NEMETSCHEK
Scia

Seismic Analysis in Scia Engineer

How to take mass eccentricity into account in a 3D modelization

Scia
Engineer

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1. Introduction

Most of the seismic codes require that structures are checked for torsion due to mass eccentricity including an additional eccentricity – so-called accidental eccentricity. This is required to cover inaccuracies between the real structure and the modelization, as well as the fact that masses that are linked to service loads may vary during the life of the structure.

Two types of eccentricity must be distinguished for the analysis: the structural eccentricity and the accidental eccentricity.

The structural eccentricity is the offset between the center of mass and the center of stiffness of the structure. It is part of the structure. In a simplified seismic analysis via 2D models, where typically the X and Y directions are analyzed separately, the impact of the structural eccentricity is taken into account by manually distributing the torsional effects on the structure. An additional safety factor is usually applied to the structural eccentricity to cover inaccuracies due to that simplified method.

When using a 3D modelization of the structure, the structural eccentricity is automatically taken into account due to the fact that the X and Y and linked and analyzed together, allowing torsional effects to appear directly in the analysis without having to add them manually afterwards.

The accidental eccentricity accounts for inaccuracies in the distribution of masses in the structure. Design codes usually take it into account as an additional eccentricity that is defined as a fraction of the size of the structure.

In the Eurocode 8, the accidental eccentricity for a given floor is defined as 5% of the width of the floor perpendicularly to the direction of the acting seismic action.

In simplified modelizations where the structural eccentricity appears explicitly, it is very simple to add the accidental eccentricity in the calculation. In general 3D modelizations, the structural eccentricity does not appear as such and it is therefore more difficult to account for its effects in such a case.

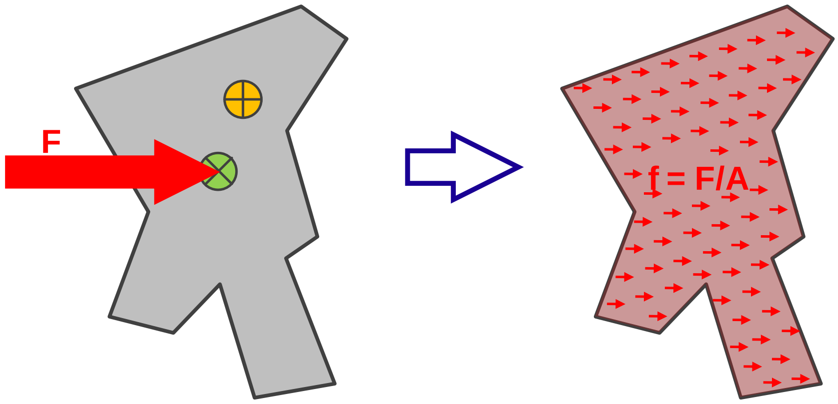
This document shows several ways to account for eccentricity in a 3D modelization.

2. Theoretical background

The explanations in this paragraph refer mainly to the method of equivalent loads for seismic analysis, but some of the exposed principles also apply to a analysis using the response spectrum method.

As explained in the introduction, the structural eccentricity is automatically in a 3D modelization. The location of the stiffness center is taken into account by the fact that the seismic shear walls are modelized in their actual location. Therefore the location of the stiffness center does not need to be known.

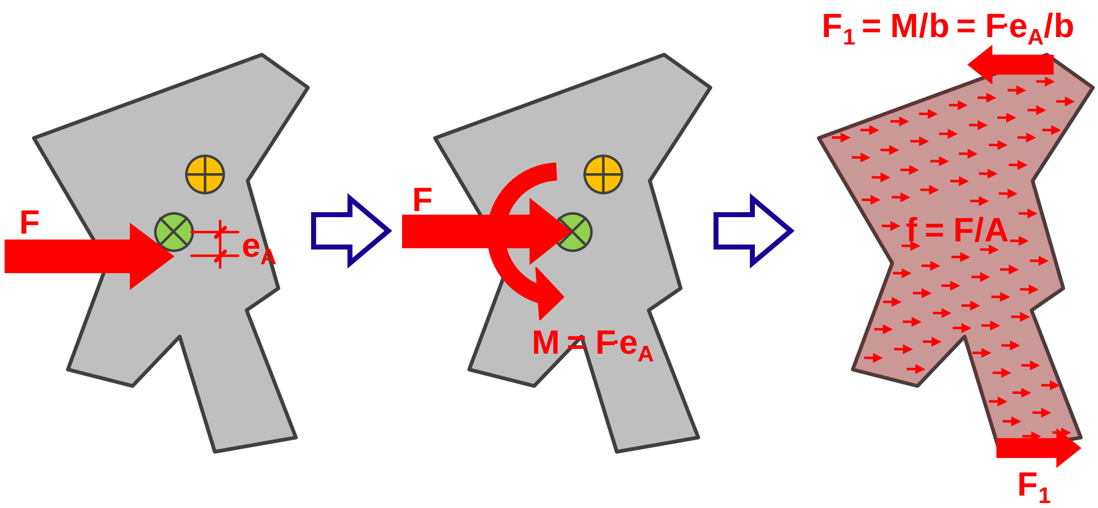
In the equivalent load method, the seismic action is usually a concentrated force applied at the mass center of each floor deck. But the location of the mass center does not need to be known either, as applying the horizontal seismic action as a distributed load on the surface of the floor instead of a concentrated force at the mass center will automatically lead to the correct result.



Another advantage of this method is, that if the floor deck may not be considered as a rigid diaphragm, applying the seismic action as a distributed way will result in a more realistic in-plane behavior of the slab.

Hence the location of neither the mass center nor the stiffness center need to be known.

The accidental eccentricity may be represented as follows:



Instead of applying the seismic force at the mass center, it is applied with an additional eccentricity e_A. This can expressed as a force plus a moment applied at the mass center. Going one step further, the force can be applied as a distributed load on the entire surface of the slab, as previously. The moment can be expressed as a couple of concentrated forces, applied in opposite directions at each end of the slab. Ultimately, it is again not needed to know the location of the mass center.

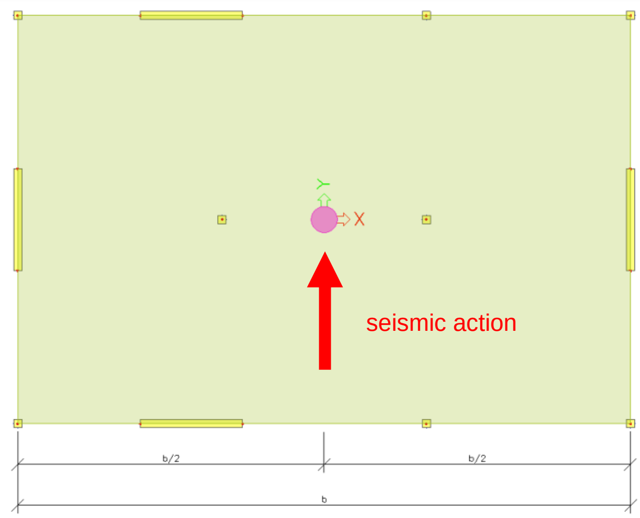
3. Practical application in Scia Engineer

Accidental eccentricity currently cannot be taken into account automatically in Scia Engineer (v2011.1). Here are two possible ways to take it into account in a 3D modelization.

- offset the mass center using additional masses
- apply equivalent forces to introduce torsion in the structure

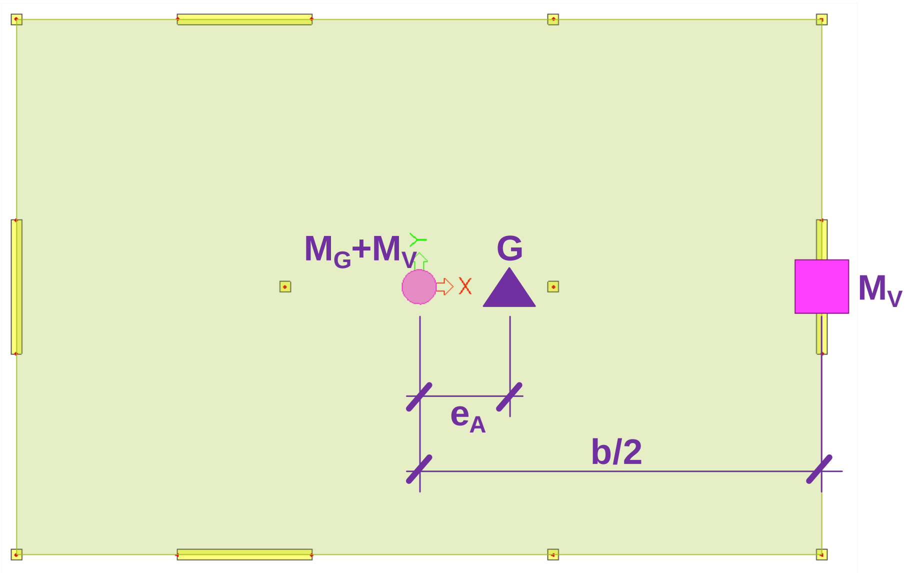
3.1 Offset the mass center

Although it is not necessary to know the exact location of the mass center to apply this method, it is based on the assumption that the mass center of the considered slab is located at equal distance from the edges of the slab.



The further the mass center is from the geometrical center of the slab, the bigger the inaccuracy of the eccentricity will be.

The general principal is to add concentrated masses at each floor and to use correction factors to offset the mass center accordingly.



The accidental eccentricity can expressed as

$$k = \frac{e_A}{b} = \frac{1}{2} \cdot \frac{\alpha\beta}{1 - \alpha\beta}$$

where

k relative eccentricity; usually k=5% in the codes

e_A value of the accidental eccentricity

b width of the slab in the direction perpendicular to the seismic action

α factor used to adjust the eccentricity; defines what percentage of the eccentered mass is to be taken into account in the analysis

β ratio between the eccentered mass and the total mass of the floor

$$\beta = \frac{M_V}{M_G + M_V}$$

M_G mass of the slab, directly calculated by Scia Engineer from the self weight

M_V mass related to the dead load and the part or the live load that is taken into account in the dynamic analysis; the eccentered concentrated mass will also use that value

M_V must be determined manually for each floor and a concentrated mass will be created on the outermost edge of the slab in the direction of the desired eccentricity.

As Scia Engineer currently takes into account 100% of the mass of the structure (related to the self weight), this part of the mass cannot be modified by a factor in a mass combination. There are two possibilities:

- zero the self mass of the structure, either by setting a zero density for the corresponding materials or using property modifiers; this method has the advantage of being transparent for the user, but it implies re-inputting the self mass of the structure manually in a mass group, which might be quite heavy and potential source of mistakes; it would lead to M_G = 0 and β = 1 in the equations above and α = 0.0909 when k = 5%
- use the equations above as such, without simplification, which leads to

$$\alpha = \frac{2k}{\beta(1 + 2k)}$$

Example

Consider a rectangular slab 10x15m, 20cm thick, with 2kN/m^2 dead load and 2 kN/m^2 live load, under seismic action perpendicular to its longer edge

- self mass M_G = 10 x 15 x 0.2 x 2500 = 75 to
- mass related to the dead load M_{DL} = 10 x 15 x 200 = 30 to
- mass related to the live load M_{LL} = 10 x 15 x 200 x 0.3 = 9 to
- total mass of the floor M_{tot} = 75’000 + 30’000 + 9’000 = 114 to
- eccentered mass to be added M_V = M_{DL} + M_{LL} = 39 to
- β = 39 / 114 = 0.342
- k = 0.05
- α = 0.266

Data input in Scia Engineer

- create 3 mass groups
  - M-DL will contain the mass related to the dead load, converted from the loadcase DL
  - M-LL will contain the mass related to the live load, converted from the loadcase LL
  - M-X+ will contain the concentrated eccentered mass, manually input
  - Note that this setup is valid if β has the same value for all the floors. If not, mass groups should be split in such a way that the value of β is the same for all the floor in each group.
- create 1 mass combination with the following factors, so that the total mass of the floor is M_{tot}
  - (1- α) * M-DL = 0.734 * M-DL
  - (1- α) * 0.3 * M-LL = 0.220 * M-LL
  - α * M-X+ = 0.266 * M-X+

Ideally, repeat the above for each considered seismic direction and changing the sign of eccentricity.

For each case, create a seismic loadcase associated with the corresponding mass combination.

For a typical configuration, there would be

- 5 mass combinations
  - M0: without eccentricity
  - MX+: with eccentricity in direction +X
  - MX-: with eccentricity in direction -X
  - MY+: with eccentricity in direction +Y
  - MY-: with eccentricity in direction -Y
- 6 seismic loadcases
  - seismic action in direction X without eccentricity (M0)
  - seismic action in direction X with eccentricity +Y (MY+)
  - seismic action in direction X with eccentricity -Y (MY-)
  - seismic action in direction Y without eccentricity (M0)
  - seismic action in direction Y with eccentricity +X (MX+)
  - seismic action in direction Y with eccentricity -X (MX-)

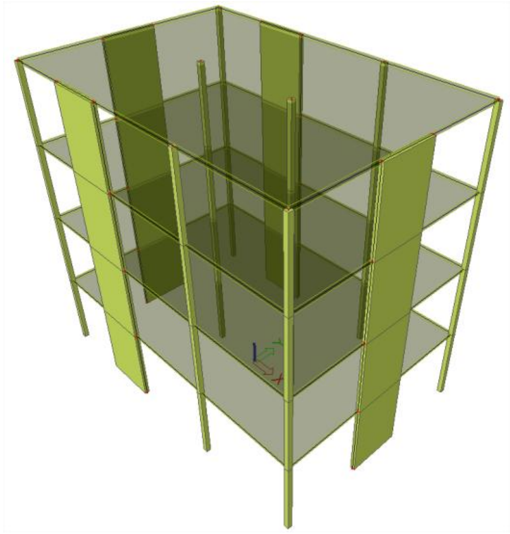
Advantages of the method

- dynamic behavior of the structure calculated including the effect of accidental eccentricity
- usually leads to less conservative results than simplified methods

Disadvantages of the method

- heavy computation time (multiple resolutions of natural frequencies as well as modal superposition)

Example in Scia Engineer (see project file ecc1.esa)



Simple 4-storey building

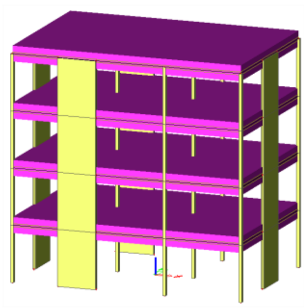
20cm-thick slabs, 10x15m

Storey height 3.6m

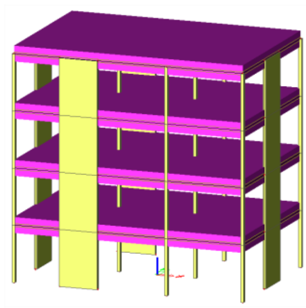
Dead load 2kN/m^2 on each slab

Live load 2kN/m^2 on each slab
with quasi-permanent factor 0.3

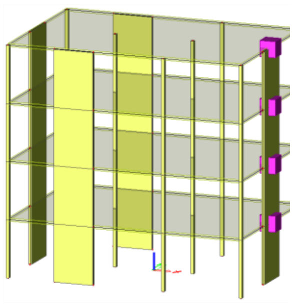
Mass groups



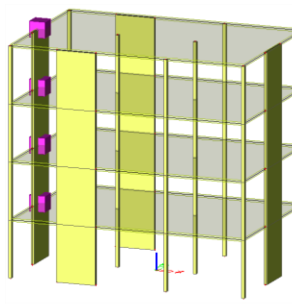
M-DL



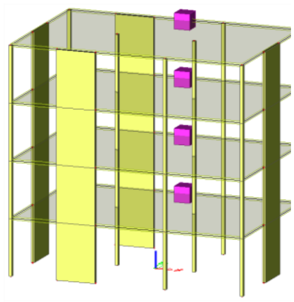
M-LL



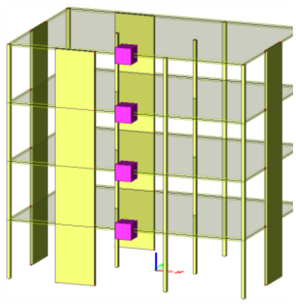
M-X+



M-X-

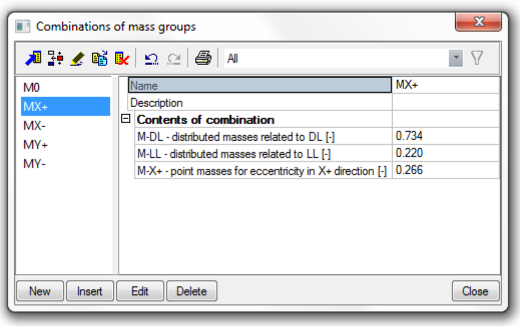


M-Y+



M-Y-

Mass combinations



Seismic loadcases

SX0 uses mass combi M0

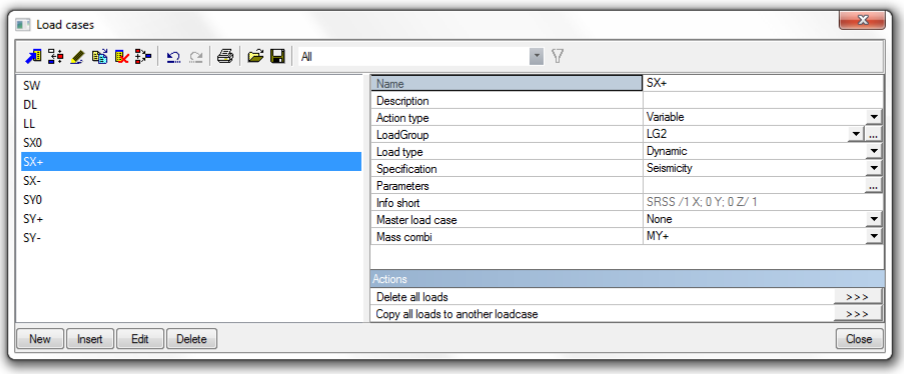
SX+ uses mass combi MY+

SX- uses mass combi MY-

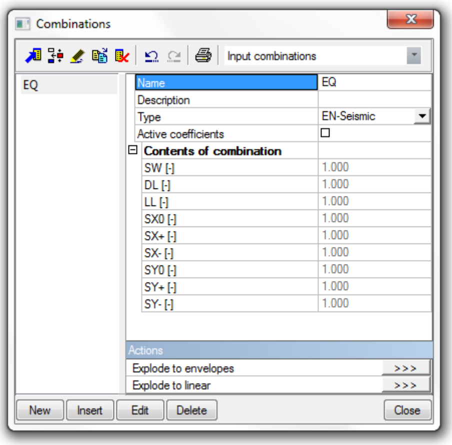
SY0 uses mass combi M0

SY+ uses mass combi MX+

SY- uses mass combi MX-



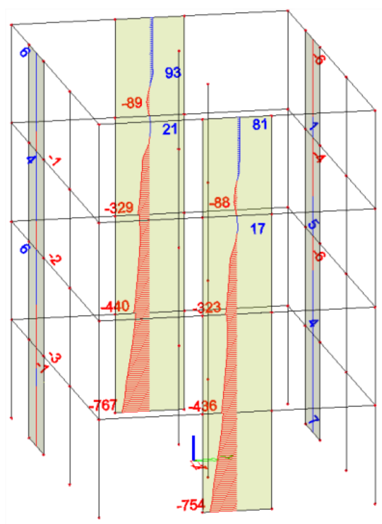
Loadcase combinations



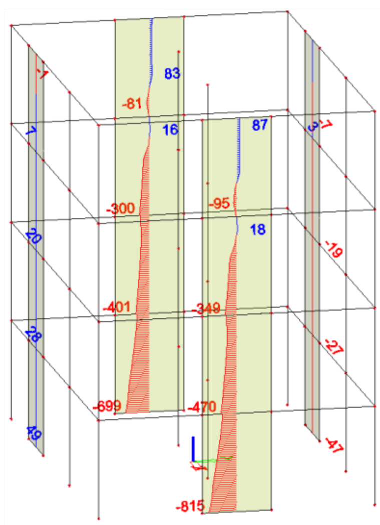
As all seismic loadcases belong to the load group LG2, which is defined as seismic exclusive, a single loadcase combination is sufficient to cover all possible cases.

Results

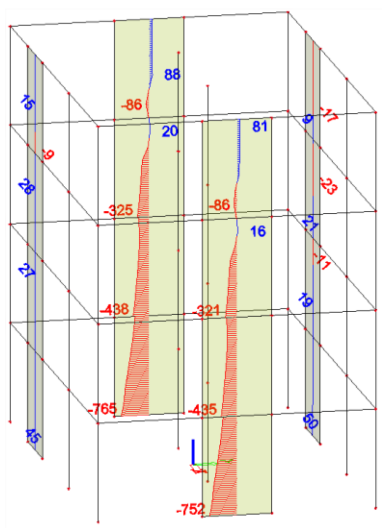
Bending moments in shear walls in the Y direction under seismic action in the same direction



SY0



SY+



SY-

3.2 Equivalent torsional forces

It is possible to perform a standard seismic analysis without accidental eccentricity, using the response spectrum method. The effects of accidental eccentricity may be added afterwards using equivalent statical loads, based on the theoretical background presented earlier in this document.

Based on the principles explained in chapter **Error! Reference source not found.**, a torsion moment may be applied at each level (floor) using a couple of concentrated forces. If b is the lever arm of the 2 applied point forces, their intensity is

$$F_{torsion} = F_{translation} \cdot \frac{e_A}{b}$$

where

$F_{torsion}$ value of point load applied at each end of the slab in opposite directions

$F_{translation}$ value of the equivalent seismic force applied to the slab

e_A accidental eccentricity; usually 5% of b

b dimension of the slab in the direction perpendicular to the seismic action **and** lever arm of the applied equivalent point loads $F_{torsion}$

In the case of an equivalent statical analysis, $F_{translation}$ is calculated anyway, so it may be reused directly for the input of torsional actions.

In the case of the response spectrum method, $F_{translation}$ may be determined as follows

$$F_{translation} = a_{RSM} \cdot M_{floor}$$

where

a_{RSM} acceleration at the mass center of the floor, obtained from the RSM analysis by modal superposition

M_{floor} total mass of the considered floor

Note: at this point, it is necessary to know the location of the mass center of each floor in order to read the correct value of the acceleration from the RSM results. Nevertheless, the value of the acceleration does not vary much across the floor and a rough estimate of that location is therefore usually sufficient.

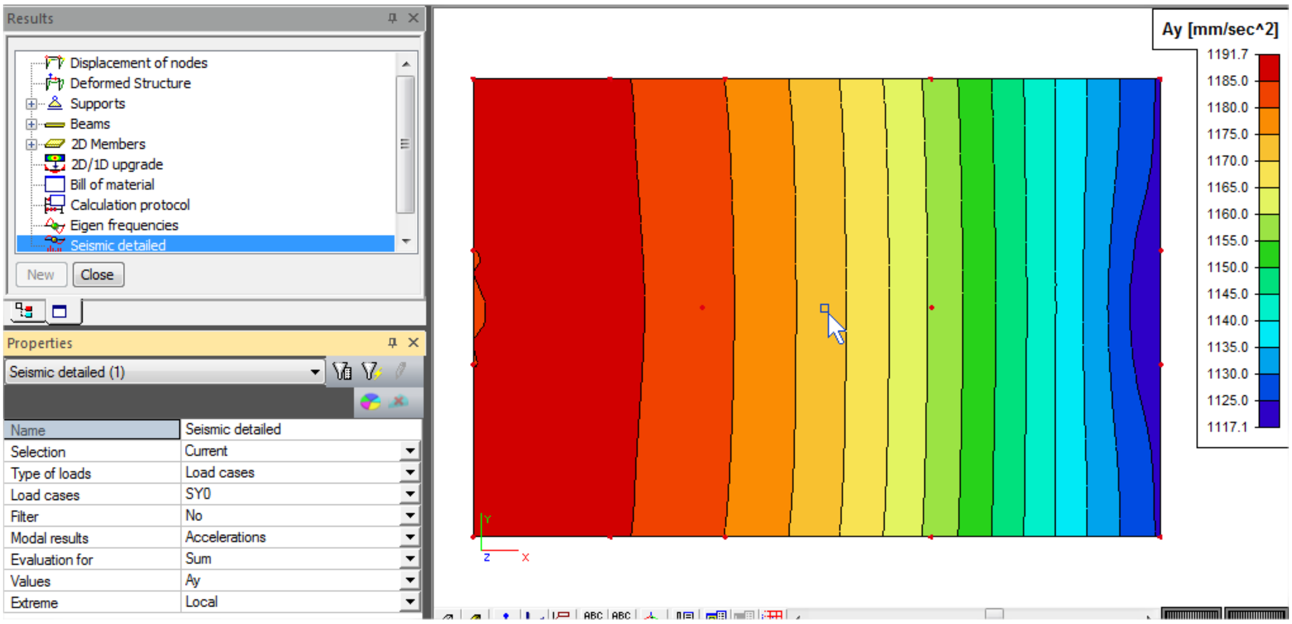
Advantages of the method

- dynamic behavior of the structure calculated only once, hence computation time is not increased

Disadvantages of the method

- simplified method – usually leads to more conservative results than strictly necessary

Example in Scia Engineer (see project file ecc2.esa)



For instance here, the acceleration at the mass center of the top slab of the building under seismic action in Y-direction is approximately

$$a_{RSM} = 1172\ mm/s^2$$

$$M_{floor} = (0.2 \cdot 2500 + 203.9 + 0.3 \cdot 203.9) \cdot 10 \cdot 15 = 114'755\ kg$$

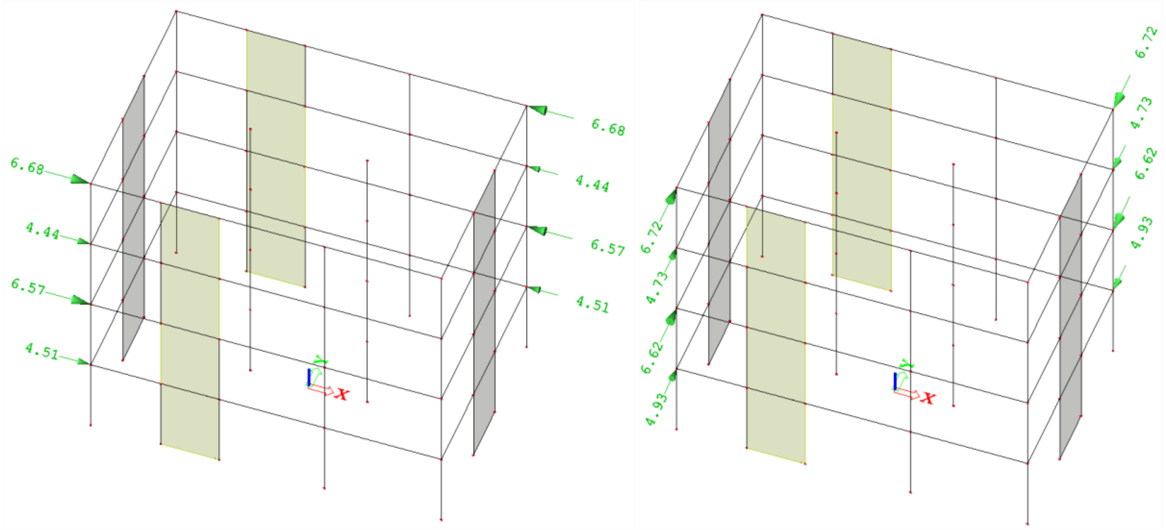
$$F_{translation} = 134.5\ kN$$

$$F_{torsion} = 5\% \cdot 134.5 = 6.72\ kN$$

Repeating this at each floor and for each direction, we obtain

		Seism X			Seism Y		
Floor	M_{floor} [kg]	a_{RSM} [mm/s²]	$F_{translation}$ [kN]	$F_{torsion}$ [kN]	a_{RSM} [mm/s²]	$F_{translation}$ [kN]	$F_{torsion}$ [kN]
4	114'755	1'164	133.6	6.68	1'172	134.5	6.72
3	114'755	773	88.7	4.44	828	95.0	4.75
2	114'755	1'145	131.4	6.57	1'153	132.3	6.62
1	114'755	786	90.2	4.51	860	98.7	4.93

And the floor torsion forces may be applied:

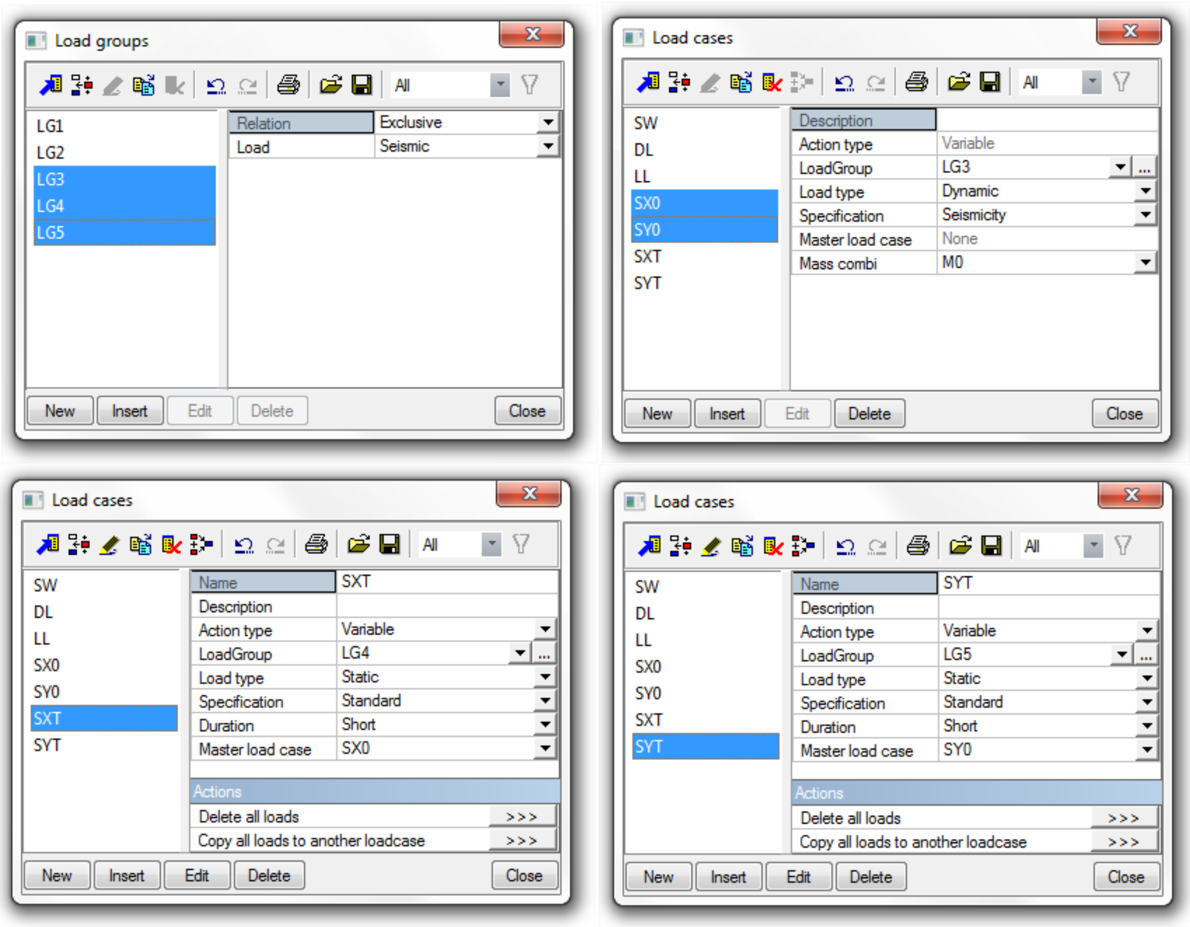


Hence we have now in Scia Engineer two additional torsion loadcases.

- SX0 seismic action in direction X, without eccentricity, from RSM analysis
- SY0 seismic action in direction Y, without eccentricity, from RSM analysis
- SXT torsional action for seism in direction X, applied as equivalent statical loads
- SYT torsional action for seism in direction Y, applied as equivalent statical loads

Loadcases and load groups relationships:

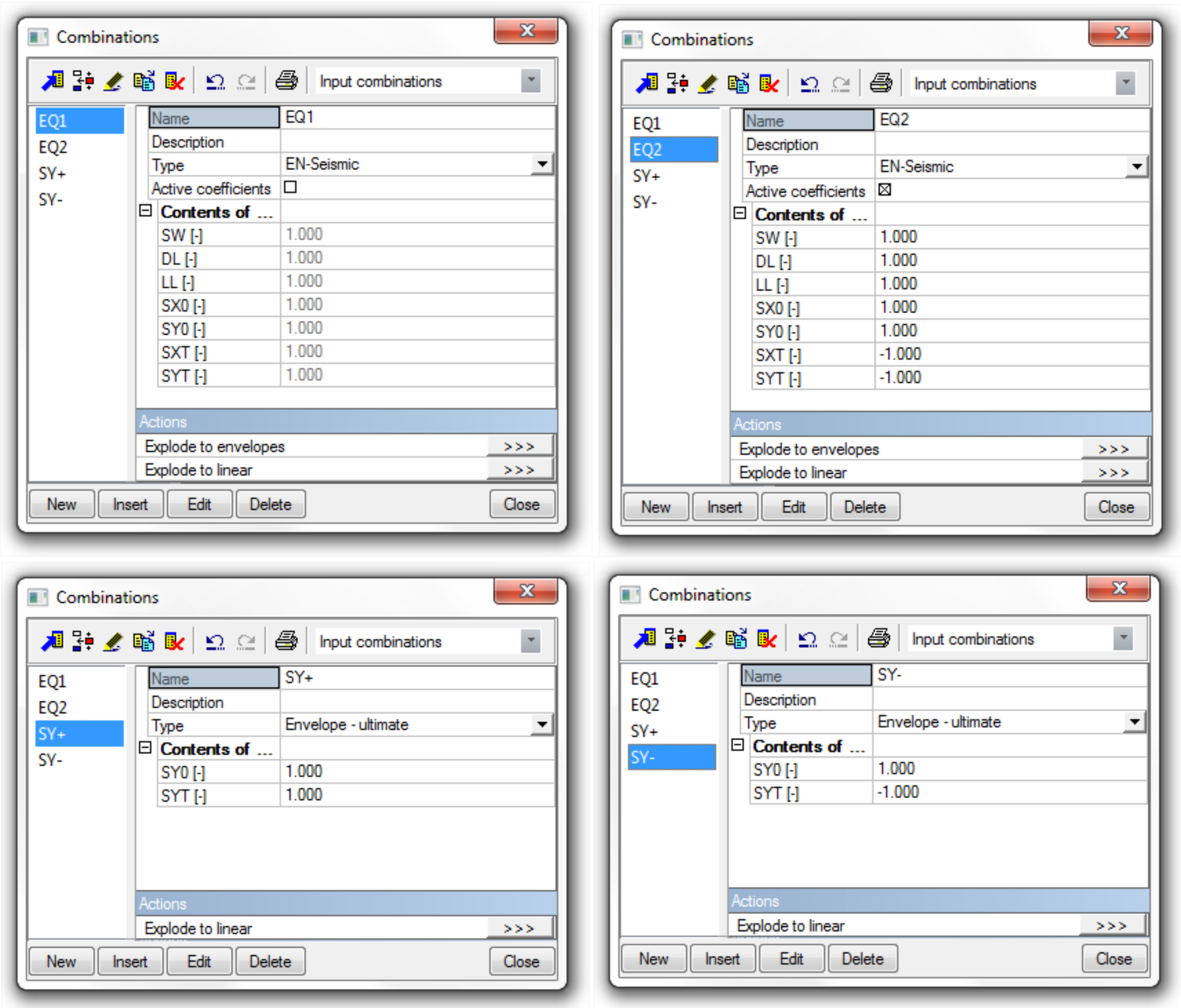
- SX0 and SY0 are in the load group LG3, defined as seismic exclusive.
- SXT is in the load group LG4, defined as seismic exclusive, with SX0 as master loadcase.
- SYT is in the load group LG5, defined as seismic exclusive, with SY0 as master loadcase.



These relationships ensure that the torsional actions will applied only when the corresponding translational seismic action is applied.

Two loadcase combinations must be defined:

- EQ1: SW, DL, LL, SX0, SY0, SXT, SYT
- EQ2: SW, DL, LL, SX0, SY0, -1.0*SXT, -1.0*SYT



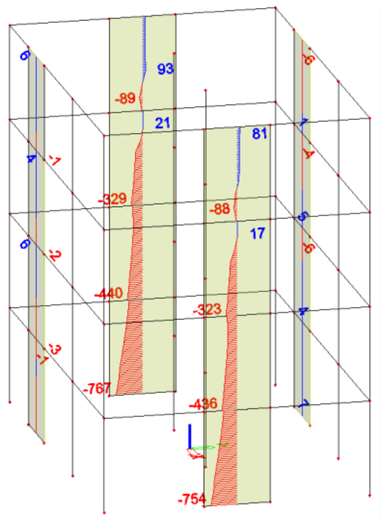
This is necessary as the torsional actions are not defined strictly as seismic actions and Scia Engineer will therefore not apply them automatically with + and – sign.

And finally one class result that contains the loadcase combinations EQ1 and EQ2.

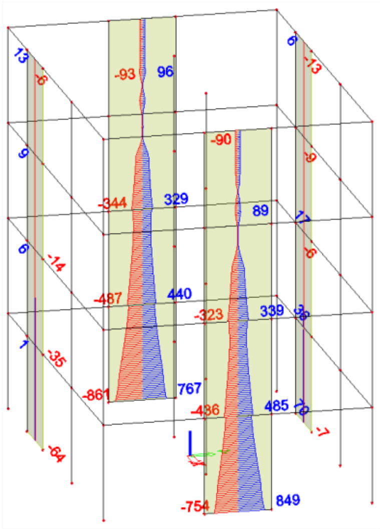
For comparison of the results, two more combinations are created, containing only the seismic loadcase SY0 and +/- SYT.

Results

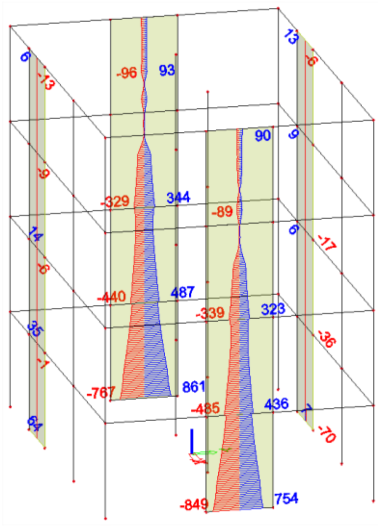
Bending moments in shear walls in the Y direction under seismic action in the same direction



SY0



SY+: SY0+SYT



SY-: SY0-SYT

3.3 Newmark's combinations

Many codes use the combinations of Newmark to take into account possible interactions between the components of the seismic actions. Typically, the following cases should be considered

$$\pm SX \pm 0.3 \cdot SY \pm 0.3 \cdot SZ$$

$$\pm 0.3 \cdot SX \pm SY \pm 0.3 \cdot SZ$$

$$\pm 0.3 \cdot SX \pm 0.3 \cdot SY \pm SZ$$

To apply this to the cases described in the previous sections, some changes are necessary.

3.3.1 Case with mass eccentricity

See modified data in project file ecc3.esa.

Loadgroups

- LG2 statical variable actions (LL)
- LGX seismic actions in X-direction, seismic exclusive
- LGY seismic actions in Y-direction, seismic exclusive

Note: the vertical seismic action is not taken into account in this example. An additional loadgroup would be necessary for it.

Loadcases

- SX0, SX+ and SX- are in loadgroup LGX
- SY0, SY+ and SY- are in loadgroup LGY

Combinations

- EQ1: SW, DL, LL, SX0, SX+, SX-, 0.3*SY0, 0.3*SY+, 0.3*SY-
- EQ2: SW, DL, LL, 0.3*SX0, 0.3*SX+, 0.3*SX-, SY0, SY+, SY-

3.3.2 Case with torsional equivalent loads

See modified data in project file ecc4.esa.

Loadgroups

- LG2 statical variable actions (LL)
- LG3 seismic actions in X-direction, seismic together

Loadcases

- SX0, SXT, SY0 and SYT are in loadgroup LG3

Combinations

8 loadcase combinations:

	EQ1	EQ2	EQ3	EQ4	EQ5	EQ6	EQ7	EQ8
SW, DL, LL	1	1	1	1	1	1	1	1
SX0	1	1	1	1	0.3	0.3	0.3	0.3
SXT	1	-1	1	-1	0.3	-0.3	0.3	-0.3
SY0	0.3	0.3	0.3	0.3	1	1	1	1
SYT	0.3	0.3	-0.3	-0.3	1	1	-1	-1