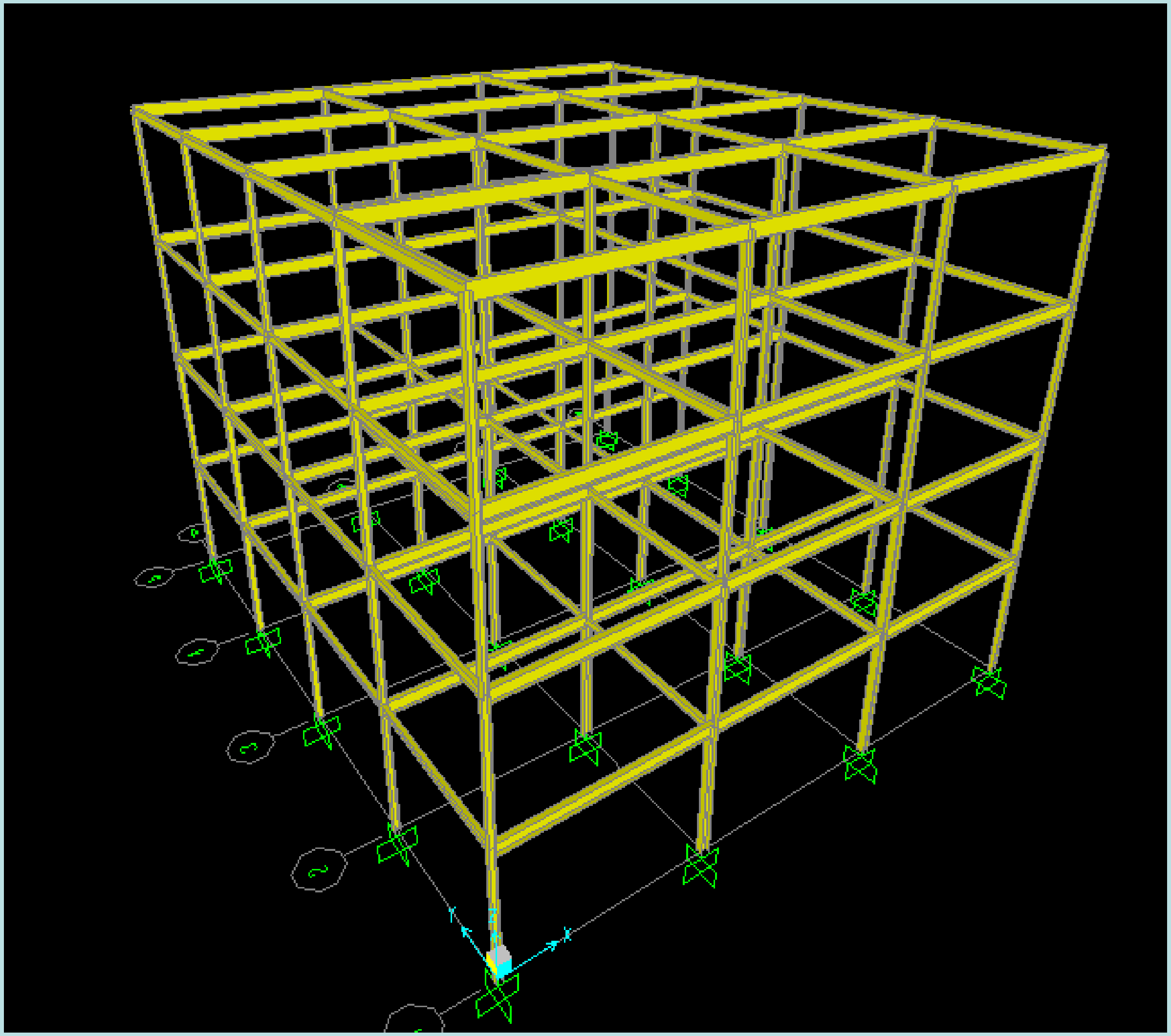
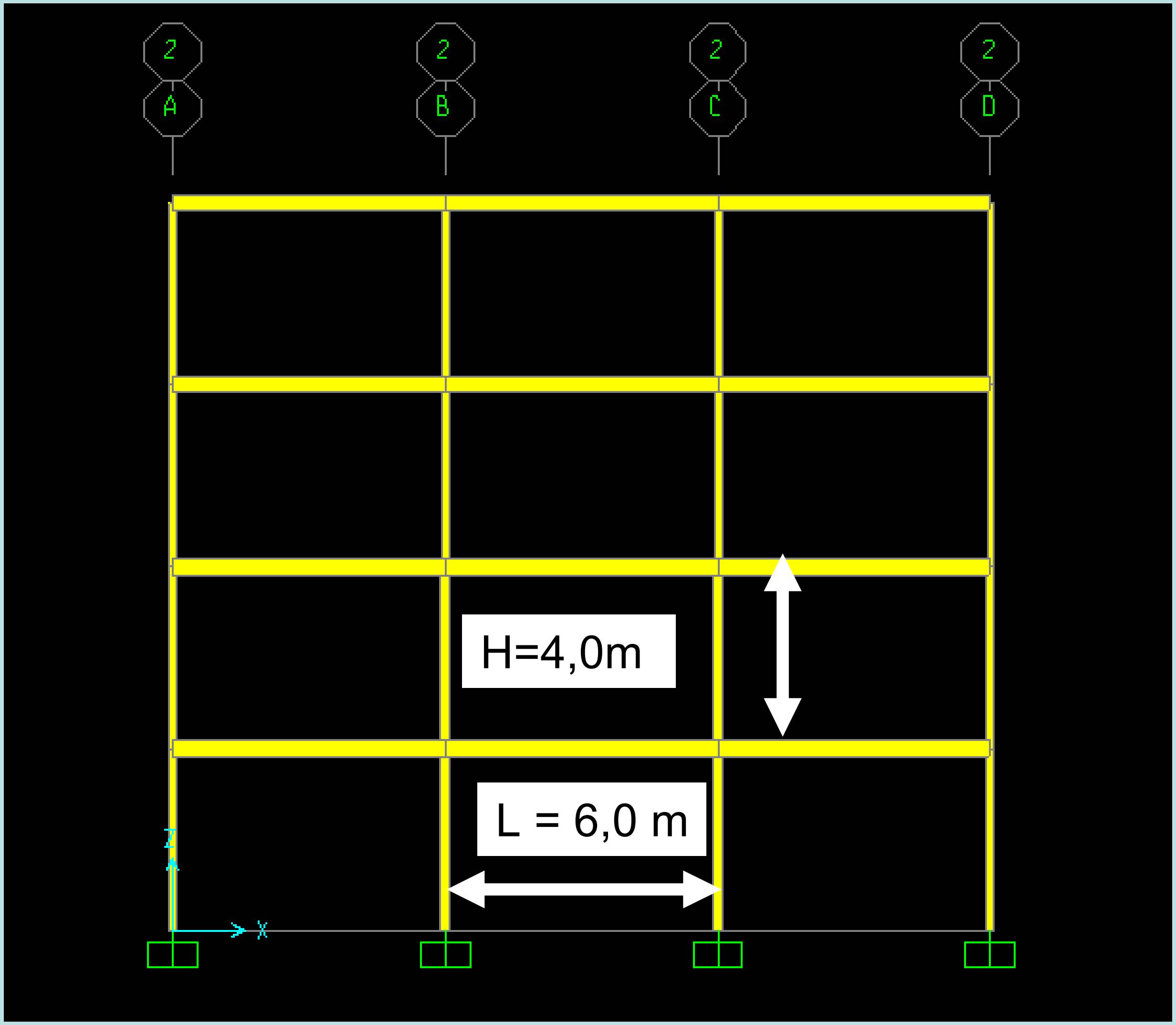
Application nr. 1
(Global Analysis)

Structure imperfection and
member imperfection to EC.3-1-1

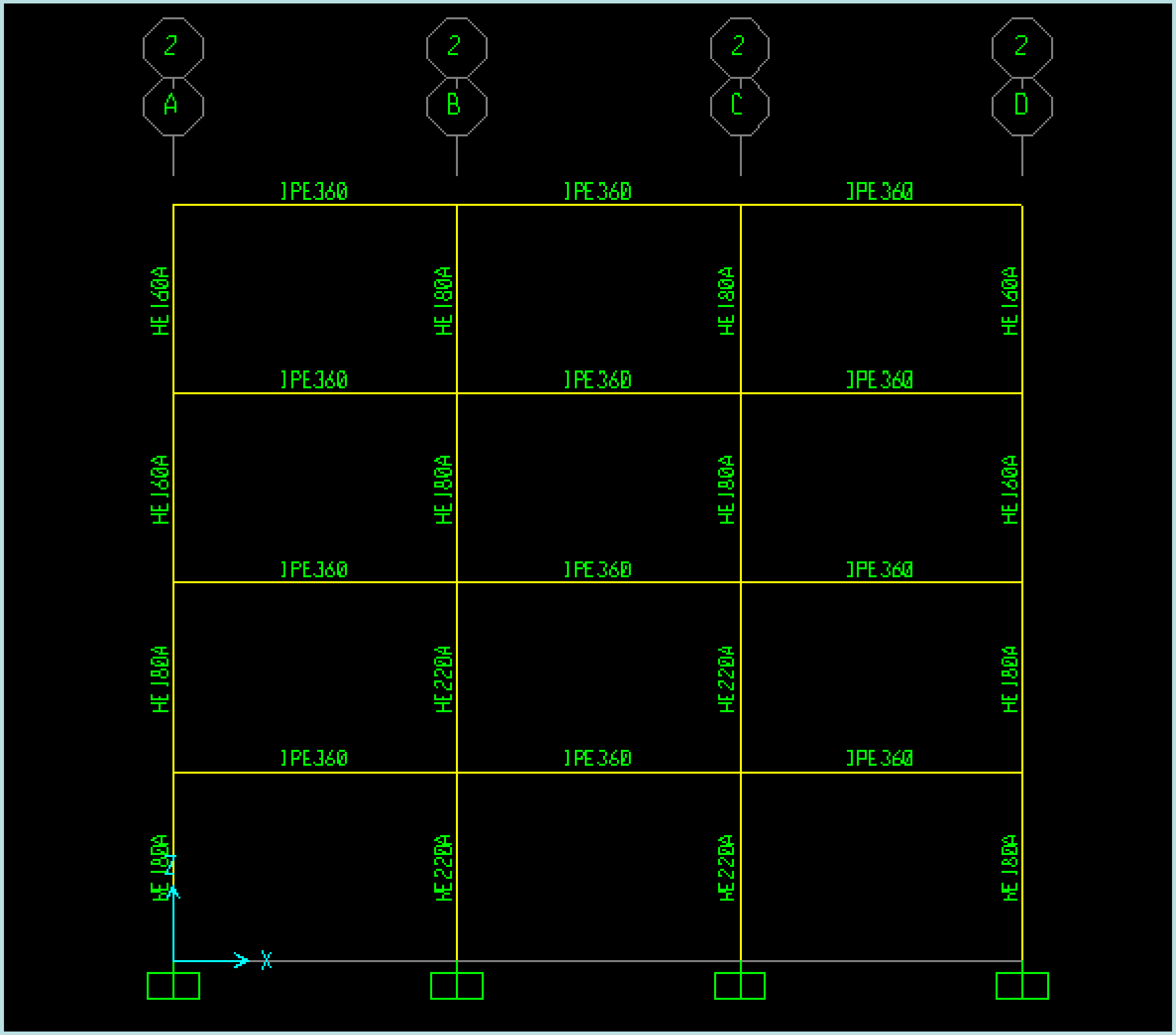
Object of study: multistorey structure (SAP 2000 nonlinear)



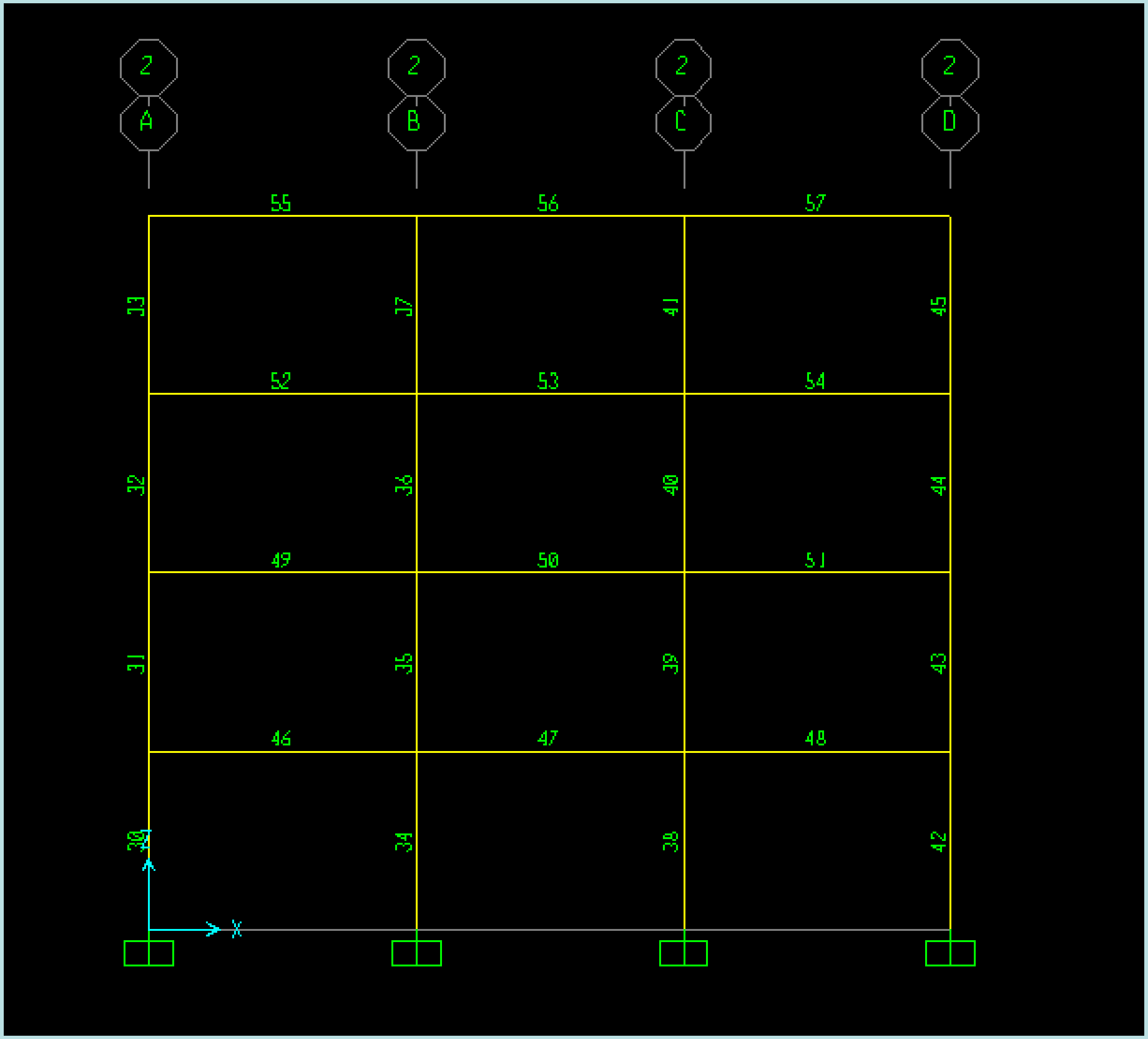
Geometry of structure



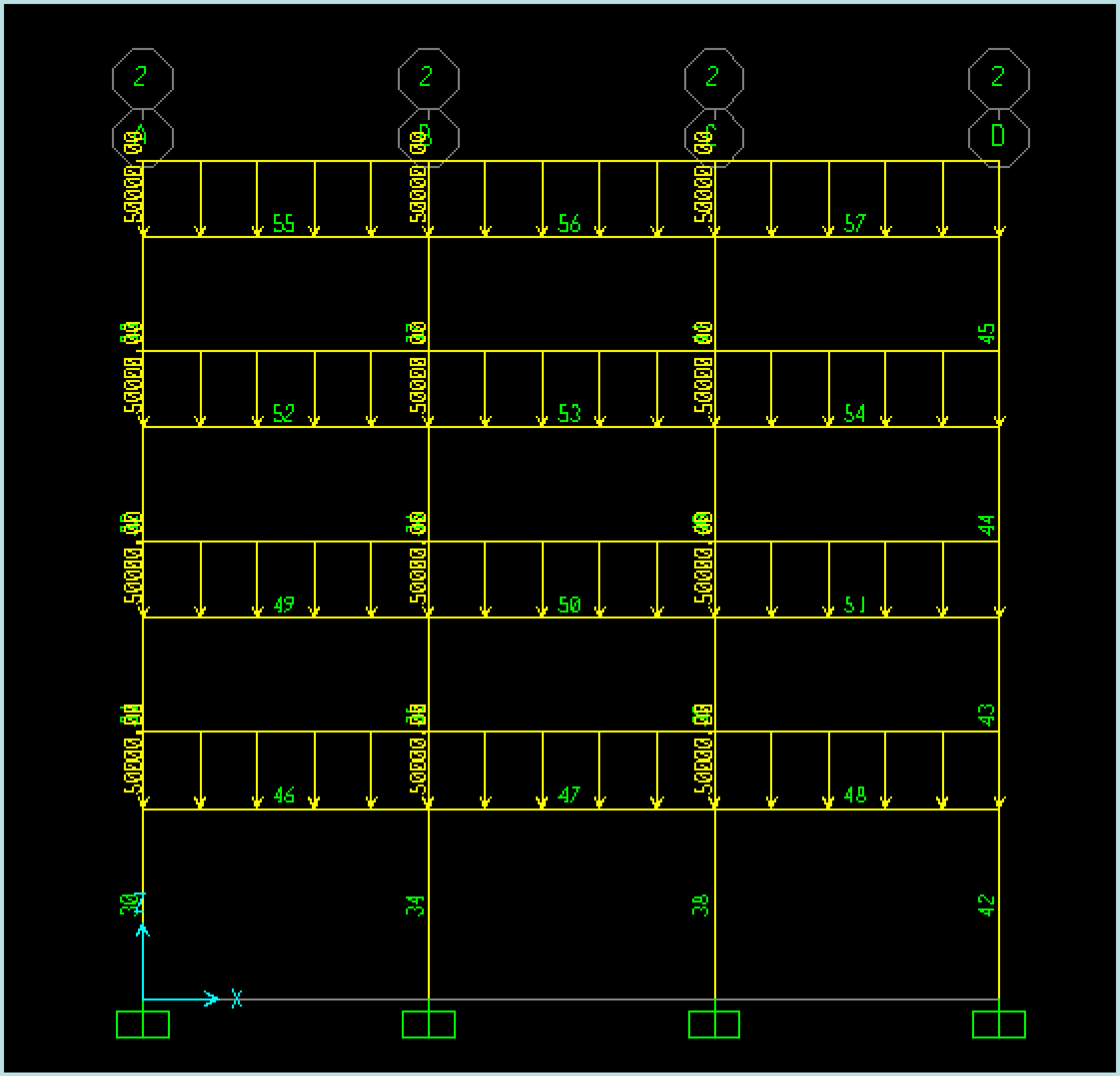
Cross-sections for columns and beams:



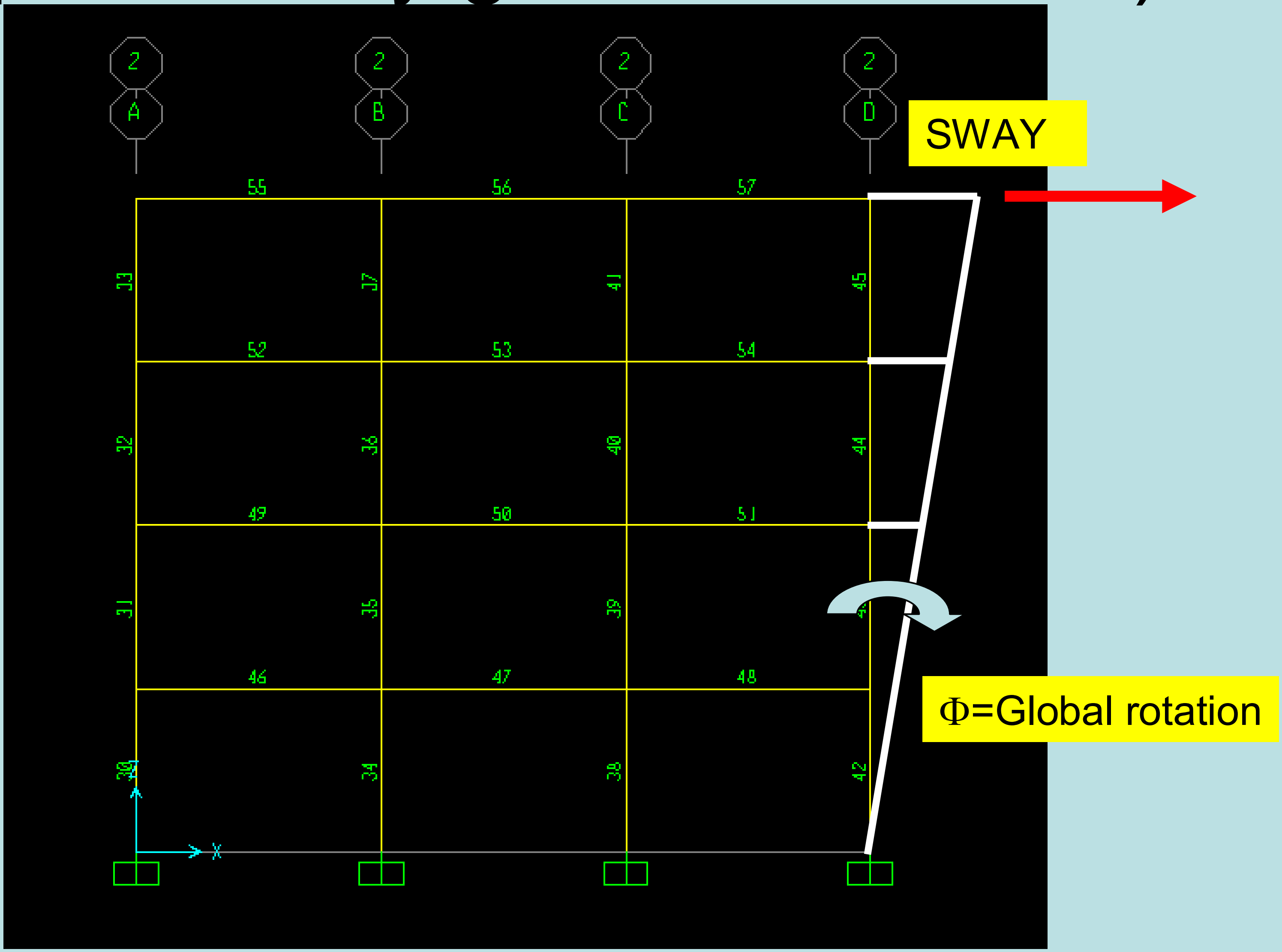
Labels (names) of columns and beams:



Uniformly distributed load:



Global sway of the structure (expressed by global rotation Φ)



Calculation of global initial sway imperfection (Φ):

$$\Phi = \Phi_0 \cdot \alpha_h \cdot \alpha_m$$

Where:

$$\Phi_0 = \frac{1}{200}$$

α_h = reduction factor for height (h) applicable to columns;

α_m = reduction factor for the number of columns in a row;

Calculation of factor (α_h)

Height of the structure = 4 storey x 4,0 m = 16,0 m

$$\Rightarrow \alpha_h = \frac{2}{\sqrt{h}} = \frac{2}{\sqrt{16}} = 0,5$$

Code supplementary condition: → $$\frac{2}{3} \leq \alpha_h \leq 1,0$$

Result: α_h = 2/3=0,667

Calculation of factor (α_m):

$$\alpha_m = \sqrt{0{,}5\left(1+\frac{1}{m}\right)}$$

Where m=4 =number of columns in a row (in our case)

$$\alpha_m = \sqrt{0{,}5\left(1+\frac{1}{4}\right)} = 0{,}791$$

Calculation of global initial sway imperfection (Φ)

$$\Phi = \frac{1}{200} \cdot 0{,}667 \cdot 0{,}791 = 0{,}00265\, radians$$

OBSERVATION: The result is a rotation angle measured in radians. This value is not simple to implement in static calculation of structures. Therefore equivalent horizontal forces (F_x) are used

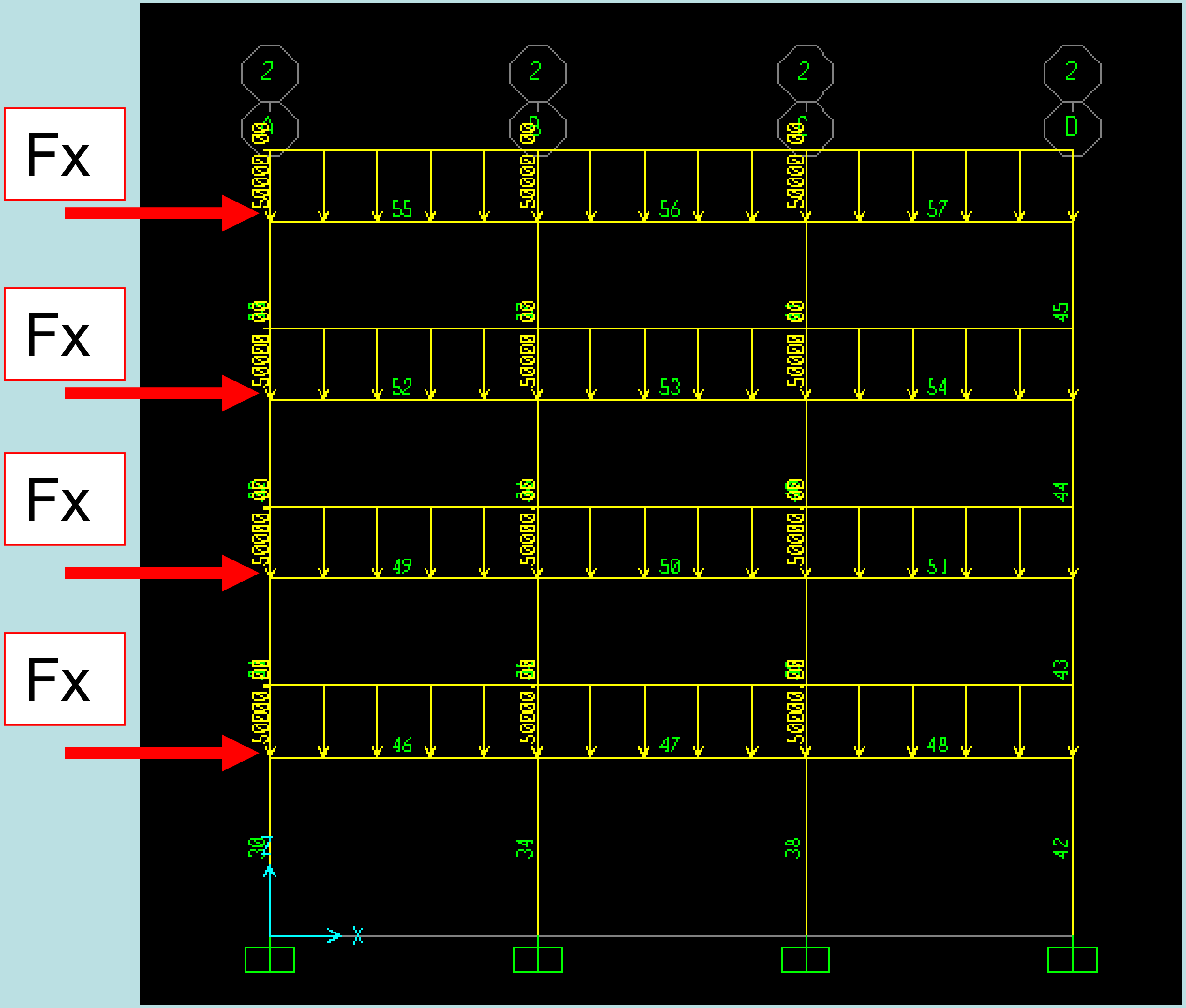
Equivalent horizontal forces shall be applied at each level to produce the same sway (they replace rotation Φ)

$$F_x = V \cdot \Phi$$

V = sum of vertical force at each storey = 3 span x 6,0m x 50000 N/m = 900000 N

$$\Rightarrow F_x = 0{,}00265 \cdot 900000 = 2385 \ N$$

Equivalent horizontal forces:

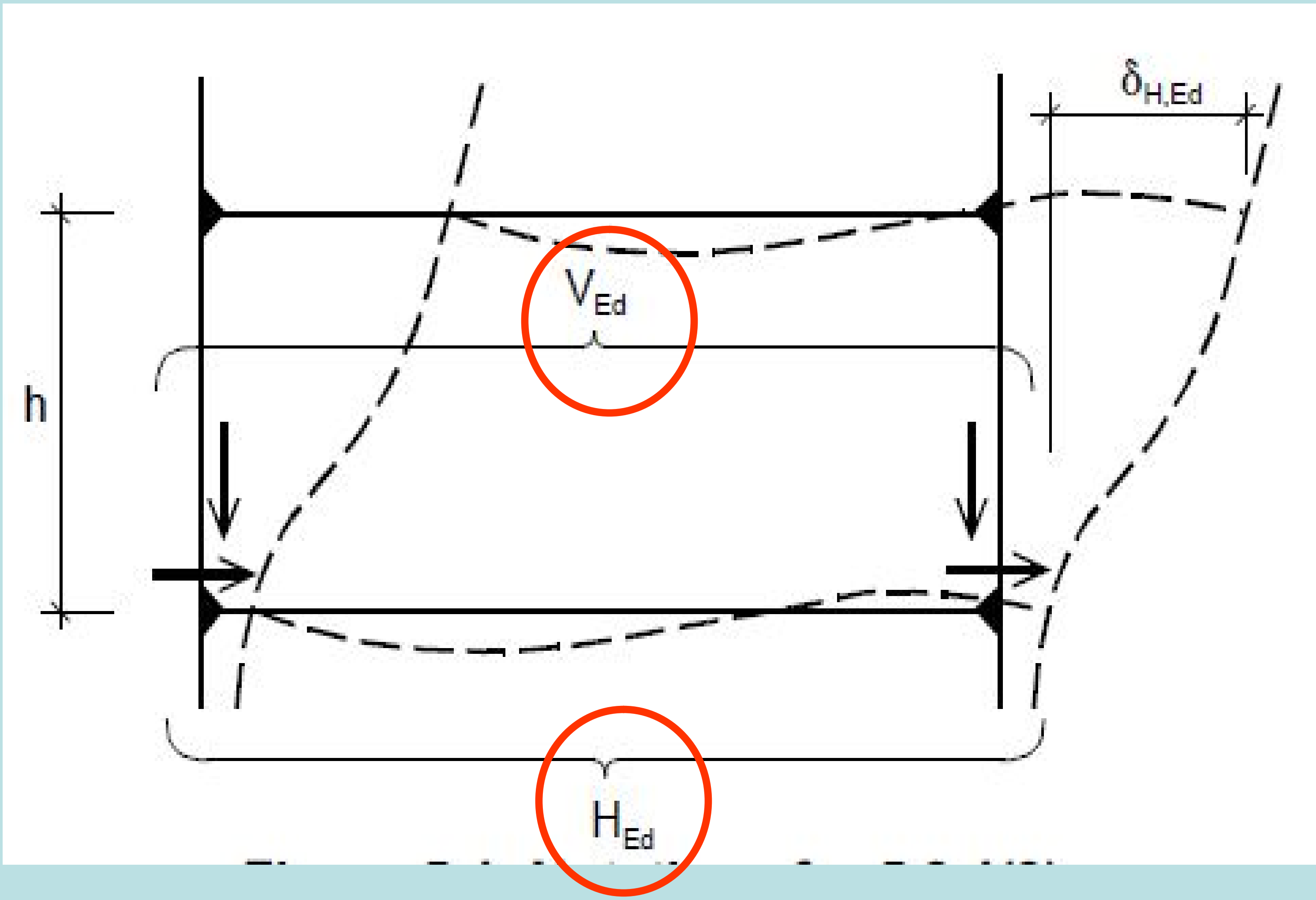


OBSERVATION-1:

- The global initial sway imperfection shall always be taken into consideration in the analysis of structures.
- The internal forces resulting from this use are serving for member calculation.
- For building frames, sway imperfection may be **disregarded** where:

$$H_{Ed} \geq 0{,}15 V_{Ed}$$

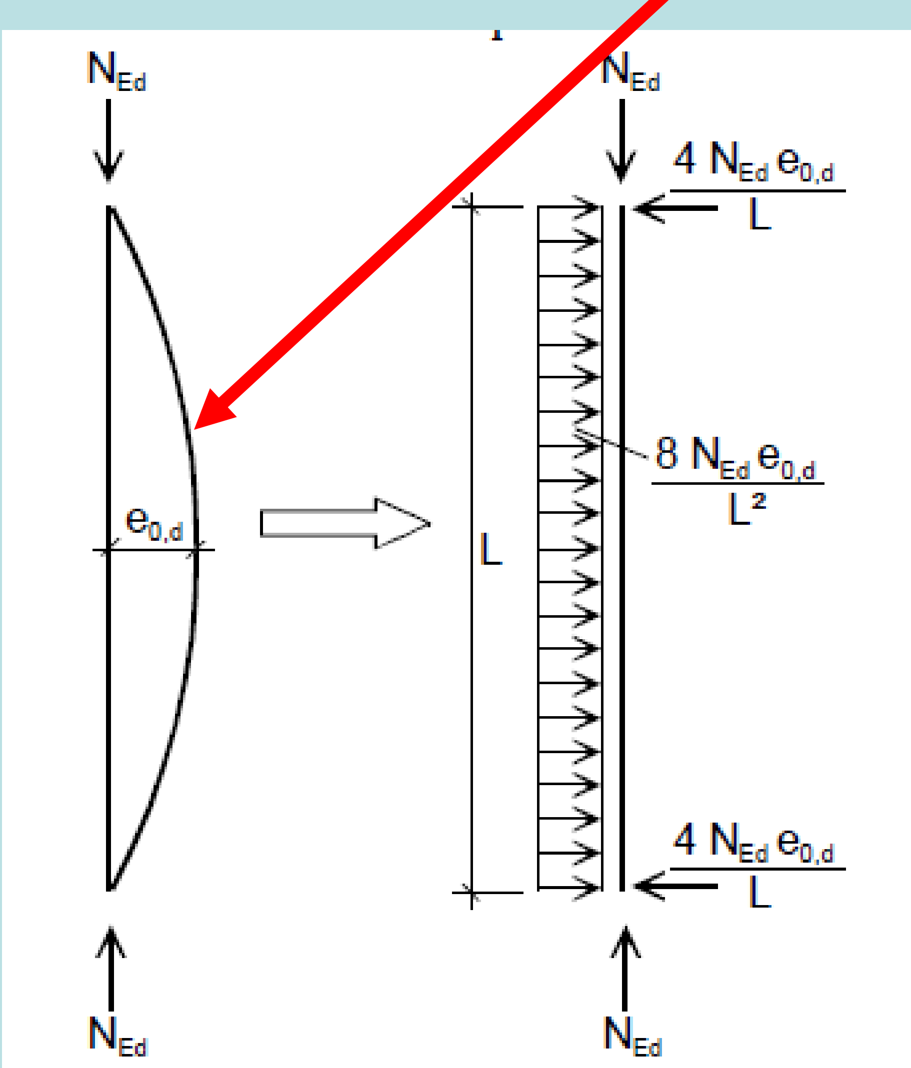
Significance of H_{Ed} and V_{Ed}



OBSERVATION-2:

- The initial sway imperfection should apply in all relevant horizontal directions, but need only be considered in one direction at a time !

The individual bow imperfection of members (columns):



- The effect of initial bow imperfection may be replaced in practical analysis by an equivalent horizontal force, uniformly distributed on corresponding columns
- This is an easier way to deal with this local imperfection in static analysis, when necessary.
- Otherwise, the geometrical bow shape is difficult to use directly into analysis

Formula for the equivalent bow imperfection:

$$q_{H.ech} = \frac{8N_{Ed}}{L} \cdot \left(\frac{e_{0,d}}{L} \right)$$

In which:

N_{Ed} = Axial force value in the analyzed column;

L = column height

(e_0/L) = relative bow imperfection to be taken from next table:

Relative bow imperfection to EC.3-1-1:

Buckling curve acc. to Table 6.1	elastic analysis	plastic analysis
	e_0 / L	e_0 / L
a_0	1 / 350	1 / 300
a	1 / 300	1 / 250
b	1 / 250	1 / 200
c	1 / 200	1 / 150
d	1 / 150	1 / 100

Taking into consideration bow imperfection?

- When performing the global analysis for end forces and end moments to be used in member checks, local bow imperfection may be neglected.

- For frames sensitive to second order effect, local bow imperfection of members should be introduced in addition to global sway imperfection, if the following conditions are met:

Conditions to consider local bow imperfection:

$$\bar{\lambda} > 0,5\sqrt{\frac{A \cdot f_y}{N_{Ed}}}$$

Where N_{Ed} = value of compression force and:

$\bar{\lambda}$ = in-plane non-dimensional slenderness calculated for the analyzed member, considered hinged at its ends;

$$\bar{\lambda} = \frac{L_{cr}}{i} \cdot \frac{1}{\lambda_1} \rightarrow \lambda_1 = 93,9\sqrt{\frac{235}{f_y}}$$

In our case,

L_{cr} = h=4,0 m

The analyzed column should have at least one moment resistant joint !

In order to see if the bow imperfection should be considered for any of the columns, a table calculation is performed to check conditions:

Column label	Cross-section	Gyration radius [cm]	A [cm^2]	Lcr [cm]	**Lmd-bar**	Axial force [N]	NEd [daN]	fy [daN/cm^ 2]	**Lmbd-Comp**
34	HE220A	9.17	64.3	400	**0.46**	1299328	129932.8	2400	**0.54**
35	HE220A	9.17	64.3	400	**0.46**	973866	97386.6	2400	**0.63**
38	HE220A	9.17	64.3	400	**0.46**	1299328	129932.8	2400	**0.54**
39	HE220A	9.17	64.3	400	**0.46**	973866	97386.6	2400	**0.63**
30	HE180A	7.45	45.3	400	**0.57**	534602	53460.2	2400	**0.71**
31	HE180A	7.45	45.3	400	**0.57**	399511	39951.1	2400	**0.82**
36	HE180A	7.45	45.3	400	**0.57**	973355	97335.5	2400	**0.53**
37	HE180A	7.45	45.3	400	**0.57**	649219	64921.9	2400	**0.65**
40	HE180A	7.45	45.3	400	**0.57**	973355	97335.5	2400	**0.53**
41	HE180A	7.45	45.3	400	**0.57**	649219	64921.9	2400	**0.65**
42	HE180A	7.45	45.3	400	**0.57**	534602	53460.2	2400	**0.71**
43	HE180A	7.45	45.3	400	**0.57**	399511	39951.1	2400	**0.82**
32	HE160A	6.57	38.8	400	**0.65**	398549	39854.9	2400	**0.76**
33	HE160A	6.57	38.8	400	**0.65**	263478	26347.8	2400	**0.94**
44	HE160A	6.57	38.8	400	**0.65**	398549	39854.9	2400	**0.76**
45	HE160A	6.57	38.8	400	**0.65**	263478	26347.8	2400	**0.94**

Conclusion: for ALL the columns, the condition is met:

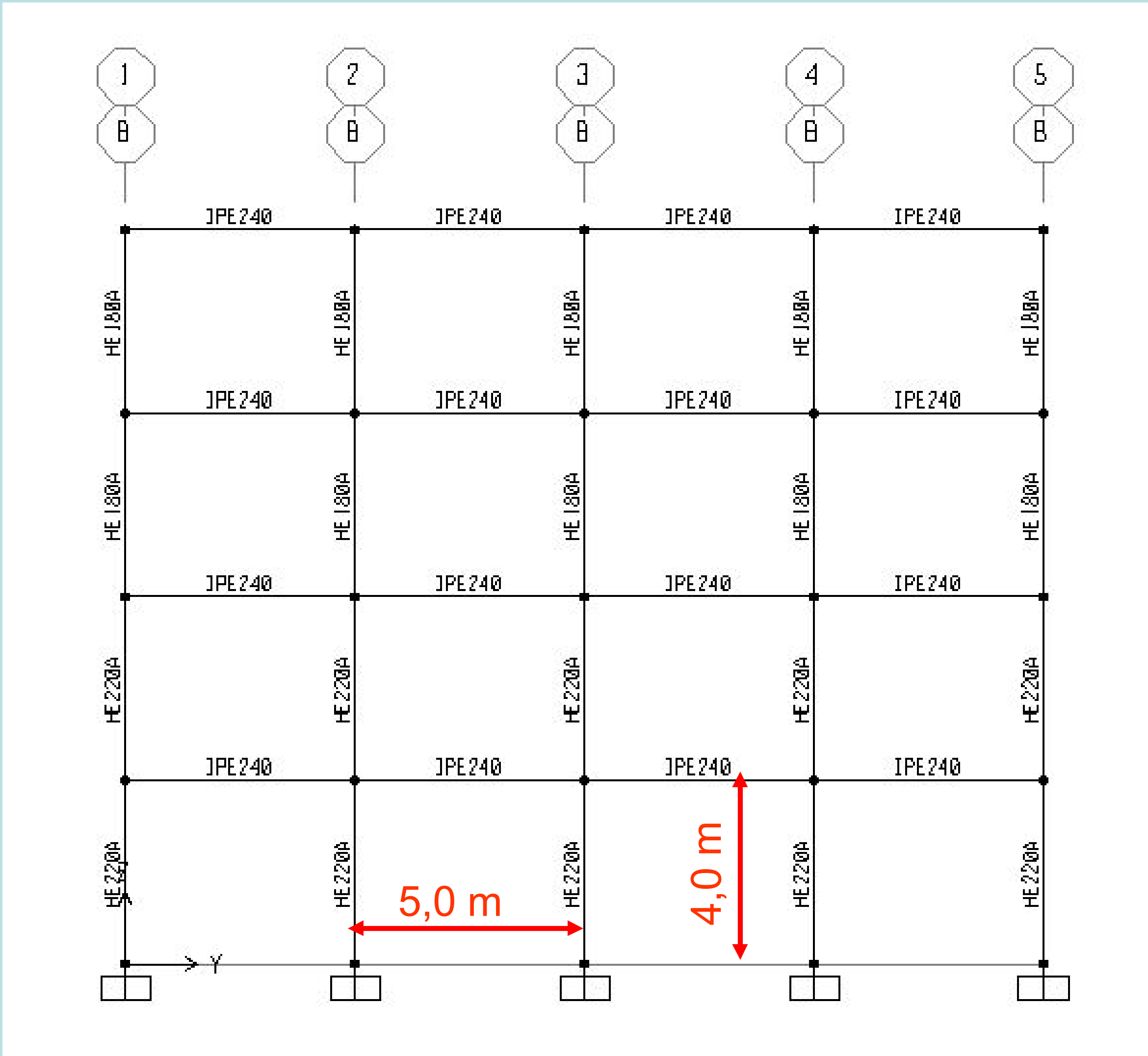
$$\overline{\lambda} < 0{,}5\sqrt{\frac{A \cdot f_y}{N_{Ed}}}$$

⇒In this case, for the transverse frame, the bow imperfection shall NOT be taken into consideration for all the columns, (it is not necessary)

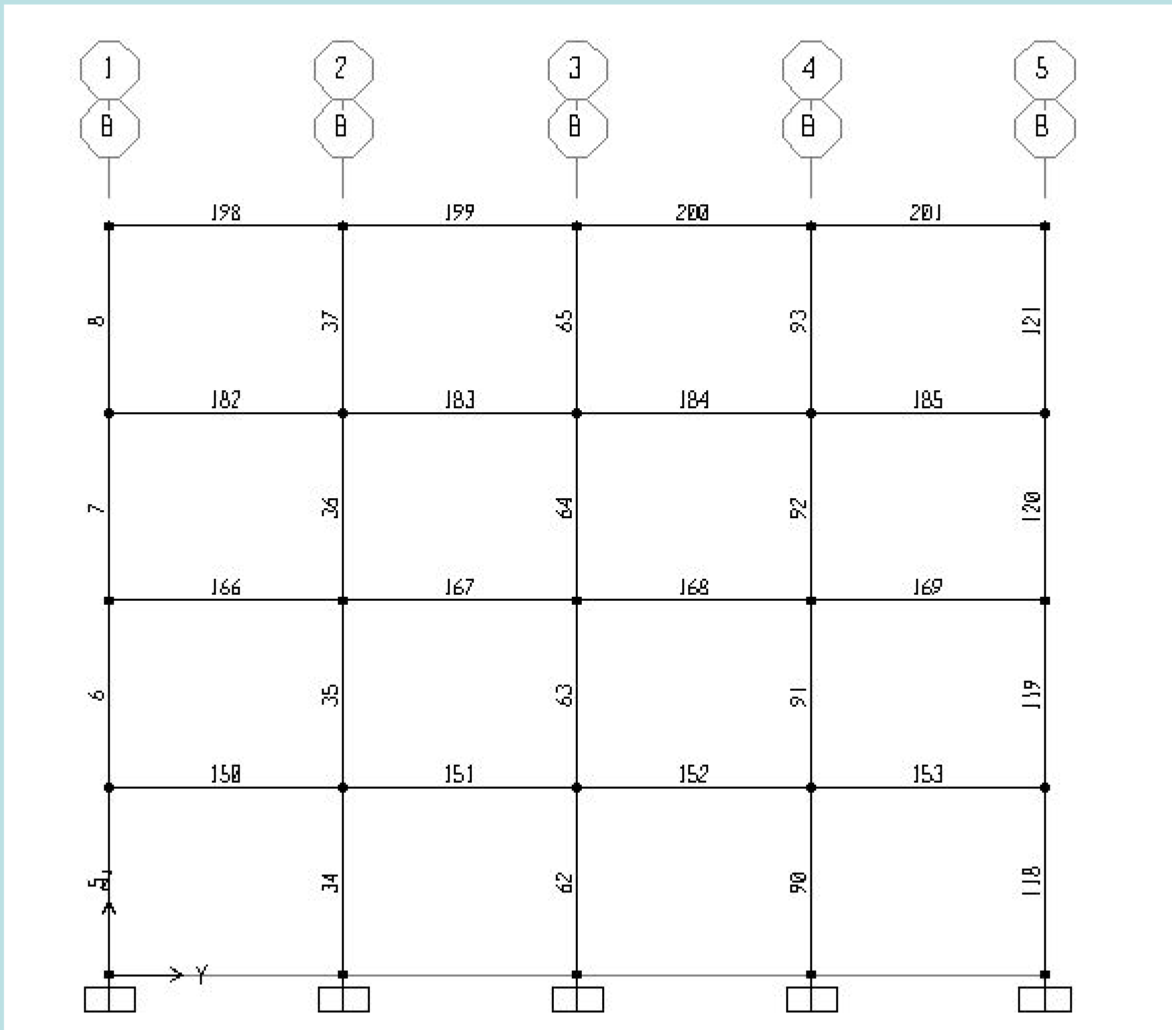
⇒However, the same condition should be checked for the longitudinal frame, also operating with the gyration radius about minimum inertia axis

(plus profiles labels and sections accordingly!)

Longitudinal frame: profiles and geometry:



Labels of the columns for longitudinal frame (used to find the new values of axial forces)



Checking of the bow imperfection condition for the longitudinal frame:

Column Label	Cross Section	Gyration radius [cm]	A [cm^2]	Lcr [cr]	**Lmd-bar**	Axial force [N]	NEd [daN]	fy [daN/cm^]	**Lmbd-Comp**
5	HE220A	5.51	64.3	400	**0.77**	668491	66849.1	2400	**0.76**
6	HE220A	5.51	64.3	400	**0.77**	501743	50174.3	2400	**0.88**
34	HE220A	5.51	64.3	400	**0.77**	1299675	129967.5	2400	**0.54**
35	HE220A	5.51	64.3	400	**0.77**	974335	97433.5	2400	**0.63**
62	HE220A	5.51	64.3	400	**0.77**	1310463	131046.3	2400	**0.54**
63	HE220A	5.51	64.3	400	**0.77**	983719	98371.9	2400	**0.63**
90	HE220A	5.51	64.3	400	**0.77**	1299675	129967.5	2400	**0.54**
91	HE220A	5.51	64.3	400	**0.77**	974335	97433.5	2400	**0.63**
118	HE220A	5.51	64.3	400	**0.77**	668491	66849.1	2400	**0.76**
119	HE220A	5.51	64.3	400	**0.77**	501743	50174.3	2400	**0.88**
7	HE180A	4.52	45.3	400	**0.94**	335030	33503	2400	**0.90**
8	HE180A	4.52	45.3	400	**0.94**	168462	16846.2	2400	**1.27**
36	HE180A	4.52	45.3	400	**0.94**	650614	65061.4	2400	**0.65**
37	HE180A	4.52	45.3	400	**0.94**	327617	32761.7	2400	**0.91**
64	HE180A	4.52	45.3	400	**0.94**	657532	65753.2	2400	**0.64**
65	HE180A	4.52	45.3	400	**0.94**	331119	33111.9	2400	**0.91**
92	HE180A	4.52	45.3	400	**0.94**	650614	65061.4	2400	**0.65**
93	HE180A	4.52	45.3	400	**0.94**	327617	32761.7	2400	**0.91**
120	HE180A	4.52	45.3	400	**0.94**	335030	33503	2400	**0.90**
121	HE180A	4.52	45.3	400	**0.94**	168462	16846.2	2400	**1.27**

Conclusion: for ALL the columns, except 6, 8, 119, 121, the condition is met:

$$\bar{\lambda} > 0{,}5\sqrt{\frac{A \cdot f_y}{N_{Ed}}}$$

⇒For the longitudinal frame, the bow imperfection shall be taken into consideration for all the columns except 6, 8, 119, 121

The values of the equivalent horizontal load to the bow imperfection are calculated in the table below:

Column label	Cross-section	NEd [N]	L [m]	(e0/L)	qH.ech [N/m]
5	HE220A	668491	4	0.004	**5348**
6	HE220A	501743	4	0.004	**NOT necessary**
34	HE220A	1299675	4	0.004	**10397**
35	HE220A	974335	4	0.004	**7795**
62	HE220A	1310463	4	0.004	**10484**
63	HE220A	983719	4	0.004	**7870**
90	HE220A	1299675	4	0.004	**10397**
91	HE220A	974335	4	0.004	**7795**
118	HE220A	668491	4	0.004	**5348**
119	HE220A	501743	4	0.004	**NOT necessary**
7	HE180A	335030	4	0.004	**2680**
8	HE180A	168462	4	0.004	**NOT necessary**
36	HE180A	650614	4	0.004	**5205**
37	HE180A	327617	4	0.004	**2621**
64	HE180A	657532	4	0.004	**5260**
65	HE180A	331119	4	0.004	**2649**
92	HE180A	650614	4	0.004	**5205**
93	HE180A	327617	4	0.004	**2621**
120	HE180A	335030	4	0.004	**2680**
121	HE180A	168462	4	0.004	**NOT necessary**

Equivalent horizontal load to bow imperfection applied on the frame (for SAP analysis!):