SHELVING LEVEL CALCULATION

Castalla, July 2013

REQUESTED BY: ACTIU

Ingenia
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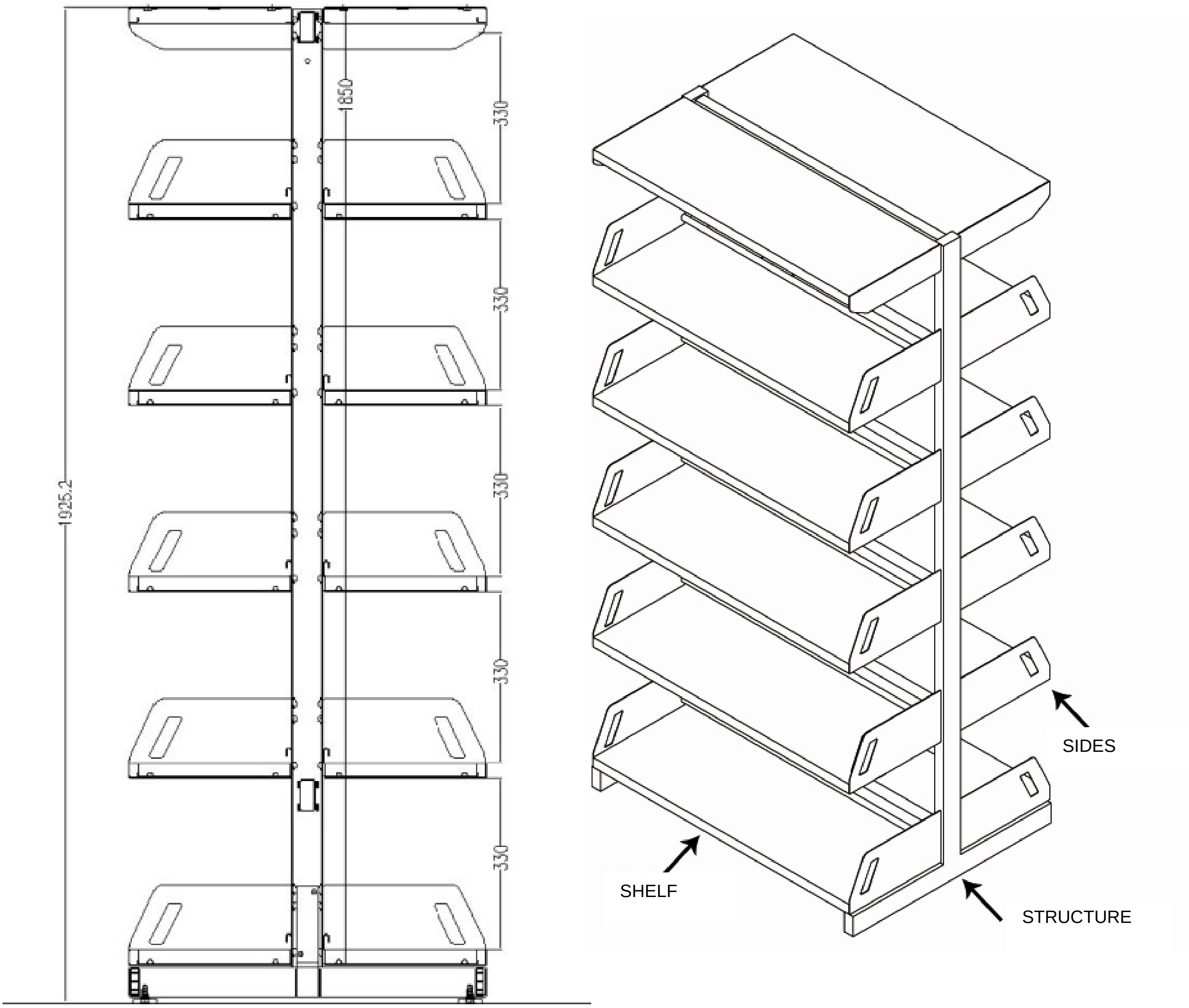
DESCRIPTION.

The document presented develops the level shelving calculation by using the structure calculation method of the SAP 2000 programme. The shelving geometry is shown as follows.



General shelving geometry of the object studied.

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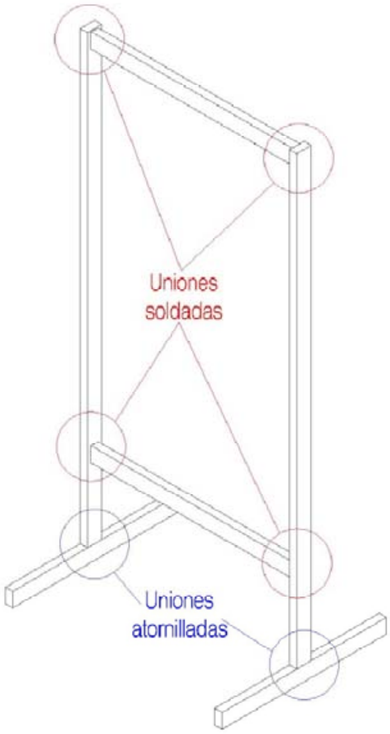
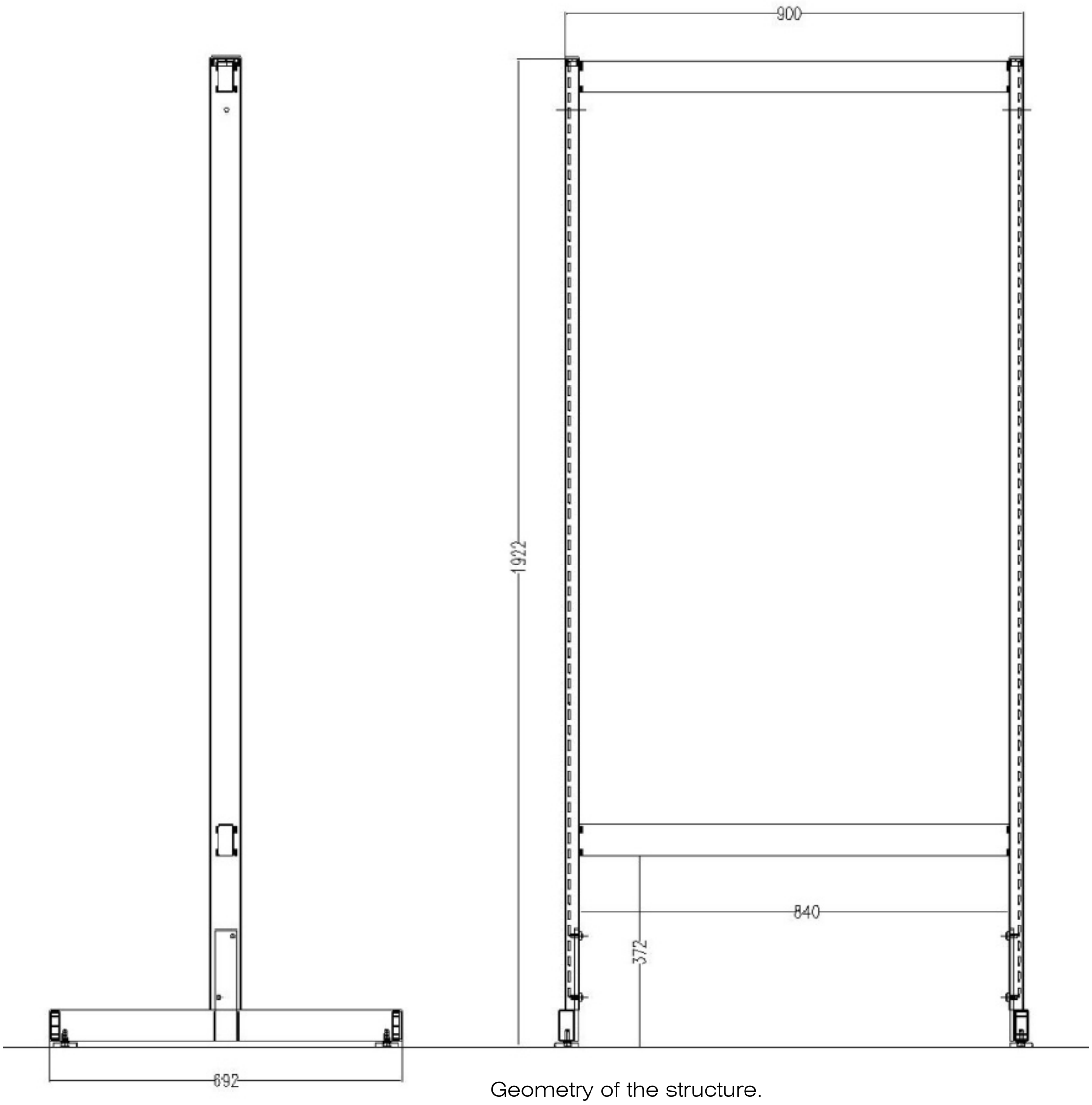
The shelving unit is formed by several different structural components. Consisting of a frame of width 900 mm and by height 1850mm and formed internally by a four sided cross section with welded joins. The bases are 682mm in length and are joined by metal brackets with medium screws to hold the frame and support the shelving structure.





Geometry of the structure.

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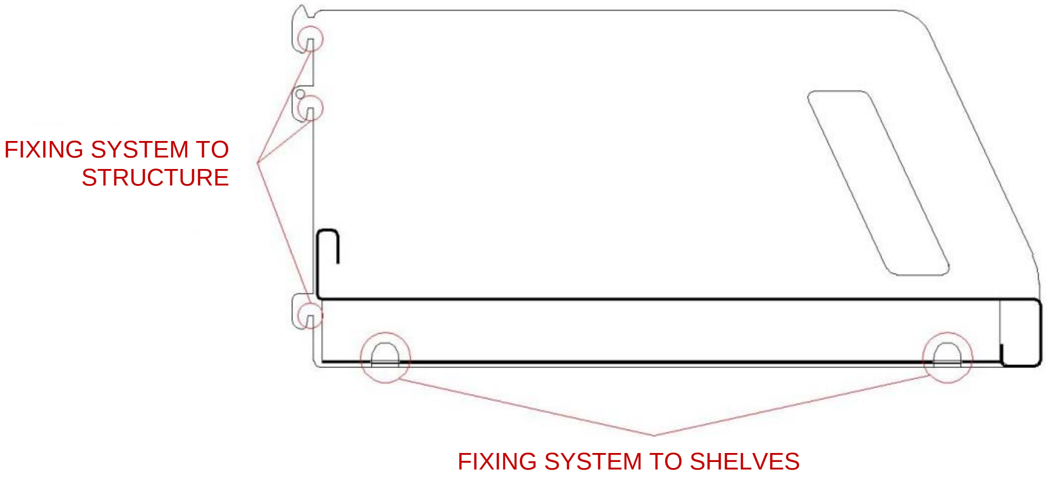
The vertical columns of the frame are perforated in order to fix the metal sheets that later support the shelves. These joins are made to the same shape of the metal sheet without the need of screws. The shelf height can be chosen depending on the intended use, but in principal the shelving unit is designed to support 5 shelves at each side of the frame and each separated by 33cm.

These side metal sheets are doubled at the lower part to receive the shelves, which at the same time are also formed by a cold rolled laminated sheet and cut by laser. Their structure is will be described as follows.



Although the shelf and side joins that are fastened together are not screwed, regarding components of large surfaces, when the shelving unit is fully mounted, they do entrust great stability and stiffness to the whole ensemble.

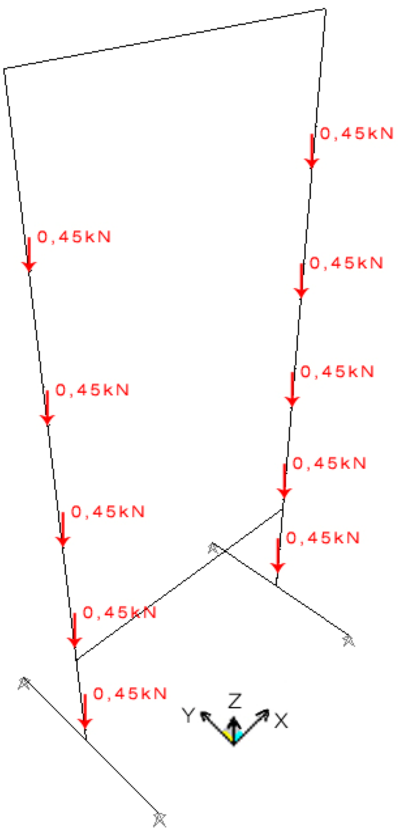
To summarize, we are dealing with designed and manufactured components of a high level of perfection of which there is no room for error in the assembly. A stable main structure that uses screws and welded joins. A versatile shelving configuration with supporting joins that entrusts great stability to the unit as a whole.

CALCULATION THEORY.

- PERMANENT POSITION:

The shelving unit is designed for storing books. This type of load remains immobile during all the process of storage (since that a prompt modification of one or few books will do very little to change the state.

The shelving unit is made to support 45kg on each shelf. This configuration is determined by the permanent position of the shelving unit by means of testing the mechanical resistance of each separate component as well the whole ensemble.



Load state in permanent position.

- ADDITIONAL POSTIONS:

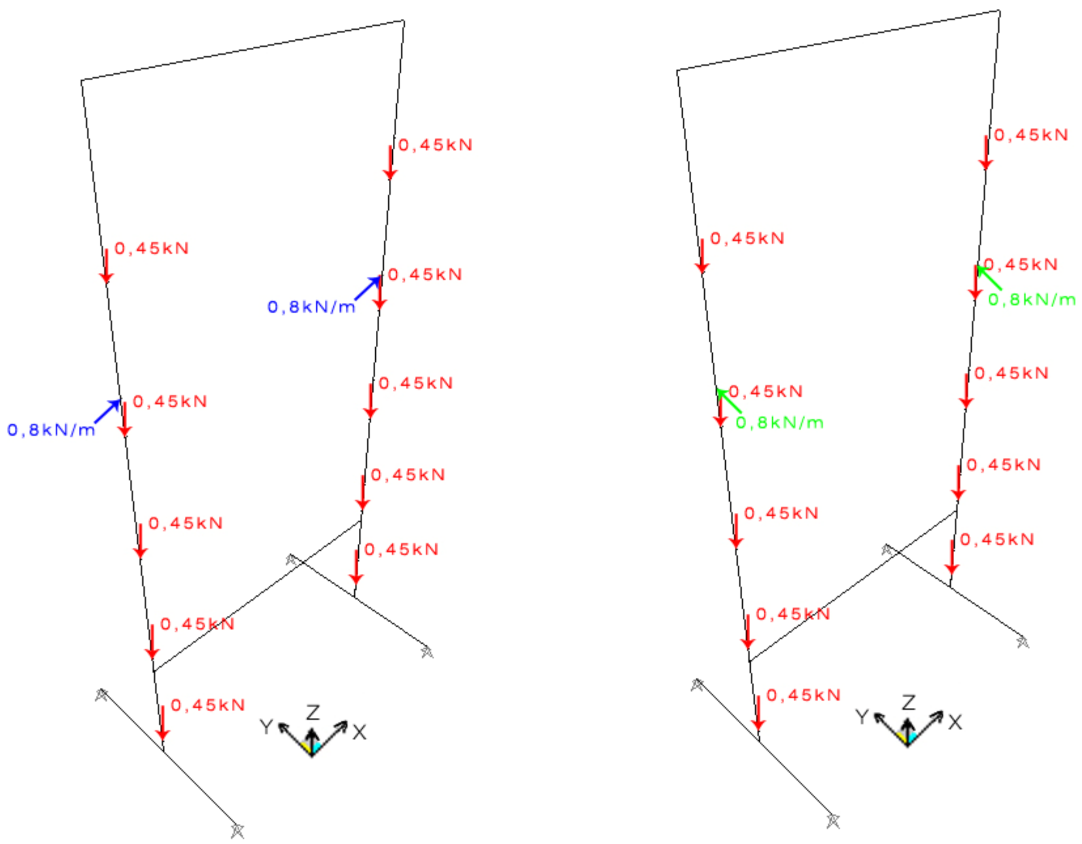
However, there are accidental cases where the global stability of the shelving unit could be compromised. These cases could be caused by the shelving unit being loaded as mentioned in the permanent position, but due to a knock by a person or another type of moving object this would then produce a horizontal force that would destabilize the structure as a whole.

According to the Technical Building Regulation (CTE), in their basic security document of Structural Building Act (DB-SE-A), section 3.2, the acts are established to bear in mind the railings and dividing elements, meaning to say that the vertical components could be subject to pushes from their own users or hits from objects as in the case of the shelving unit of this report. The vertical components must resist a horizontal force distributed equally (extension factor: 8) and for its worth, must be for public access zones with table and chairs (as simulated in a library) of 0.8 kN/m. This force would be considered at a height of 1.2m

This additional calculated position is going to be applied in the study of the structure of the shelving unit being loaded since that it could destabilize the whole unit including being knocked over.
This load position must be studied in the main instructions of the shelving unit:

-Plan of the force of the structure (e.g. X)

-Plan of the perpendicular force of the structure (e.g. Y)



Load state in the additional position. To the left, according to the parallel plan of the structure, (e.g. X) and to the right, according to the perpendicular plan of the structure (e.g. Y)

CALCULATION STRATEGY.

In order to carry out the calculation for all parts of the shelving unit, commercial software SAP 2000 has been used which is based on the finite element method. This is a validated tool which predicts the behaviour of the structure. In order to introduce this into the calculation programme, we must model all its components along with the surrounding conditions and applied load, in order to define the material properties and the geometry of the cross section frame.

The programme allows us to model the components depending on their way of working. Superficial elements that exist are represented by means of putting together all the finite elements. SAP 2000 offers us these objects by using coloured graphics showing the distortion and the tension state that suffer when the load is applied. On the other side, the bar components are modeled as lines. The programme gives us the effort that is needed (axis and flexion moment)

Since that the shelving unit is made up of different individual units, analysis has been carried out on all of these and introduced separately, this way all surrounding conditions are unified. In this manner we have simpler calculation models that allow us to better study each separate component that is represented in the most reliable way as possible. These parts are:

-Shelf: is the first component which receives the weight of the books and objects to withstand. It consists of a cold rolled steel sheet. The model in the calculation programme has introduced this by means of a superficial element.

-Lateral sides: are responsible for supporting the shelves and are equally made with steel sheets and have been modeled again as superficial elements.

-General structure: is the combination of the cross section frame which hooks onto the sides, receiving the load to transmit to the floor. These consist of steel tubular columns in which the calculation model has introduced as linear elements.

As such the problem is resolved: Following the strategy in the calculation has been to evaluate what distortion and tension state each component has and establish what the safety factor is in relation to its flexible limit.

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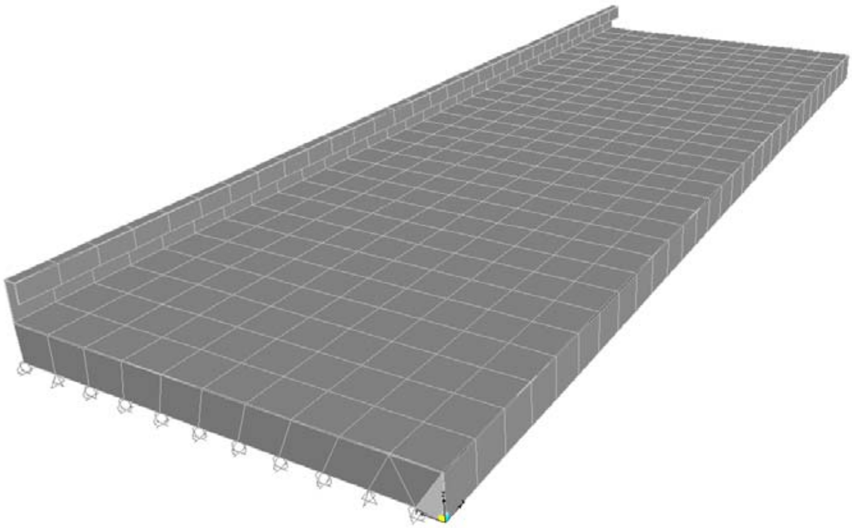
SHELF ELEMENT.

The shelves are formed by a cold rolled metal sheet of depth 315mm and width 880mm with a thickness of 0.7mm and have been modeled by way of superficial elements. It has an up turned lip both on its front and rear edges in order to give it stiffness.

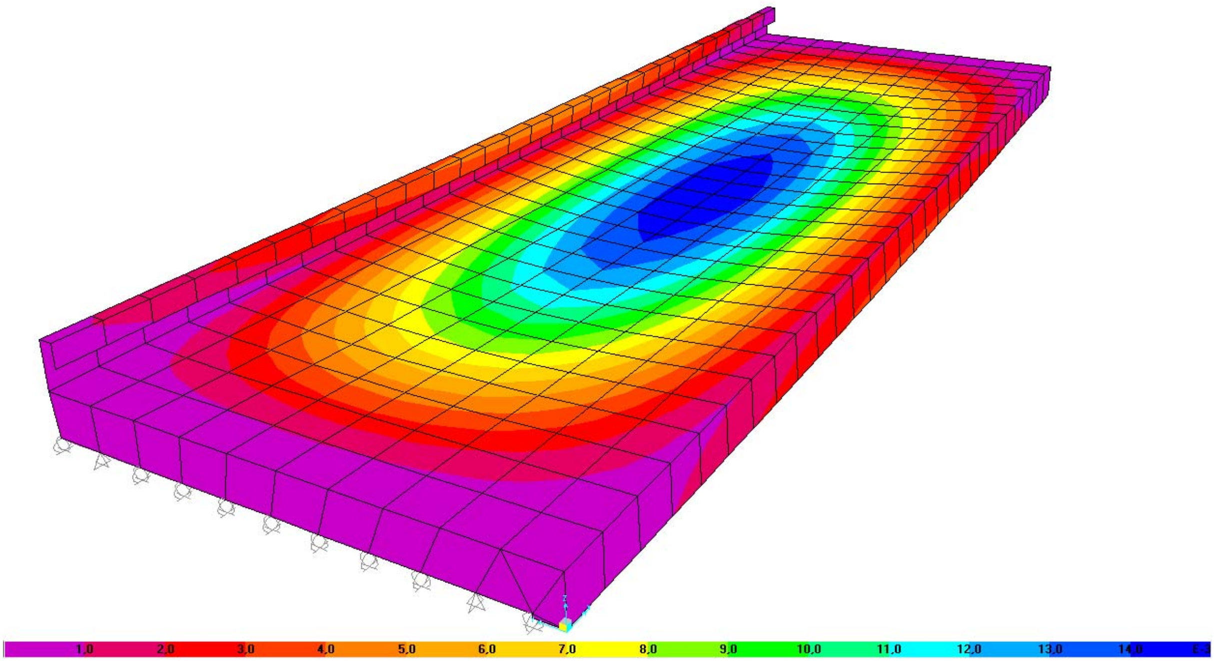
These components are represented as a bi-dimensional grid plan. In the model, the surrounding conditions are established that relate to the side laterals that bear the weight as form of supports that allow turn but not the displacement.

Also the designed load has been introduced. A shared weight of 45kg has been applied covering all of the surface.



Shelf calculation programme model.

The first data received can inform us how the element is working in its distorted form.



Distortion state of the shelf.

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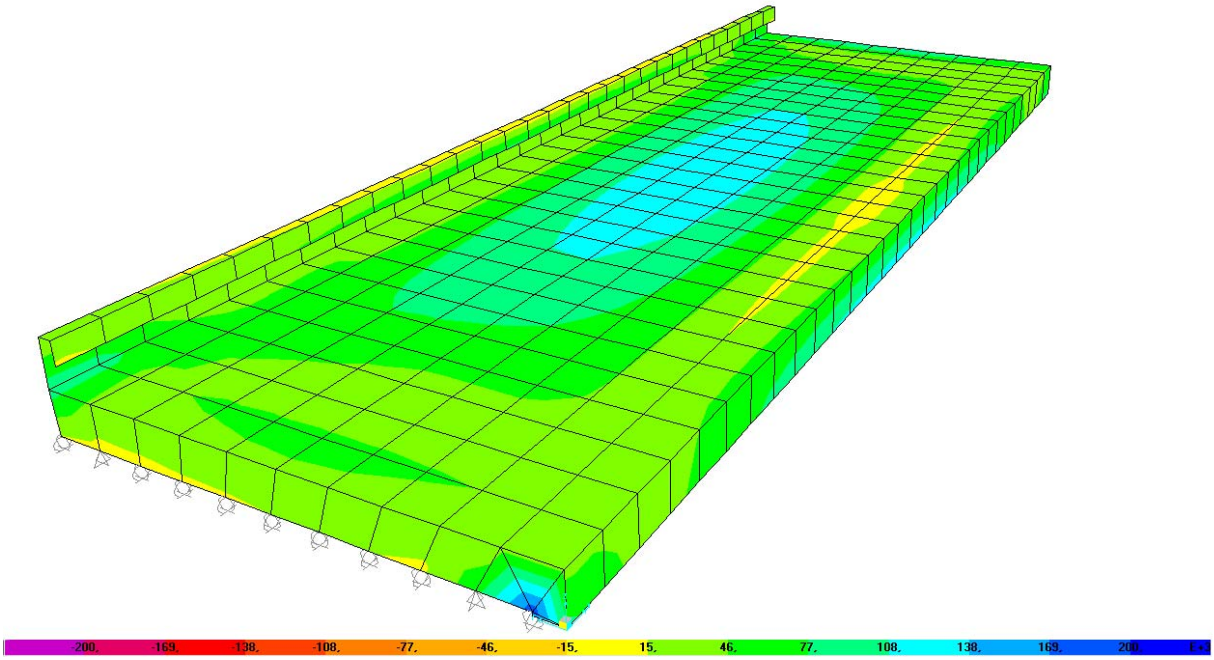
You can see in the graphic of the deformation what was hoped for, that this suffers a light convex of its central area of 19 mm.

However this will be the tension state which will give us the true data of how worn out the material is.



Maximum tension state of the shelf.

In this diagram, the programme shows us the tension in each point of the grid using a colour scale. Generally the sheet has a tension between 20-90MPa (green tones). The maximum is produced in the centre and in the front fold of the centre area (which really is giving the piece its stiffness) of 150MPa traction (cyan tone).

The steel used in production of this element is DC01, of which has a flexible limit is 200 MPa (dark blue and magenta tones).

Therefore we can say that the material is working at a 60% flexible regime or similarly it has a safety coefficient of 1.66.

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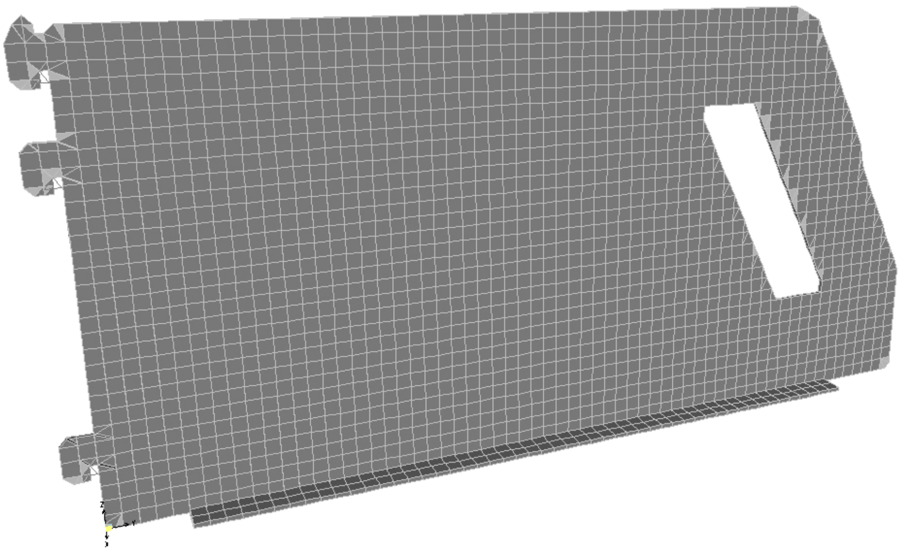
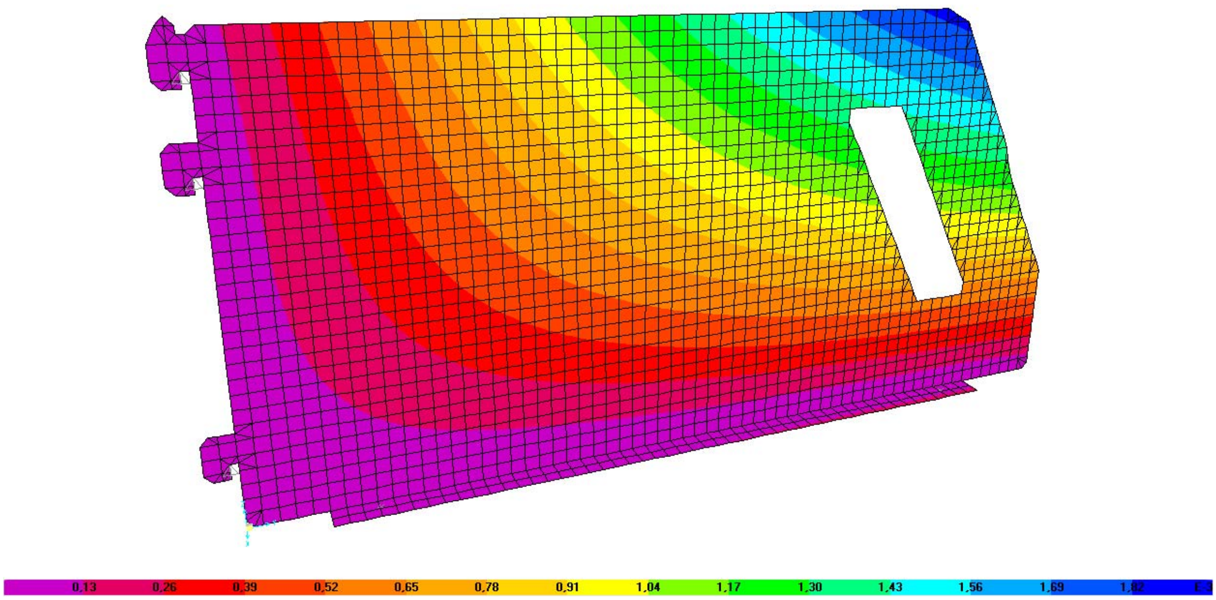
LATERAL SIDE ELEMENT.

Similar to the shelves, the side lateral parts that support them are also produced from folded steel sheets and these too have been modeled as superficial elements. It consists of a level sheet of width 315mm, an edge of 155mm with a thickness of 1.5mm. In the front part a large decorative hole has been drilled and in the lower part it has an up turned lip to gain the support of the shelves. Since that each shelf supports 45kg and is supported by two lateral parts, a load of 22.5kg has been introduced into the calculation model.



SAP 2000 calculation model programme.

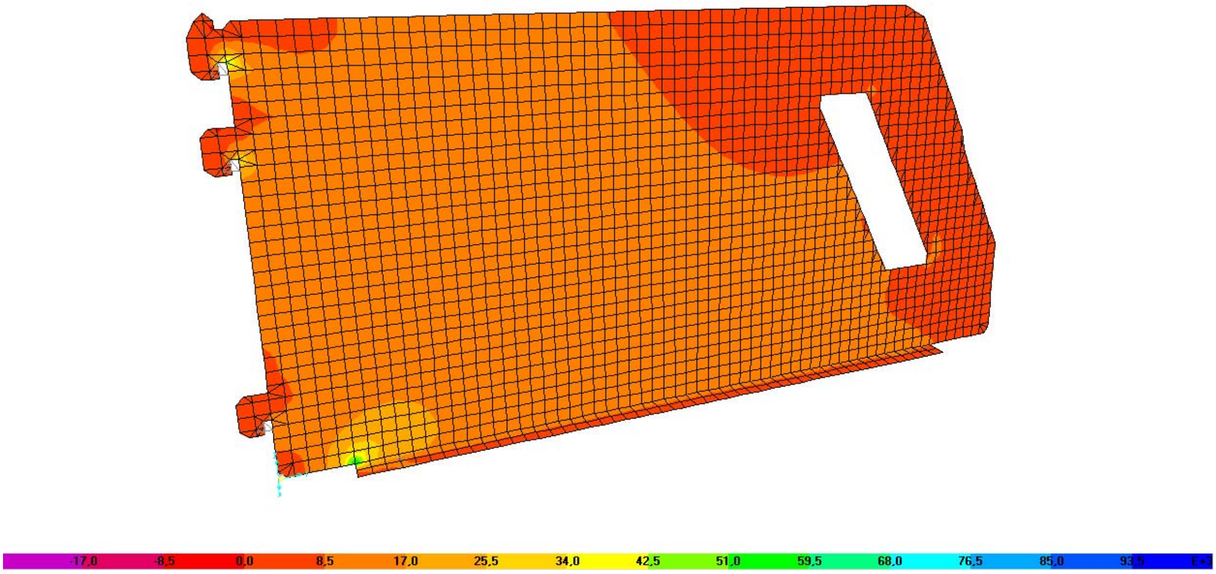
These elements are hooked onto the tabs of the cross section structure of the shelving unit. These are the outer surrounding conditions of the model that again allow turn but not the displacement and have been modeled simply as supports. Also the bracing effect has been introduced which is offered to the shelf on this metal sheet, now it doesn't allow a horizontal movement on its lower part.



Distortion according to the calculation programme of the lateral components.

The distorted image that the programme shows us gives us plenty of information of how these components work. As you can observe, it deforms 1.9mm at the opposite side towards the centre.

This is due to the turn that is produced in the lower part of the piece of which the load is not found centered on its axis. Due to its large edge the vertical component will hardly distort and doing it this way some components are very effective finally than was thought.



Lateral elements tensional state.

The tension state is really what indicates to us of how the side parts of the shelving unit work. As was hoped these function as wide edge traction cantilevers in which really work the metal sheet encompassed in its vertex triangles, and are the opposite side front support for the shelf and the upper and lower tabs. The other side of the sheet where the perforation is situated hardly works.

Due to the large edge the tensions are very low. In general you will find some 20MPa (orange tones) arriving up to some 55Mpa (green tones).

Similar to the shelves the steel used in the manufacture of this element is DC01 which has a flexible limit of 200 MPa.

However we can say that the material is working at a 27% flexible regime or similarly has a safety coefficient of 3.64.

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GENERAL STRUCTURE.

The structure of the shelving unit has also been processed using the structure calculation programme of SAP 2000. It is formed by rectangular section bars of 60mm and 30mm with a 2mm thickness, which has been modeled in the programme as lines.

In this case the surrounding conditions are as follows:

-Base support on the floor: the design of the shelving unit anticipates its support on the floor by means of small rubber silem blocks which allows movement in its three axes but not vertical displacement. With respect of a displacement, this will depend on the force of the friction between the rubber silem blocks and the floor. This calculation is not going to be subjected to this study since the coefficient of the friction of the floor where the shelving unit is going to be placed is unknown, but supposing that while the horizontal reactions will be less than the vertical produced by the weight of the books, the vertical pressure exercised will maintain the whole ensemble, avoiding it's displacement in block (as a rigid solid).

-External forces: these are transmitted to the elements that hold the shelves. Since that these elements are related at three points, the same load obtained is introduced into the previous calculation where the standard configuration of the shelving unit was anticipated.

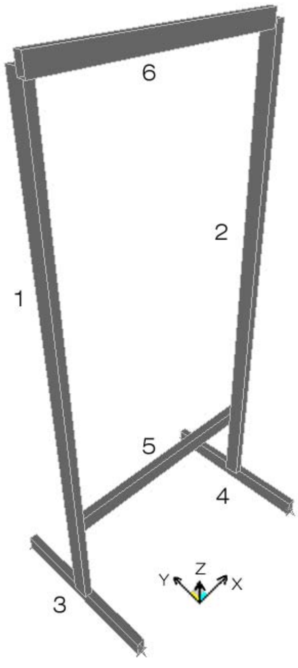
- Additional position: as commented previously, an equally distributed force of 0.8kN/m and a height of 1.2m was introduced. This force must be placed in two orthogonal directions. This is arranged in the two main axes of the shelving unit X and Y. The range of the perpendicular plan (axis Y) is 0.9m, so that the force applied would be 0.72 kN. In the parallel plan of the structure (axis X) this range is 0.69m therefore we have a force of 0.55 kN.

The quality of the steel of these cross sections is E260 with a flexible limit of 290 MPa. The mechanical characteristics of this cross section which depend on its geometry and the steel used are:

- Section area: 3.39 cm2
- Flexible unit yy (main axis): 6616cm3
- Flexible unit zz (secondary axis):4026cm3
- Turn radius yy (main axis): 2.15cm
- Turn radius zz (secondary axis):1.24cm

With this data, we obtain the flexible resistance of the cross section frame

- Maximum resistance axis: 98 kN
- Flexion moment yy maximum resistance (main axis): 1.92 mkN.
- Flexion moment zz maximum resistance (secondary axis): 1.17 mkN.

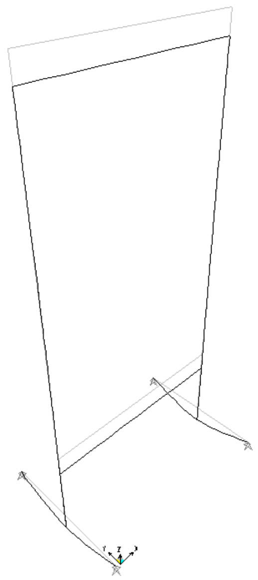


Bar model of the general structure.

CALCULATION RESULT.

PERMANENT LOCATION

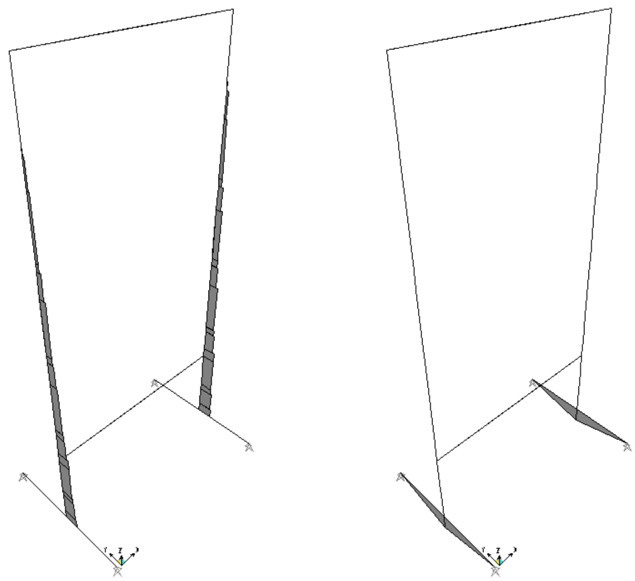
As we did earlier, a first estimate of how the structure works will be given to us as the distorted.



Distorted structure (Extension factor: 200)

As we can observe in the distorted, upright vertical columns (bars 1 and 2) pick up the weight of the shelves and transmit them to the base (bars 3 and 4), which are the only components that distort given that they are involved in flexion. This distortion is very small of some 0.4mm in the central lower part (axis Z), although in the programme this distortion has been increased to 200 in order to observe its effect.

The effort diagrams of as bars are as follows:



From left to right: Axis effort and flexion moment.

The numerical results such as the coefficient safety in respect of the flexible limit of the material are summarized in the following table.

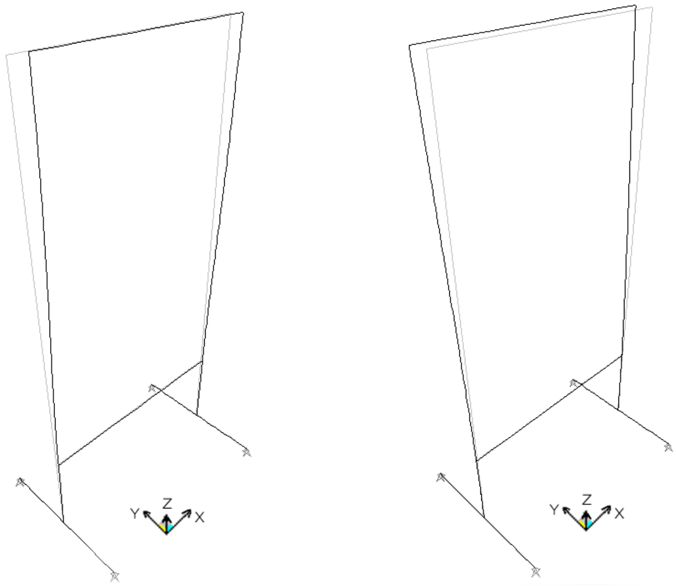
Bar	Axis (kN)	Moment (kNm)	Coefficient safety
1	2,38	0	**41,18**
2	2,38	0	**41,18**
3	0	0,38	**5,05**
4	0	0,38	**5,05**
5	0	0	**100**
6	0	0	**100**

As we can observe in the permanent load position, the shelving unit complies with a number 5. in safety. In this position the extensions 5 and 6 don't work since that the load runs central across the vertical (upright) columns.

ADDITIONAL POSITION

In the additional position, the effect of the horizontal load is studied such as the mechanical resistance with each separate component as with the unit as a whole ensemble. Also the orthogonal directions are studied which coincide with the main axis of the shelving unit.

Again we will start to analyze the distortion of the unit as a whole.



On the left, distorted according to the plan force of the structure axis X (extension factor: 8)
On the right distorted according to the plan force perpendicular to the structure axis Y (extension factor: 6)

As we can see, on applying a horizontal force, the distortion is passed to the vertical columns (1 and 2) which must support this mentioned force as free cantilevers on the higher opposite side. This distortion is 0.84cm according to axis X when the force works on the structure plan and 1.16 according to axis Y when the force is perpendicular to the structure plan.

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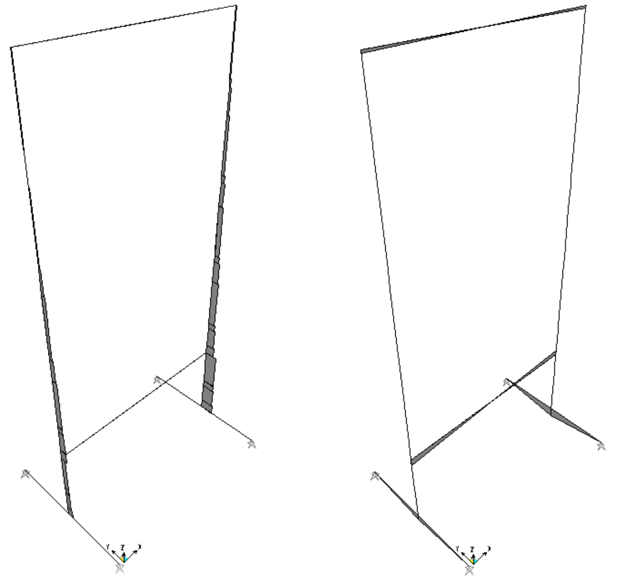
The effort diagrams as bars are the following for the force carried out on the structure plan (axis X):



To the left the diagram of the axis effort.To the right the diagram of the Flexion moment.

Numerically these results are:

Bar	Axis (kN)	Moment (kNm)	Coefficient safety
1	1,7	0,18	**6,50**
2	3,28	0,19	**6,16**
3	0	0,23	**8,35**
4	0	0,52	**3,69**
5	0	0,31	**6,19**
6	0	0,1	**19,20**

One can observe how the structure distorts towards one side, as the load is situated more on this side (in this case towards bar 2 and base 4). Nevertheless the structure continues to comply with a safety of 3.69. In this position the extensions 5 and 6 start to work, since that they must strengthen the structure of the unit as a whole.

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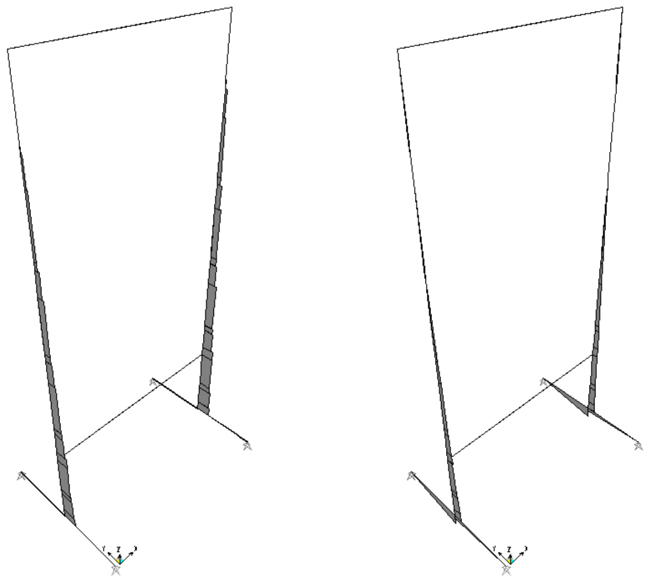
Finally the tension diagrams of the bars when the force is carried out in the perpendicular direction of the structure plan (axis Y) are as follows:



From left to right: axis effort diagram, diagram of the flexion moment.

Bar	Axis (kN)	Moment (kNm)	Coefficient safety
1	2,38	0,41	**2,85**
2	2,38	0,37	**3,16**
3	0,18	0,58	**3,31**
4	0,14	0,56	**3,43**
5	0	0	**100**
6	0	0	**100**

As we can see this is the hypothesis of the load that penalizes the structure, obtaining the lowest safety coefficient. But even then, we continue to have a safety of 2.85. As one can observe, again the extensions 5 and 6 don't enter the load since that the vertical columns 1 and 2 are the ones that carry the force until bases 3 and 4.

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