209,777 |
| 3 | 8 | 4 | 133 | 21,371 | 1,295,261 |
| 2 | 4 | 4 | 66 | 21,504 | 1,381,276 |
| Ground | 0 | 4 | 0 | 21,570 | 1,467,556 |
| B1 | -4 | 4 | 0 | 21,570 | 1,553,836 |
| B2 | -8 | 4 | 0 | 21,570 | 1,640,117 |
| B3 | -12 | | | 21,570 | 1,726,397 |
| | | | 21,570 | | |

**Figure 8: Lateral Force Analysis Method-Story Shear and Moment**

In addition to lateral forces, *Para* 5.3* requires a consideration for accidental torsion effects. The lateral force is required to be offset 0.05 the horizontal dimension of the floor plate. For this example building, the X dimension is 52m and the Y dimension is 32m. The offset dimension is thus 0.05x52 = 2.6m and 0.05x32 = 1.6m respectively. These computations are shown in Figure 9. These force offsets can be applied as a point torque at the center of mass of each level for analysis purposes. Additionally, the computed lateral force should be applied at the center of mass for the floor to appropriately capture any inherent torsional effects due to the differences between the center of mass and the center of rigidity. For completeness, the building story torques are computed and tabulated in Figure 10.

| Storey | Elevation (m) | Flr to Flr (m) | X Building Dimension (m) | Y Building Dimension (m) | X Dimension to Offset Force (m) | Y Dimension to Offset Force (m) | X Torque (kN-m) | Y Torque (kN-m) |
|---|---|---|---|---|---|---|---|---|
| 26 | 100 | 4 | 52 | 32 | 2.6 | 1.6 | 4,374 | 2,691 |
| 25 | 96 | 4 | 52 | 32 | 2.6 | 1.6 | 4,137 | 2,546 |
| 24 | 92 | 4 | 52 | 32 | 2.6 | 1.6 | 3,964 | 2,440 |
| 23 | 88 | 4 | 52 | 32 | 2.6 | 1.6 | 3,792 | 2,334 |
| 22 | 84 | 4 | 52 | 32 | 2.6 | 1.6 | 3,620 | 2,227 |
| 21 | 80 | 4 | 52 | 32 | 2.6 | 1.6 | 3,447 | 2,121 |
| 20 | 76 | 4 | 52 | 32 | 2.6 | 1.6 | 3,275 | 2,015 |
| 19 | 72 | 4 | 52 | 32 | 2.6 | 1.6 | 3,103 | 1,909 |
| 18 | 68 | 4 | 52 | 32 | 2.6 | 1.6 | 2,930 | 1,803 |
| 17 | 64 | 4 | 52 | 32 | 2.6 | 1.6 | 2,758 | 1,697 |
| 16 | 60 | 4 | 52 | 32 | 2.6 | 1.6 | 2,585 | 1,591 |
| 15 | 56 | 4 | 52 | 32 | 2.6 | 1.6 | 2,413 | 1,485 |
| 14 | 52 | 4 | 52 | 32 | 2.6 | 1.6 | 2,241 | 1,379 |
| 13 | 48 | 4 | 52 | 32 | 2.6 | 1.6 | 2,068 | 1,273 |
| 12 | 44 | 4 | 52 | 32 | 2.6 | 1.6 | 1,896 | 1,167 |
| 11 | 40 | 4 | 52 | 32 | 2.6 | 1.6 | 1,724 | 1,061 |
| 10 | 36 | 4 | 52 | 32 | 2.6 | 1.6 | 1,551 | 955 |
| 9 | 32 | 4 | 52 | 32 | 2.6 | 1.6 | 1,379 | 849 |
| 8 | 28 | 4 | 52 | 32 | 2.6 | 1.6 | 1,207 | 742 |
| 7 | 24 | 4 | 52 | 32 | 2.6 | 1.6 | 1,034 | 636 |
| 6 | 20 | 4 | 52 | 32 | 2.6 | 1.6 | 862 | 530 |
| 5 | 16 | 4 | 52 | 32 | 2.6 | 1.6 | 689 | 424 |
| 4 | 12 | 4 | 52 | 32 | 2.6 | 1.6 | 517 | 318 |
| 3 | 8 | 4 | 52 | 32 | 2.6 | 1.6 | 345 | 212 |
| 2 | 4 | 4 | 52 | 32 | 2.6 | 1.6 | 172 | 106 |
| Ground | 0 | 4 | 52 | 32 | 2.6 | 1.6 | 0 | 0 |
| B1 | -4 | 4 | | | | | | |
| B2 | -8 | 4 | | | | | | |
| B3 | -12 | | | | | | | |

**Figure 9: Lateral Force Analysis Method-Accidental Torsion Effects *(Para* 5.3)***

| Storey | Elevation (m) | Flr to Flr (m) | X Torque (kN-m) | Y Torque (kN-m) | Storey Torque X (kN-m) | Storey Torque Y (kN-m) |
|---|---|---|---|---|---|---|
| 26 | 100 | 4 | 4,374 | 2,691 | | |
| 25 | 96 | 4 | 4,137 | 2,546 | 4,374 | 2,691 |
| 24 | 92 | 4 | 3,964 | 2,440 | 8,510 | 5,237 |
| 23 | 88 | 4 | 3,792 | 2,334 | 12,475 | 7,677 |
| 22 | 84 | 4 | 3,620 | 2,227 | 16,267 | 10,010 |
| 21 | 80 | 4 | 3,447 | 2,121 | 19,886 | 12,238 |
| 20 | 76 | 4 | 3,275 | 2,015 | 23,333 | 14,359 |
| 19 | 72 | 4 | 3,103 | 1,909 | 26,608 | 16,374 |
| 18 | 68 | 4 | 2,930 | 1,803 | 29,711 | 18,284 |
| 17 | 64 | 4 | 2,758 | 1,697 | 32,641 | 20,087 |
| 16 | 60 | 4 | 2,585 | 1,591 | 35,399 | 21,784 |
| 15 | 56 | 4 | 2,413 | 1,485 | 37,984 | 23,375 |
| 14 | 52 | 4 | 2,241 | 1,379 | 40,397 | 24,860 |
| 13 | 48 | 4 | 2,068 | 1,273 | 42,638 | 26,239 |
| 12 | 44 | 4 | 1,896 | 1,167 | 44,706 | 27,512 |
| 11 | 40 | 4 | 1,724 | 1,061 | 46,602 | 28,678 |
| 10 | 36 | 4 | 1,551 | 955 | 48,326 | 29,739 |
| 9 | 32 | 4 | 1,379 | 849 | 49,877 | 30,694 |
| 8 | 28 | 4 | 1,207 | 742 | 51,256 | 31,542 |
| 7 | 24 | 4 | 1,034 | 636 | 52,462 | 32,285 |
| 6 | 20 | 4 | 862 | 530 | 53,497 | 32,921 |
| 5 | 16 | 4 | 689 | 424 | 54,358 | 33,451 |
| 4 | 12 | 4 | 517 | 318 | 55,048 | 33,876 |
| 3 | 8 | 4 | 345 | 212 | 55,565 | 34,194 |
| 2 | 4 | 4 | 172 | 106 | 55,910 | 34,406 |
| Ground | 0 | 4 | 0 | 0 | 56,082 | 34,512 |
| B1 | -4 | 4 | | | 56,082 | 34,512 |
| B2 | -8 | 4 | | | 56,082 | 34,512 |
| B3 | -12 | | | | 56,082 | 34,512 |

**Figure 10: Lateral Force Analysis Method-Building Torques**

The computed storey forces, storey shears, storey moments and storey torques are graphically illustrated in Figures 11 and 12.

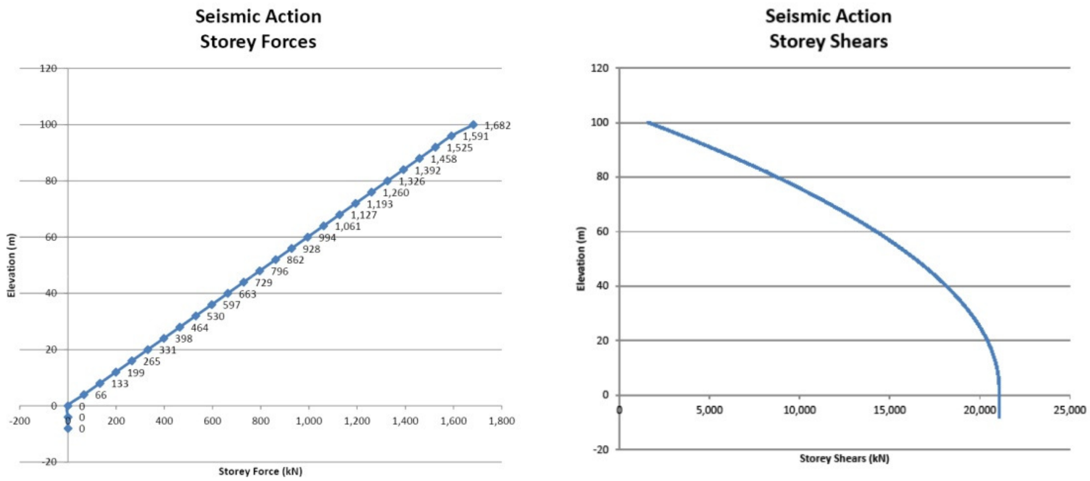


**Figure 11: Lateral Force Analysis Method-Story Forces and Shears**

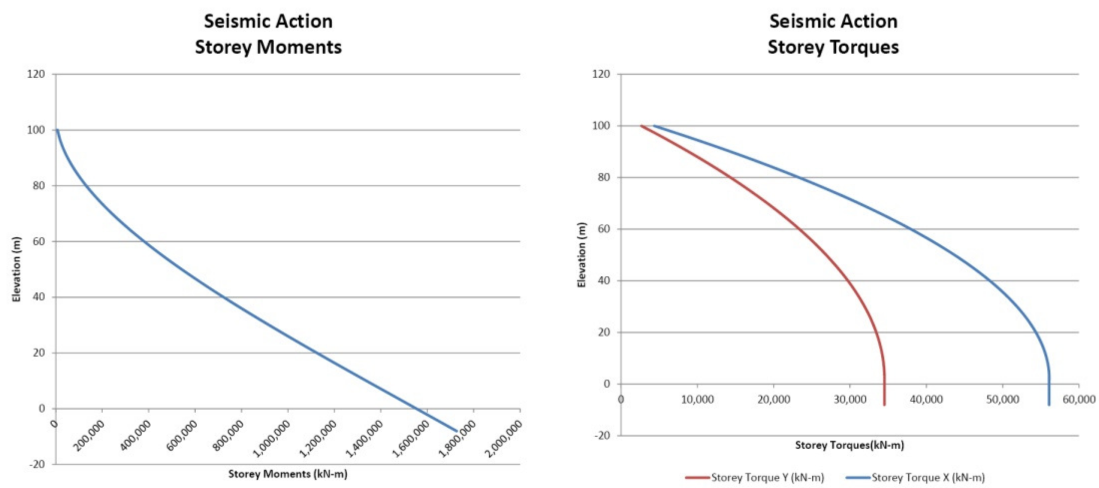


**Figure 12: Lateral Force Analysis Method-Story Moments and Torques**

Additionally, the lateral force distribution profile along the building height is also illustrated in Figure 13 for clarity.

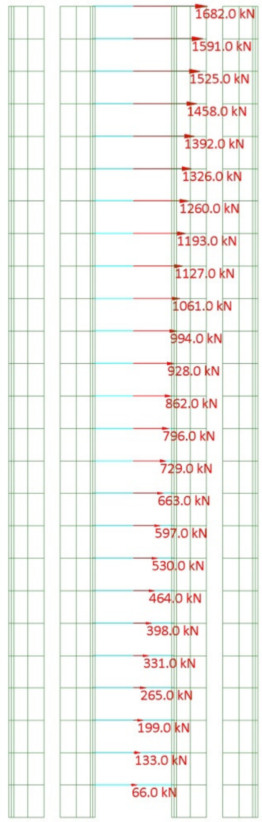


**Figure 13: Lateral Force Analysis Method-Lateral Force Profile**

## 7. Modal Response Spectrum Analysis Method *(Para* 4.5)*

The intent of a more rigorous dynamic analysis approach is to more accurately capture the vertical distribution of forces along the height of the building. The steps for a dynamic analysis are summarized below.

1. Solve for the building's period and mode shapes.
2. Ensure sufficient modes are used in the dynamic analysis by inspecting the cumulative modal participation.
3. Determine base shears obtained through response spectrum in each direction under consideration.

### *Determine Design Spectrum (Para* 3.2)*

For illustration, the design spectrum (ground type D, ordinary building) is plotted in Figure 14 in terms of m/sec$^2$.

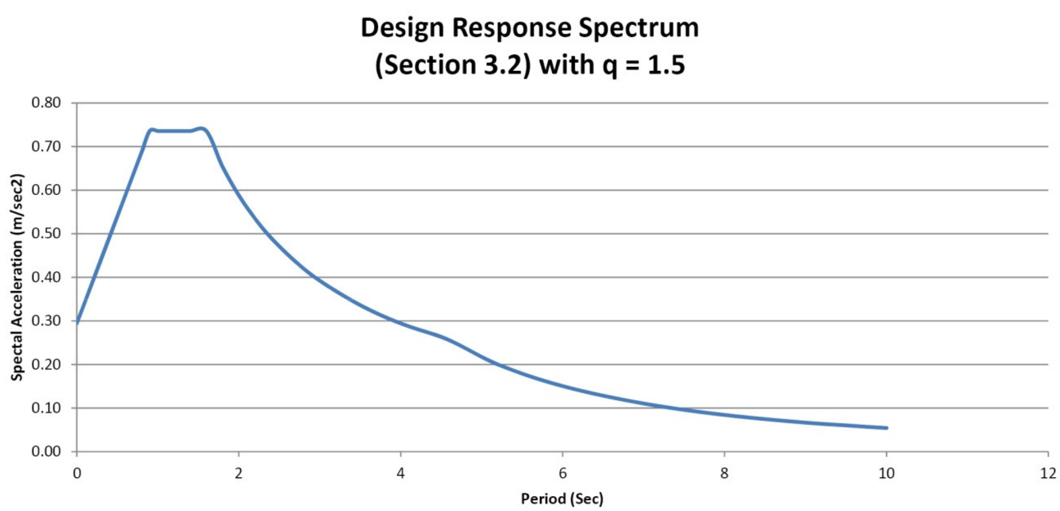


**Figure 14: Design Spectrum (m/sec$^2$)**

The above design spectrum can be entered into any commercial analysis software capable of free vibration and response spectrum analysis. For the example building, the first three time periods and mode shapes are illustrated in Figure 15.

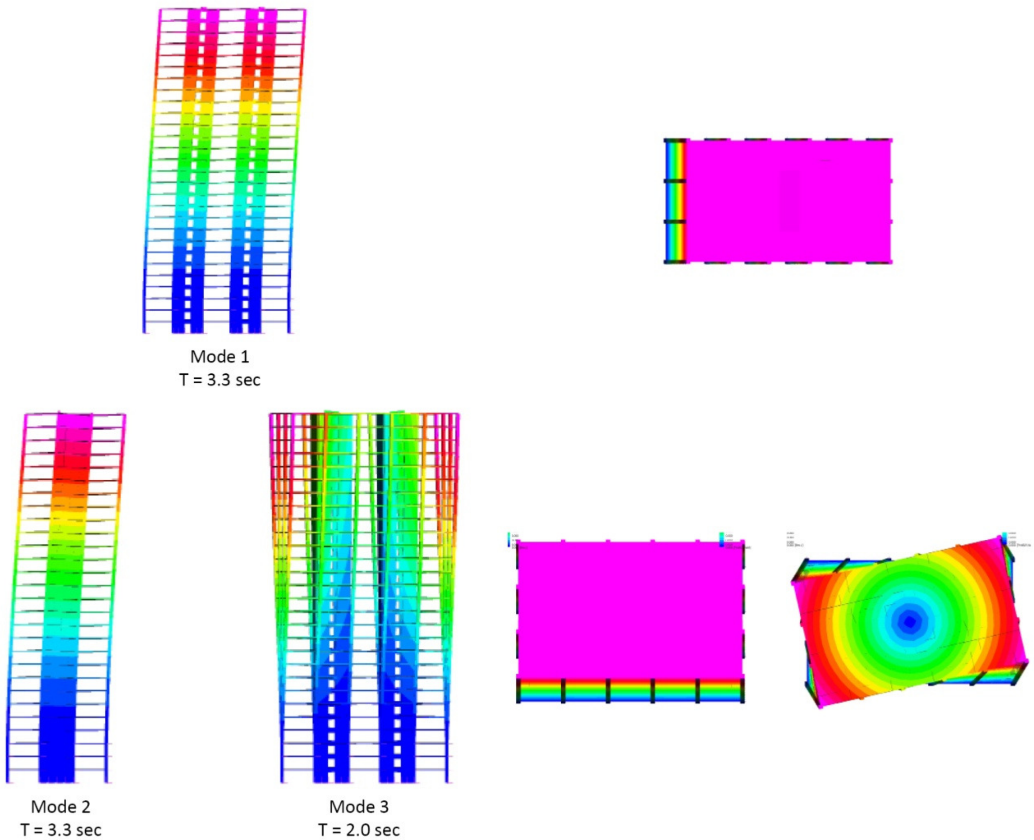


**Figure 15: Mode Shapes**

## *Modal Response Spectrum Analysis*

A response spectrum analysis is then run in two orthogonal directions with a scale factor of 1. Sufficient building modes should be used to ensure sufficient modal mass is activated. 90% mass participation is assumed as sufficient per SS EN 1998-1 Clause 4.3.3.3.1-3. The modal participations for the example building are shown in Figure 16 and the base shear contributions for the selected modes is shown in Figure 17.

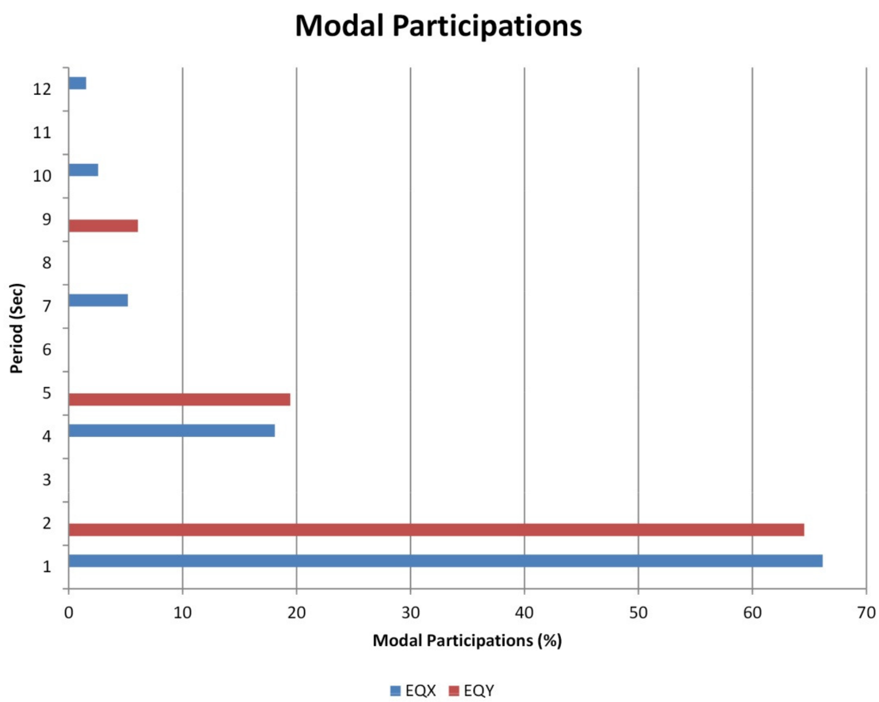


**Figure 16: Modal Participations**

The cumulative mass participations for the first 12 modes are 92% and 90% respectively.

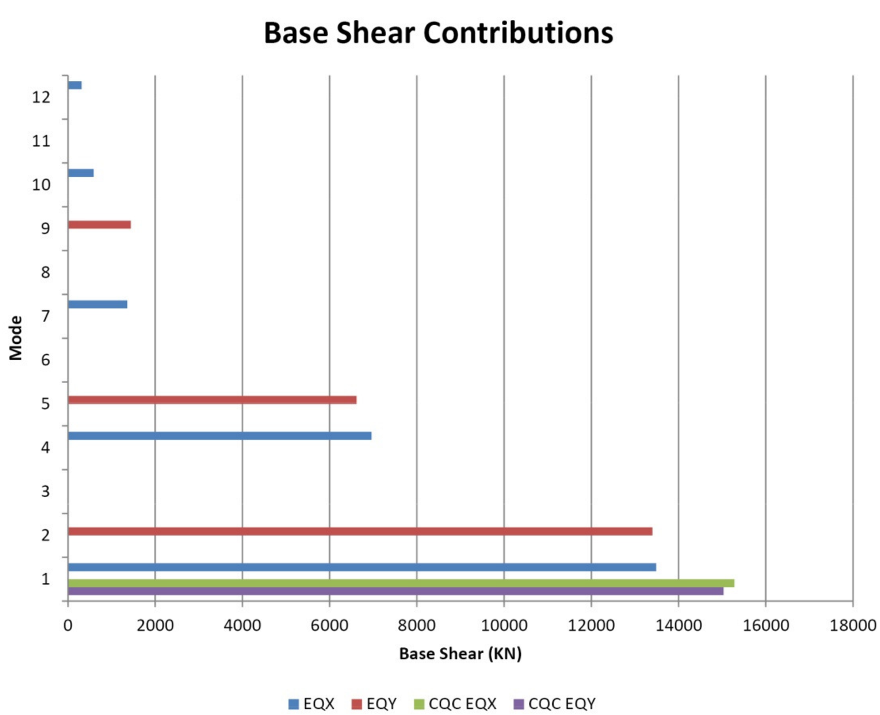


**Figure 17: Modal Base Shears**

After confirming that sufficient modes have been utilized in the analysis, the modal base shears can be extracted and combined. Modal combinations for each seismic direction can be performed by any accepted method such as Complete Quadratic Combination (CQC) or Square Root Sum of Squares (SRSS). For this example building, the modal responses are combined using the CQC method assuming a modal damping of 5%.

For directional effects, per *Para* 5.2*, it is permitted to combine the two directions using the 100% - 30% rule or a SRSS combination of the two analyzed directions (X and Y). For this design example, the former approach has been adopted.

Similar to the Lateral Force Analysis Method, consideration for accidental torsion effects, per *Para* 5.3,* need to be considered in the Modal Response Spectrum Analysis Method. This is analytically addressed by entering a mass offset in any commercial structural analysis software which then calculates and adds the torsional response to the response spectrum output to account for the additional design forces caused by accidental eccentricity.

## 8. Required Combinations of Actions (Load Combinations) *(Para* 5.2)*

Load Combinations per *Paras* 5.1 and 5.2,* using the 100% - 30% combination rule, are expanded below. A list of +/- combination of permutations is illustrated.

| Load Combination Number | Dead | SDL | LL | Sesimic Action X | Sesimic Action Torque X | Sesimic Action Y | Sesimic Action Torque Y | Geometric Imperfection Effects (X direction) | Geometric Imperfection Effects (Y direction) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.00 | 1.00 | 0.24 | 1.00 | 1.00 | 0.30 | 0.30 | 1.00 | 0.00 |
| 2 | 1.00 | 1.00 | 0.24 | 1.00 | -1.00 | 0.30 | 0.30 | 1.00 | 0.00 |
| 3 | 1.00 | 1.00 | 0.24 | -1.00 | 1.00 | 0.30 | 0.30 | 1.00 | 0.00 |
| 4 | 1.00 | 1.00 | 0.24 | -1.00 | -1.00 | 0.30 | 0.30 | 1.00 | 0.00 |
| 5 | 1.00 | 1.00 | 0.24 | 1.00 | 1.00 | -0.30 | 0.30 | 1.00 | 0.00 |
| 6 | 1.00 | 1.00 | 0.24 | 1.00 | -1.00 | 0.30 | -0.30 | 1.00 | 0.00 |
| 7 | 1.00 | 1.00 | 0.24 | -1.00 | 1.00 | -0.30 | 0.30 | 1.00 | 0.00 |
| 8 | 1.00 | 1.00 | 0.24 | -1.00 | -1.00 | 0.30 | -0.30 | 1.00 | 0.00 |
| 9 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | 1.00 | 1.00 | 1.00 | 0.00 |
| 10 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | 1.00 | -1.00 | 1.00 | 0.00 |
| 11 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | -1.00 | 1.00 | 1.00 | 0.00 |
| 12 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | -1.00 | -1.00 | 1.00 | 0.00 |
| 13 | 1.00 | 1.00 | 0.24 | -0.30 | 0.30 | 1.00 | 1.00 | 1.00 | 0.00 |
| 14 | 1.00 | 1.00 | 0.24 | 0.30 | -0.30 | 1.00 | -1.00 | 1.00 | 0.00 |
| 15 | 1.00 | 1.00 | 0.24 | -0.30 | 0.30 | -1.00 | 1.00 | 1.00 | 0.00 |
| 16 | 1.00 | 1.00 | 0.24 | 0.30 | -0.30 | -1.00 | -1.00 | 1.00 | 0.00 |
| 17 | 1.00 | 1.00 | 0.24 | 1.00 | 1.00 | 0.30 | 0.30 | -1.00 | 0.00 |
| 18 | 1.00 | 1.00 | 0.24 | 1.00 | -1.00 | 0.30 | 0.30 | -1.00 | 0.00 |
| 19 | 1.00 | 1.00 | 0.24 | -1.00 | 1.00 | 0.30 | 0.30 | -1.00 | 0.00 |
| 20 | 1.00 | 1.00 | 0.24 | -1.00 | -1.00 | 0.30 | 0.30 | -1.00 | 0.00 |
| 21 | 1.00 | 1.00 | 0.24 | 1.00 | 1.00 | -0.30 | 0.30 | -1.00 | 0.00 |
| 22 | 1.00 | 1.00 | 0.24 | 1.00 | -1.00 | 0.30 | -0.30 | -1.00 | 0.00 |
| 23 | 1.00 | 1.00 | 0.24 | -1.00 | 1.00 | -0.30 | 0.30 | -1.00 | 0.00 |
| 24 | 1.00 | 1.00 | 0.24 | -1.00 | -1.00 | 0.30 | -0.30 | -1.00 | 0.00 |
| 25 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | 1.00 | 1.00 | -1.00 | 0.00 |
| 26 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | 1.00 | -1.00 | -1.00 | 0.00 |
| 27 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | -1.00 | 1.00 | -1.00 | 0.00 |
| 28 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | -1.00 | -1.00 | -1.00 | 0.00 |
| 29 | 1.00 | 1.00 | 0.24 | -0.30 | 0.30 | 1.00 | 1.00 | -1.00 | 0.00 |
| 30 | 1.00 | 1.00 | 0.24 | 0.30 | -0.30 | 1.00 | -1.00 | -1.00 | 0.00 |
| 31 | 1.00 | 1.00 | 0.24 | -0.30 | 0.30 | -1.00 | 1.00 | -1.00 | 0.00 |
| 32 | 1.00 | 1.00 | 0.24 | 0.30 | -0.30 | -1.00 | -1.00 | -1.00 | 0.00 |

**Figure 18: Load Combinations Considering Geometric Imperfection in X Direction**

| Load Combination Number | Dead | SDL | LL | Sesimic Action X | Sesimic Action Torque X | Sesimic Action Y | Sesimic Action Torque Y | Geometric Imperfection Effects (X direction) | Geometric Imperfection Effects (Y direction) |
|---|---|---|---|---|---|---|---|---|---|
| 33 | 1.00 | 1.00 | 0.24 | 1.00 | 1.00 | 0.30 | 0.30 | 0.00 | 1.00 |
| 34 | 1.00 | 1.00 | 0.24 | 1.00 | -1.00 | 0.30 | 0.30 | 0.00 | 1.00 |
| 35 | 1.00 | 1.00 | 0.24 | -1.00 | 1.00 | 0.30 | 0.30 | 0.00 | 1.00 |
| 36 | 1.00 | 1.00 | 0.24 | -1.00 | -1.00 | 0.30 | 0.30 | 0.00 | 1.00 |
| 37 | 1.00 | 1.00 | 0.24 | 1.00 | 1.00 | -0.30 | 0.30 | 0.00 | 1.00 |
| 38 | 1.00 | 1.00 | 0.24 | 1.00 | -1.00 | 0.30 | -0.30 | 0.00 | 1.00 |
| 39 | 1.00 | 1.00 | 0.24 | -1.00 | 1.00 | -0.30 | 0.30 | 0.00 | 1.00 |
| 40 | 1.00 | 1.00 | 0.24 | -1.00 | -1.00 | 0.30 | -0.30 | 0.00 | 1.00 |
| 41 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | 1.00 | 1.00 | 0.00 | 1.00 |
| 42 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | 1.00 | -1.00 | 0.00 | 1.00 |
| 43 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | -1.00 | 1.00 | 0.00 | 1.00 |
| 44 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | -1.00 | -1.00 | 0.00 | 1.00 |
| 45 | 1.00 | 1.00 | 0.24 | -0.30 | 0.30 | 1.00 | 1.00 | 0.00 | 1.00 |
| 46 | 1.00 | 1.00 | 0.24 | 0.30 | -0.30 | 1.00 | -1.00 | 0.00 | 1.00 |
| 47 | 1.00 | 1.00 | 0.24 | -0.30 | 0.30 | -1.00 | 1.00 | 0.00 | 1.00 |
| 48 | 1.00 | 1.00 | 0.24 | 0.30 | -0.30 | -1.00 | -1.00 | 0.00 | 1.00 |
| 49 | 1.00 | 1.00 | 0.24 | 1.00 | 1.00 | 0.30 | 0.30 | 0.00 | -1.00 |
| 50 | 1.00 | 1.00 | 0.24 | 1.00 | -1.00 | 0.30 | 0.30 | 0.00 | -1.00 |
| 51 | 1.00 | 1.00 | 0.24 | -1.00 | 1.00 | 0.30 | 0.30 | 0.00 | -1.00 |
| 52 | 1.00 | 1.00 | 0.24 | -1.00 | -1.00 | 0.30 | 0.30 | 0.00 | -1.00 |
| 53 | 1.00 | 1.00 | 0.24 | 1.00 | 1.00 | -0.30 | 0.30 | 0.00 | -1.00 |
| 54 | 1.00 | 1.00 | 0.24 | 1.00 | -1.00 | 0.30 | -0.30 | 0.00 | -1.00 |
| 55 | 1.00 | 1.00 | 0.24 | -1.00 | 1.00 | -0.30 | 0.30 | 0.00 | -1.00 |
| 56 | 1.00 | 1.00 | 0.24 | -1.00 | -1.00 | 0.30 | -0.30 | 0.00 | -1.00 |
| 57 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | 1.00 | 1.00 | 0.00 | -1.00 |
| 58 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | 1.00 | -1.00 | 0.00 | -1.00 |
| 59 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | -1.00 | 1.00 | 0.00 | -1.00 |
| 60 | 1.00 | 1.00 | 0.24 | 0.30 | 0.30 | -1.00 | -1.00 | 0.00 | -1.00 |
| 61 | 1.00 | 1.00 | 0.24 | -0.30 | 0.30 | 1.00 | 1.00 | 0.00 | -1.00 |
| 62 | 1.00 | 1.00 | 0.24 | 0.30 | -0.30 | 1.00 | -1.00 | 0.00 | -1.00 |
| 63 | 1.00 | 1.00 | 0.24 | -0.30 | 0.30 | -1.00 | 1.00 | 0.00 | -1.00 |
| 64 | 1.00 | 1.00 | 0.24 | 0.30 | -0.30 | -1.00 | -1.00 | 0.00 | -1.00 |

**Figure 19: Load Combinations Considering Geometric Imperfection in Y Direction**

*Paras* 5.1 and 5.2* gives rise to a total of 64 combinations. However, engineering judgment can be applied to reduce the total of required combinations.

## 9. Interstorey Drift Limitation – Modal Response Analysis Method (Para* 7.1)

*Para* 7.1* requires that the design inter-story drift, $d_r$, shall not exceed 0.005 / $v.q$ of the story height.

- $v$ = 0.5 (Ordinary buildings)
- $q$ = 1.5 (Reinforced Concrete structures, DCL)

The inter-storey drifts from the Modal Response Spectrum Analysis are plotted with the prescribed drift limit in Figure 20. It is seen that the structure drift is well within the stipulated drift limit. For cases where the drift exceeds the stipulated limit, additional lateral load resisting elements may have to be introduced to the structural system or existing structural elements may have to be enlarged.

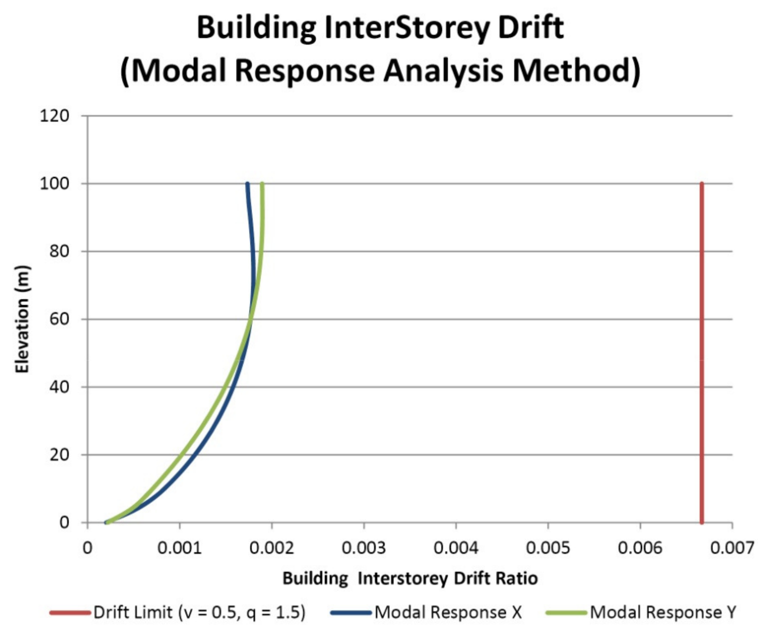


**Figure 20: Interstorey Drift (Modal Response Analysis Method)**

## 10. Separation from Property Line -Modal Response Analysis Method *(Para* 8.1)*

For the example building, drifts are illustrated in Figure 21. The drift limit per *Para* 8.1* states that the minimum structural separation, $\Delta_A$, for the new building should at least be the deflection of the building at that floor determined from the structural analysis multiplied by the behavior factor, *q*, but not less than 0.1% of the height of that floor measured from the base.

The required separation in both the X and Y Direction is evaluated separately. In this example, the maximum drifts at the top of the building from the Modal Response Spectrum Analysis are as follows:

EQX drift = 0.150 m

EQY drift = 0.155 m

Required separations at the top of the building in both X and Y Directions are as follows:

Dx separation: EQx drift x $q$ = 0.150 x 1.5 = 0.225 m

Dy separation: EQy drift x $q$ = 0.155 x 1.5 = 0.233 m

Both these values are greater than the minimum limit at the top of the building which is 100mm (0.1% of the 100m building height above the basement).

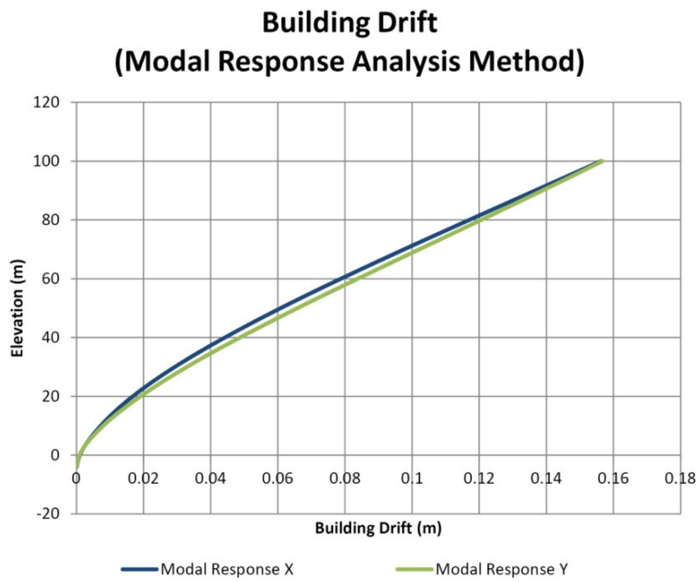


**Figure 21: Building Displacement (Modal Response Spectrum Analysis Method**

## 11. Foundation Design (*Para* 6)*

Since the action effects for the foundation for this design example have been determined for Ductility Class Low (DCL) with $q$ = 1.5, the structure is categorised as a low-dissipative structure. For low-dissipative structures, the reaction forces derived directly from the structural analyses can be used in the design of foundation elements, without the need for capacity design considerations accounting for the development of possible overstrength per SS EN 1998-1, Clause 4.4.2.6 (3).

The design of the foundation elements must ensure that the ultimate reaction forces from the structural analyses are less than the ultimate resistance of the foundation elements. For example, for pile foundations resisting compression loads, if a column has an ULS load of 54,000 kN, and the ultimate geotechnical limit state design resistance of one pile, determined in accordance with SS EN 1997-1, Clause 7.6.3, is 9000 kN, then the total number of piles required under the column would be 6 numbers.

It is to be noted that foundation elements of structures designed for Ductility Classes other than Low, would require capacity design considerations in accordance with the requirements of SS EN 1998-1, Clause 4.4.2.6.