Computational Mechanic Tools

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Project 3: Building subjected to Wind Loads

MASTER'S DEGREE IN NUMERICAL METHODS IN ENGINEERING
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Contents

List of Figures

1 INTRODUCTION

Nowadays structures are slender, optimizing materials and geomtries in order to generate less pollution and develope new techonologies. The new methodologies and constructions push to invesitgate new phenomenas that previously did not appear at oversized ancient structures.

This is the case of office and resindential builings of today's located in the big cites, where turbulent air flow due to various volumetries become a necessary field of study.

Through this report that is divided in several parts, firstly is described the problem statement and the different cases that will be analized. The methodology related with the different commertial software used for the Structura and dynamic analysis is presented.

Later on, the structural design verification is carryed out using an application tool that verifies how much of the sturcutral profile is being used according to given national starfards. On the other side, a carefully dynamic analysis through a modal analysis is compared and discussed with the collected related with the wind frequencies datum.

Finally the conclusions of the wind load applied to residential/office buildings and the strcutrual verification are presented.

2 PROBLEM STATEMENT

In our work, we are supposed to do the static and dynamic analysis for a two-store building shown in figure 1 and there are several load cases and boundary conditions.

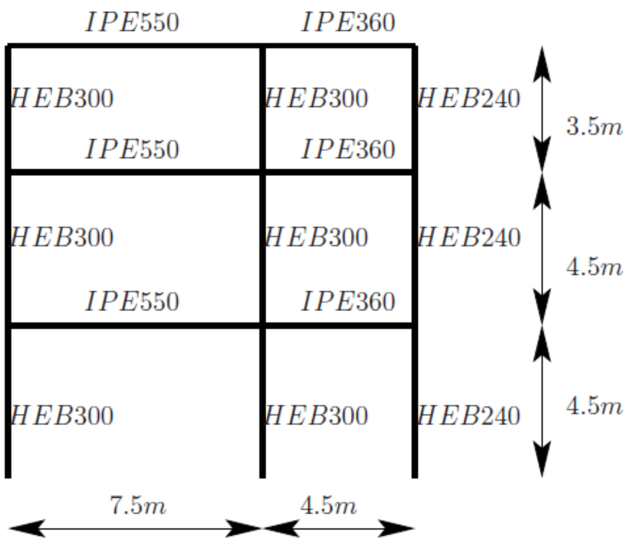

Figure 1: Geometry and properties of the frame

The model is a 2-D frame whose compositions have different properties. Since the geometry is not symmetric or antisymmetric, we couldn't do any simplifications for the model.

The boundary conditions include:

1) Clamped: All displacements and rotations are set to be zero.
2) Hinged: Except that the rotation on the plane is free, all displacements and rotations are set to be zero.

We need to combine the boundary conditions listed above to get different constraints cases. The constrains are imposed on the base of the columns.

Also we have several load cases. Three types of loads are considered, including wind load, point load and distributed load. The distriuted load is computed as:

$$f = \alpha_{dl} q_{dl} + \alpha_{ll} q_{ll}$$

Where the nominal loads q_{dl} and q_{ll}, and the security factors α_{dl} and α_{ll} are already given.

The load cases are:

1) Wind load plus point load. This load case is shown in figure 2.

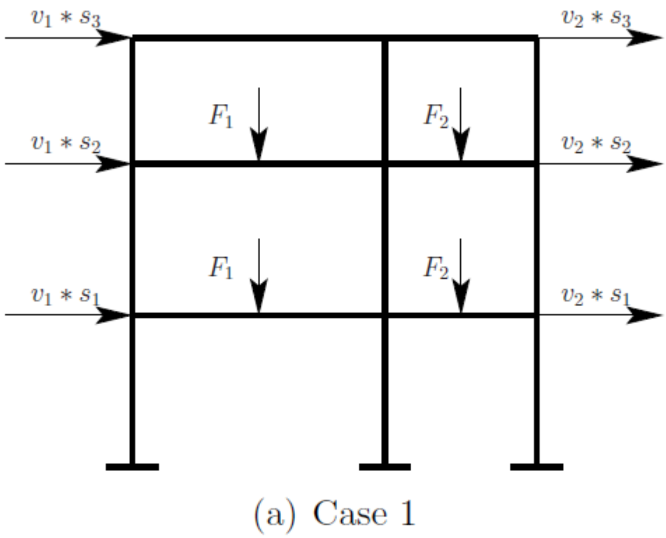

Figure 2: Wind load plus point load

2) Wind load plus distributed load. This load case is shown in figure 3.

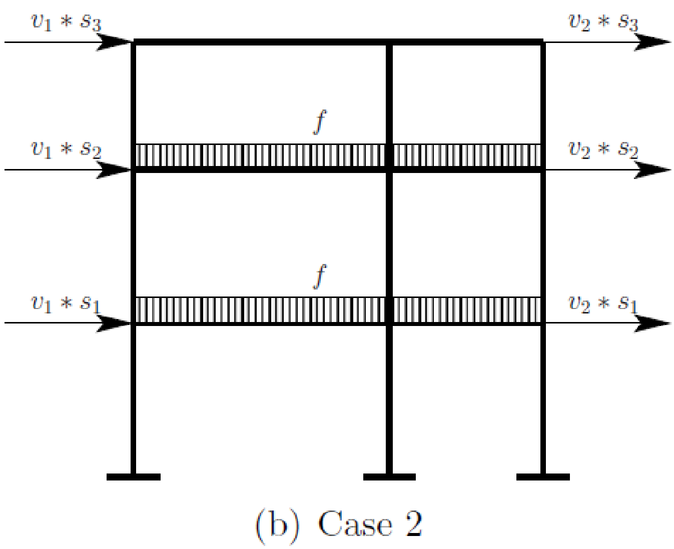

Figure 3: Wind load plus distributed load

For static analysis,the results needed to be analyzed are deformations, axial stresses and bending moments for different loads and constriants combinations. Then we need to do modal analysis for dynamic analysis.

3 METHODOLOGY

In order to carry out the structural verification of the already proposed profiles for the three story and two bay buliding it is necessary to create the geometry. For this problem type a 2D model is enough. The geometry is defiend using the pre-process tool provided by SAP 2000 V20.

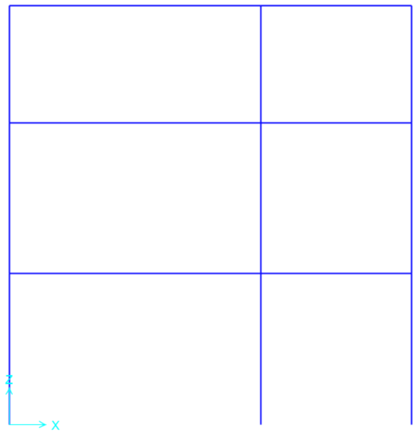

Figure 4: SAP 2000 geometry user defined

Once the geomrety was set, the material definition was introduced. The commertial structural software SAP 2000 provides a material library, where European steel, grade S275 was chosen for this project, as it wasn't defined in the project statement, according to figure 5.

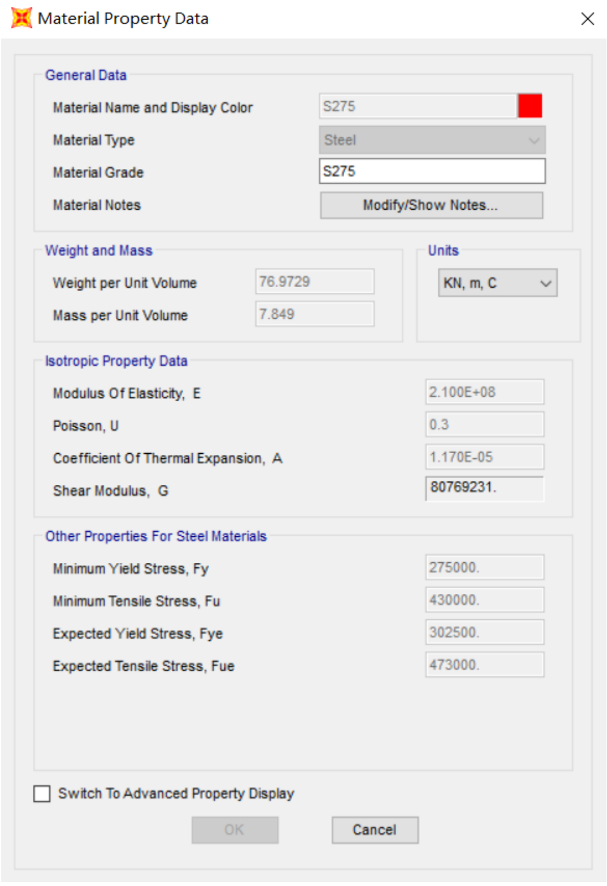

Figure 5: SAP 2000 material properties

In the same direction, once the geometry and the material were defined, the structural sections were loaded from the SAP 2000 libraries for Europe. The different sections HEB 300, HEB 240, IPE 550 and IPE 260 where assigned to the linear elements of the geometry, figures 6 and 7.

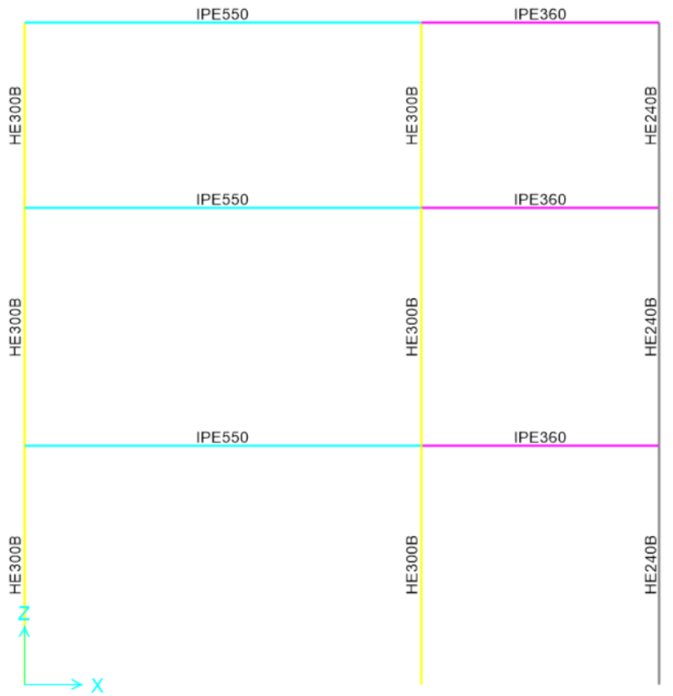

Figure 6: SAP 2000 geometry user defined

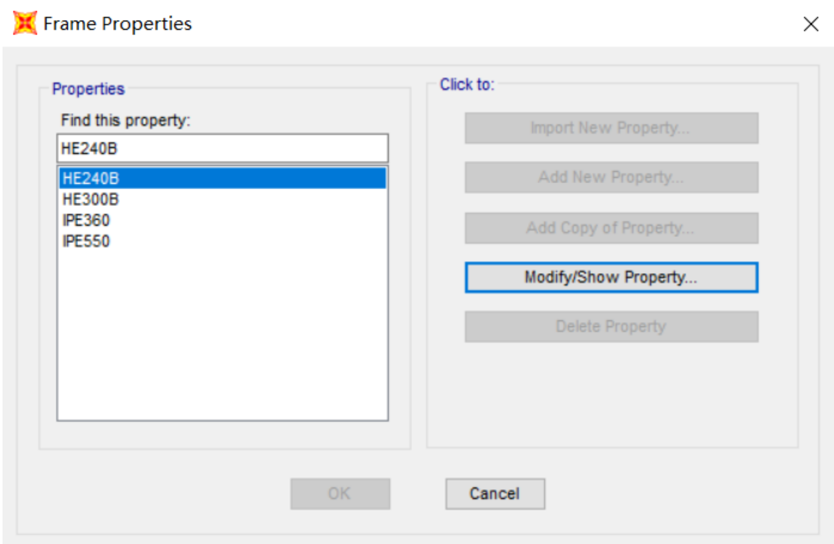

Figure 7: SAP 2000 material properties

A necessary definition is the boundary conditions, being the column supports for this case. The supports can be hinged, fixed or mixed according to the needs of the study in order to evaluate how the structure behavies, these are imposed in the column base nodes.

Two different load cases are applied, involing vertical loads (point and distributed) and horizontal loads simulating the wind force applied to each slab story, the loads were defiend and combiend with dead load for each load case, figure 8.

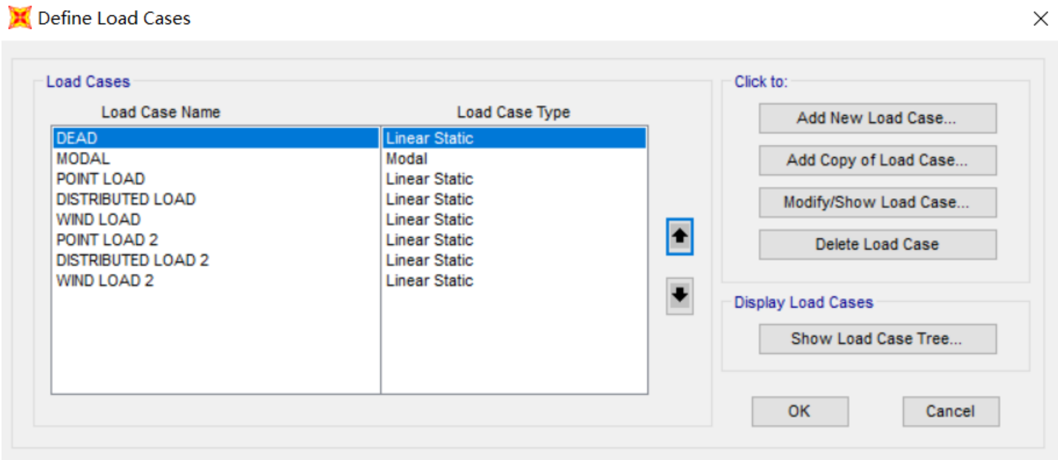

Figure 8: SAP 2000 load case definition

Finally, the modal anaylsis was set in order to provide the natural frequencies of the structure, we did this by considering different mass sources and different supports. The number of modes were choosen in order to mobilize at least the 90% of the structure in order to rely on the significant modes to check, figure 9.

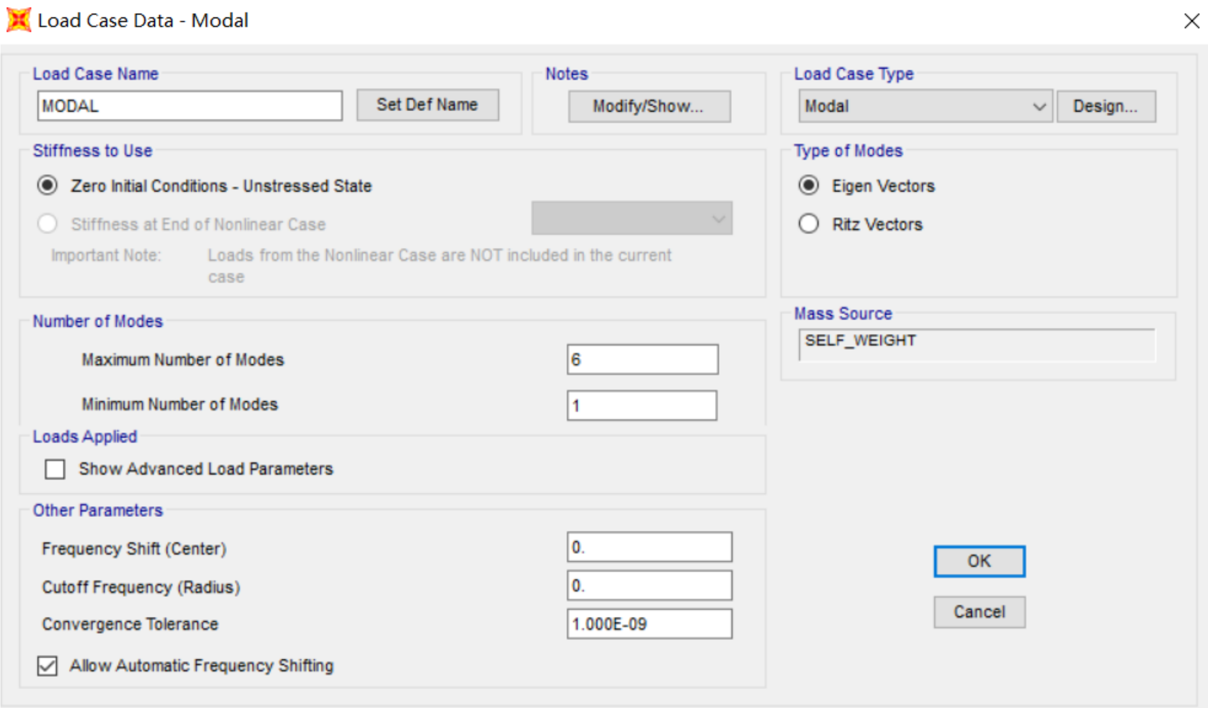

Figure 9: SAP 2000 Modal analyisis setting

Once all the conditions and parameters are defined, the solver can be invoked inside SAP 2000 V20, and the post-process can be discussed on the following stage.

4 Results

The problem was solved with the commential structure software SAP 2000 V20. On the following lines we are going to show the results and comment the structrual behavioir depending on different conditions:

4.1 Clampled supports

4.1.1 Load case 1

This section analyzes the load case 1 for the puntual loads on the beam midspan combiend with the wind forces (horizontally applied on the façade). The supports are fixed on the base columns, that means restraints on all displacements and moments.

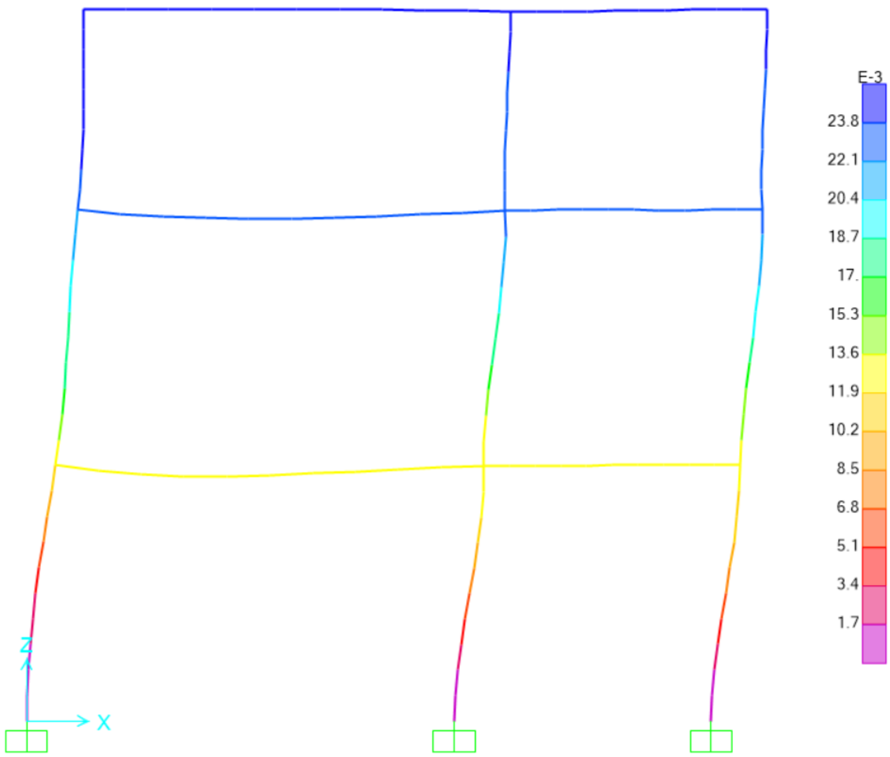

Figure 10: Displacement in X direction, clampled supports with load case 1

In the figure 10, the structure displacement on X direction is plotted. The maximum displacement happens on the top of the structure, with value 2.38 cm. According with the B.c, the base columns displacements are 0 cm. The clamped supports keep the horizontal forces to the foundations, helping to the structures to have smaller deformation on the X direction.

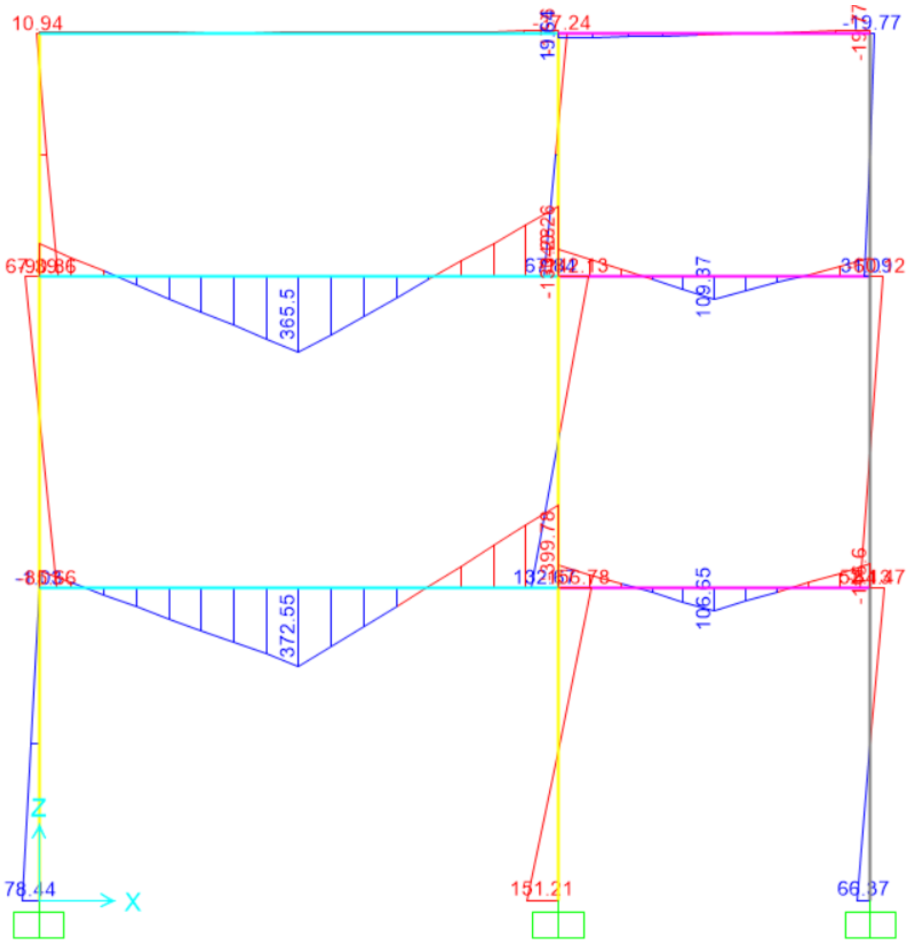

Figure 11: Bending moment, clampled supports with load case 1

Figure 11, the bending moments (positive and negative) on the structure are bigger on the beams where the punctual load is applied, the ones with longer span present the biggest positive bending moment 372.55 kNm $-$ 365.5 kNm . In that case, the magnitude of the vertical loads are much bigger compared with the horizontal loads (for example the bending moment on the base columns are 151 kNm).

The next figure 12, the axial stress plot is shown. In that figure, the maximum stresses are located under the punctual loads. This is due to the high bending moments we have seen in the picture 11. The stress distribution is according to the point loads applied on the façada and beams.

This figure 13, shows the ratios of use of each element according to USA steel national standards. In accordance to the figure 11 and 12, the elements that are using around 50% $-$ 60% of its mechanical properties are the beams with punctual load and the base middle column (have more loaded width).

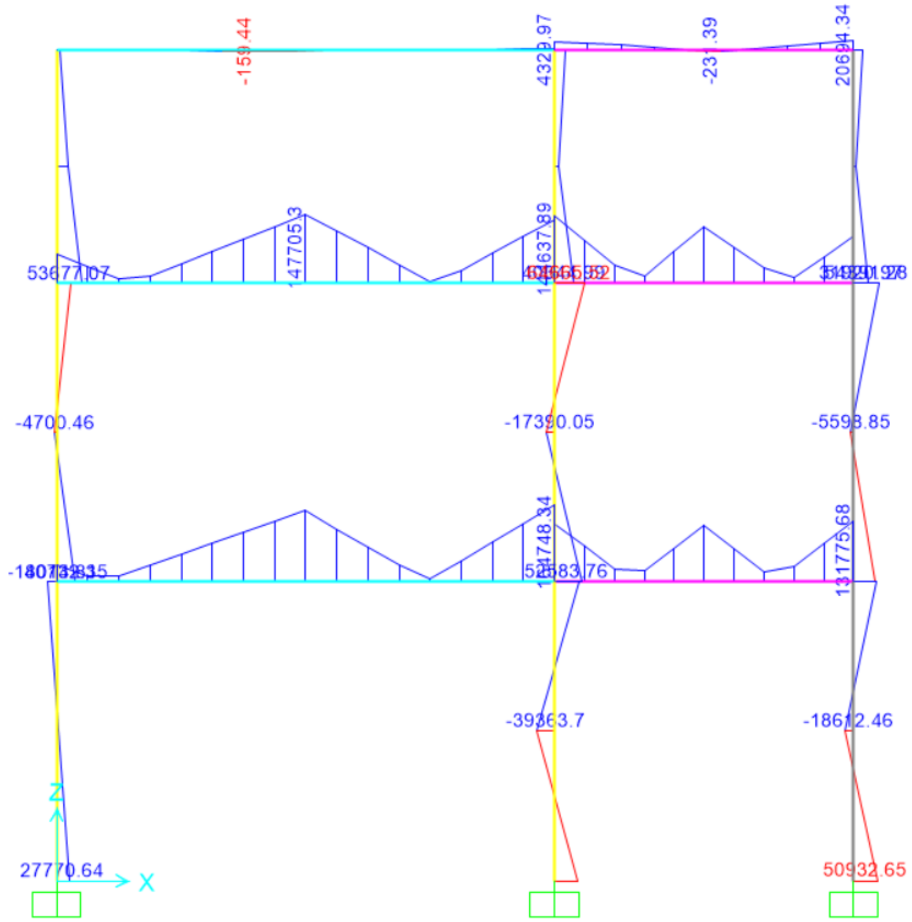

Figure 12: Axial stresst, clampled supports with load case 1

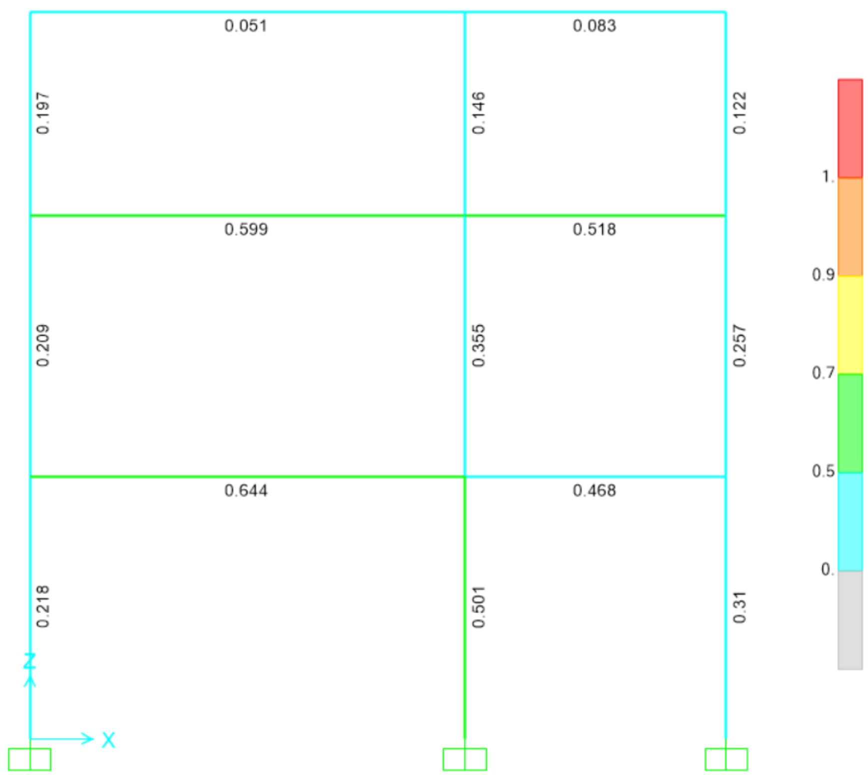

Figure 13: Axial stresst, clampled supports with load case 1

4.1.2 Load case 2

This section analyzes the load case 2 for the distributed loads along the beams combiend with the wind forces (horizontally applied on the façade). The supports are fixed on the base columns, that means restraint in all displacements and moments.

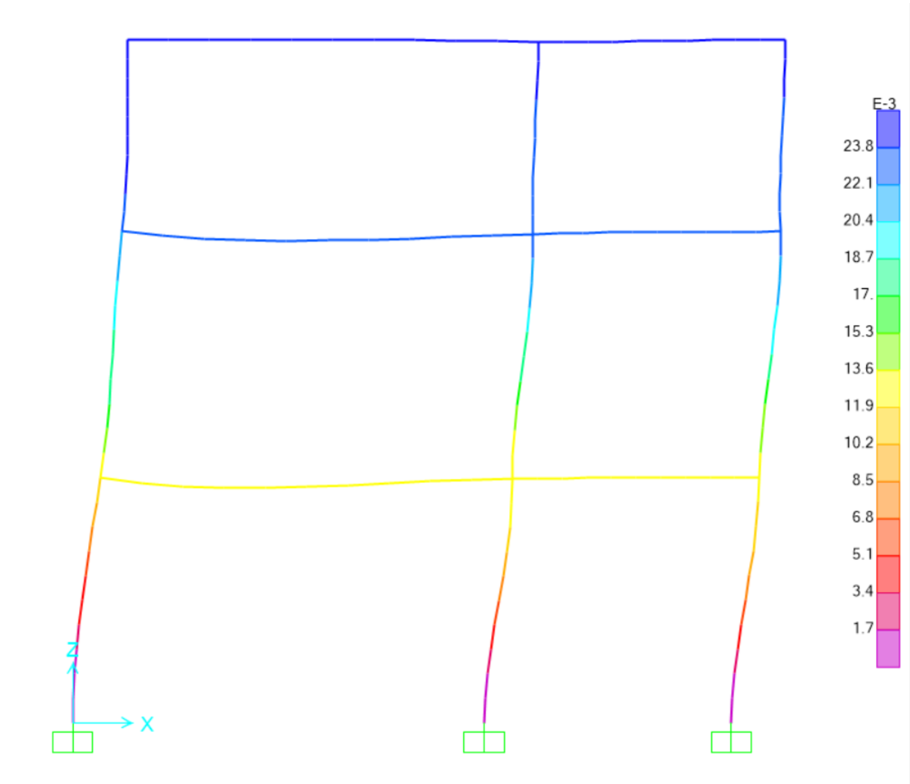

Figure 14: Displacement in X direction, clampled supports with load case 2

In the figure 14, the structure displacement on X direction are similar to load caes 1, meaning that the vertical forces applied on the beams have little influences on the X direction displacements.

Figure 15 shows the bending moments (positive and negative) whose distribution on the beams have changed to parabolic shape. In point load case, the bending moments distribution on the beams are linear shape. Also, the maximum bending moments values on the beams have decreased to about 226 kNm, 210 kNm and the maximum values are appearing on the joint points of the middle column and horizontal beams. The bending moments values on the columns have changed little.

In the figure 16, we can appreciate the stress distribution for the load case 2. The biggest stresses are located in the beam where the distributed load are applied. The stress distribution is parabolic. In this case the maximum stress is close to the joints, due to the high negative bending moment close to the supports.

For the ratio of use, figure 18, the values are similar to the load case 1.

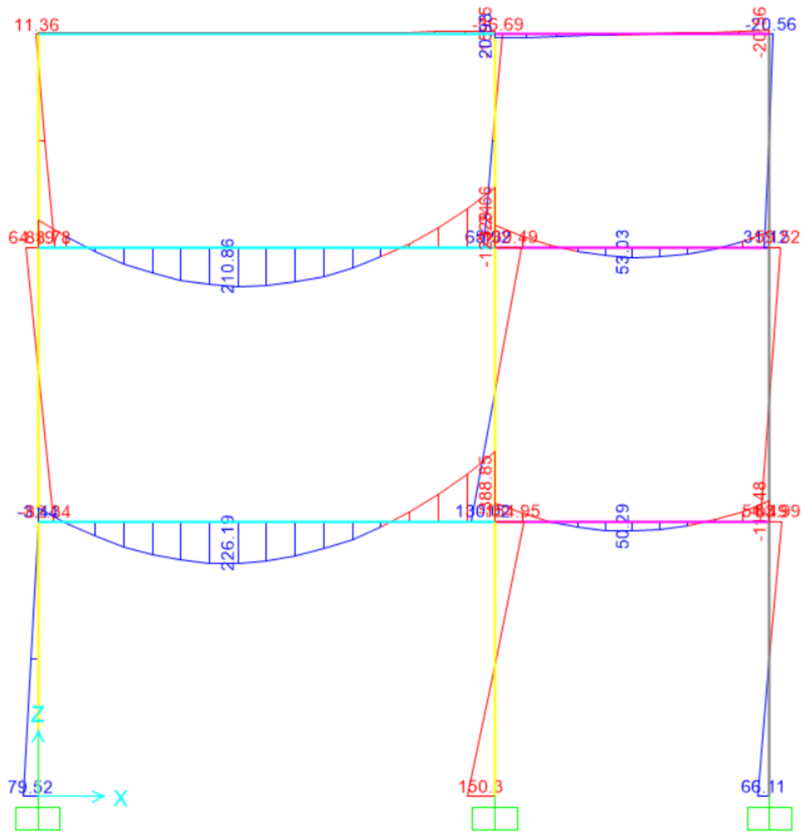

Figure 15: Bending moment, clampled supports with load case 2

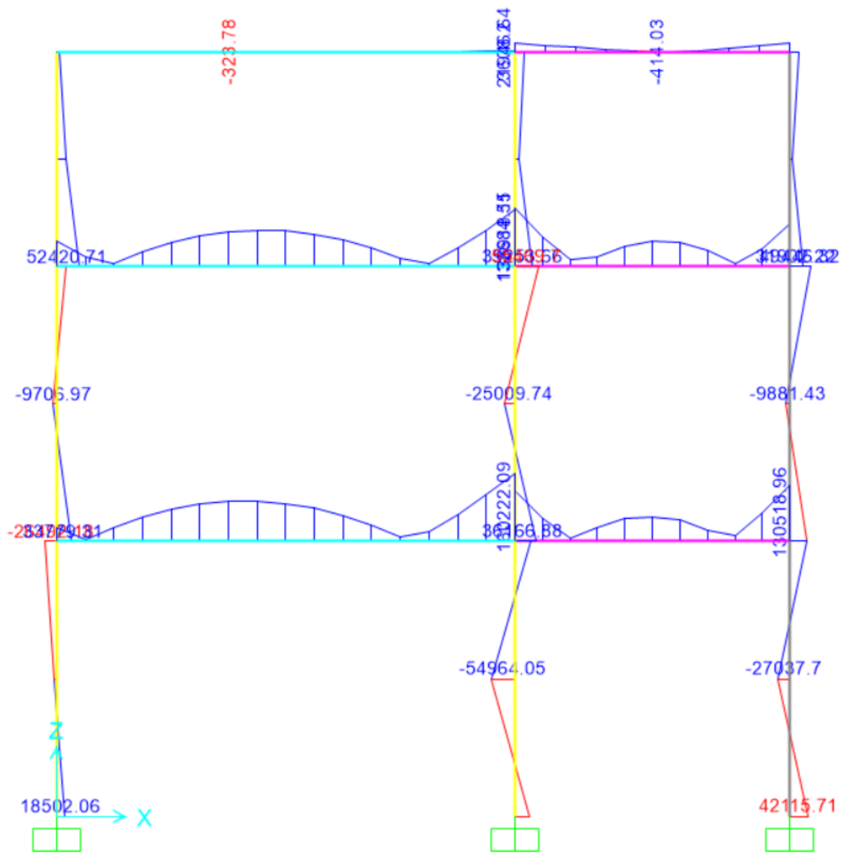

Figure 16: Axial stress, clampled supports with load case 2

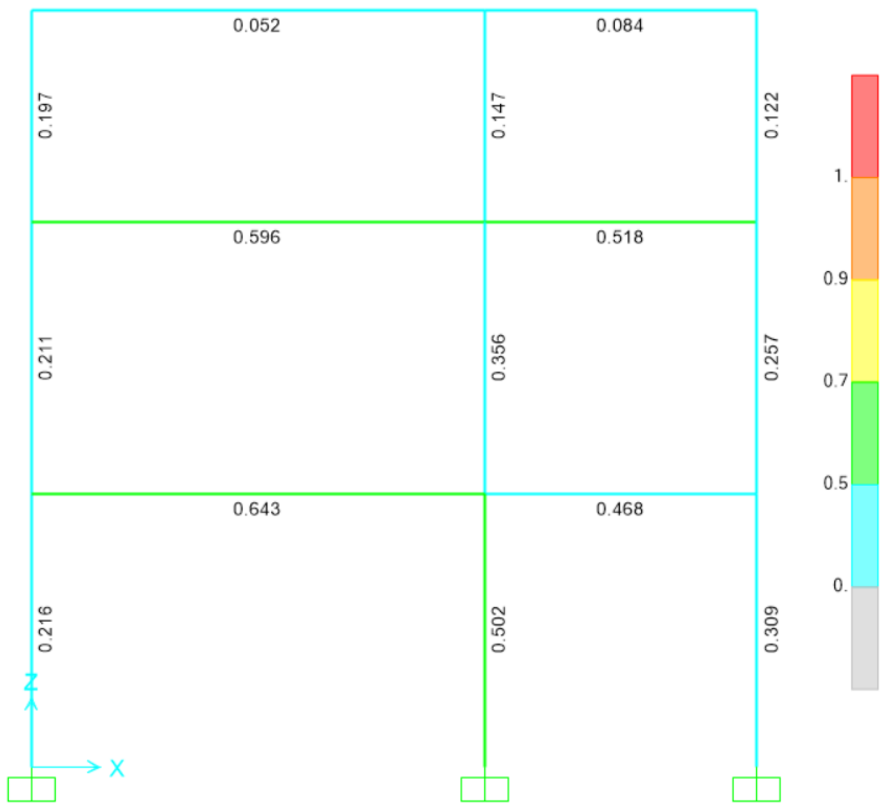

Figure 17: Axial stresst, clampled supports with load case 1

4.2 Hinged supports

4.2.1 Load case 1

This section analyzes the load case 1 for the puntual loads on the beam midspan combiend with the wind forces (horizontally applied on the façade). The supports are hinged on the base columns, that means displacements are restrains and allows the rotation.

In figure 18, we find the displacement on X direction. In this case, the deformation of the structure is bigger comapred to clamped supports, being 6.3 cm. This is due to the supports have released the beding moment, allowing the whole structure to sway.

For figure 19, the maximum bending moments values are similar to the clamped case. However, the bending moments on the base column become zero, due to that the constraints on the rotation have been removed.

The figure 20 shows us the axial stress distribution, which is similar to the clampled case.

In figure 21, we can clearly see that the ratio of use of bottom beams and middle base column have increased. There are two reasons,first,due to that different support condtions, the struture has suffered stress redistribution. Then, the displacement on X direction has increased, leading to the increasing of the ratios of use.

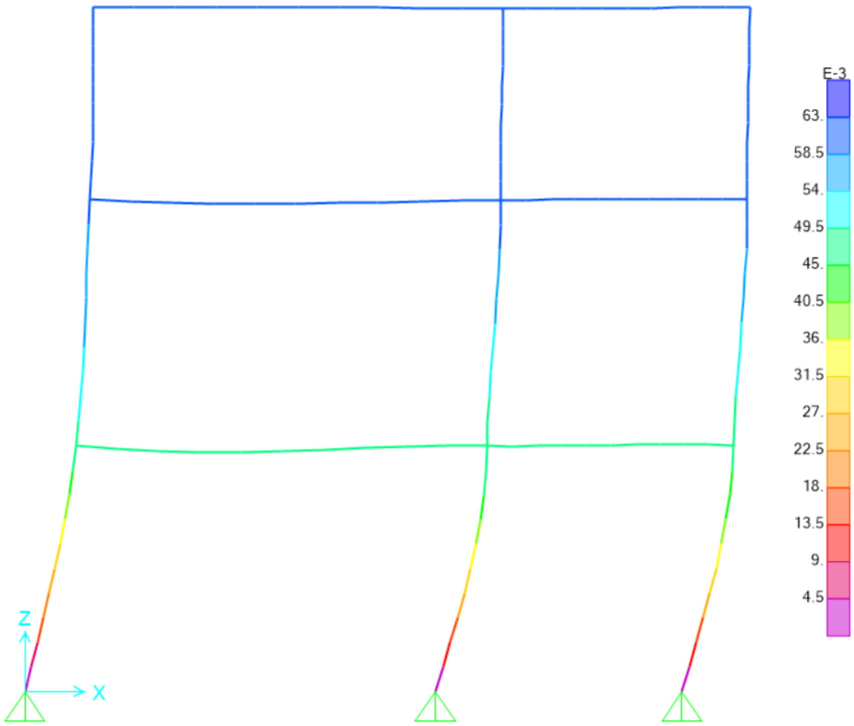

Figure 18: Displacement in X direction, hinged supports with load case 1

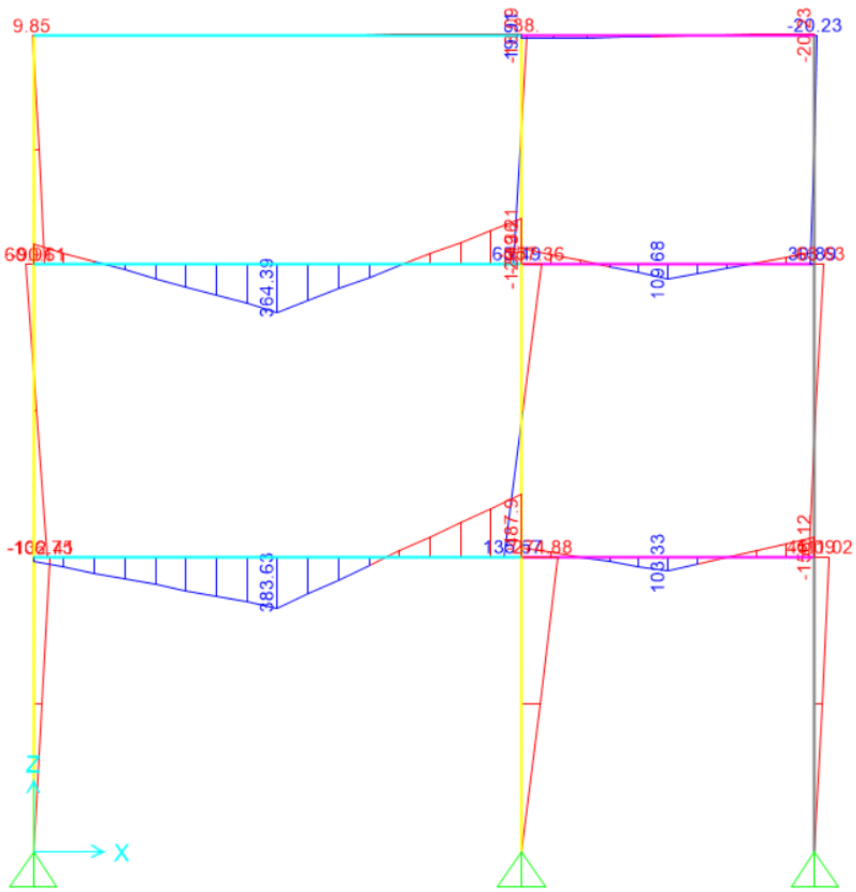

Figure 19: Bending moment, hinged supports with load case 1

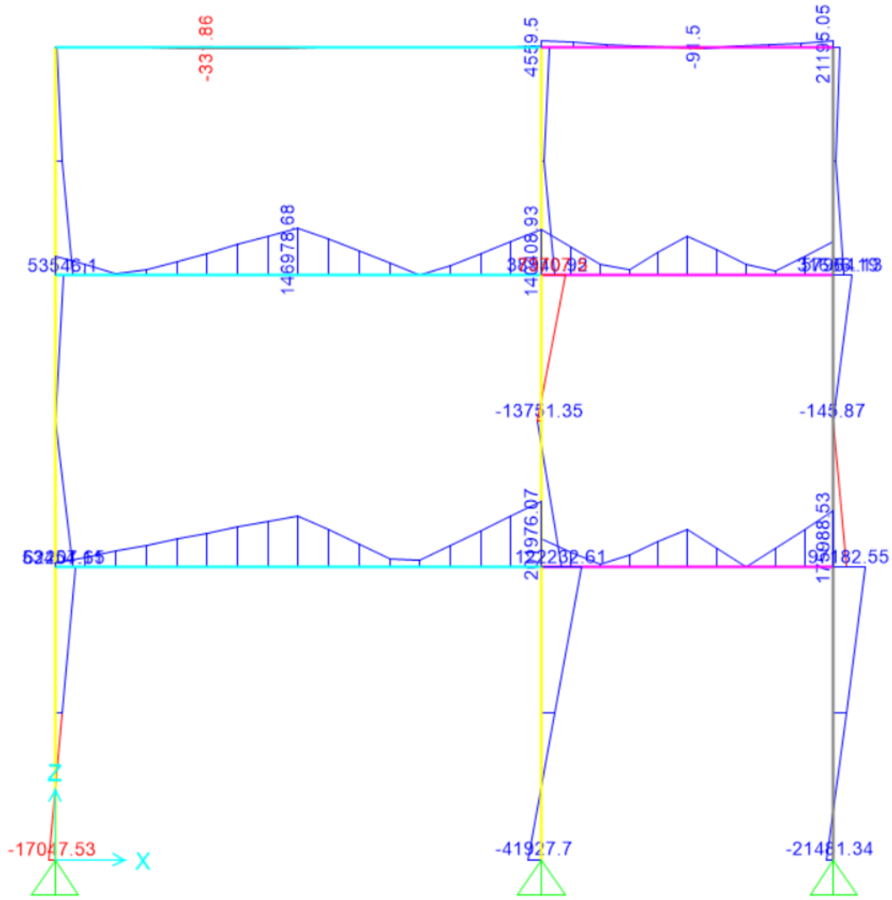

Figure 20: Axial stresst, clampled supports with load case 1

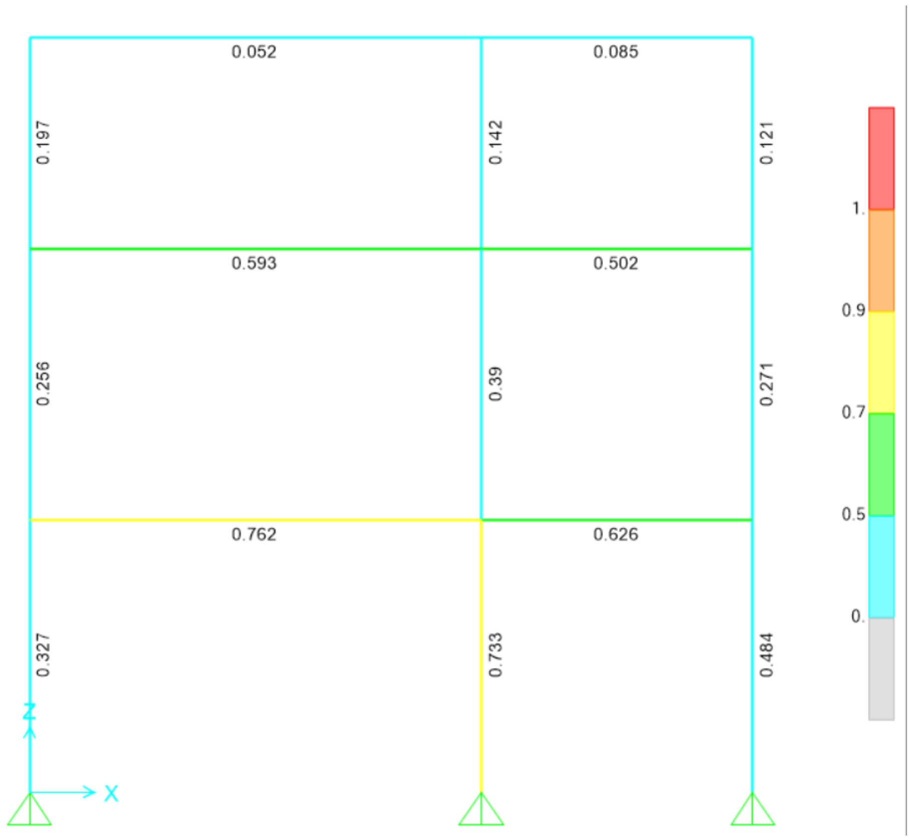

Figure 21: Axial stresst, clampled supports with load case 1

4.2.2 Load case 2

This section analyzes the load case 2 for the uniform loads on the beams combiend with the wind forces (horizontally applied on the façade). The supports are hinged on the base columns, that means displacements are restrains and allows the rotation.

From figure 22, we can see that the displacement on X direction in this case is similar to the load case 1. The maximum displacement is 6.3 cm.

However, in figure 23,the bending moments distribution has changed because of the application of uniform loads on the beams. The distribution of bending moments becomes parabolic shape and the maximum values on the beams have decreased. The bending moments on the columns are similar to the load case 1.

We can also find the change of stress distribution on the beams to parabolic shape in figure 24. And the maximum stress are located in the joint of the beams and middle column, since the axial stresses on the beams have decreased.

For the ratio of use, figure 25, we can see an increment of the percentages for the middle column and the beams, due to a redistributions of the internal stress caused by the hinged supports.

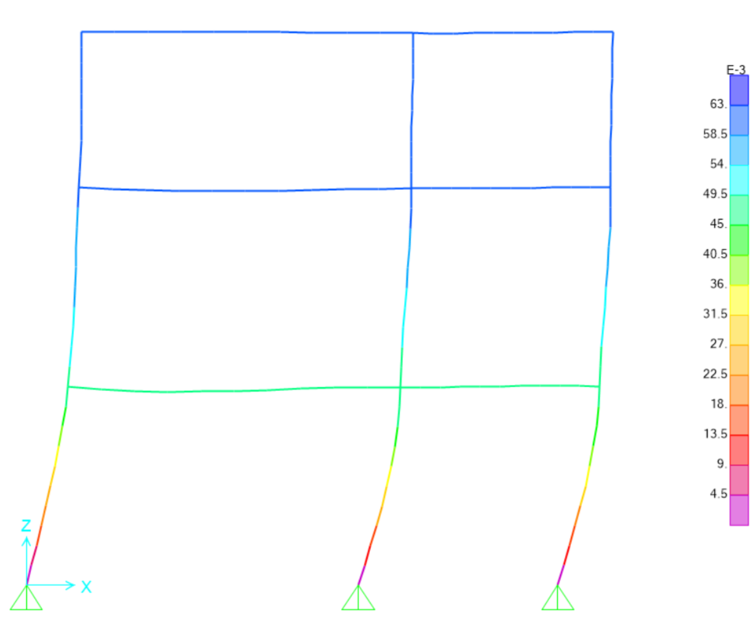

Figure 22: Displacement in X direction, clampled supports with load case 2

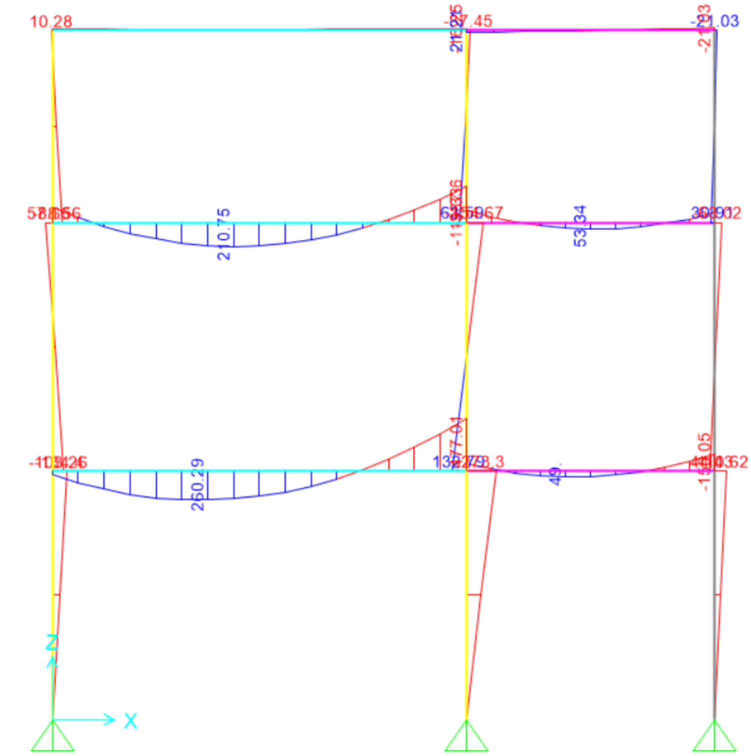

Figure 23: Bending moment, clampled supports with load case 2

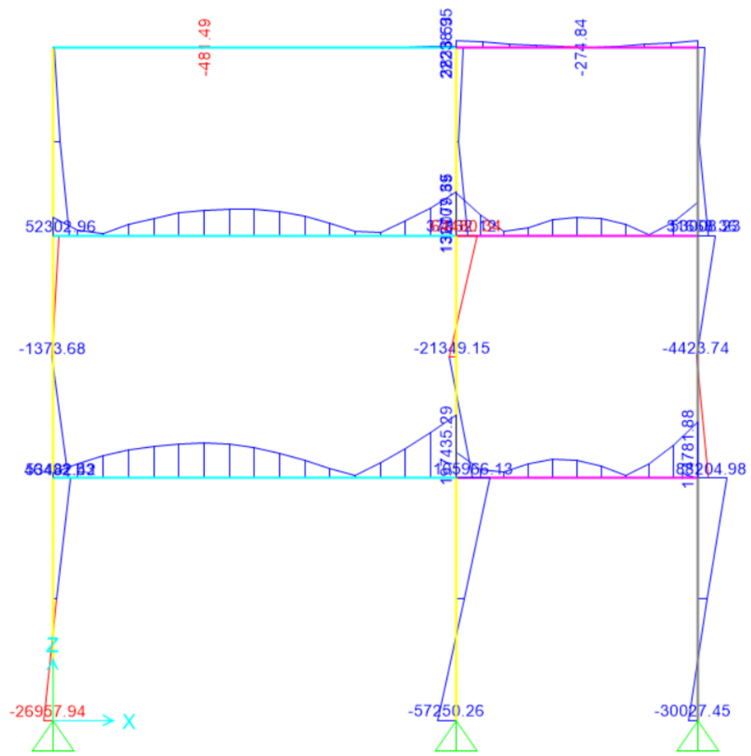

Figure 24: Axial stress, clampled supports with load case 2

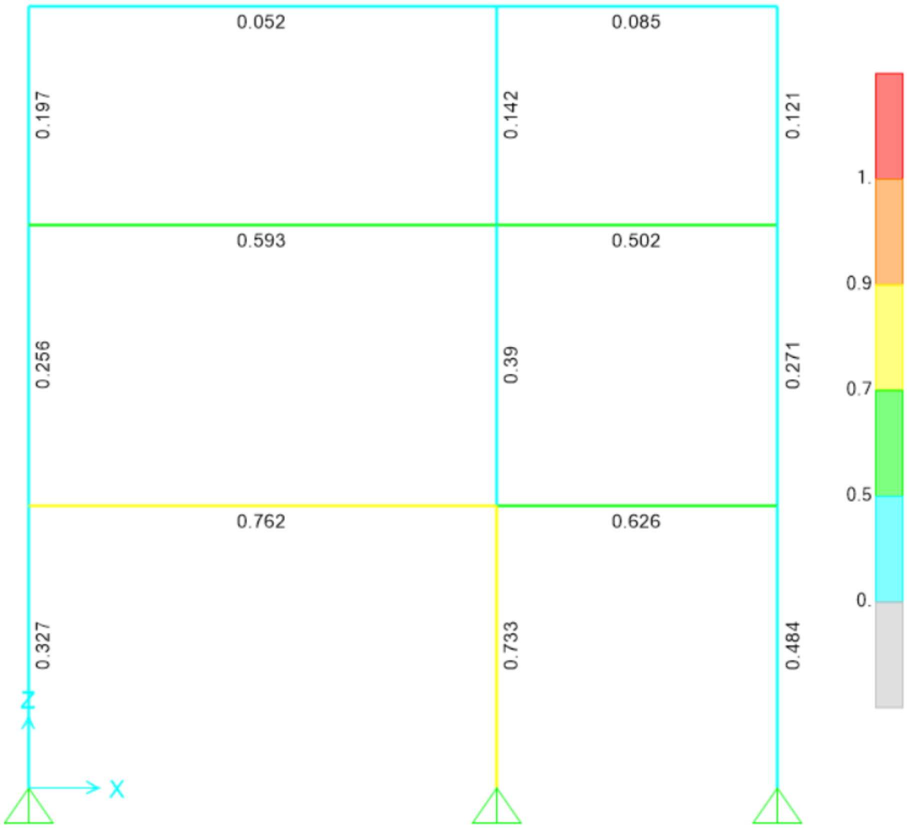

Figure 25: Axial stresst, clampled supports with load case 2

4.3 Dynamic analysis

For this case, we have set 6 modes for the modal analyisi in order to use all the principal modes. We have tried different anaylsis by changing the mass, Structure self-weigth, Structure self-weigth + load case 1 and 2. Aslo different supports conditions were analyzed.

For the clamped supports, the figure 26 shows the table values for the perior and frequency. We have found that for different mass sources generally the natural frequency is below than 2 Hz, thus leading to be in the same frequacny range of the wind loads.

On the other side, considering only the self-weight as mass source with clamped supports; the model shows a higher natural frequencies.

Figure 27, presents a table for the hinged cases. As a remark, it is not possible to get the natural frequency for all hinged support conditions due to the matrix of the system becomes ill-conditioned since the bending moments are realeased and not enough b.c are given to solve the problem.

In general lines, the introduction to hinged supports to the columns affects directly to the system, leading to the decrease of structure stiffness and low frequencies.

Modal Load Participation Ratios (Self-weigth + Case 2 Loads) CLAMPED						
OutputCase	**StepType**	**StepNum**	**Period**	**Frequency**	**CircFreq**	**Eigenvalue**
Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
MODAL	Mode	1	5,188767	0,192724016	1,210920708	1,466328962
MODAL	Mode	2	4,377288	0,22845193	1,43540581	2,060389838
MODAL	Mode	3	1,712322	0,584002282	3,669394557	13,46445642
MODAL	Mode	4	1,009281	0,990804076	6,22540561	38,75567501
MODAL	Mode	5	0,807481	1,238419933	7,781221929	60,54741471
MODAL	Mode	6	0,702132	1,42423293	8,948719418	80,07957922
Modal Load Participation Ratios (Self-weigth + Case 1 Loads) CLAMPED						
OutputCase	**StepType**	**StepNum**	**Period**	**Frequency**	**CircFreq**	**Eigenvalue**
Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
MODAL	Mode	1	4,373608	0,228644194	1,436613839	2,063859322
MODAL	Mode	2	3,702147	0,270113505	1,697173204	2,880396886
MODAL	Mode	3	1,436223	0,696270538	4,374796814	19,13884717
MODAL	Mode	4	0,846961	1,180692605	7,418510429	55,03429698
MODAL	Mode	5	0,684174	1,461617439	9,183613216	84,3387517
MODAL	Mode	6	0,595503	1,679252652	10,55105559	111,3247741
Modal Load Participation Ratios (Self-weigth) CLAMPED						
OutputCase	**StepType**	**StepNum**	**Period**	**Frequency**	**CircFreq**	**Eigenvalue**
Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
MODAL	Mode	1	1,364439	0,732901872	4,604958277	21,20564073
MODAL	Mode	2	1,273311	0,785353845	4,934523738	24,34952452
MODAL	Mode	3	0,391247	2,555930066	16,05938224	257,9037578
MODAL	Mode	4	0,222607	4,492229024	28,2255074	796,679268
MODAL	Mode	5	0,215183	4,647199641	29,1992165	852,5942444
MODAL	Mode	6	0,202901	4,928520062	30,96680484	958,9430021

Figure 26: Frequencies for different mas sourced with Clamped supports

Modal Load Participation Ratios (Self-weigth) 1 CLAMPED, 2 HINGE

OutputCase	StepType	StepNum	Period	Frequency	CircFreq	Eigenvalue
Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
MODAL	Mode	1	12,62318	0,079219371	0,497749991	0,247755053
MODAL	Mode	2	1,328093	0,752959299	4,730982803	22,38219828
MODAL	Mode	3	0,420956	2,375547747	14,9260067	222,785676
MODAL	Mode	4	0,306702	3,260492775	20,4862803	419,6876805
MODAL	Mode	5	0,266834	3,74765021	23,54718074	554,4697207
MODAL	Mode	6	0,252936	3,953565334	24,84098362	617,0744672

Modal Load Participation Ratios (Self-weigth) 2 CLAMPED, 1 HINGE

OutputCase	StepType	StepNum	Period	Frequency	CircFreq	Eigenvalue
Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
MODAL	Mode	1	14,39382	0,069474243	0,436519543	0,190549311
MODAL	Mode	2	1,73767	0,575483186	3,615867498	13,07449776
MODAL	Mode	3	0,407465	2,454200459	15,42019626	237,7824528
MODAL	Mode	4	0,3016	3,315644607	20,83280948	434,0059509
MODAL	Mode	5	0,293587	3,406139814	21,40140763	458,0202486
MODAL	Mode	6	0,272609	3,668255351	23,04832812	531,2254293

Modal Load Participation Ratios (Self-weigth) 1 HINGE, 1 CAMPLED, 1 HINGED

OutputCase	StepType	StepNum	Period	Frequency	CircFreq	Eigenvalue
Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
MODAL	Mode	1	8,702349	0,114911503	0,722010265	0,521298822
MODAL	Mode	2	1,898949	0,526607055	3,308769713	10,94795701
MODAL	Mode	3	0,413404	2,418939366	15,19864429	230,9987881
MODAL	Mode	4	0,290029	3,447930838	21,66398838	469,3283927
MODAL	Mode	5	0,272083	3,675346379	23,09288236	533,2812159
MODAL	Mode	6	0,262401	3,810966574	23,94500918	573,3634649

Figure 27: Frequencies for different mas sourced with Clamped supports

5 Conclusion

We have seen different supports conditions affect directly to the stress distribution and internal forces. Also we have seen that hinged supports lead to cheap connections and cheaper foundations that doesn't have to resist a big moment on the base column. So in order to apply the hinged supports on the structure, we need to provide a horizontal resistance for the wind force by introducing a bracing system that helps to tranfrom the horizontal wind force to vertical force that goes to the foundations.

for the dynamic analysis we conclude that the structure is sensible to the wind dynamic load. We have seen the main modes 1 and 2 for all the different cases test the natural frequency is below than 2. Also we have seen the introduction of hinged supports leads to the reducing of system's stiffness.

6 Task divided

The entire porject was carried with half and half amount of work for its developement. The report and the problem were done together in several meetings. No splliting of the job was necessary.