COMPUTATIONAL MECHANIC TOOLS
Master of Science in Computational Mechanics/ Numerical Methods
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Course Simulation project
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1. Introduction

Computational structural analysis is a widely used tool that allows engineers to design structures (among others) under complex loading cases and boundary conditions, giving a reliable result. Those results can be either for static load cases or dynamic analysis.

The aim of this work is to assess the results dependency of a structure on the type of boundary condition at which is subjected. For several types of BC configurations, static and dynamics analysis are going to be carried out in order to determine which the worst BC configuration is.

The work will be done using the commercial code Abaqus FEA and using beam elements to discretize the structure. Beam elements give us the advantage of simplifying the study by means of a one dimensional analysis, likewise it is possible to obtain results in 1D that are going to be used to assess a 3D-structure; the main importance of the mentioned is that the computational costs are reduced.

2. Case of study

The building structure follows the DIN normative which deals among other matters with the normalization of beam profiles [1]; concretely 4 different profiles are considered.

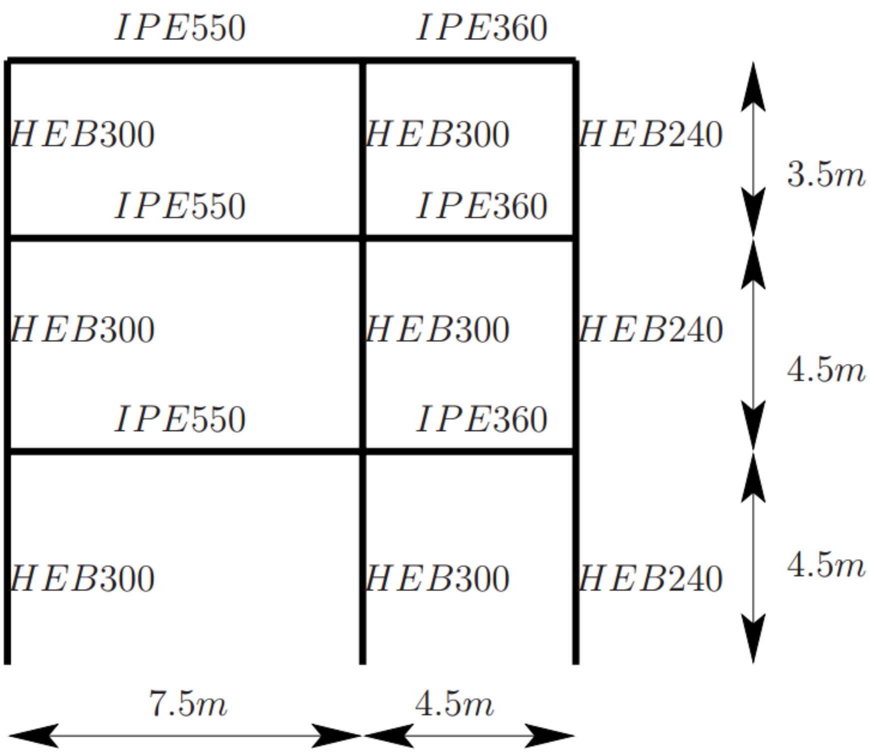


Figure 2.1. *Building aim of study*

3. Methodology

One fundamental part of a simulation is deciding which type of discretization is going to be used. For structural analysis while it may be possible to use a 3D discretization of the model [and solve it using the typical finite element type] the best option is to use the so called 'beam elements' which in a 2D problem consist of one-dimensional elements with 3 degrees of freedom (dof's) per node. It is necessary to distinguish between beam and truss element since the former can handle with bending moment because of having 3 dof's whilst truss elements only have 2 dof's (not rotation).

This choice of element reduces considerable the computational cost of the simulation (recall element are 1D). It can be done consequence of meeting the following requirements:

- Length-width and length-depth ratios are big
- Cross sectional properties can be computed (or extracted from tables)

Once the element type has been selected it is important to realize that the size of the discretization becomes critical since a coarse mesh can become a source of errors.

For this reason, prior to the calculation process it is important to find out how the size of the mesh such that, the results do not depend on it anymore, this is done by conducting a mesh dependence analysis. For this case the selected variable of control is the horizontal displacement of the upper-right corner. This choice is due to the fact that in that point the larger displacement happens; oppositely, selecting stress as a variable of control would be a bad idea due to the existence of stress concentrators near the joints.

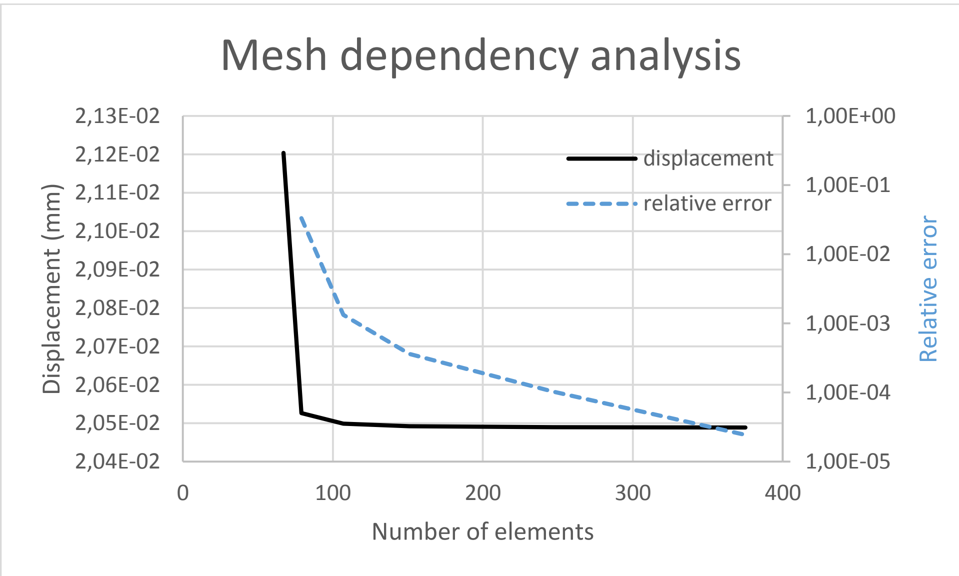


Figure 3.1. *Plot of displacement and relative error vs number of elements*

It is clearly observed how the solution (displacement field) tends to be significantly independent of the number of elements when we the domain is divided in 150 elements, this accordingly with the related size of the element which is 0.25m. As expected, the solution turns out to be very accurate with the mentioned element size, giving a relative error of order 10^{-4}. The relative error is computed as follows,

$$e_{rel} = \frac{\|u_i - u_{i-1}\|}{u_i}$$

A dynamics analysis in front of the building response against wind loads is also conducted, and at this point the number of elements selected becomes also important since it is directly related with the number of modes in which the structure will be able to vibrate.

4. Boundary conditions

Depending on how this degrees of freedom are fixed at the nodes there appear different types of BC. In structural analysis the most common ones are:

- Fixed supports: All 3 degrees of freedom are fixed; therefore there are 2 force reaction and 1 moment reaction
- Pinned supports: The two displacements are restrained but rotation is left free, being there no moment reaction.
- Roller support: Tangential displacement and rotation are not restrained

It's important to recall that there exist other types of supports like simple contacts (where only the vertical displacement is fixed to avoid penetration on the soil, but not separation), however they are not commonly used in structures. Finally the combinations of boundary conditions to be solved are as shows in figure X. It has been made that all combinations have at least 2 fixed columns in order to reduce the quantity of possible combinations.

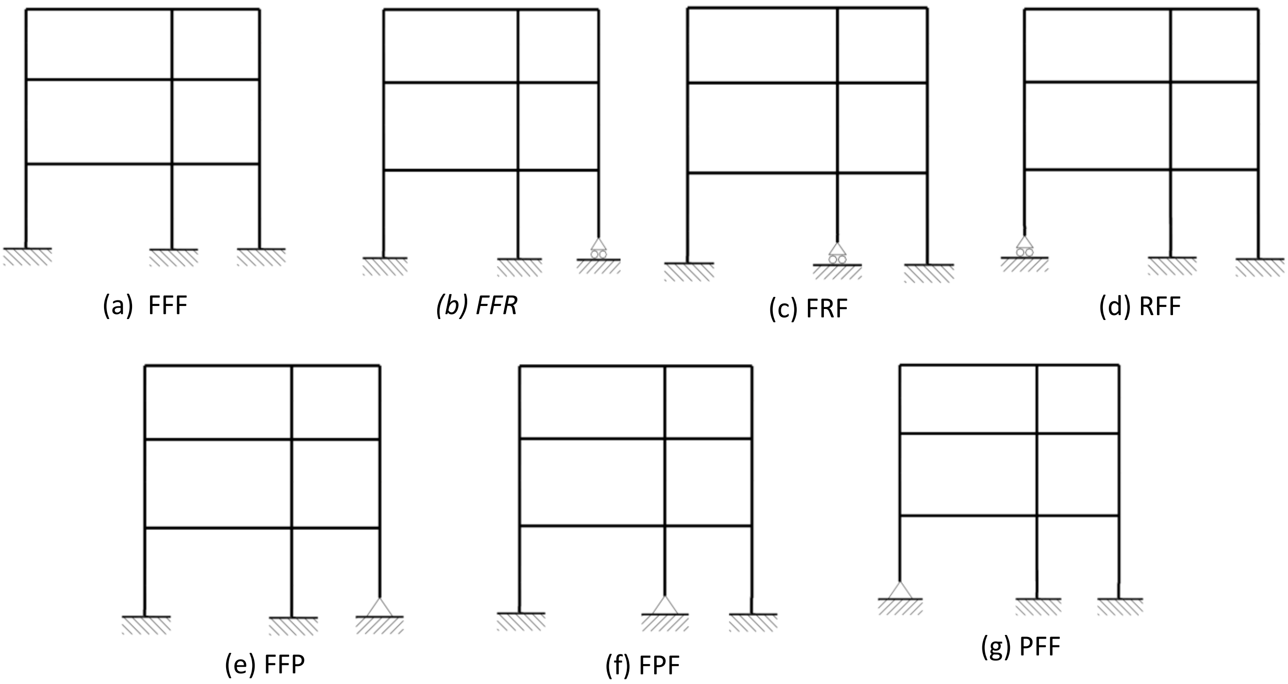


Figure 4.1. *Different combinations for the BC's. F=fixed, R=roller, and P=pinned*

5. Load cases

Once the different types of supports have been stated, the different load cases for the static analysis are described, both cases will be simulated using different combinations of BC's.

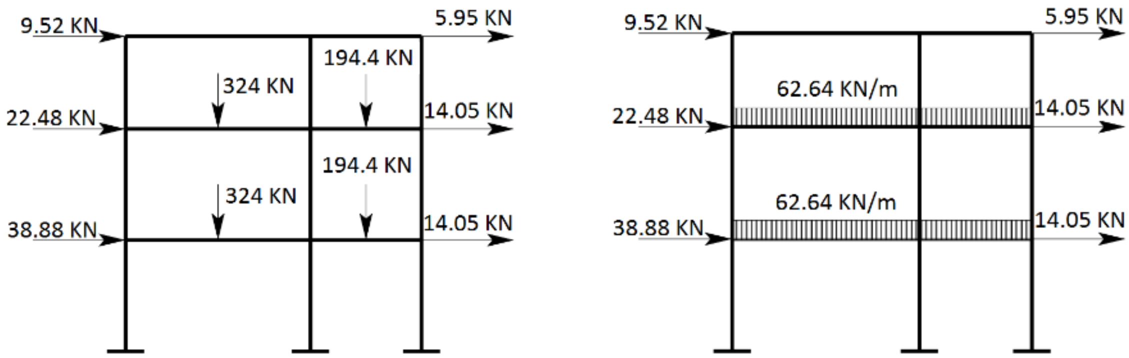


Figure 5.1. (Left) wind + punctual loads. (Right) Wind + distributed loads

6. Results and discussions: static

After simulating all the boundary conditions stated in section 4 for both load cases stated in section 5, the results for the maximum displacement, maximum Von Misses stress, maximum shear stress and maximum bending moment are shown in table 6.1

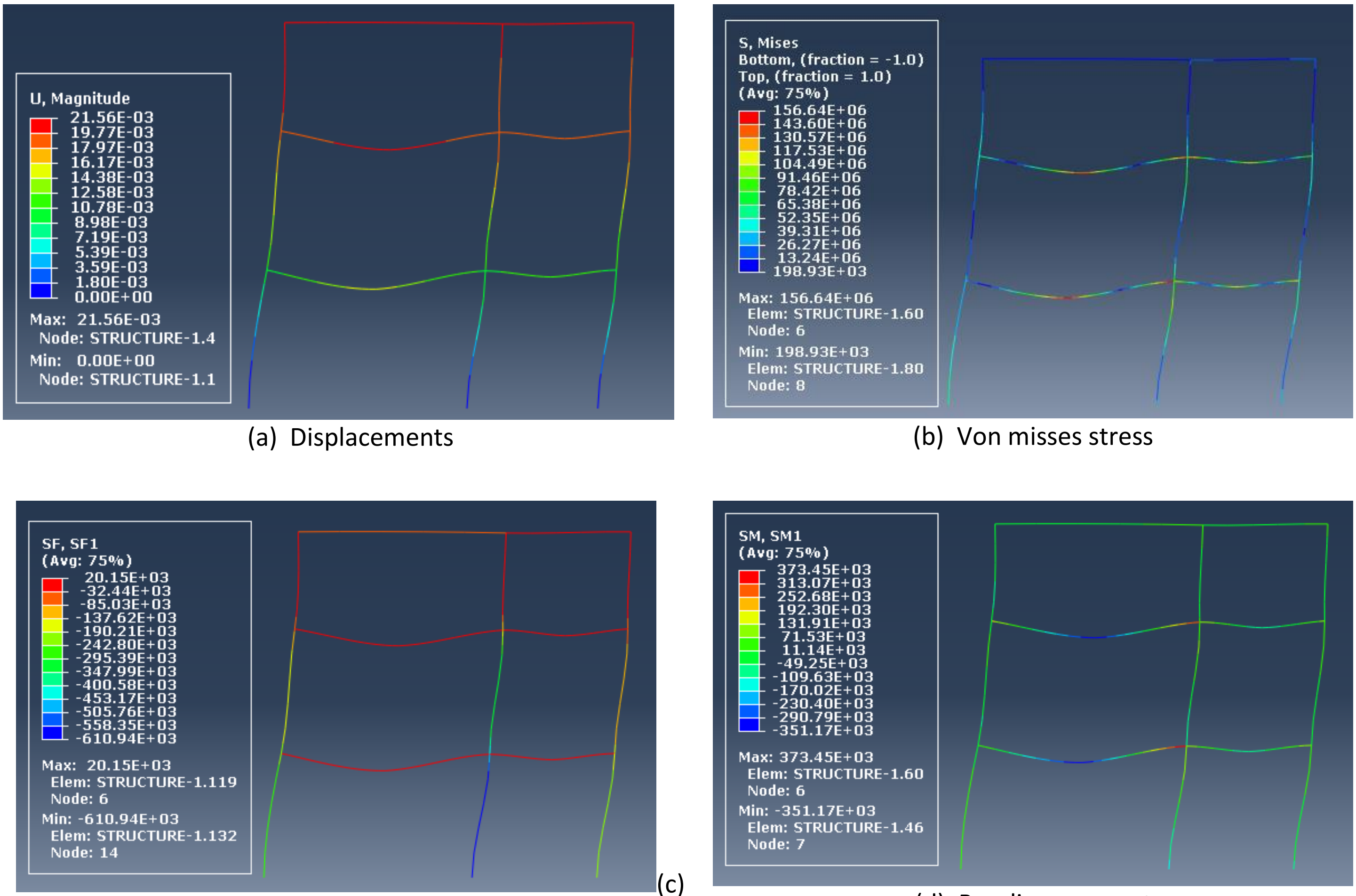
Table 6.1. *Values of variables*

	BC	Max displ	Max VM	Max shear	Max Bending
Load case 1	FFF	21.56E-3	156.64E6	-610.94E3	373.45E3
	FFP	23.33E-3	163.77E6	-616.98E3	388.59E3
	FPF	27.32E-3	158.58E6	612.55E3	372.49E3
	PFF	24.15E-3	161.14E6	-608.30E3	384.78E3
	FFR	23.99E-3	168.44E6	-626.28E3	398.34E3
	FRF	32.13E-3	174.98E6	-610.02E3	-406.23E3
	RFF	23.88E-3	161.19E6	-609.81E3	385.55E3
Load case 2	FFF	20.87E-3	148.53E6	-839.21E3	354.12E3
	FFP	22.88E-3	152.19E6	-845.25E3	369.19E3
	FPF	27.24E-3	150.45E6	-480.84E3	353.16E3
	PFF	23.85E-3	153.23E6	-836.56E3	365.62E3
	FFR	23.58E-3	160.24E6	-854.45E3	378.83E3
	FRF	31.99E-3	132.33E6	-838.34E3	306.77E3
	RFF	23.62E-3	153.27E6	-837.74E3	366.22E3

Considering the general yield strength and ultimate tensile strength of 250 MPa and 400 MPa, we can see that none of the cases studied overdoes the limits. From the yield strength and the highest von misses stress we can compute a security factor of 1.4, however is important to recall that usually buildings overcome the elastic limit and start the formation of plastic hinges. These last phenomena is not a problem while the number of hinges formed does not go further than the limit at which the building acquires liberty of movement and becomes a mechanism (instead of a structure).

From the contour maps (plotted in sections 6.1 and 6.2) it can be seen that the central column is the critical one, especially at the locations where the juncture with the lateral floors take place. For load case 1 it is also important to remark that another critical point is the middle of the left floors being there precisely the location of the punctual force.

6.1. Load case 1



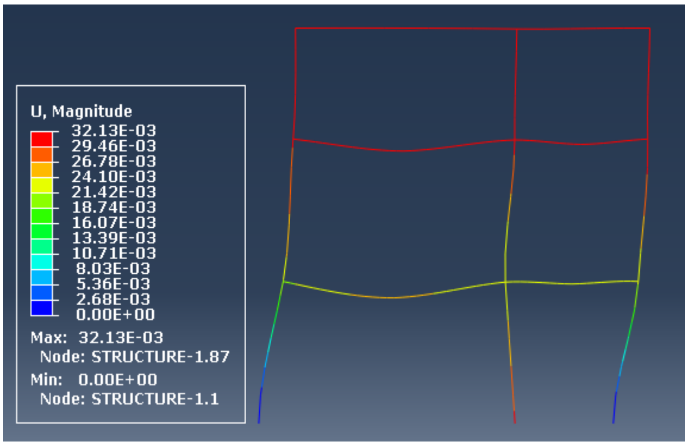
(a) Displacements

(b) Von misses stress

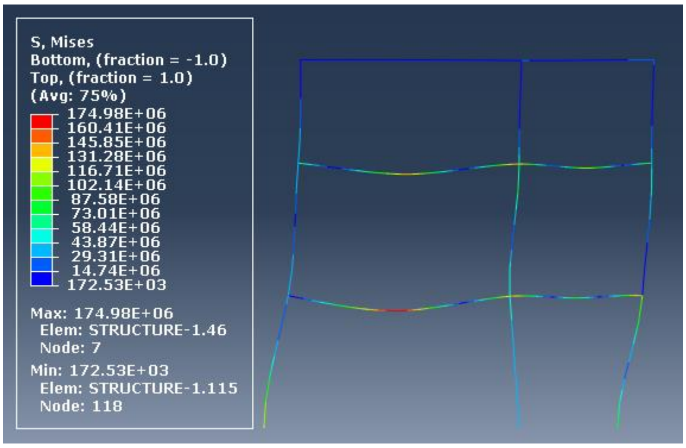
(c) Shear stress

(d) Bending moment

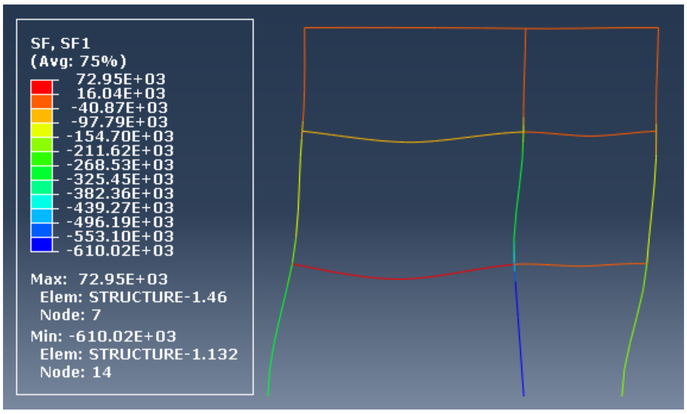
Figure 6.2. *Different contour fields with BC combination FFF*



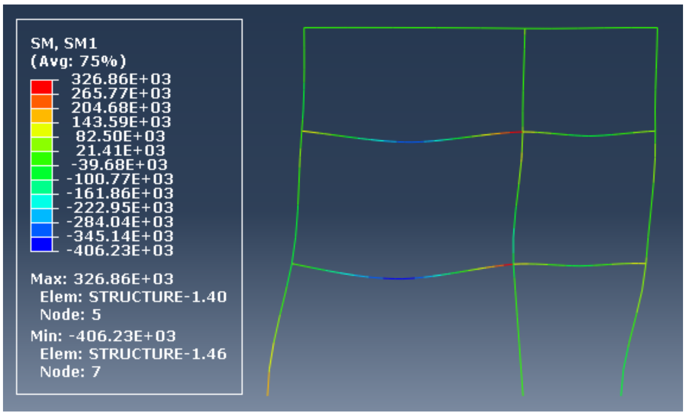
(a) Displacements



(b) Von misses stress



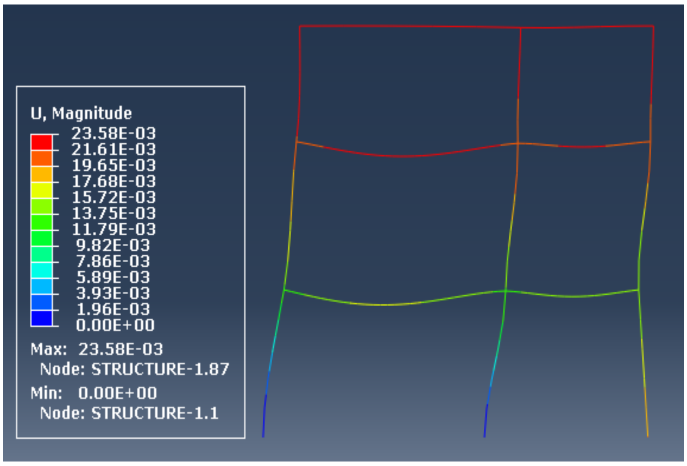
(c) Shear stress



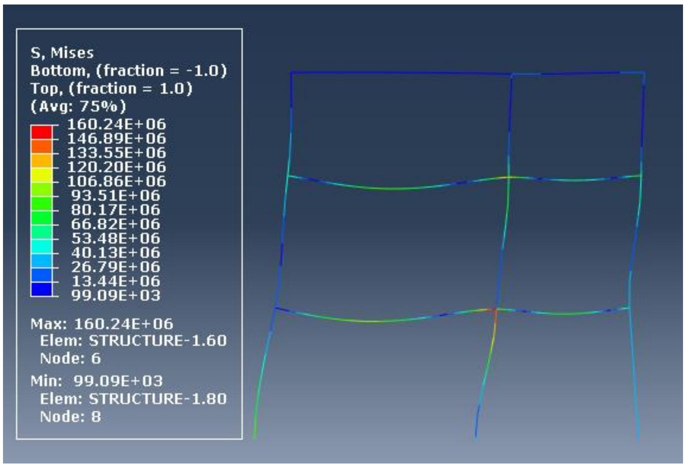
(d) Bending moment

Figure 6.7. *Different contour fields with BC combination* FRF

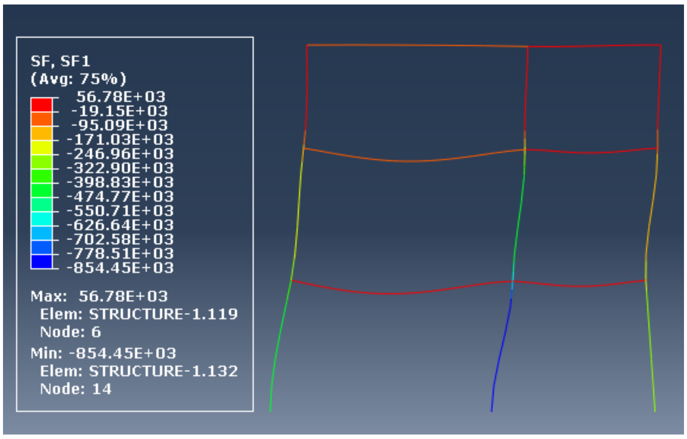
6.2. Load case 2



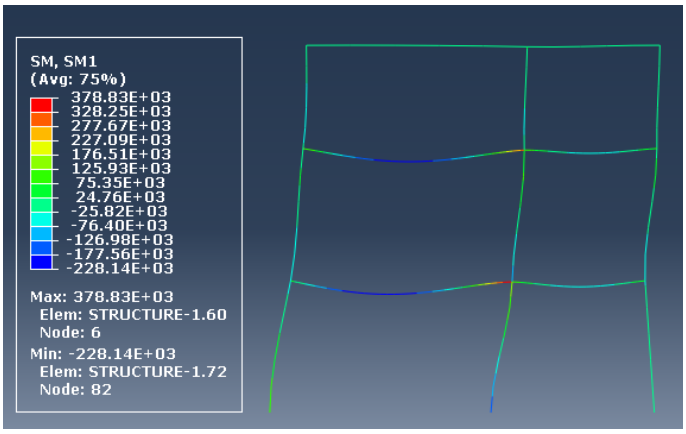
(a) Displacements



(b) Von misses stress

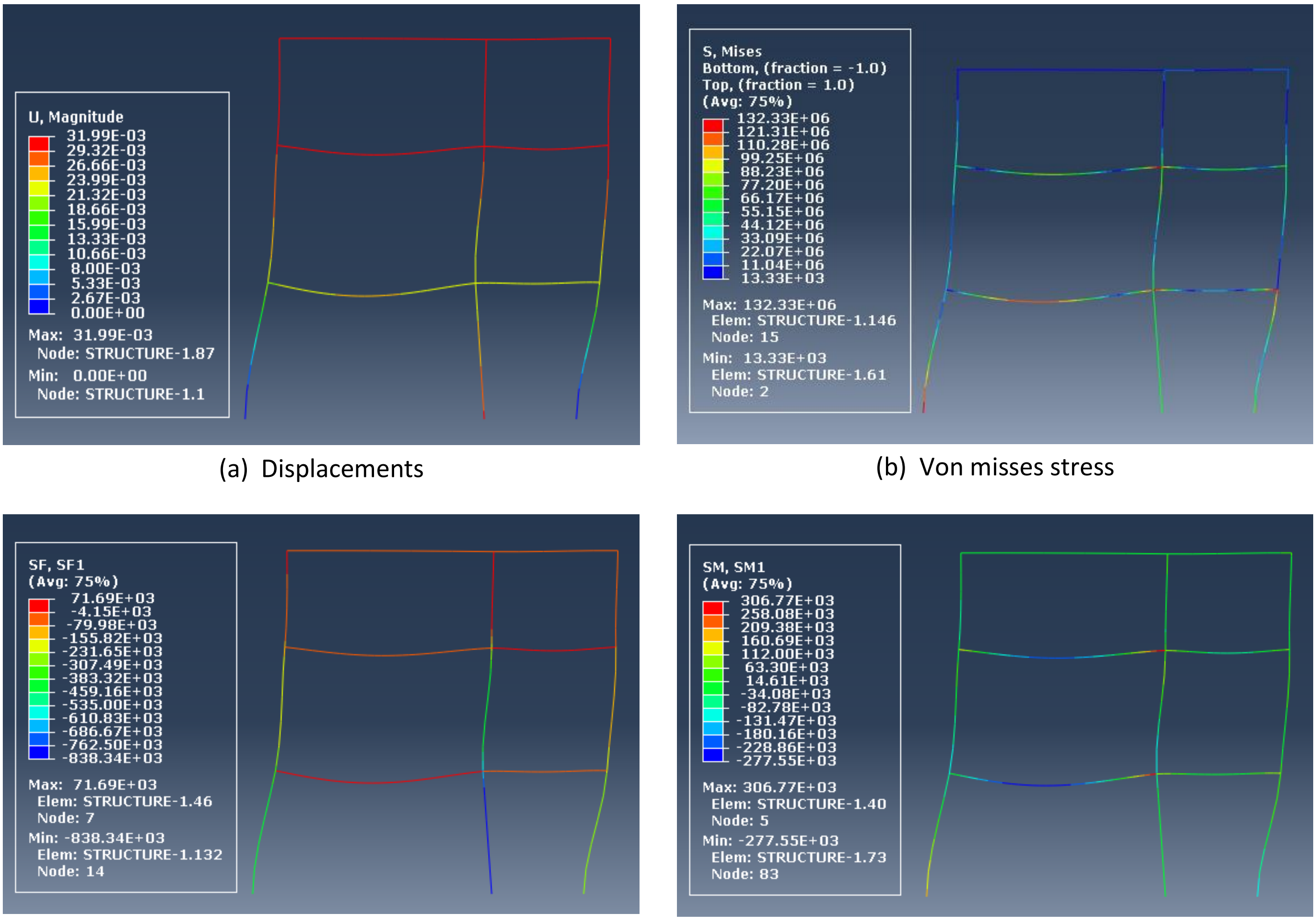


(c) Shear stress



(d) Bending moment

Figure 6.13. *Different contour fields with BC combination*. FFR



(a) Displacements

(b) Von misses stress

(c) Shear stress

(d) Bending moment

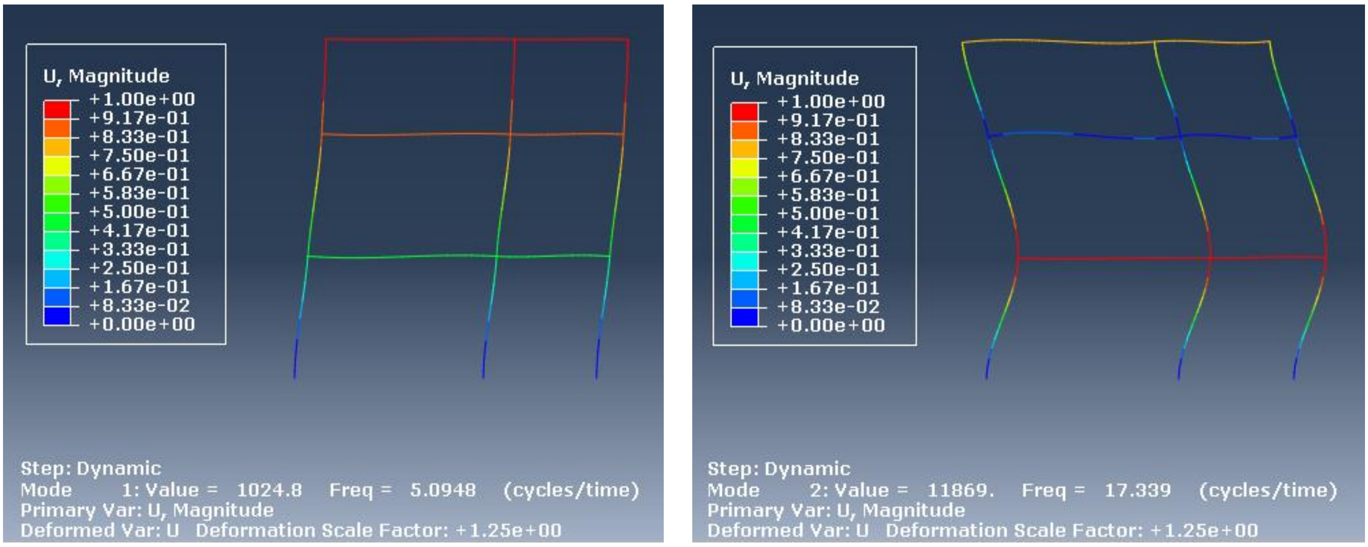
Figure 6.14. *Different contour fields with BC combination*. FRF

7. Results and discussions: dynamic

In order to study which is the dynamic building response in front of wind loads a modal analysis is carried out. It should be outlined that the domain discretization should be accordingly to the number of modes selected to study since, a building is able to vibrate in as many frequencies as number of degrees of freedom of the structure.

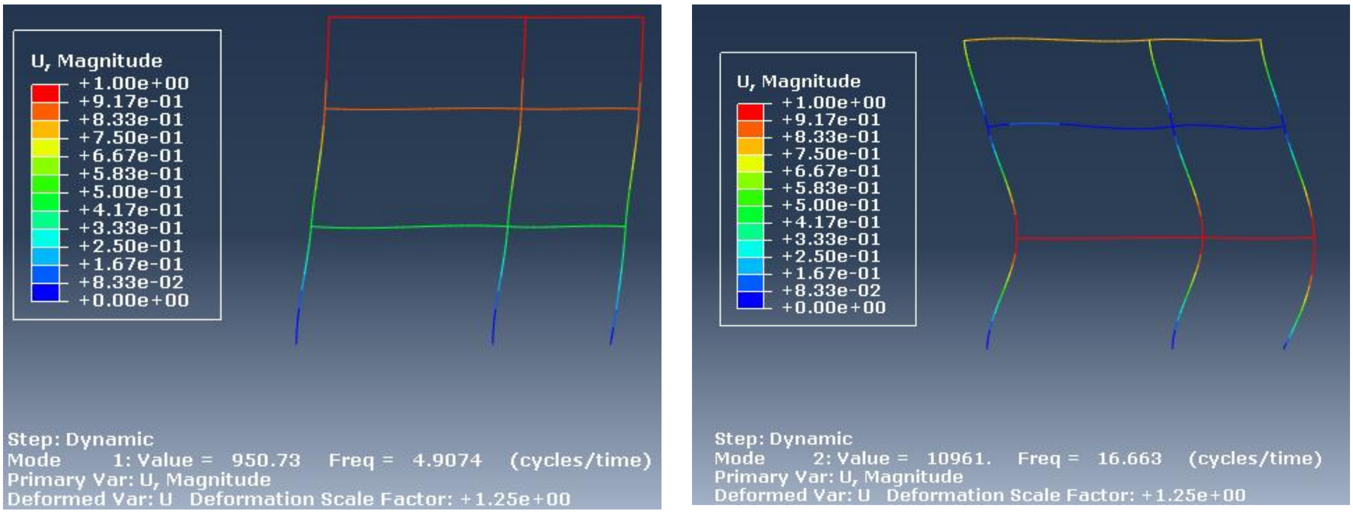
As well as in the static case, a sort of combination of boundary conditions it's been realized, however, in the dynamics analysis the exterior loads are not taken into account due to the fact that these forces don't excite the building in a periodic way. *Boggs and Dragovich (2006)* studied the response of building to wind loads; they state that in these kinds of study only the first modes are considered because the frequencies of the wind are closer to them, this is because we have selected only the first two modes of vibration to assess the response due to the presence of a wind load of frequency 3Hz. Oppositely in earthquakes this assumption would not be suitable since the such a frequencies are higher and thus more modes of vibration should be studied.

Comparing the different combinations of boundary conditions of fixed and pinned supports we get to the conclusion that placing the pinned support onto the middle is the worst situation due to the fact that the frequency is the lower, likewise the response of placing a roller support is similar, the worst situation is to place the roller support at the middle of the building, in addition the frequency in this case is even lower what means that would be more suitable to select a pinned support.



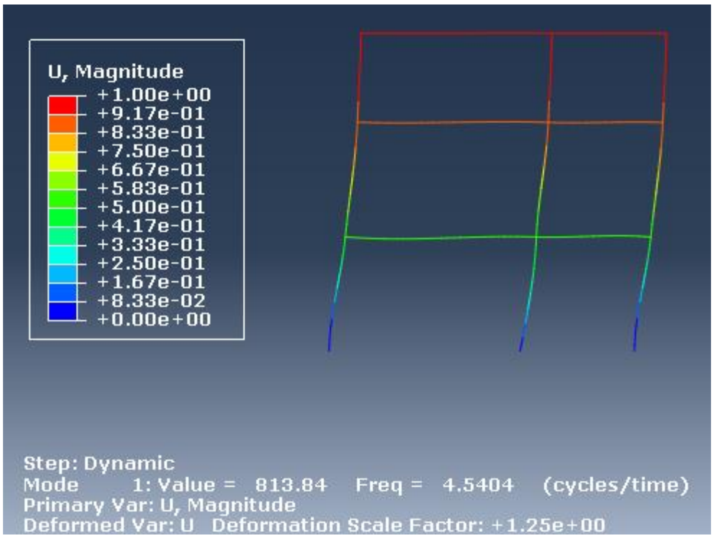
Vibration mode 1 *Vibration mode 2*

Figure 7.1. *Contour field deformed variable "U". BC combination* FFF

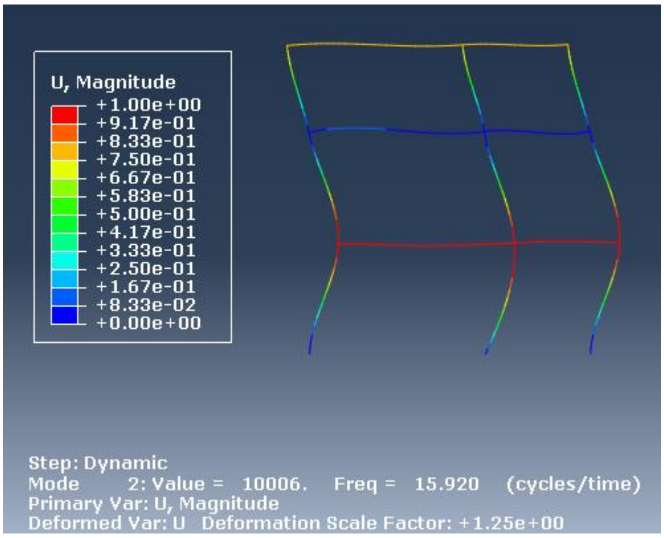


Vibration mode 1 *Vibration mode 2*

Figure 7.2. *Contour field deformed variable "U". BC combination* FFP

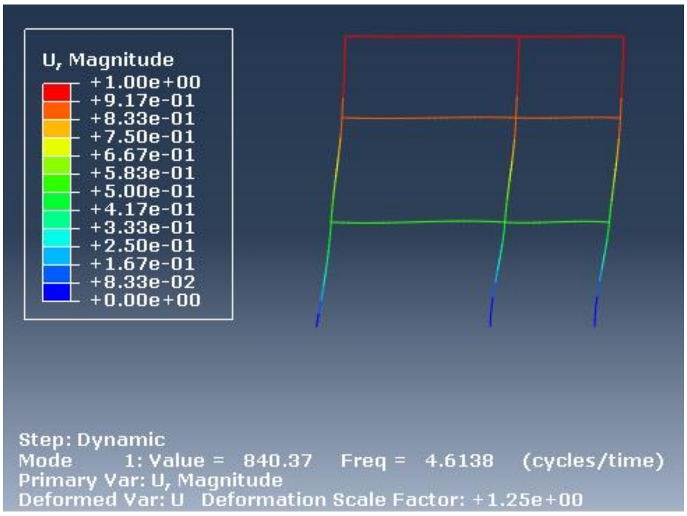


Vibration mode 1

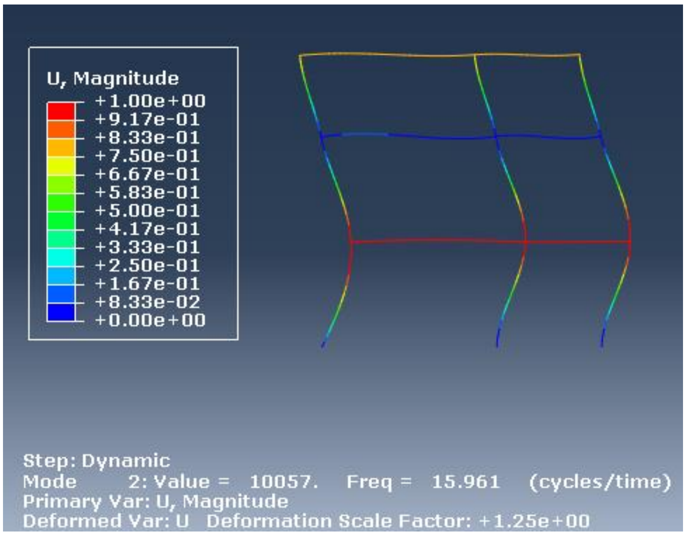


Vibration mode 2

Figure 7.3. *Contour field deformed variable "U". BC combination* FPF

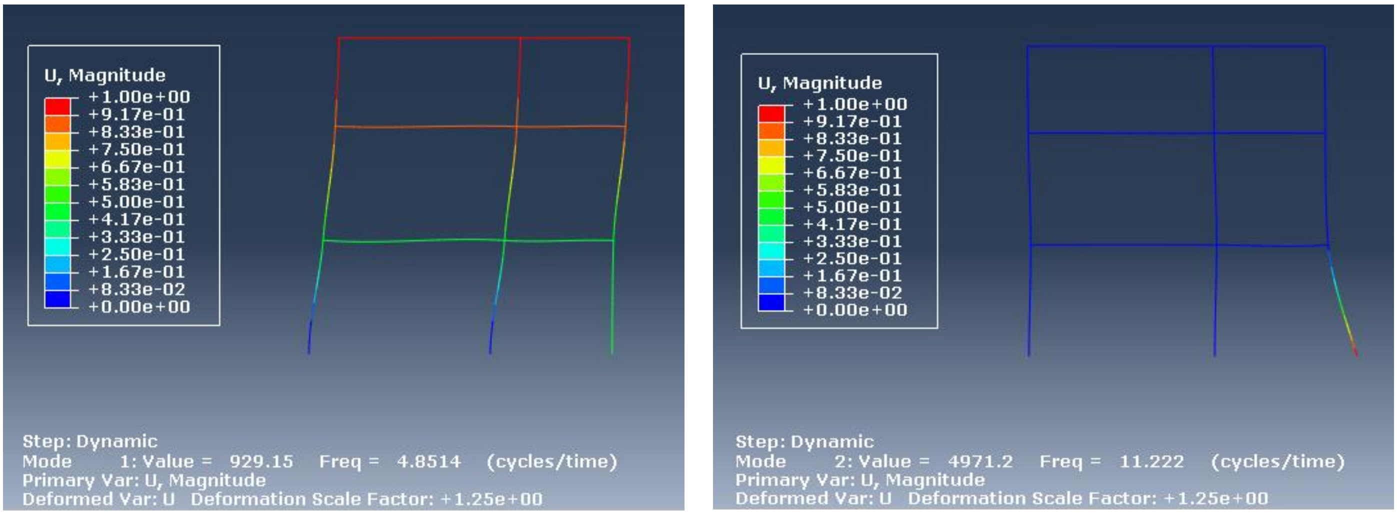


Vibration mode 1



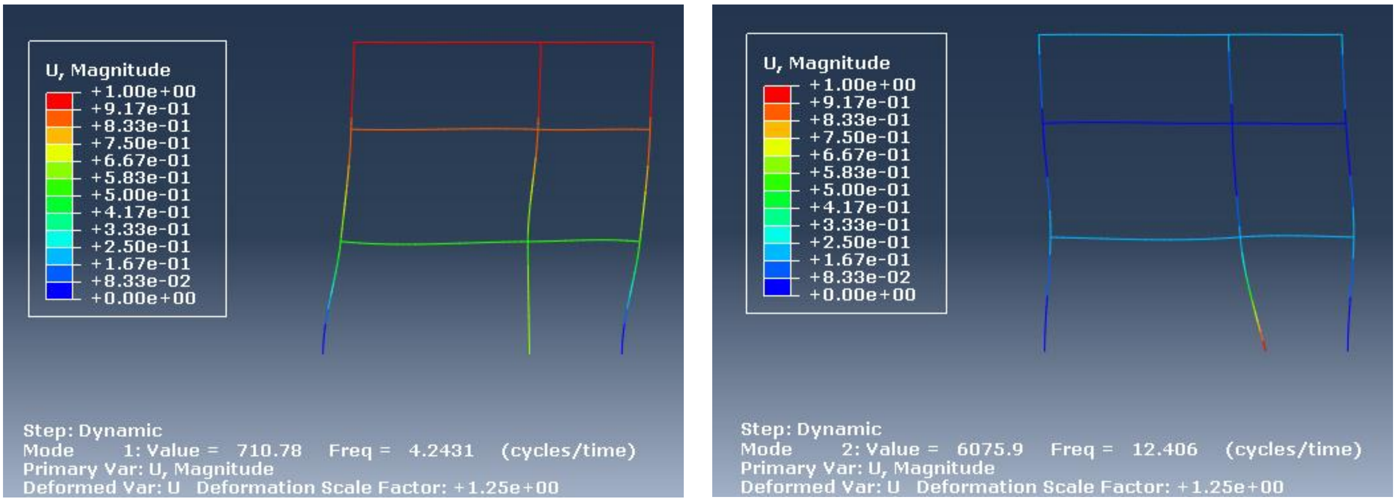
Vibration mode 2

Figure 7.4. *Contour field deformed variable "U". BC combination* PFF



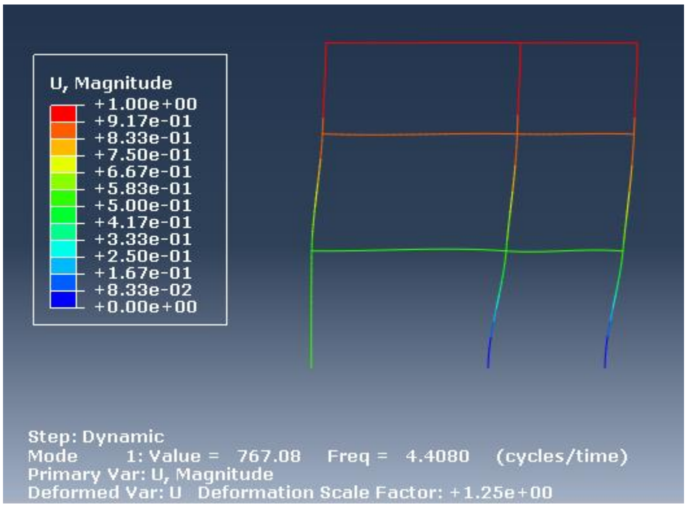
Vibration mode 1 *Vibration mode 2*

Figure 7.5. *Contour field deformed variable "U". BC combination* FFR

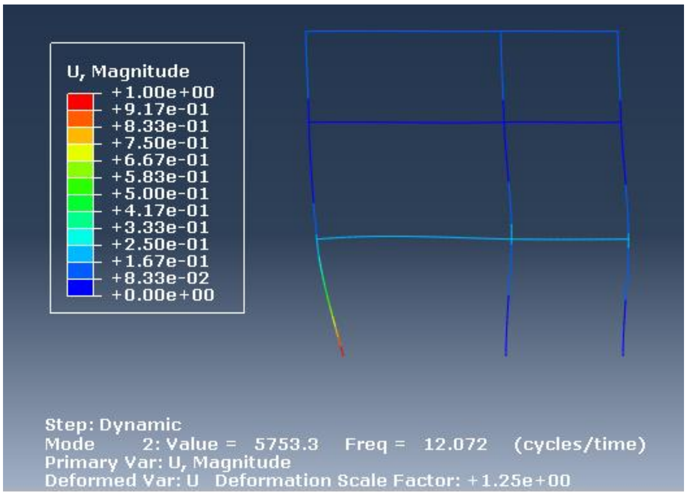


Vibration mode 1 *Vibration mode 2*

Figure 7.7. *Contour field deformed variable "U". BC combination* FRF



Vibration mode 1



Vibration mode 2

Figure 7.8. *Contour field deformed variable "U". BC combination* RFF

8. Conclusions

After performing the static and dynamic analysis of the building with different types of support, it is possible to say that it will hold for all the static and dynamic load cases.

While for each load case there is not much difference between the configurations of boundary conditions, as general statement it has been seen that fixing all the columns is the optimized setup in order to minimize the stress on the structures. It has also been shown that maximum stresses tend to happen in the joints between the central column and the left floors.

However as it will be introduced in the following section, having the critical points near corners is a case easily correctable (even 'a posteriori') with the use of stiffeners like haunches.

For the part of the dynamic analysis we have seen that the lowest natural frequencies happens above 2 Hz, meaning that a wind of that frequency will never cause resonance on the building. However it may important to consider that the frequency of the lowest modes of vibration are not so far from the value of the wind frequency and some change in the latter could lead to some resonance effects onto the building.

Another aspect to take into account is that to enlarge the building height by means of the construction of more floors (in case of being able) would lead to an increment of mass and due to this the natural frequency of the system would get lower, this could lead also to resonance effects.

9. Future work

While during the design phase of a structure it may be possible to apply modifications (change cross sections) in order to improve the behavior, once the structure has been build it becomes more complicated to do so.

One of the possible solutions may be the addition of stiffeners as haunches (figure 9.1). This type of stiffener consist in a reinforcement near the corners such that:

- In static cases the span between columns is reduced, meaning a decrease in the bending moment and therefore in the stresses
- In dynamic cases the stiffness of the structure is increased without increasing much the mass. Recalling that the modal frequencies are proportional to stiffness and inversely proportional to mass ($w \propto \sqrt{\frac{k}{m}}$), this means that all modal frequencies increase.

It would be interesting to test the same structure using haunches on the point with most stresses in order to quantify the reduction of those. For altering the results of the modal analysis is not so clear where the haunches should be placed

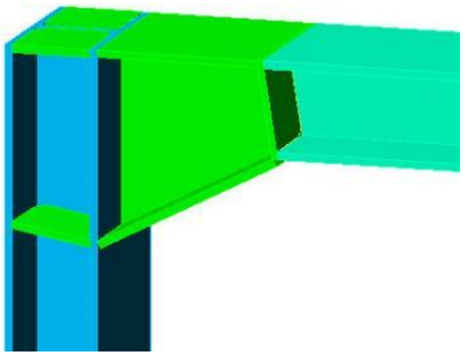


Figure 9.1. *Example of a haunch.*

10. References

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11. Bibliography

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- http://download.autodesk.com/us/algor/userguides/mergedProjects/setting_up_the_analysis/linear/Elements/Beam_Elements.htm
- http://www.din.de/de/. 2016 DIN Deutsches Institut für Normung e. V.

<u>Appendix: work distribution</u>

- Static analysis : Albert Capalvo Viladot
- Dynamic analysis: Jordi Parra Porcar and Yuyang Wang