Research Programme of the Research Fund for Coal and Steel

# FIre and Seismic performances of Hybrid fire walls in case of single-storey industrial and commercial steel buildings (FISHWALL)

## Analysis of seismic behaviour of typical single-storey buildings

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## WP1: Analysis of regulation requirements, fire and seismic action applied to partition walls and design of tests

## Deliverable: D1.3

Grant agreement No: 101034083

| Version | Issue | Purpose | Author | Reviewer | Approved |
|---|---|---|---|---|---|
| A | D1.3 | first version (19/04/2022) | S.Pascali<br>N Tondini<br>G. Zanon | ALL | C. Renaud |
| B | D1.3 | revised version following comments from EC (24/10/2023) | S.Pascali<br>N Tondini<br>G. Zanon | C. Renaud | C. Renaud |
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# TABLE OF CONTENTS

# ABSTRACT

It is well known that the intrinsic fire resistance of single-storey unprotected steel-framed buildings is largely sufficient to guarantee the evacuation of occupants in the event of fire. In consequence, for this type of building, the main concern of national fire regulations in Europe is how to prevent the spread of fire to the whole building. To achieve this objective, two performances shall be usually satisfied, namely, the appropriateness of constructive systems to ensure that there is no progressive collapse between fire compartments, and the efficiency of fire walls to stop the fire inside the initial compartment regardless of the state of structures exposed to fire. In practice, many constructional solutions can be implemented in order to preserve the integrity of the fire walls, while accepting that the fire exposed part of the structure may collapse. One of the most common solutions is to place a non-load bearing wall between two independent steel structures and to connect it to them by means of "fusible" links. In fire situation, these fusible links have to allow the wall to be disconnected from the structure affected by fire without endangering the separating function of the wall, which shall remain fixed to the steel structure on the other side of the wall and therefore not exposed to fire. However, due to the lack of corresponding scientific evidence, questions are being very often raised about the real efficiency of such systems in fire situation, which, in certain cases, have also to provide an adequate seismic resistance, if they are used in seismic areas.

Today, concrete or masonry wall solutions are frequently used for the compartmentation of buildings, predominately for low-rise commercial and industrial steel buildings. However, as an alternative, lightweight sandwich panels (comprising two thin flat metal faces and an insulated core) could become an appropriate steel fire wall solution, offering numerous benefits in comparison to other solutions, including fire resistance, durability, flexibility, easy dismounting and fast construction times. But, there is an evident lack of technical information about the adequate fire performance of such type of wall solutions when they are implemented in single-storey buildings with unprotected steel structure, which constitutes a major obstacle for their large use.

In this context, the overall goal of the FISWHALL project is to develop a design guidance and recommendations for an innovative hybrid fire wall solution based on lightweight steel-faced sandwich panels associated with unprotected steel structure under both fire and seismic actions, but considered individually. This will be achieved through the following specific tasks: i) Establishing of a full range of experimental evidence about the fire and seismic behaviour of the investigated hybrid fire wall solution by carrying out a number of tests; ii) Investigating intensively the fire and seismic performances of the above hybrid fire wall solution in combination with unprotected single-storey steel structures through a variety of parametric numerical studies by means of validated FE numerical models; iii) Developing both cost-effective and innovative "fusible" connection systems for fire walls to be used in combination with unprotected steel structures of single-storey buildings; and iv) Developing a design guidance and practical recommendations for the studied hybrid fire wall and fusible links solutions, on the basis of above studies, from which engineers can carry out very efficient design.

The present report aims at summarising the main results of preliminary seismic analyses performed on single-storey steel-framed buildings based on the reference ones defined in task 1.2 of the project. The main objective of these analyses was to estimate an order of magnitude of forces that could act at level of "fusible" links connecting the fire walls to steel structures of buildings in earthquake situation.

# 1 INTRODUCTION

One aim of the project FISHWALL is to provide a hybrid steel-based fire wall solution using sandwich panels for single-storey buildings with unprotected steel structure. This fire wall can be placed between two independent building structures and connect it to them by means of "fusible" links. In case of fire event, the fusible links have to be designed to break and to allow the wall to be disconnected from the structure affected by the fire, without endangering the separating function of the wall, which remains fixed to the steel structure on the other side of the wall and therefore not exposed to the fire. Considering that buildings can be located in seismic prone region, it is necessary to verify that fire walls and fusible links can withstand earthquake forces.

This deliverable summarises the seismic study of typical single-storey buildings conducted in Task 1.4. The main objective of preliminary numerical analyses that have been performed was to estimate the forces that could act at level of investigated "fusible" links connecting the fire walls to steel structures. In this respect, the four reference steel-framed buildings described in detail in the deliverable D1.1 [1] were analysed. For each case study, a Finite Element model was developed, following the same modelling assumptions. According to the project, the considered fusible links was based on common steel connections using aluminium bolts acting as the fusible component. They were located at the roof level and was modelled as a frame element with M16 aluminium bolt characteristics. Considering all configurations, a total of 20 analysis were conducted.

Simulation results will be used to define the range of seismic actions to consider in the tests foreseen on fusible links in Work Package 4 as well as in the design of test specimens made in Task 1.5.

# 2 CASE STUDIES

The case studies considered in this deliverable correspond to the reference steel-framed buildings described in detail in the deliverable D1.1 of the project FISHWALL [1]. It should be noted that the buildings have been seismically designed in accordance with Eurocode 8 and the French National Annex, considering soil type A. Based on their location, case study n°2 and n°4 were designed for moderate seismicity, while case n°1 and 3 were not seismically designed due to their location in a low seismic region.

The main characteristics of investigated buildings are summarised hereafter. More detailed information can be found in deliverable D1.1.

## 2.1 Hot-rolled sections

### 2.1.1 Reference case n°1 - Carcassone

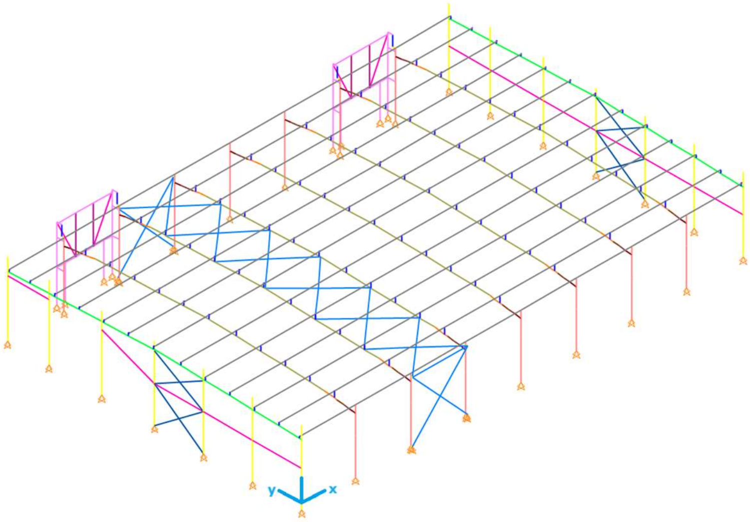



Figure 2.1: Perspective view of the first case study located in Carcassone

The steel structure of the first selected building, shown in Figure 2.1, is made by hot-rolled sections, and it has a floor area of about 1400 m$^2$ (46.6 m x 30 m).

The main building features are:

- Single-bay portal frame along the y direction;
- HEA600 section for columns hinged at their base;
- IPE600 section for rafters;
- Gable frame is composed of IPE200 for columns and cold-formed channel sections for rafters;
- Steel grade is S275;
- Purlins are thin cold-formed sections (C profile);
- The roof bracing system is made of L70x7 angles, whilst the vertical bracing systems are made either of L70x7 or of 140x4 square hollow section;
- The building is located in a weak seismic zone, in a second importance class, with soil type E.

Based on modal analyses results, Table 2.1 reports the dynamic properties of the Case study n°1 in terms of periods and modal participation masses of the three global modes, i.e. 2 translational and 1 torsional, with the diagonals of the bracing system active both in tension and in compression. Due to the model complexity some local modes appeared. Nevertheless, the translational mode in the direction of the bracing system is the lowest global mode, followed by the translational mode in the direction of the portal frames and the torsional mode.

Table 2.1: Dynamic properties of Case study n°1

| N. Mode | Period (s) | Relative modal participation mass UX (-) | Relative modal participation mass UY (-) | Relative modal participation mass RZ (-) |
|---|---|---|---|---|
| 3 | 0.49 | 0.98 | 0.00 | 0.00 |
| 9 | 0.40 | 0.99 | 0.80 | 0.03 |
| 11 | 0.30 | 0.99 | 0.82 | 0.82 |

Given the high slenderness of the braces of the bracing system, more accurate analyses were performed on Case study n°1, where in the direction of the bracing system only the diagonal active in tension was considered. Both +x and -x directions were taken into account. Thus, the diagonals in compression were not included into the two models and a linear modal analysis was carried out. Table 2.2 and Table 2.3 report the dynamic properties of the two models.

Table 2.2: Dynamic properties of Case study n°1 (+x)

| N. Mode | Period (s) | Relative modal participation mass UX (-) | Relative modal participation mass UY (-) | Relative modal participation mass RZ (-) |
|---|---|---|---|---|
| 1 | 0.99 | 0.99 | 0.00 | 0.00 |
| 4 | 0.45 | 0.99 | 0.87 | 0.00 |
| 6 | 0.35 | 0.99 | 0.88 | 0.89 |

Table 2.3: Dynamic properties of Case study n°1 (-x)

| N. Mode | Period (s) | Relative modal participation mass UX (-) | Relative modal participation mass UY (-) | Relative modal participation mass RZ (-) |
|---|---|---|---|---|
| 1 | 1.41 | 0.99 | 0.00 | 0.00 |
| 4 | 0.45 | 0.99 | 0.87 | 0.00 |
| 6 | 0.36 | 0.99 | 0.88 | 0.90 |

As expected, the period in the direction of the bracing system increased and a clear difference in stiffness between the two principal direction is observed. Nonetheless, the stiffness difference in the two principal directions is recurring in single-storey industrial halls due to the inherent difference in lateral-resisting systems, i.e., portal frames in one principal direction and bracing systems in the other. Despite this stiffness difference, linear dynamic analyses with the response spectra relative to the actual location of the building showed that both the damage limitation (DL) limit state, i.e. interstorey drift limitation, and the ultimate limit state (ULS) were satisfied.

## 2.1.2 Reference case n°2 - Montreuil

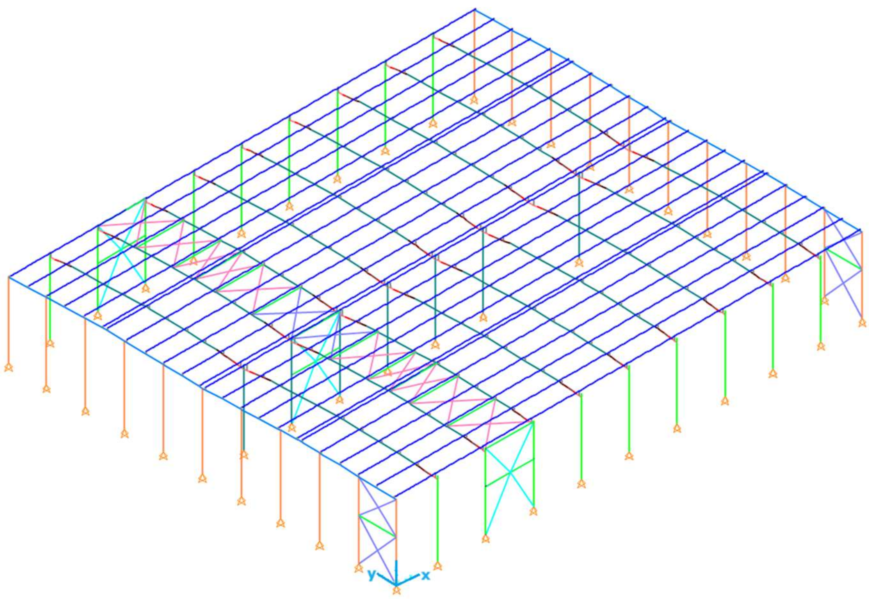



Figure 2.2: Perspective view of the second case study located in Montreuil

The steel structure of the second selected building, shown in Figure 2.2, is made of hot-rolled sections, and it has a floor area of about 3100 m$^2$ (61.2 m x 51.2 m).

The main building features are:

- Two-bay portal frame along the y direction;
- HEA360 section for columns hinged at their base;
- IPE500 section for rafters;
- Gable frame is composed of IPE240 for columns and cold-formed channel sections for rafters;
- Steel grade is S275;
- Purlins are thin cold-formed sections (sigma profile);
- The roof bracing system is made of L70x7 and L60x6 angles, whilst the vertical bracing systems are made of L70x7 and of L100x10;
- The building is located in a moderate seismic zone, in a second importance class, with a soil type A.

Based on modal analyses results, Table 2.4 reports the dynamic properties of the Case study n°2 in terms of periods and modal participation masses of the three global modes, i.e. 2 translational and 1 torsional, with the diagonals of the bracing system active both in tension and in compression. Modelling assumptions as for Section 3, with the roof stiffness, included were employed. Due to the model complexity some local modes appeared. Nevertheless, the translational mode in the direction of the bracing system is the lowest global mode, followed by the translational mode in the direction of the portal frames and the torsional mode.

Table 2.4: Dynamic properties of Case study n°2

| N. Mode | Period (s) | Relative modal participation mass UX (-) | Relative modal participation mass UY (-) | Relative modal participation mass RZ (-) |
|---|---|---|---|---|
| 1 | 0.94 | 0.99 | 0.00 | 0.00 |
| 2 | 0.80 | 0.99 | 0.99 | 0.00 |
| 11 | 0.53 | 0.99 | 0.99 | 0.98 |

Given the high slenderness of the braces of the bracing system, more accurate analyses were performed on Case study n°2, where in the direction of the bracing system only the diagonal active in tension was considered. Both +x and -x directions were taken into account. Thus, the diagonals in compression were not included into the two models and linear modal analyses was carried out. Table 2.5 and Table 2.6 report the dynamic properties of the two models.

Table 2.5: Dynamic properties of Case study n°2 (+x)

| N. Mode | Period (s) | Relative modal participation mass UX (-) | Relative modal participation mass UY (-) | Relative modal participation mass RZ (-) |
|---|---|---|---|---|
| 1 | 0.94 | 1.00 | 0.00 | 0.00 |
| 2 | 0.81 | 1.00 | 1.00 | 0.00 |
| 9 | 0.53 | 1.00 | 1.00 | 0.99 |

Table 2.6: Dynamic properties of Case study n°2 (-x)

| N. Mode | Period (s) | Relative modal participation mass UX (-) | Relative modal participation mass UY (-) | Relative modal participation mass RZ (-) |
|---|---|---|---|---|
| 1 | 1.42 | 1.00 | 0.00 | 0.00 |
| 2 | 0.73 | 1.00 | 0.99 | 0.00 |
| 9 | 0.56 | 1.00 | 0.99 | 0.99 |

As expected, the period in the direction of the bracing system increased and a clear difference in stiffness between the two principal direction is observed (up to 2 times). Despite this stiffness difference, linear dynamic analyses with the response spectra relative to the actual location of the building showed that both the damage limitation limit state, i.e. interstorey drift limitation, and the ultimate limit state were satisfied.

## 2.2 Welded sections

### 2.2.1 Reference case n°3 - Pibrac

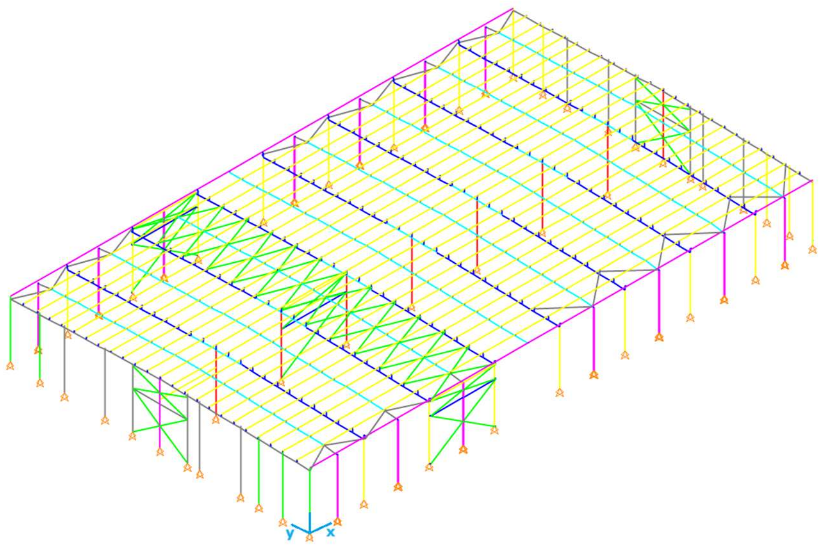



Figure 2.3: Perspective view of the third case study located in Pibrac

The steel structure of the third selected building, shown in Figure 2.3 is made of welded sections, and it has a floor area of about 6000 m$^2$ (100.44 m x 60 m).

The main building features are:

- Two-bay portal frame along the y direction;
- Portal frames are composed of welded sections with columns hinged at their base;
- Gable frame is composed of IPE300 or IPE330 sections for posts and cold-formed channel sections for rafters;

- Steel grade is S355 for welded sections and S275 for hot-rolled section and cold-formed sections;
- Purlins are thin cold-formed sections (sigma profile);
- Secondary columns are made of IPE270 section;
- The roof bracing system is made of L60x6 angles, as the vertical bracing system, made of L60x6;
- The building is located in a weak seismic zone, in a second importance class, with a soil type E.

Based on modal analyses results, Table 2.7 reports the dynamic properties of the Case study n°3 in terms of periods and modal participation masses of the three global modes, i.e. 2 translational and 1 torsional, with the diagonals of the bracing system active both in tension and in compression. Due to the model complexity some local modes appeared. Nevertheless, the translational mode in the direction of the bracing system is the lowest global mode, followed by the translational mode in the direction of the portal frames and the torsional mode.

Table 2.7: Dynamic properties of Case study n°3

| N. Mode | Period (s) | Relative modal participation mass UX (-) | Relative modal participation mass UY (-) | Relative modal participation mass RZ (-) |
|---|---|---|---|---|
| 3 | 0.98 | 1.00 | 0.00 | 0.00 |
| 4 | 0.67 | 1.00 | 0.99 | 0.00 |
| 7 | 0.54 | 1.00 | 1.00 | 0.98 |

Given the high slenderness of the braces of the bracing system, more accurate analyses were performed on Case study n°3, where in the direction of the bracing system only the diagonal active in tension was considered. Both +x and -x directions were taken into account. Thus, the diagonals in compression were not included into the two models and linear modal analyses was carried out. Table 2.8 and Table 2.9 report the dynamic properties of the two models.

Table 2.8: Dynamic properties of Case study n°3 (+x)

| N. Mode | Period (s) | Relative modal participation mass UX (-) | Relative modal participation mass UY (-) | Relative modal participation mass RZ (-) |
|---|---|---|---|---|
| 1 | 1.23 | 1.00 | 0.00 | 0.00 |
| 4 | 0.67 | 1.00 | 0.99 | 0.00 |
| 6 | 0.54 | 1.00 | 1.00 | 0.98 |

Table 2.9: Dynamic properties of Case study n°3 (-x)

| N. Mode | Period (s) | Relative modal participation mass UX (-) | Relative modal participation mass UY (-) | Relative modal participation mass RZ (-) |
|---|---|---|---|---|
| 2 | 1.22 | 1.00 | 0.00 | 0.00 |
| 4 | 0.67 | 1.00 | 0.99 | 0.00 |
| 6 | 0.54 | 1.00 | 1.00 | 0.98 |

As expected, the period in the direction of the bracing system increased and a clear difference in stiffness between the two principal direction is observed (almost up to 2 times). Despite this stiffness difference, linear dynamic analyses with the response spectra relative to the actual location of the building showed that both the damage limitation limit state, i.e. interstorey drift limitation, and the ultimate limit state were satisfied.

## 2.2.2 Reference case n°4 - Bressuire

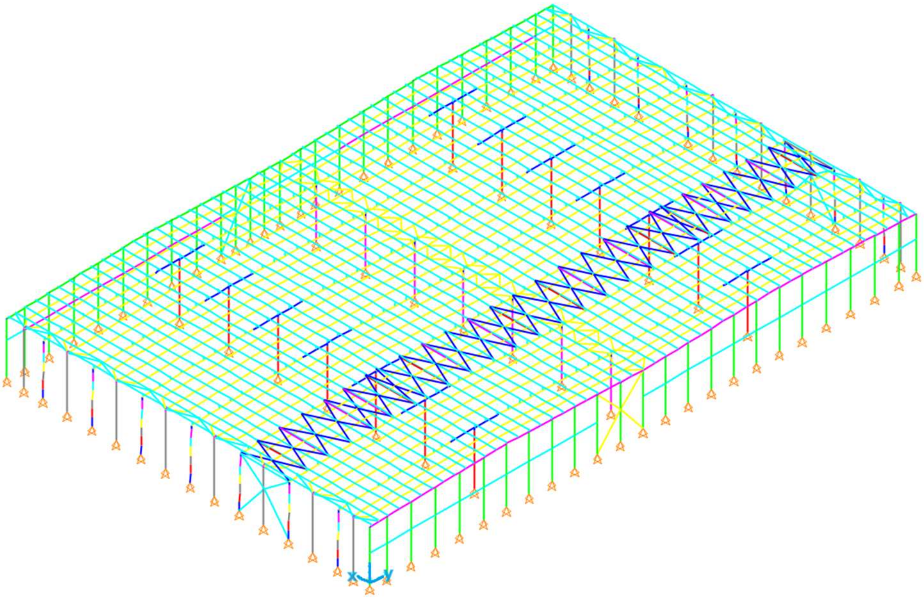


Figure 2.4: Perspective view of the fourth case study located in Bressuire

The steel structure of the fourth selected building, shown in Figure 2.4 is made of welded sections, and it has a floor area of about 12000 $m^2$ (88.9 m x 134 m).

The main building features are:

- Four bay portal frame along the y direction;
- Portal frames are composed of welded sections with columns hinged at their base, except for intermediary columns which are HEA340 section;
- Gable frame is composed of IPE300 for columns and cold-formed channel sections for rafters;
- Steel grade is S355 for welded sections and S275 for hot-rolled section and cold-formed sections;
- Purlins are thin cold-formed sections (sigma profile);
- Secondary columns are made of IPE270 section;

  The roof bracing system is made of L60x6 angles, whilst the vertical bracing systems are made of L70x7 and of L40x4;
- The building is located in a moderate seismic zone, in a second importance class, with a ground type A.

Based on modal analyses results, Table 2.10 reports the dynamic properties of the Case study n°4 in terms of periods and modal participation masses of the three global modes, i.e. 2 translational and 1 torsional, with the diagonals of the bracing system active both in tension and in compression. Due to the model complexity some local modes appeared. Moreover, contrary to the other case studies, the first global mode is in the direction of the portal frame and the second is the direction of the bracing system, whilst the third one remains the torsional one. Given the flexibility in the direction of the portal frames that are hinged at their base, the first period exceeds 2 s.

Table 2.10: Dynamic properties of Case study n°4

| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
|---|---|---|---|---|
| 1 | 2.03 | 0.00 | 0.91 | 0.01 |
| 4 | 1.46 | 0.99 | 0.91 | 0.01 |
| 6 | 0.94 | 0.99 | 0.93 | 0.95 |

Also in this case, given the high slenderness of the braces of the bracing system, more accurate analyses were performed on Case study n°4, where in the direction of the bracing system only the diagonal active in tension was considered. Both +x and -x directions were taken into account. Thus, the diagonals in compression were not included into the two models and linear modal analyses was carried out. Table 2.11 and Table 2.12 report the dynamic properties of the two models.

Table 2.11: Dynamic properties of Case study n°4 (+x)

| N. Mode | Period (s) | Relative modal participation mass UX (-) | Relative modal participation mass UY (-) | Relative modal participation mass RZ (-) |
|---|---|---|---|---|
| 1 | 2.06 | 0.06 | 0.83 | 0.02 |
| 2 | 2.05 | 0.99 | 0.89 | 0.03 |
| 5 | 1.25 | 0.99 | 0.91 | 0.96 |

Table 2.12: Dynamic properties of Case study n°4 (-x)

| N. Mode | Period (s) | Relative modal participation mass UX (-) | Relative modal participation mass UY (-) | Relative modal participation mass RZ (-) |
|---|---|---|---|---|
| 1 | 2.07 | 0.03 | 0.85 | 0.03 |
| 2 | 2.05 | 0.99 | 0.88 | 0.03 |
| 5 | 1.26 | 0.99 | 0.91 | 0.96 |

As expected, the period in the direction of the bracing system increased and it is in the same order as the one in the direction of the portal frames. Finally, linear dynamic analyses with the response spectra relative to the actual location of the building, showed that both the damage limitation limit state, i.e. interstorey drift limitation, and the ultimate limit state were satisfied.

# 3 MODELLING ASSUMPTIONS

In order to estimate the seismic forces that can act in the fusible links, a FE model in SAP2000 [2] was created for each selected case study.

Below the simplifying modelling assumption that were used for all the models:

- All the analyses were linear dynamic analyses with response spectrum;
- Only soil type E was. Such soil condition leads to higher seismic ground motions and then to higher forces in fusible links;
- The response spectra were computed in both horizontal directions and in vertical direction and they were combined according to the following rule included in Eurocode 8 [4]:

  $a)\ E_{Edx}$ "+" $0.30E_{Edy}$ " + " $0.30E_{Edz}$

  $b)\ 0.30E_{Edx}$ "+" $E_{Edy}$ " + " $0.30E_{Edz}$

  $c)\ 0.30E_{Edx}$ " + " $0.30E_{Edy}$ " + " $E_{Edz}$
- The seismic action in the elements along each direction was evaluated by means of the Complete Quadratic Combination (CQC);
- Steel members are of either S275 (hot rolled profiles) or S355 (welded profiles) grading, according to [1]. The steel Young's modulus was taken equal to 200000 MPa;
- The FEs analyses were performed on buildings consisting of two steel structures obtained by a reflective symmetry of the real structure of the considered reference case study around the fire wall located between the two steel structures;
- The frame elements used in the software are defined as elastic beam elements that follow Timoshenko formulation;
- The portal frames, the columns and the bracing system were modelled as frame elements;
- The bracing system members were considered both in tension and in compression, neglecting however flexural buckling effects;
- Any local instability phenomena on members with a class 4 cross-section were not taken into account;
- Hinged bases were considered for all columns;
- Mesh sensitivity analysis was performed and mesh sizes related to the shell elements of the fire wall and the roof were of about 30x30 cm and 60x60 cm, depending on the case study, respectively;
- The fire wall placed between steel structures was attached to these structures by means of fusible links. The fire wall was modelled by means of shell elements with a thickness of 17.5 cm and with elastic modulus equal to 31500 MPa that is equivalent to a concrete strength class equal to C25/30. The fire wall stiffness value was selected conservatively to obtain higher forces on the fusible links;
- The roof was modelled by means of shell elements fixed to the structure with an equivalent thickness of 4 cm and 3,76 cm representing the actual flexural and in-plain stiffness of the roof panels, respectively;
- Each fire wall was connected to steel structures by means of fusible links located at the roof level and based on different details;
- Fusible links were modelled with frame elements by considering aluminium M16 bolts;
- For each case study, at least two levels of seismicity, i.e. low and moderate, were considered;
- For each case study, at least two structural configurations were considered: taking into account or not the roof stiffness;
- The behaviour factor was considered equal to 1.5.

It should be underlined that all the assumptions were made to provide, as far as possible at this state of the project, an upper bound estimate of the forces that could act in the fusible links.

## 3.1 Structural and fire wall configurations

In order to provide a comprehensive information, several configurations were modelled for each case studies. As shown in Figure 3.1, three main configurations were analysed: i) the fire wall parallel to steel portal frames and actual position of bracing system, ii) a configuration with the fire wall parallel to portal frames and the bracing system located close to it to estimate the influence of the bracing system and iii) a configuration with the fire wall orthogonal to steel portal frames.

Thus, it is expected that the presence of the fire wall with the fusible links that connect it to the structures will affect the dynamic properties of the single case studies that were reported in Section 2.

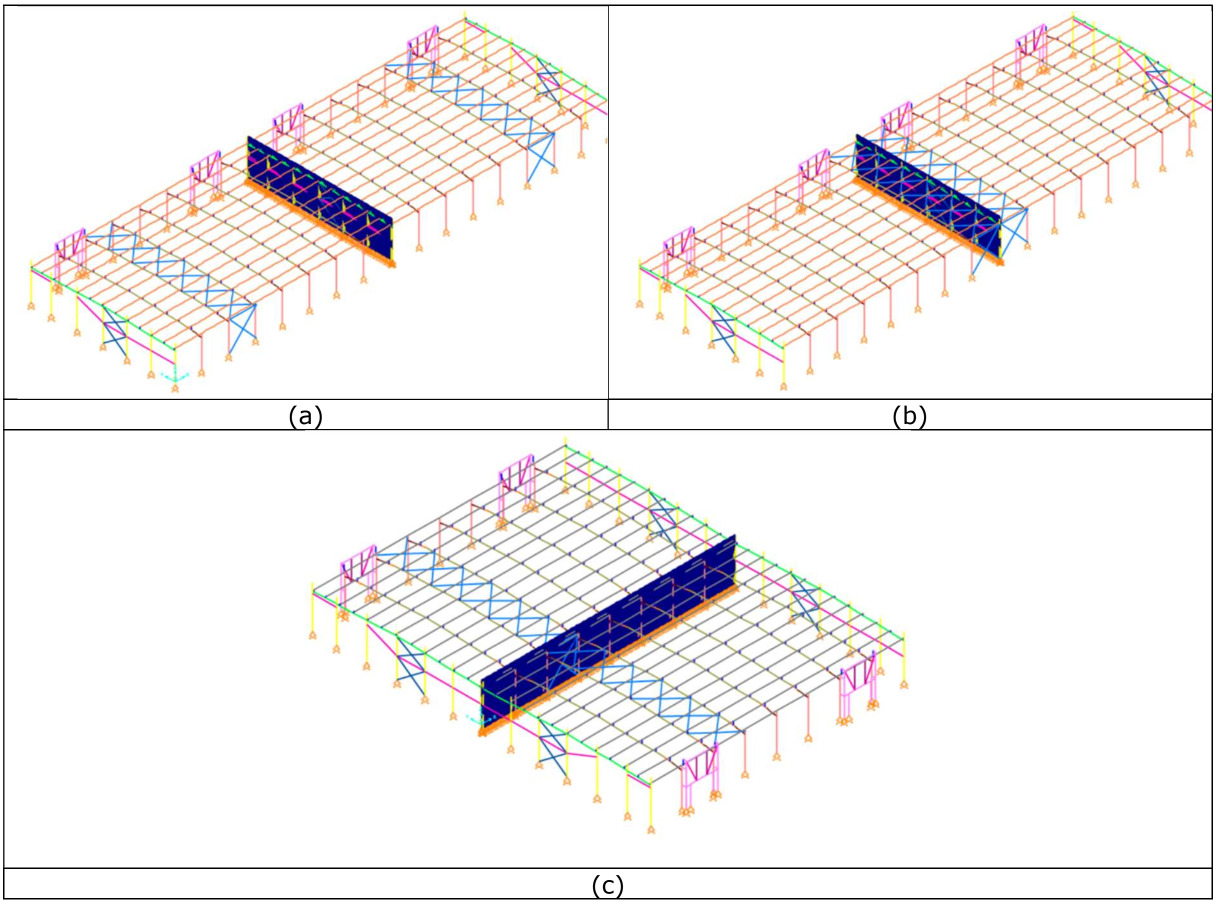



Figure 3.1: Configurations analysed: a) fire wall parallel to portal frames and actual position of bracing system; b) fire wall parallel to portal frames and bracing system near the fire wall; c) fire wall orthogonal to portal frames

Afterwards, for each configuration, were conducted two analyses, to study the behaviour of the structure while considering or not the possible stiffness brought by the steel roof decking.

## 3.2 Response Spectra

For each case study, as indicated above, a linear dynamic analysis with response spectrum was performed, for at least with two levels of seismicity.

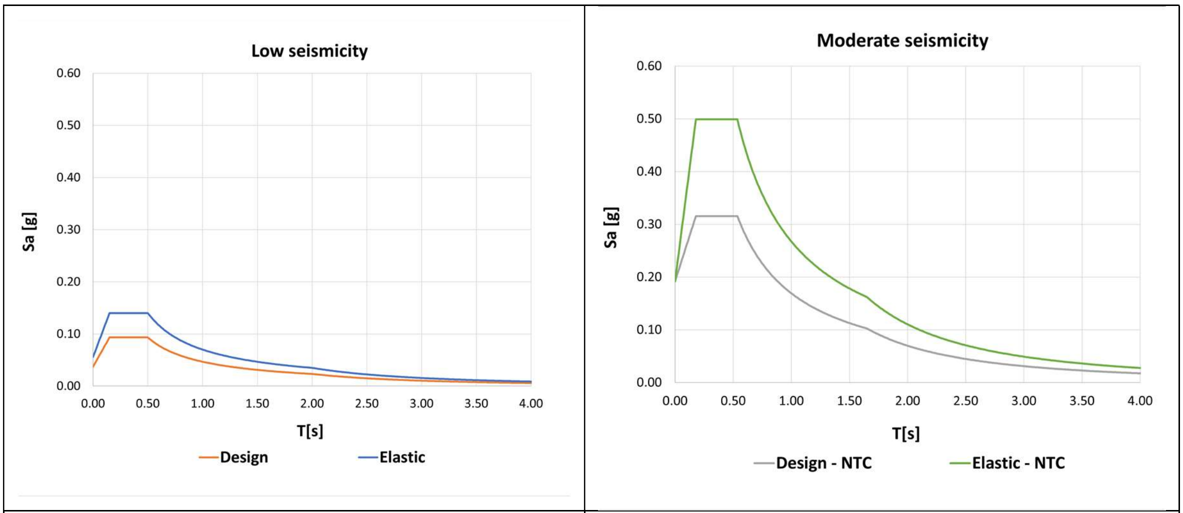
A site characterized by a value of peak ground acceleration (pga) equal to 0.04 g and soil type E (as Carcassone is) was selected as low seismicity.

A site characterized by a value of peak ground acceleration (pga) equal to 0.12 g, representing the Italian area of Riva del Garda [5], and soil type E was selected as moderate seismicity. It was considered as worst scenario to estimate the seismic forces in the fusible links.

Moreover, for each case study, the response spectrum corresponding to the actual building location was also used. Finally, all response spectra used for each case study are listed in Table 3.1.

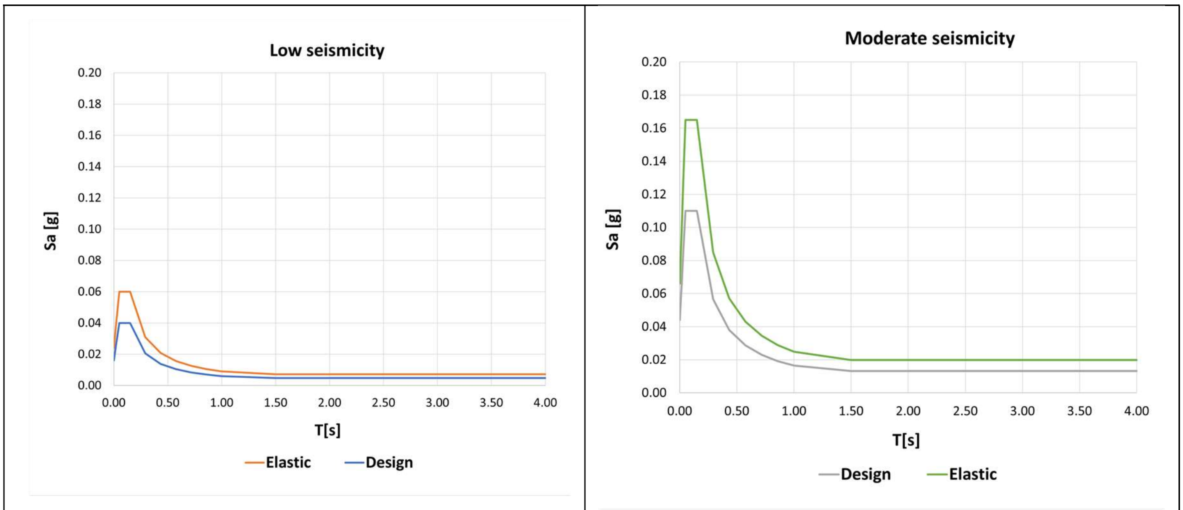
Table 3.1: Response spectra

| Reference Case | Low seismicity | Moderate seismicity | Local actual seismicity |
|---|---|---|---|
| 1 (Carcassone) | pga = 0.04 g<br>soil type: E | pga = 0.12 g<br>soil type: E | Same as low seismicity |
| 2 (Montreuil) | pga = 0.04 g<br>soil type: E | pga = 0.12 g<br>soil type: E | pga = 0.11 g<br>soil type: A |
| 3 (Bressuire) | pga = 0.04 g<br>soil type: E | pga = 0.12 g<br>soil type: E | pga = 0.11 g<br>soil type: A |
| 4 (Pibrac) | pga = 0.04 g<br>soil type: E | pga = 0.12 g<br>soil type: E | Same as low seismicity |




(a) (b)

Figure 3.2: Horizontal response spectra along both main directions at ULS




(a) (b)

Figure 3.3: Vertical response spectra at ULS

## 3.3 Design resistances for aluminium M16 bolt

According to EN 1999-1-1 [6] the shear resistance and the tension resistance of an aluminium M16 bolt were calculated. The bolt considered is the "AlZn5,5MgCu" (7075) according to ISO 209 [3], with a nominal ultimate tensile strength $f_u$ taken equal to 490 MPa. The resistant section used in the calculation is 157 mm$^2$.

Therefore, the shear resistance was calculated as:

$$F_{v,Rd} = \frac{a_v f_{ub} A_s}{\gamma_{M2}} = 30.77\ kN$$

Where:

$a_v$ = 0.5 for aluminium bolts;

$\gamma_{M2} = 1.25$

And the tension resistance:

$$F_{t,Rd} = \frac{k_2 f_{ub} A_s}{\gamma_{M2}} = 30.77\ kN$$

Where:

$k_2$ = 0.5 for aluminium bolts;

$\gamma_{M2} = 1.25$

Finally, the combined resistance reads:

$$\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1{,}4F_{t,Rd}} \leq 1.0$$

The number of bolts required for each detail was estimated, in safe way, taking into account the interaction between shear and tension force using the following formulation.

$$n_{bolts} = roundup\left(\frac{V_{Ed}}{F_{v,Rd}} + \frac{P_{Ed}}{1{,}4F_{t,Rd}}\right)$$

Where:

$V_{Ed}$ is the resultant of the shear forces in the fusible link;

$P_{Ed}$ is the tensile force in the fusible link.

# 4 RESULTS OF THE ANALYSES

Despite the following figures of modelled structures are shown without the roof shell, the analyses were carried out with, see Figure 4.1, in both cases of with or without roof. The latter was obtained by reducing the in-plane stiffness of the shell elements composing the roof. It is worth noting that in the figures the shell elements were removed only for visualization purposes of the whole structure.

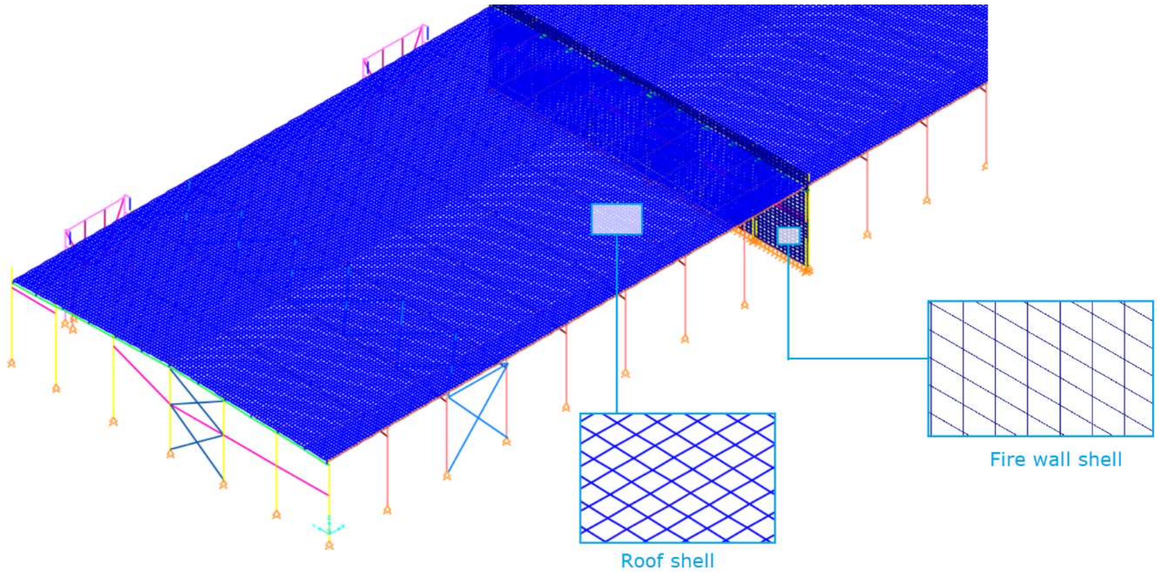



Figure 4.1: Detail of the mesh of the shell elements of the fire wall, sizes of about 60x60 cm and of the roof, sizes of about 30x30 cm.

## 4.1 Reference case n°1: Carcassone

The first case study is composed of two steel structures made of hot-rolled sections separated by a fire wall. It was analysed according to three configurations: i) the fire wall parallel to portal frames, ii) the fire wall parallel to portal frames but with the bracing system close to them and iii) finally the fire wall orthogonal to portal frames.

The design response spectra used for these analyses are shown in Figure 4.2: the low seismicity is represented by the Carcassone spectrum, while the moderate seismicity is represented by the Riva del Garda response spectrum.

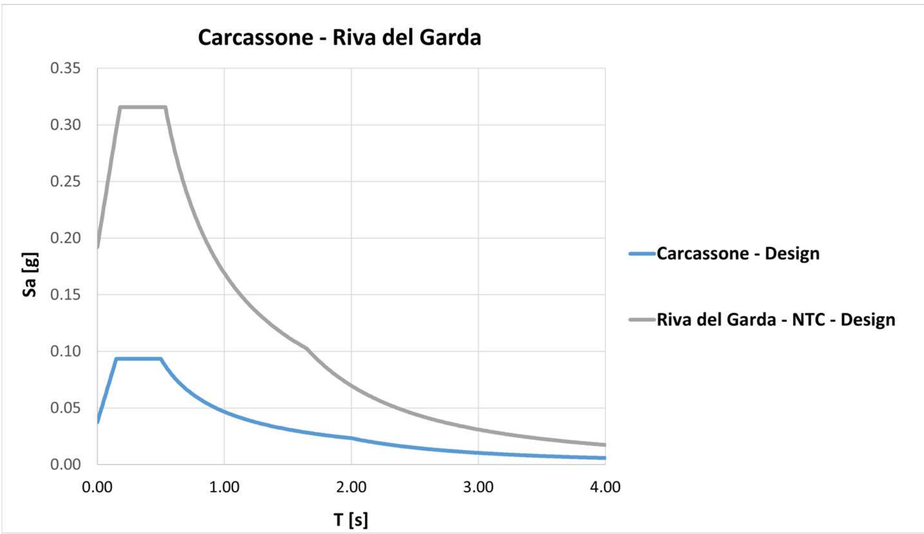



Figure 4.2: Horizontal design response spectra at the ULS for Carcassone case study

### 4.1.1 Parallel fire wall and bracing system in the actual position

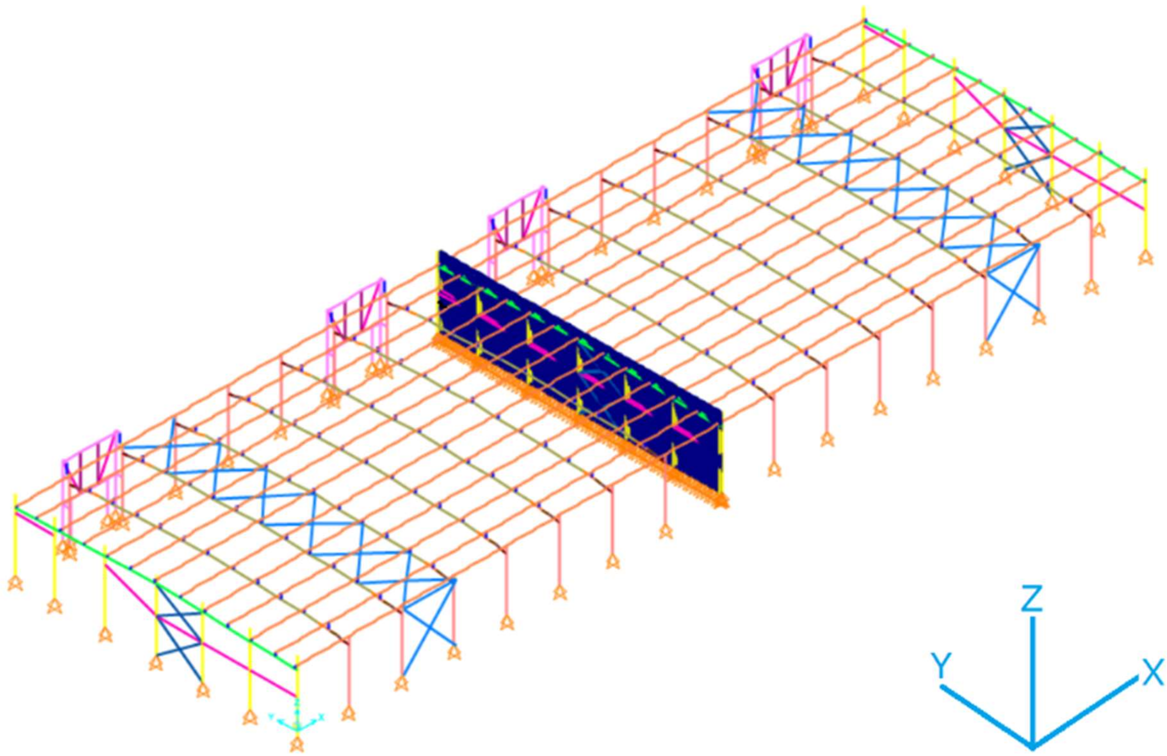



Figure 4.3: Fire wall parallel to portal frames

The first analysed configuration is shown in Figure 4.3, with the fire wall parallel to portal frames.

From the analyses, the dynamic properties of the model are summarized in Table 4.1 and Table 4.2. It should be noted that the first period of the structure was in both cases around 1.2 s, with a purely translational mode along X direction.

Table 4.1: Dynamic properties of the model with roof

| **With Roof** | | | | | |
|---|---|---|---|---|---|
| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| **Mode 1** | **1.22** | **0.94** | 0.00 | 0.00 |
| Mode 2 | 0.70 | 0.94 | 0.00 | 0.00 |
| Mode 3 | 0.70 | 0.94 | 0.00 | 0.00 |
| Mode 4 | 0.59 | 0.94 | 0.00 | 0.00 |
| Mode 5 | 0.59 | 0.94 | 0.00 | 0.00 |
| Mode 6 | 0.58 | 0.94 | 0.00 | 0.00 |
| Mode 7 | 0.58 | 0.94 | 0.00 | 0.00 |
| Mode 8 | 0.53 | 0.94 | 0.02 | 0.00 |
| Mode 9 | 0.48 | 0.94 | 0.02 | 0.00 |
| Mode 10 | 0.47 | 0.94 | 0.02 | 0.36 |
| **Mode 11** | **0.47** | 0.94 | 0.02 | **0.94** |
| **Mode 49** | **0.20** | 0.96 | **0.76** | 0.99 |

Table 4.2: Dynamic properties of the model without roof

| Without Roof | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| **Mode 1** | **1.24** | **0.94** | 0.00 | 0.00 |
| Mode 2 | 0.90 | 0.94 | 0.00 | 0.00 |
| Mode 3 | 0.90 | 0.94 | 0.00 | 0.00 |
| Mode 4 | 0.82 | 0.94 | 0.00 | 0.00 |
| Mode 5 | 0.82 | 0.94 | 0.00 | 0.00 |
| Mode 6 | 0.67 | 0.94 | 0.00 | 0.00 |
| Mode 7 | 0.66 | 0.94 | 0.00 | 0.00 |
| Mode 8 | 0.59 | 0.94 | 0.00 | 0.00 |
| Mode 9 | 0.59 | 0.94 | 0.00 | 0.00 |
| Mode 10 | 0.58 | 0.94 | 0.00 | 0.00 |
| Mode 11 | 0.58 | 0.94 | 0.00 | 0.00 |
| **Mode 44** | **0.25** | 0.95 | **0.79** | **0.98** |

As can be noticed from Table 4.1 and Table 4.2, the fire wall presence changed the building dynamic properties in the direction parallel to the fire wall. This is the reason why the translational global mode parallel to the fire wall decreased its period with respect to the single case studies without fire wall.

For this preliminary estimation of forces, it was considered that the fire wall solution associated to fusible links placed between the two steel structures could be those given in Figure 4.4, Solution (a) or in Figure 4.5, Solution (b).

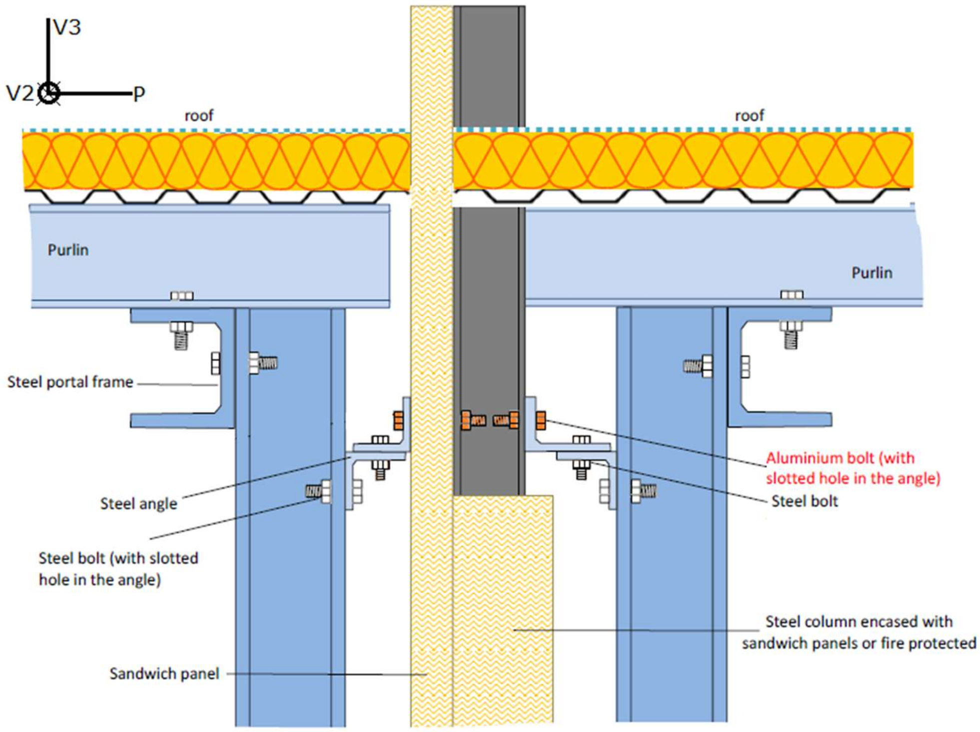



Figure 4.4: Possible fusible link detail assumed in the modelling: Solution (a)

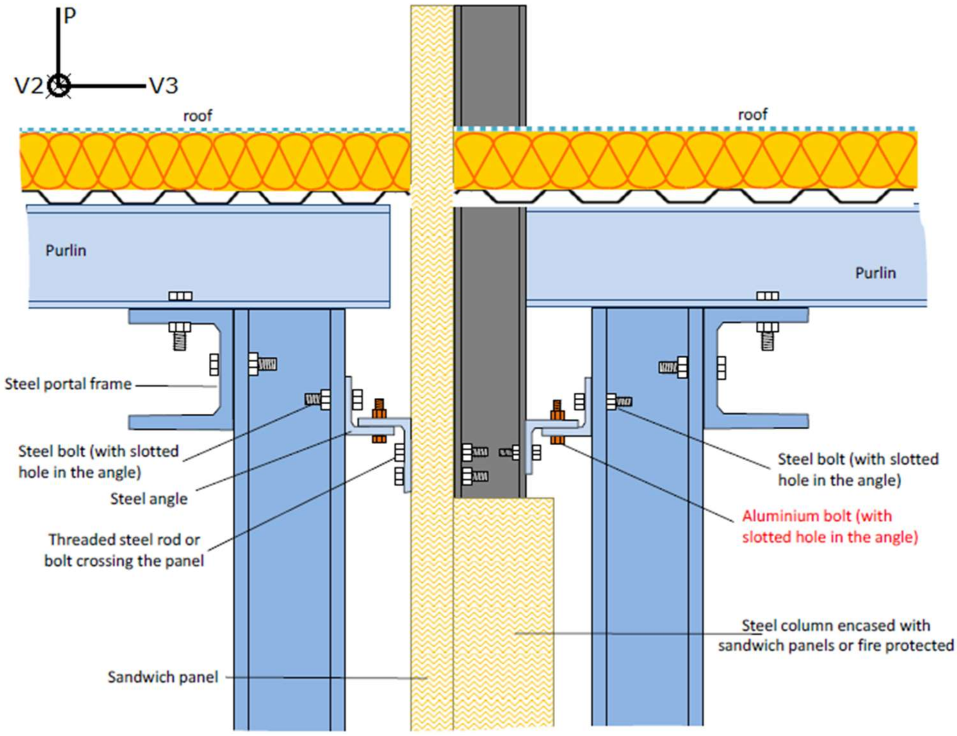



Figure 4.5: Possible fusible link detail assumed in the modelling: Solution (b)

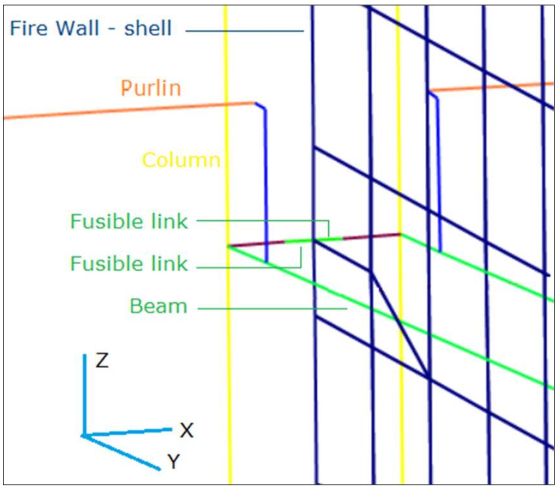



Figure 4.6: Schematic view of the detail of Figure 4.4 implemented in the FE model.

For this case study all forces acting on all fusible links along the fire wall are shown in Table 4.3, Table 4.4, Table 4.5 and Table 4.6. On each line of the table there is the seismicity level and the combination; then, the left part of the columns refers to the internal actions in the fusible link on one side of the wall, the right part refers to the corresponding fusible link on the other side of the wall, as shown in the Figure 4.6.

In Figure 4.7 is shown the position of each couple of fusible links along the wall.

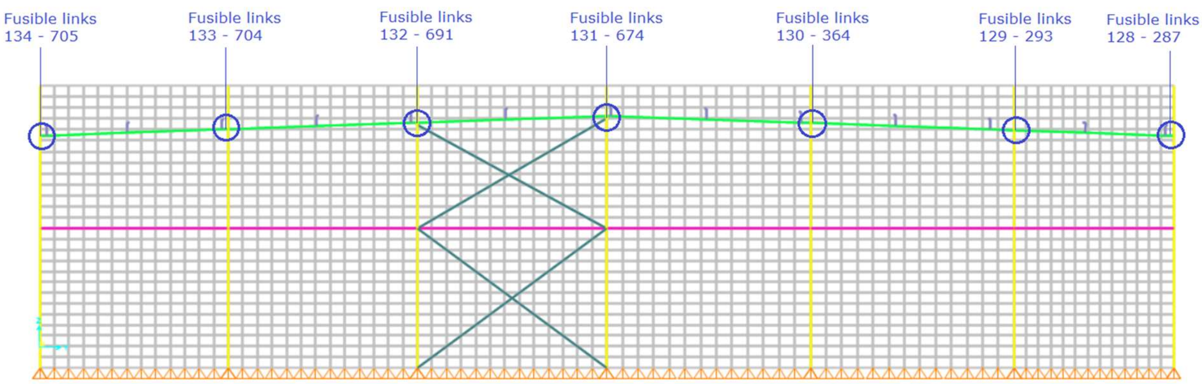



Figure 4.7: Position of fusible links along the wall

Table 4.3: Forces in the fusible links according to Figure 4.4, considering the roof with a low seismicity level.

| With Roof | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Seismicity | Combination | Frame | P | V2 | V3 | Frame | P | V2 | V3 |
| | | | kN | kN | kN | | kN | kN | kN |
| Low | Max | 128 | 8.09 | 4.42 | -2.30 | 287 | 8.04 | 5.09 | 17.66 |
| Low | Max | 129 | 0.50 | 2.16 | -7.85 | 293 | 0.53 | 6.91 | 23.10 |
| Low | Max | 130 | -5.71 | -0.38 | -6.84 | 364 | -5.71 | 8.88 | 20.76 |
| Low | Max | 131 | -12.72 | -24.54 | 4.41 | 674 | -12.69 | 32.64 | 11.09 |
| Low | Max | 132 | -4.39 | -0.83 | 9.94 | 691 | -4.30 | 9.42 | 2.94 |
| Low | Max | 133 | 3.77 | 6.85 | 16.10 | 704 | 3.62 | 1.48 | -3.35 |
| Low | Max | 134 | 13.16 | 3.85 | 15.88 | 705 | 13.20 | 5.05 | 2.54 |
| Seismicity | Combination | Frame | P | V2 | V3 | Frame | P | V2 | V3 |
| | | | kN | kN | kN | | kN | kN | kN |
| Low | Min | 128 | -2.03 | -5.05 | -17.90 | 287 | -2.09 | -4.35 | 2.11 |
| Low | Min | 129 | -5.00 | -6.96 | -23.42 | 293 | -4.95 | -2.22 | 7.57 |
| Low | Min | 130 | -11.10 | -8.97 | -21.41 | 364 | -11.10 | 0.30 | 6.24 |
| Low | Min | 131 | -20.76 | -32.59 | -9.42 | 674 | -20.73 | 24.59 | -2.68 |
| Low | Min | 132 | -13.13 | -9.63 | -2.85 | 691 | -13.03 | 0.62 | -9.78 |
| Low | Min | 133 | -8.41 | -1.74 | 3.36 | 704 | -8.58 | -7.15 | -16.01 |
| Low | Min | 134 | -2.66 | -5.19 | -2.92 | 705 | -2.61 | -3.97 | -16.25 |

Table 4.4: Forces in the fusible links according to Figure 4.4, considering the roof with a moderate seismicity level.

| With Roof | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Seismicity | Combination | Frame | P | V2 | V3 | Frame | P | V2 | V3 |
| | | | kN | kN | kN | | kN | kN | kN |
| Moderate | Max | 128 | 20.89 | 17.31 | 17.11 | 287 | 20.85 | 17.94 | 37.02 |
| Moderate | Max | 129 | 7.52 | 14.59 | 11.48 | 293 | 7.54 | 19.35 | 42.37 |
| Moderate | Max | 130 | 1.33 | 11.31 | 11.26 | 364 | 1.33 | 20.56 | 38.79 |
| Moderate | Max | 131 | -2.46 | -13.57 | 21.55 | 674 | -2.43 | 43.60 | 28.16 |
| Moderate | Max | 132 | 6.60 | 11.16 | 25.81 | 691 | 6.67 | 21.40 | 18.74 |
| Moderate | Max | 133 | 18.94 | 18.55 | 31.93 | 704 | 18.81 | 13.25 | 12.37 |
| Moderate | Max | 134 | 32.78 | 16.16 | 39.16 | 705 | 32.80 | 17.32 | 25.82 |
| Seismicity | Combination | Frame | P | V2 | V3 | Frame | P | V2 | V3 |
| | | | kN | kN | kN | | kN | kN | kN |
| Moderate | Min | 128 | -14.84 | -17.94 | -37.32 | 287 | -14.90 | -17.20 | -17.26 |
| Moderate | Min | 129 | -12.02 | -19.39 | -42.75 | 293 | -11.96 | -14.66 | -11.71 |
| Moderate | Min | 130 | -18.13 | -20.66 | -39.51 | 364 | -18.14 | -11.39 | -11.79 |
| Moderate | Min | 131 | -31.02 | -43.55 | -26.55 | 674 | -31.00 | 13.62 | -19.76 |
| Moderate | Min | 132 | -24.12 | -21.62 | -18.72 | 691 | -24.00 | -11.36 | -25.58 |
| Moderate | Min | 133 | -23.58 | -13.45 | -12.47 | 704 | -23.77 | -18.92 | -31.73 |
| Moderate | Min | 134 | -22.27 | -17.51 | -26.20 | 705 | -22.21 | -16.24 | -39.54 |

Table 4.5: Forces in the fusible links according to Figure 4.4 without the roof and with a low seismicity level.

| Without Roof | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Seismicity | Combination | Frame | P | V2 | V3 | Frame | P | V2 | V3 |
| | | | kN | kN | kN | | kN | kN | kN |
| Low | Max | 128 | 11.72 | 4.86 | 4.72 | 287 | 11.68 | 4.76 | 13.31 |
| Low | Max | 129 | 0.99 | 1.90 | -1.99 | 293 | 1.02 | 7.53 | 19.18 |
| Low | Max | 130 | -10.54 | 0.44 | -1.46 | 364 | -10.50 | 8.31 | 17.85 |
| Low | Max | 131 | -6.83 | -0.16 | 8.67 | 674 | -6.90 | 8.09 | 7.14 |
| Low | Max | 132 | -11.33 | 0.66 | 10.98 | 691 | -11.20 | 8.23 | 3.69 |
| Low | Max | 133 | 0.08 | 7.41 | 16.10 | 704 | -0.04 | 1.18 | -1.85 |
| Low | Max | 134 | 13.63 | 4.39 | 15.58 | 705 | 13.66 | 4.72 | 5.02 |
| Seismicity | Combination | Frame | P | V2 | V3 | Frame | P | V2 | V3 |
| | | | kN | kN | kN | | kN | kN | kN |
| Low | Min | 128 | -0.51 | -4.79 | -13.37 | 287 | -0.55 | -4.87 | -4.75 |
| Low | Min | 129 | -5.17 | -7.42 | -19.30 | 293 | -5.13 | -1.79 | 1.87 |
| Low | Min | 130 | -16.04 | -8.35 | -18.05 | 364 | -16.00 | -0.48 | 1.27 |
| Low | Min | 131 | -13.96 | -8.30 | -6.91 | 674 | -14.04 | -0.05 | -8.45 |
| Low | Min | 132 | -19.43 | -8.31 | -3.52 | 691 | -19.28 | -0.72 | -10.82 |
| Low | Min | 133 | -11.91 | -1.31 | 2.08 | 704 | -12.04 | -7.60 | -15.85 |
| Low | Min | 134 | -3.54 | -4.76 | -5.18 | 705 | -3.50 | -4.40 | -15.77 |

Table 4.6: Forces in the fusible links according to Figure 4.4, without the roof and with a moderate seismicity level.

| Without Roof | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Seismicity | Combination | Frame | P | V2 | V3 | Frame | P | V2 | V3 |
| | | | kN | kN | kN | | kN | kN | kN |
| Moderate | Max | 128 | 27.24 | 18.08 | 27.29 | 287 | 27.21 | 17.96 | 35.85 |
| Moderate | Max | 129 | 8.92 | 14.66 | 19.50 | 293 | 8.93 | 20.28 | 40.67 |
| Moderate | Max | 130 | -3.28 | 12.50 | 19.15 | 364 | -3.24 | 20.35 | 38.46 |
| Moderate | Max | 131 | 2.28 | 11.00 | 27.97 | 674 | 2.21 | 19.24 | 26.46 |
| Moderate | Max | 132 | -1.21 | 12.93 | 28.99 | 691 | -1.10 | 20.49 | 21.71 |
| Moderate | Max | 133 | 14.89 | 19.35 | 33.51 | 704 | 14.80 | 13.19 | 15.54 |
| Moderate | Max | 134 | 34.82 | 16.91 | 41.24 | 705 | 34.83 | 17.21 | 30.71 |
| Seismicity | Combination | Frame | P | V2 | V3 | Frame | P | V2 | V3 |
| | | | kN | kN | kN | | kN | kN | kN |
| Moderate | Min | 128 | -16.02 | -18.01 | -35.94 | 287 | -16.08 | -18.07 | -27.29 |
| Moderate | Min | 129 | -13.10 | -20.17 | -40.80 | 293 | -13.04 | -14.54 | -19.63 |
| Moderate | Min | 130 | -23.30 | -20.41 | -38.66 | 364 | -23.26 | -12.51 | -19.34 |
| Moderate | Min | 131 | -23.06 | -19.45 | -26.21 | 674 | -23.15 | -11.20 | -27.77 |
| Moderate | Min | 132 | -29.54 | -20.58 | -21.54 | 691 | -29.38 | -12.98 | -28.83 |
| Moderate | Min | 133 | -26.73 | -13.26 | -15.34 | 704 | -26.89 | -19.61 | -33.23 |
| Moderate | Min | 134 | -24.73 | -17.28 | -30.85 | 705 | -24.67 | -16.89 | -41.47 |

Table 4.7 and Table 4.8 summarize the maximum and minimum value of force in the "fusible links" stated in the previous tables taking into account the single force, P, $V_2$ and $V_3$ and the design forces, maximum tensile and resultant shear force, to evaluate the number of bolts in the “fusible link”.

In Table 4.7 and Table 4.8, the following convention is used: P corresponds to axial forces in fusible links while V2 and V3 corresponds to shear forces. In addition, the negative value of P represents a compression stress, while a positive value represents a tension stress. It is clear that the compression forces for the details shown in Figure 4.4 and Figure 4.5 do not affect the bolts but the fire wall and they were shown for sake of completeness. Moreover, in the last column the design force variation is stated comparing the building with and without roof.

For each configuration and level of seismicity, the required number of aluminium M16 bolts to withstand the forces obtained from the analyses were computed with and without taking into consideration the roof effect. In particular, with the roof and for the detail shown in Figure 4.4, a maximum of 2 and 3 M16 aluminium bolts were required for low and moderate seismicity, respectively, as reported in Table 4.7. When the roof effect was not considered, the maximum number of bolts became 1 and 3 M16 aluminium bolts for low and moderate seismicity, respectively (see Table 4.7).

Table 4.7: Forces in the fusible links considering detail shown in Figure 4.4

| **Force** | | **With roof** | | | **Without roof** | | | **Design Force Variation (%)** |
|---|---|---|---|---|---|---|---|---|
| **Single** | **Design** | **Value (kN)** | | **N of M16 bolts** | **Value (kN)** | | **N of M16 bolts** | |
| **Low seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | -12.72 | ***13.20*** | **Combined actions** | -11.33 | ***13.66*** | **Combined actions** | ***3.48%*** |
| P | | 13.20 | | | 13.66 | | | |
| V2 | $V_{Ed}$ | 32.64 | ***39.98*** | **2** | 8.31 | ***20.90*** | **1** | ***-47.73%*** |
| V3 | | 23.10 | | | 19.18 | | | |
| **Low seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -20.76 | - | **Combined actions** | -19.43 | - | **Combined actions** | - |
| P | | -2.03 | | | -0.51 | | | |
| V2 | $V_{Ed}$ | 32.59 | ***40.13*** | **2** | 8.35 | ***21.03*** | **1** | ***-47.59%*** |
| V3 | | 23.42 | | | 19.30 | | | |
| **Moderate seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | -2.46 | ***32.80*** | **Combined actions** | -3.28 | ***34.83*** | **Combined actions** | ***6.20%*** |
| P | | 32.80 | | | 34.83 | | | |
| V2 | $V_{Ed}$ | 43.60 | ***60.80*** | **3** | 20.49 | ***46.05*** | **3** | ***-24.25%*** |
| V3 | | 42.37 | | | 41.24 | | | |
| **Moderate seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -31.02 | - | **Combined actions** | -29.54 | - | **Combined actions** | - |
| P | | -11.96 | | | -13.04 | | | |
| V2 | $V_{Ed}$ | 43.55 | ***61.02*** | **2** | 20.58 | ***46.29*** | **2** | ***-24.14%*** |
| V3 | | 42.75 | | | 41.47 | | | |

In this configuration, reducing the in-plane stiffness of the roof determines in the fusible links a general decreasing of the resultant shear action, up to 48%, however it can be noted an increasing of the tension action, between 3% to 6%.

Now, by considering the fusible link detail shown in Figure 4.5 and with the effect of the roof, a maximum of 2 and 3 M16 aluminium bolts were required for low and moderate seismicity, respectively, as reported in

Table 4.8. When the roof effect was not considered, the maximum number of bolts became 2 and 3 M16 aluminium bolts for low and moderate seismicity, respectively (see

Table 4.8). Thus, a higher stiffness of the roof induced overall larger forces in the fusible links.

Table 4.8: Forces in the fusible links considering detail shown Figure 4.5

| **Force** | | **With roof** | | | **Without roof** | | | **Design Force Variation (%)** |
|---|---|---|---|---|---|---|---|---|
| **Single** | **Design** | **Value (kN)** | | **N of M16 bolts** | **Value (kN)** | | **N of M16 bolts** | |
| **Low seismicity - max combination** | | | | | | | | |
| P | ***$P_{Ed}$*** | -24.54 | ***32.64*** | **Combined actions** | -0.16 | ***8.31*** | **Combined actions** | ***-74.54%*** |
| P | | 32.64 | | | 8.31 | | | |
| V2 | **$V_{Ed}$** | 23.10 | ***26.60*** | **2** | 19.18 | ***23.54*** | **1** | ***-11.50%*** |
| V3 | | 13.20 | | | 13.66 | | | |
| **Low seismicity - min combination** | | | | | | | | |
| P | ***$P_{Ed}$*** | -32.59 | ***24.59*** | **Combined actions** | -8.35 | **-** | **Combined actions** | **-** |
| P | | 24.59 | | | -0.05 | | | |
| V2 | **$V_{Ed}$** | 23.42 | ***31.30*** | **2** | 19.30 | ***27.38*** | **1** | ***-12.50%*** |
| V3 | | 20.76 | | | 19.43 | | | |
| **Moderate seismicity - max combination** | | | | | | | | |
| P | ***$P_{Ed}$*** | -13.57 | ***43.60*** | **Combined actions** | 11.00 | ***20.49*** | **Combined actions** | ***-53.01%*** |
| P | | 43.60 | | | 20.49 | | | |
| V2 | **$V_{Ed}$** | 42.37 | ***53.58*** | **3** | 41.24 | ***53.99*** | **3** | ***0.75%*** |
| V3 | | 32.80 | | | 34.83 | | | |
| **Moderate seismicity - min combination** | | | | | | | | |
| P | ***$P_{Ed}$*** | -43.55 | ***13.62*** | **Combined actions** | -20.58 | **-** | **Combined actions** | **-** |
| P | | 13.62 | | | -11.20 | | | |
| V2 | **$V_{Ed}$** | 42.75 | ***52.82*** | **3** | 41.47 | ***50.91*** | **2** | ***-3.60%*** |
| V3 | | 31.02 | | | 29.54 | | | |

In this configuration, reducing the in-plane stiffness of the roof determines in the fusible links a general decreasing of the shear action, up to 12.5%, and of the tension action, up to 75%.

### 4.1.2 Parallel wall and bracing system close to the fire wall

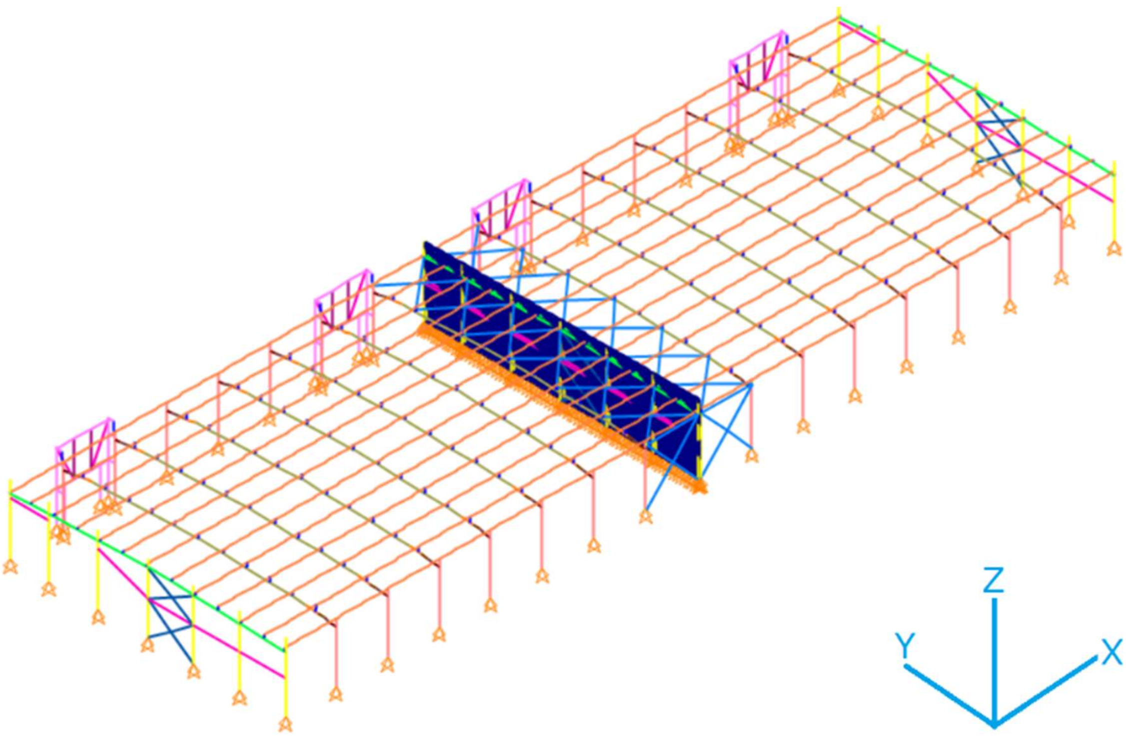



Figure 4.8: Fire wall parallel to portal frames with bracing system close to it

The second configuration analysed is shown in Figure 4.8, with the fire wall parallel to portal frames and the bracing system moved close to it.

The dynamic properties of the structure with and without the roof effect are reported in Table 4.9 and Table 4.10, where the first period of the structure was in both cases a purely translational mode in X direction. It is evident from Table 4.9 and Table 4.10 that the effect of the roof stiffens the structure by decreasing the first period of about 10%. Moreover, by moving the bracing close to the fire wall a stiffening of the structure occurred. Indeed, the first period for the configuration with the roof changes from 1.22 s to 0.87 s.

Table 4.9: Dynamic properties of the model

| **With Roof** | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| | **Sec** | | | |
| **Mode 1** | **0.87** | **0.91** | 0.00 | 0.03 |
| Mode 2 | 0.70 | 0.91 | 0.00 | 0.03 |
| Mode 3 | 0.70 | 0.92 | 0.00 | 0.03 |
| Mode 4 | 0.48 | 0.92 | 0.00 | 0.03 |
| Mode 5 | 0.47 | 0.92 | 0.00 | 0.03 |
| Mode 6 | 0.47 | 0.92 | 0.00 | 0.03 |
| Mode 7 | 0.47 | 0.92 | 0.00 | 0.03 |
| Mode 8 | 0.46 | 0.92 | 0.02 | 0.03 |
| Mode 9 | 0.46 | 0.92 | 0.20 | 0.03 |
| Mode 10 | 0.46 | 0.92 | 0.23 | 0.04 |
| **Mode 12** | **0.45** | 0.94 | 0.23 | **0.92** |
| **Mode 20** | **0.38** | 0.94 | **0.61** | 0.95 |

Table 4.10: Dynamic properties of the model

| **Without Roof** | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| | **Sec** | | | |
| **Mode 1** | **0.95** | **0.88** | 0.00 | 0.03 |
| Mode 2 | 0.90 | 0.88 | 0.00 | 0.03 |
| Mode 3 | 0.90 | 0.91 | 0.00 | 0.03 |
| Mode 4 | 0.82 | 0.91 | 0.00 | 0.03 |
| Mode 5 | 0.82 | 0.91 | 0.00 | 0.03 |
| Mode 6 | 0.67 | 0.91 | 0.00 | 0.03 |
| Mode 7 | 0.67 | 0.91 | 0.00 | 0.03 |
| Mode 8 | 0.52 | 0.91 | 0.01 | 0.03 |
| Mode 9 | 0.51 | 0.91 | 0.01 | 0.03 |
| **Mode 10** | **0.49** | 0.94 | 0.01 | **0.92** |
| Mode 11 | 0.48 | 0.94 | 0.42 | 0.92 |
| **Mode 50** | **0.23** | 0.94 | **0.78** | 0.99 |

As can be noticed from Table 4.9 and Table 4.10 the fire wall presence changed the building dynamic properties in the direction parallel to the fire wall. This is the reason why the translational global mode parallel to the fire wall decreased its period with respect to the single case studies without fire wall.

The fire wall solutions with fusible links considered in this configuration are the same of the previous ones shown in Figure 4.4 and Figure 4.5, because the main difference between these two models is only the position of the bracing system.

For this case study all forces acting on all fusible links along the fire wall are shown in Table 4.11, Table 4.12, Table 4.13 and Table 4.14. On each line of the table there is the seismicity level and the combination; then, the left part of the tables refers to the internal actions in the fusible link on one side of the wall, the right part refers to the corresponding fusible link on the other side of the wall, as shown in the Figure 4.6.
In Figure 4.9 is shown the position of each couple of fusible links along the wall.

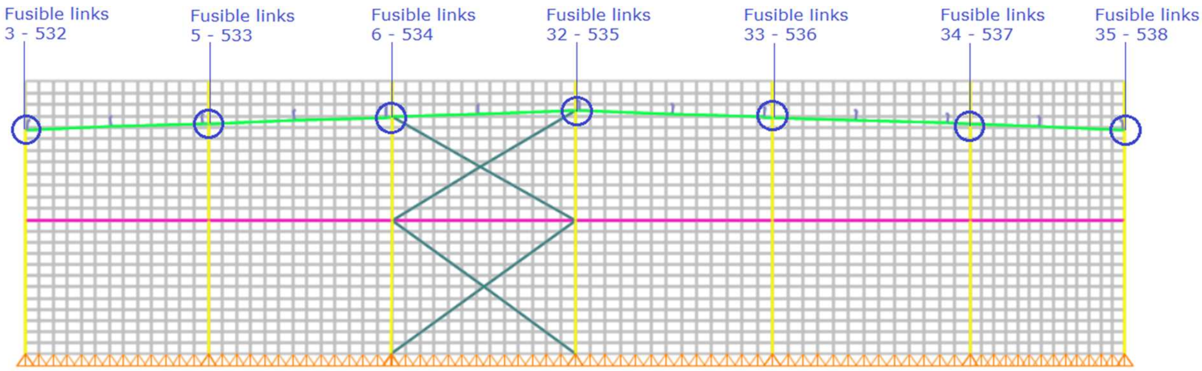



Figure 4.9: Position of fusible links along the wall

Table 4.11: Forces in the fusible links according to Figure 4.4, considering the roof with a low seismicity level.

| With roof | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Seismicity** | **Combination** | **Frame** | **P** | **V2** | **V3** | **Frame** | **P** | **V2** | **V3** |
| | | | kN | kN | kN | | kN | kN | kN |
| Low | Max | 3 | 1.81 | 4.79 | 22.77 | 532 | 1.79 | 4.98 | -7.56 |
| Low | Max | 5 | 37.13 | -0.08 | 23.98 | 533 | 37.17 | 5.98 | -14.88 |
| Low | Max | 6 | -1.37 | -1.80 | 11.32 | 534 | -1.48 | 6.89 | -0.70 |
| Low | Max | 32 | 30.63 | -27.18 | -0.94 | 535 | 30.82 | 32.64 | 12.78 |
| Low | Max | 33 | -4.30 | -1.58 | -12.35 | 536 | -4.43 | 8.27 | 24.24 |
| Low | Max | 34 | 8.76 | 1.11 | -13.15 | 537 | 8.66 | 6.35 | 27.03 |
| Low | Max | 35 | 0.56 | 3.42 | -11.44 | 538 | 0.62 | 4.06 | 26.47 |
| Low | Min | 3 | -26.45 | -4.87 | 9.30 | 532 | -26.46 | -4.69 | -21.09 |
| Low | Min | 5 | 4.86 | -5.49 | 14.07 | 533 | 4.90 | 0.60 | -24.81 |
| Low | Min | 6 | -17.71 | -6.49 | 0.65 | 534 | -17.81 | 2.21 | -11.39 |
| Low | Min | 32 | -1.01 | -32.49 | -11.83 | 535 | -0.82 | 27.33 | 1.87 |
| Low | Min | 33 | -17.38 | -7.75 | -25.22 | 536 | -17.45 | 2.10 | 11.36 |
| Low | Min | 34 | -6.59 | -5.63 | -27.79 | 537 | -6.72 | -0.40 | 12.39 |
| Low | Min | 35 | -26.23 | -3.77 | -26.22 | 538 | -26.11 | -3.11 | 11.71 |

Table 4.12: Forces in the fusible links according Figure 4.4, considering the roof with a moderate seismicity level.

| With roof | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Seismicity | Combination | Frame | P | V2 | V3 | Frame | P | V2 | V3 |
| | | | kN | kN | kN | | kN | kN | kN |
| Moderate | Max | 3 | 36.84 | 17.68 | 39.66 | 532 | 36.83 | 17.89 | 9.30 |
| Moderate | Max | 5 | 77.14 | 7.13 | 36.33 | 533 | 77.18 | 13.15 | -2.51 |
| Moderate | Max | 6 | 18.89 | 4.46 | 24.59 | 534 | 18.78 | 13.12 | 12.60 |
| Moderate | Max | 32 | 69.86 | -20.11 | 12.59 | 535 | 70.05 | 39.73 | 26.32 |
| Moderate | Max | 33 | 11.93 | 6.64 | 3.64 | 536 | 11.73 | 16.51 | 40.25 |
| Moderate | Max | 34 | 27.77 | 10.12 | 5.02 | 537 | 27.75 | 15.37 | 45.20 |
| Moderate | Max | 35 | 33.78 | 13.01 | 6.89 | 538 | 33.77 | 13.64 | 44.79 |
| Seismicity | Combination | Frame | P | V2 | V3 | Frame | P | V2 | V3 |
| | | | kN | kN | kN | | kN | kN | kN |
| Moderate | Min | 3 | -61.48 | -17.77 | -7.59 | 532 | -61.50 | -17.60 | -37.95 |
| Moderate | Min | 5 | -35.15 | -12.70 | 1.73 | 533 | -35.11 | -6.58 | -37.17 |
| Moderate | Min | 6 | -37.97 | -12.75 | -12.62 | 534 | -38.07 | -4.03 | -24.69 |
| Moderate | Min | 32 | -40.24 | -39.56 | -25.35 | 535 | -40.05 | 20.25 | -11.68 |
| Moderate | Min | 33 | -33.61 | -15.97 | -41.21 | 536 | -33.60 | -6.13 | -4.65 |
| Moderate | Min | 34 | -25.63 | -14.64 | -45.96 | 537 | -25.80 | -9.42 | -5.78 |
| Moderate | Min | 35 | -59.45 | -13.36 | -44.56 | 538 | -59.26 | -12.68 | -6.61 |

Table 4.13: Forces in the fusible links according to Figure 4.4, without the roof and with a low seismicity level.

| Without roof | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Seismicity | Combination | Frame | P | V2 | V3 | Frame | P | V2 | V3 |
| | | | kN | kN | kN | | kN | kN | kN |
| Low | Max | 3 | -16.26 | 5.03 | 27.74 | 532 | -16.28 | 4.07 | -9.17 |
| Low | Max | 5 | 31.42 | -0.68 | 29.95 | 533 | 31.48 | 6.29 | -16.00 |
| Low | Max | 6 | 0.54 | -0.57 | 17.09 | 534 | 0.44 | 6.20 | -1.98 |
| Low | Max | 32 | 61.67 | -2.34 | 2.46 | 535 | 61.84 | 8.01 | 12.08 |
| Low | Max | 33 | -2.56 | -0.48 | -6.85 | 536 | -2.66 | 7.70 | 23.33 |
| Low | Max | 34 | 10.46 | 1.04 | -9.84 | 537 | 10.39 | 7.21 | 27.98 |
| Low | Max | 35 | -10.00 | 4.20 | -8.98 | 538 | -9.93 | 4.00 | 27.48 |
| Seismicity | Combination | Frame | P | V2 | V3 | Frame | P | V2 | V3 |
| | | | kN | kN | kN | | kN | kN | kN |
| Low | Min | 3 | -43.87 | -3.86 | 11.24 | 532 | -43.89 | -4.79 | -25.72 |
| Low | Min | 5 | 3.97 | -5.84 | 15.15 | 533 | 4.03 | 1.10 | -30.79 |
| Low | Min | 6 | -16.56 | -5.33 | 2.00 | 534 | -16.67 | 1.50 | -17.08 |
| Low | Min | 32 | 30.72 | -8.16 | -12.08 | 535 | 30.88 | 2.19 | -2.48 |
| Low | Min | 33 | -17.32 | -7.08 | -24.12 | 536 | -17.40 | 1.11 | 6.04 |
| Low | Min | 34 | -5.54 | -6.28 | -28.57 | 537 | -5.68 | -0.11 | 9.26 |
| Low | Min | 35 | -39.22 | -3.77 | -27.06 | 538 | -39.11 | -3.98 | 9.31 |

Table 4.14: Forces in the fusible links according to Figure 4.4, without the roof and with a moderate seismicity level

| Without roof | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Seismicity** | **Combination** | **Frame** | **P** | **V2** | **V3** | **Frame** | **P** | **V2** | **V3** |
| | | | kN | kN | kN | | kN | kN | kN |
| Moderate | Max | 3 | 17.98 | 17.04 | 48.31 | 532 | 17.96 | 16.04 | 11.46 |
| Moderate | Max | 5 | 65.46 | 6.29 | 48.36 | 533 | 65.53 | 13.30 | 2.39 |
| Moderate | Max | 6 | 21.75 | 5.85 | 35.83 | 534 | 21.65 | 12.55 | 16.78 |
| Moderate | Max | 32 | 100.09 | 5.52 | 20.49 | 535 | 100.26 | 15.87 | 30.15 |
| Moderate | Max | 33 | 15.76 | 8.44 | 14.58 | 536 | 15.64 | 16.62 | 44.78 |
| Moderate | Max | 34 | 30.32 | 10.93 | 13.39 | 537 | 30.33 | 17.10 | 51.21 |
| Moderate | Max | 35 | 26.25 | 14.97 | 13.45 | 538 | 26.26 | 14.77 | 50.02 |
| **Seismicity** | **Combination** | **Frame** | **P** | **V2** | **V3** | **Frame** | **P** | **V2** | **V3** |
| | | | kN | kN | kN | | kN | kN | kN |
| Moderate | Min | 3 | -78.10 | -15.86 | -9.34 | 532 | -78.12 | -16.75 | -46.35 |
| Moderate | Min | 5 | -30.08 | -12.82 | -3.25 | 533 | -30.02 | -5.91 | -49.19 |
| Moderate | Min | 6 | -37.77 | -11.75 | -16.74 | 534 | -37.88 | -4.85 | -35.84 |
| Moderate | Min | 32 | -7.69 | -16.02 | -30.11 | 535 | -7.54 | -5.66 | -20.55 |
| Moderate | Min | 33 | -35.64 | -15.99 | -45.55 | 536 | -35.69 | -7.81 | -15.41 |
| Moderate | Min | 34 | -25.41 | -16.17 | -51.80 | 537 | -25.63 | -10.00 | -13.97 |
| Moderate | Min | 35 | -75.47 | -14.54 | -49.49 | 538 | -75.30 | -14.75 | -13.24 |

Table 4.15 and Table 4.16 summarize the maximum and minimum value of force in the "fusible links" stated in the previous tables taking into account the single force, P, $V_2$ and $V_3$ and the design forces, maximum tensile and resultant shear force, to evaluate the number of bolts in the "fusible link".

In Table 4.15 and Table 4.16, the following convention is used: P corresponds to axial forces in fusible links while V2 and V3 corresponds to shear forces. In addition, the negative value of P represents a compression stress, while a positive value represents a tension stress. It is clear that the compression forces for the details shown in Figure 4.4 and Figure 4.5 do not affect the bolts but the fire wall and they were shown for sake of completeness. Moreover, in the last column the design force variation is stated comparing the building with and without roof.
For each configuration and level of seismicity, the required number of bolts to withstand the forces obtained from the analyses were computed with and without roof. In particular, with the roof and for the detail shown in Figure 4.4, a maximum of 3 and 4 M16 aluminium bolts were required for low and moderate seismicity, respectively, as reported in Table 4.15.

When the roof effect was not considered, the maximum number of bolts became 3 and 5 M16 aluminium bolts for low and moderate seismicity, respectively (see Table 4.15). For the bracing system close to the fire wall the effect of the roof was less significant, whereas there is an increase of the number of bolts with respect to the solution with the bracing system far from the fire wall and this tendency is also confirmed in Section 4.2.

Table 4.15: Forces in the fusible links considering detail shown Figure 4.4

| **Force** | | **With roof** | | | **Without roof** | | | **Design Force Variation (%)** |
|---|---|---|---|---|---|---|---|---|
| **Single** | **Design** | **Value (kN)** | | **N of M16 bolts** | **Value (kN)** | | **N of M16 bolts** | |
| **Low seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | -4.43 | ***37.17*** | **Combined actions** | -16.28 | ***61.84*** | **Combined actions** | ***66.37%*** |
| P | | 37.17 | | | 61.84 | | | |
| V2 | $V_{Ed}$ | 32.64 | ***42.38*** | **3** | 8.01 | ***31.00*** | **3** | ***-26.85%*** |
| V3 | | 27.03 | | | 29.95 | | | |
| **Low seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -26.46 | ***4.90*** | **Combined actions** | -43.89 | ***30.88*** | **Combined actions** | **-** |
| P | | 4.90 | | | 30.88 | | | |
| V2 | $V_{Ed}$ | 32.49 | ***42.75*** | **2** | 8.16 | ***31.85*** | **2** | ***-25.49%*** |
| V3 | | 27.79 | | | 30.79 | | | |
| **Moderate seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | 11.73 | ***77.18*** | **Combined actions** | 15.64 | ***100.26*** | **Combined actions** | ***29.90%*** |
| P | | 77.18 | | | 100.26 | | | |
| V2 | $V_{Ed}$ | 39.73 | ***60.17*** | **4** | 17.10 | ***53.99*** | **5** | ***-10.28%*** |
| V3 | | 45.20 | | | 51.21 | | | |
| **Moderate seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -61.50 | ***-*** | **Combined actions** | -78.12 | - | **Combined actions** | **-** |
| P | | -25.63 | | | -7.54 | | | |
| V2 | $V_{Ed}$ | 39.56 | ***60.64*** | **2** | 16.75 | 54.44 | **2** | ***-10.23%*** |
| V3 | | 45.96 | | | 51.80 | | | |

In this configuration, reducing the in-plane stiffness of the roof determines in the fusible links a general decreasing of the shear action, from 10% to 30%, however it can be noted a general increasing of the tension action, from 30% to 70%.

Now, by considering the fusible link detail shown in Figure 4.5 and with the effect of the roof, a maximum of 3 and 4 M16 aluminium bolts were required for low and moderate seismicity, respectively, as reported in Table 4.16. When the roof effect was not considered, the maximum number of bolts became 3 and 5 M16 aluminium bolts for low and moderate seismicity, respectively (see Table 4.16).

Table 4.16: Forces in the fusible links considering detail shown Figure 4.5

| Force | | With roof | | | Without roof | | | Design Force Variation (%) |
|---|---|---|---|---|---|---|---|---|
| **Single** | **Design** | **Value (kN)** | | **N of M16 bolts** | **Value (kN)** | | **N of M16 bolts** | |
| **Low seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | -27.18 | ***32.64*** | **Combined actions** | -2.34 | ***8.01*** | **Combined actions** | ***-75.46%*** |
| P | | 32.64 | | | 8.01 | | | |
| V2 | $V_{Ed}$ | 27.03 | ***45.96*** | **3** | 29.95 | ***68.71*** | **3** | ***49.51%*** |
| V3 | | 37.17 | | | 61.84 | | | |
| **Low seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -32.49 | ***27.33*** | **Combined actions** | -8.16 | ***2.19*** | **Combined actions** | **-** |
| P | | 27.33 | | | 2.19 | | | |
| V2 | $V_{Ed}$ | 27.79 | ***38.37*** | **2** | 30.79 | ***53.61*** | **2** | **39.71%** |
| V3 | | 26.46 | | | 43.89 | | | |
| **Moderate seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | -20.11 | ***39.73*** | **Combined actions** | 5.52 | ***17.10*** | **Combined actions** | ***-56.94%*** |
| P | | 39.73 | | | 17.10 | | | |
| V2 | $V_{Ed}$ | 45.20 | ***89.44*** | **4** | 51.21 | ***112.58*** | **5** | ***25.87%*** |
| V3 | | 77.18 | | | 100.26 | | | |
| **Moderate seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -39.56 | ***20.25*** | **Combined actions** | -16.75 | ***-*** | **Combined actions** | **-** |
| P | | 20.25 | | | -4.85 | | | |
| V2 | $V_{Ed}$ | 45.96 | ***76.78*** | **3** | 51.80 | ***93.74*** | **4** | ***22.09%*** |
| V3 | | 61.50 | | | 78.12 | | | |

In this configuration, reducing the in-plane stiffness of the roof determines in the fusible links a general increasing of the shear action, from 20% to 50%, however it can be noted a general decreasing of the tension action higher than 57%.

Comparing the two configurations above, it can be noticed that, in this case, moving the bracing system close to the fire wall the shear forces in the fusible links is about the same varying from 61.02 kN to 60.64 kN, whereas an increasing of 190%, from 34.83 kN to 100.26 kN, was observed in terms of tensile force.

## 4.1.3 Orthogonal wall

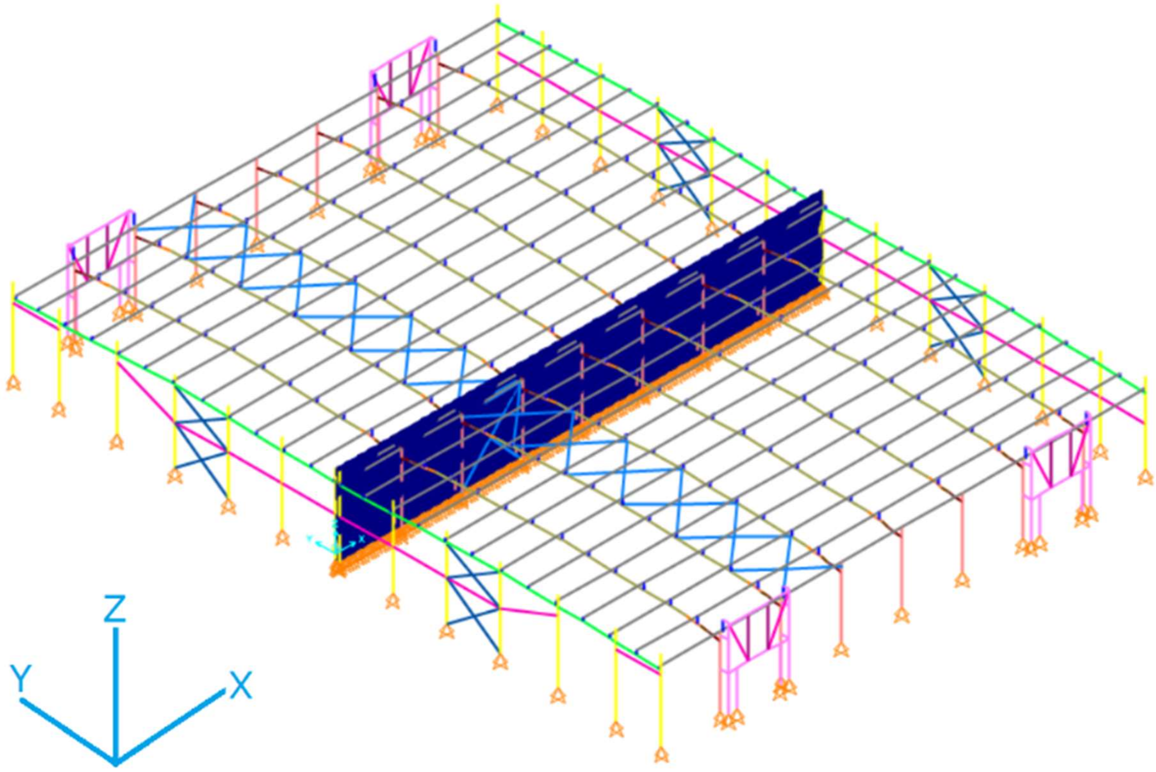



Figure 4.10: Fire wall orthogonal to portal frames

The third configuration analysed is shown in Figure 4.10, with the fire wall orthogonal to portal frames.

The dynamic properties of the structure are reported in Table 4.17 and in Table 4.18. The effect of the in-plane stiffness of the roof is to decrease the first period of about 8.5% with respect to the solution without the roof.

Table 4.17: Dynamic properties of the model with roof

| With Roof | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| | **Sec** | | | |
| Mode 1 | 0.70 | 0.00 | 0.00 | 0.00 |
| Mode 2 | 0.69 | 0.00 | 0.00 | 0.00 |
| Mode 3 | 0.59 | 0.00 | 0.00 | 0.00 |
| Mode 4 | 0.59 | 0.00 | 0.00 | 0.00 |
| **Mode 5** | **0.58** | 0.00 | **0.83** | 0.04 |
| Mode 6 | 0.58 | 0.00 | 0.83 | 0.04 |
| Mode 7 | 0.58 | 0.00 | 0.87 | 0.05 |
| **Mode 8** | **0.55** | 0.00 | 0.92 | **0.94** |
| Mode 9 | 0.48 | 0.00 | 0.92 | 0.94 |
| Mode 10 | 0.47 | 0.00 | 0.92 | 0.94 |
| Mode 11 | 0.46 | 0.00 | 0.92 | 0.94 |
| **Mode 27** | **0.28** | **0.73** | 0.93 | 0.94 |

Table 4.18: Dynamic properties of the model without roof

| Without Roof | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period**<br>**Sec** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| Mode 1 | 0.89 | 0.00 | 0.00 | 0.00 |
| Mode 2 | 0.89 | 0.00 | 0.00 | 0.00 |
| Mode 3 | 0.81 | 0.00 | 0.00 | 0.00 |
| Mode 4 | 0.81 | 0.00 | 0.00 | 0.00 |
| Mode 5 | 0.66 | 0.00 | 0.00 | 0.01 |
| Mode 6 | 0.66 | 0.00 | 0.00 | 0.01 |
| **Mode 7** | **0.63** | 0.00 | **0.82** | 0.09 |
| **Mode 8** | **0.61** | 0.00 | 0.91 | **0.90** |
| Mode 9 | 0.59 | 0.00 | 0.91 | 0.90 |
| Mode 10 | 0.59 | 0.00 | 0.91 | 0.90 |
| Mode 11 | 0.58 | 0.00 | 0.91 | 0.90 |
| **Mode 23** | **0.44** | **0.68** | 0.91 | 0.90 |

As can be noticed from Table 4.17 and Table 4.18, the fire wall presence changed the building dynamic properties in the direction parallel to the fire wall. This is the reason why the translational global mode parallel to the fire wall decreased its period with respect to the single case studies without fire wall.

For this preliminary estimation of forces, it was considered that the fire wall solution associated to fusible links placed between the two steel structures could be that given in Figure 4.11.

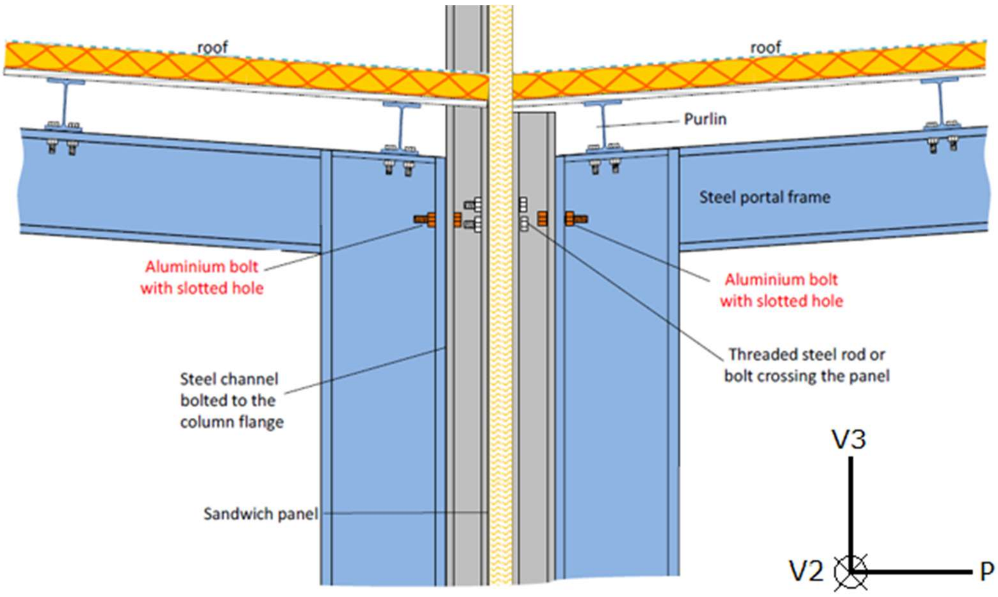



Figure 4.11: Possible fusible link details assumed in the modelling

For this case study all forces acting on all fusible links along the fire wall are shown in Table 4.19,

Table 4.20, Table 4.21, Table 4.22. On each line of the table there is the seismicity level and the combination; then, the left part of the tables refers to the internal actions in the fusible link on one side of the wall, the right part refers to the corresponding fusible link on the other side of the wall, as shown in the Figure 4.11.

In Figure 4.12 is shown the position of each couple of fusible links along the wall.

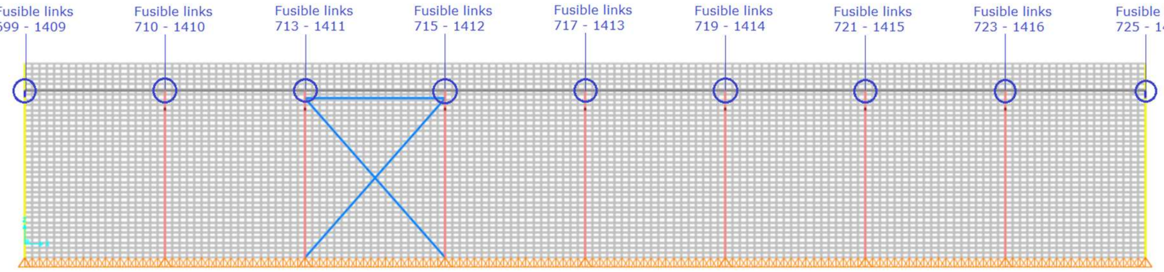



Figure 4.12: Position of fusible links along the wall

Table 4.19: Forces in the fusible links according to Figure 4.11, considering the roof with a low seismicity level.

| With Roof | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Seismicity** | **Combination** | **Frame** | **P** | **V2** | **V3** | **Frame** | **P** | **V2** | **V3** |
| | | | kN | kN | kN | | kN | kN | kN |
| Low | Max | 699 | 97.08 | 18.52 | -0.47 | 1409 | 97.08 | -15.86 | 2.84 |
| Low | Max | 710 | 305.00 | -20.88 | 0.52 | 1410 | 305.00 | 22.94 | 45.46 |
| Low | Max | 713 | -5.53 | -45.31 | 7.39 | 1411 | -5.53 | 49.10 | 39.08 |
| Low | Max | 715 | -208.90 | -47.93 | 13.97 | 1412 | -208.90 | 51.63 | 32.50 |
| Low | Max | 717 | -282.75 | -49.44 | 23.96 | 1413 | -282.75 | 53.10 | 22.62 |
| Low | Max | 719 | -205.25 | -48.14 | 33.11 | 1414 | -205.25 | 51.87 | 13.45 |
| Low | Max | 721 | 2.73 | -45.27 | 41.28 | 1415 | 2.73 | 49.11 | 5.23 |
| Low | Max | 723 | 321.41 | -36.72 | 46.45 | 1416 | 321.41 | 40.14 | 0.00 |
| Low | Max | 725 | 80.08 | 18.82 | 2.60 | 1417 | 80.08 | -16.12 | -0.39 |
| **Seismicity** | **Combination** | **Frame** | **P** | **V2** | **V3** | **Frame** | **P** | **V2** | **V3** |
| | | | kN | kN | kN | | kN | kN | kN |
| Low | Min | 699 | 84.49 | 15.81 | -3.19 | 1409 | 84.48 | -18.55 | 0.15 |
| Low | Min | 710 | 211.27 | -22.93 | -45.40 | 1410 | 211.28 | 20.89 | -0.44 |
| Low | Min | 713 | -67.44 | -49.06 | -39.00 | 1411 | -67.43 | 45.35 | -7.30 |
| Low | Min | 715 | -239.18 | -51.59 | -32.46 | 1412 | -239.18 | 47.97 | -13.92 |
| Low | Min | 717 | -290.83 | -53.05 | -22.58 | 1413 | -290.83 | 49.48 | -23.91 |
| Low | Min | 719 | -236.14 | -51.83 | -13.42 | 1414 | -236.14 | 48.17 | -33.06 |
| Low | Min | 721 | -59.59 | -49.08 | -5.20 | 1415 | -59.59 | 45.30 | -41.24 |
| Low | Min | 723 | 225.63 | -40.11 | 0.02 | 1416 | 225.63 | 36.75 | -46.42 |
| Low | Min | 725 | 70.31 | 16.12 | 0.31 | 1417 | 70.32 | -18.82 | -2.67 |

Table 4.20: Forces in the fusible links according to Figure 4.11, considering the roof with a moderate seismicity level.

| With Roof | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Seismicity | Combination | Frame | P | V2 | V3 | Frame | P | V2 | V3 |
| | | | kN | kN | kN | | kN | kN | kN |
| Moderate | Max | 699 | 112.69 | 21.88 | 2.90 | 1409 | 112.68 | -12.50 | 6.17 |
| Moderate | Max | 710 | 421.20 | -18.17 | 57.45 | 1410 | 421.19 | 25.64 | 102.38 |
| Moderate | Max | 713 | 71.24 | -40.38 | 64.91 | 1411 | 71.23 | 54.03 | 96.59 |
| Moderate | Max | 715 | -171.40 | -43.13 | 71.54 | 1412 | -171.40 | 56.43 | 90.06 |
| Moderate | Max | 717 | -273.82 | -44.70 | 81.67 | 1413 | -273.81 | 57.84 | 80.32 |
| Moderate | Max | 719 | -167.01 | -43.29 | 90.80 | 1414 | -167.01 | 56.72 | 71.13 |
| Moderate | Max | 721 | 80.01 | -40.25 | 98.92 | 1415 | 80.01 | 54.13 | 62.85 |
| Moderate | Max | 723 | 440.14 | -32.26 | 104.03 | 1416 | 440.13 | 44.61 | 57.57 |
| Moderate | Max | 725 | 92.19 | 22.37 | 5.43 | 1417 | 92.18 | -12.57 | 2.44 |
| Seismicity | Combination | Frame | P | V2 | V3 | Frame | P | V2 | V3 |
| | | | kN | kN | kN | | kN | kN | kN |
| Moderate | Min | 699 | 68.88 | 12.44 | -6.57 | 1409 | 68.88 | -21.91 | -3.18 |
| Moderate | Min | 710 | 95.07 | -25.64 | -102.33 | 1410 | 95.09 | 18.18 | -57.36 |
| Moderate | Min | 713 | -144.21 | -53.99 | -96.52 | 1411 | -144.20 | 40.42 | -64.81 |
| Moderate | Min | 715 | -276.68 | -56.39 | -90.04 | 1412 | -276.67 | 43.17 | -71.48 |
| Moderate | Min | 717 | -299.77 | -57.80 | -80.29 | 1413 | -299.77 | 44.74 | -81.60 |
| Moderate | Min | 719 | -274.38 | -56.67 | -71.11 | 1414 | -274.38 | 43.32 | -90.74 |
| Moderate | Min | 721 | -136.88 | -54.09 | -62.84 | 1415 | -136.87 | 40.28 | -98.87 |
| Moderate | Min | 723 | 106.91 | -44.57 | -57.56 | 1416 | 106.91 | 32.28 | -103.99 |
| Moderate | Min | 725 | 58.21 | 12.58 | -2.53 | 1417 | 58.22 | -22.37 | -5.50 |

Table 4.21: Forces in the fusible links according to Figure 4.11, without the roof with a low seismicity level.

| Without Roof | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Seismicity | Combination | Frame | P | V2 | V3 | Frame | P | V2 | V3 |
| | | | kN | kN | kN | | kN | kN | kN |
| Low | Max | 699 | 90.08 | 17.35 | 0.79 | 1409 | 90.08 | -8.19 | 2.73 |
| Low | Max | 710 | 21.24 | -30.11 | 12.91 | 1410 | 21.24 | 32.30 | 27.85 |
| Low | Max | 713 | -20.81 | -68.90 | 20.25 | 1411 | -20.80 | 73.17 | 21.82 |
| Low | Max | 715 | -48.23 | -70.14 | 14.75 | 1412 | -48.24 | 74.64 | 27.41 |
| Low | Max | 717 | -45.32 | -69.84 | 20.62 | 1413 | -45.31 | 74.35 | 21.33 |
| Low | Max | 719 | -45.27 | -70.22 | 23.23 | 1414 | -45.27 | 74.69 | 18.58 |
| Low | Max | 721 | -38.89 | -68.75 | 26.22 | 1415 | -38.89 | 73.11 | 15.17 |
| Low | Max | 723 | 45.19 | -52.65 | 28.77 | 1416 | 45.18 | 56.31 | 12.04 |
| Low | Max | 725 | 75.64 | 17.77 | 2.49 | 1417 | 75.64 | -8.52 | 0.53 |
| Low | Min | 699 | 44.76 | 8.14 | -2.96 | 1409 | 44.76 | -17.38 | -0.97 |
| Low | Min | 710 | -33.77 | -32.29 | -27.79 | 1410 | -33.77 | 30.12 | -12.86 |
| Low | Min | 713 | -66.94 | -73.11 | -21.70 | 1411 | -66.93 | 68.95 | -20.13 |
| Low | Min | 715 | -55.19 | -74.58 | -27.46 | 1412 | -55.20 | 70.19 | -14.80 |
| Low | Min | 717 | -51.82 | -74.29 | -21.30 | 1413 | -51.82 | 69.90 | -20.60 |
| Low | Min | 719 | -58.97 | -74.64 | -18.56 | 1414 | -58.97 | 70.27 | -23.21 |
| Low | Min | 721 | -69.21 | -73.05 | -15.15 | 1415 | -69.21 | 68.80 | -26.20 |
| Low | Min | 723 | -15.35 | -56.27 | -12.01 | 1416 | -15.35 | 52.69 | -28.75 |
| Low | Min | 725 | 38.17 | 8.55 | -0.59 | 1417 | 38.17 | -17.77 | -2.54 |

Table 4.22: Forces in the fusible links according to Figure 4.11, without the roof with a moderate seismicity level.

| Without Roof | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Seismicity** | **Combination** | **Frame** | **P** | **V2** | **V3** | **Frame** | **P** | **V2** | **V3** |
| | | | kN | kN | kN | | kN | kN | kN |
| Moderate | Max | 699 | 146.29 | 28.77 | 5.43 | 1409 | 146.29 | 3.21 | 7.31 |
| Moderate | Max | 710 | 89.45 | -27.24 | 63.39 | 1410 | 89.45 | 35.17 | 78.34 |
| Moderate | Max | 713 | 36.40 | -63.36 | 72.27 | 1411 | 36.41 | 78.71 | 73.86 |
| Moderate | Max | 715 | -39.09 | -64.30 | 67.09 | 1412 | -39.08 | 80.48 | 79.76 |
| Moderate | Max | 717 | -36.77 | -64.01 | 72.60 | 1413 | -36.76 | 80.18 | 73.32 |
| Moderate | Max | 719 | -28.28 | -64.41 | 75.06 | 1414 | -28.28 | 80.50 | 70.42 |
| Moderate | Max | 721 | -1.29 | -63.09 | 77.51 | 1415 | -1.29 | 78.76 | 66.48 |
| Moderate | Max | 723 | 120.25 | -47.90 | 79.36 | 1416 | 120.25 | 61.07 | 62.63 |
| Moderate | Max | 725 | 122.11 | 29.20 | 6.31 | 1417 | 122.11 | 2.96 | 4.33 |
| **Seismicity** | **Combination** | **Frame** | **P** | **V2** | **V3** | **Frame** | **P** | **V2** | **V3** |
| | | | kN | kN | kN | | kN | kN | kN |
| Moderate | Min | 699 | -11.45 | -3.28 | -7.60 | 1409 | -11.45 | -28.79 | -5.55 |
| Moderate | Min | 710 | -101.99 | -35.16 | -78.27 | 1410 | -101.98 | 27.25 | -63.35 |
| Moderate | Min | 713 | -124.14 | -78.65 | -73.72 | 1411 | -124.14 | 63.41 | -72.17 |
| Moderate | Min | 715 | -64.33 | -80.42 | -79.80 | 1412 | -64.36 | 64.35 | -67.15 |
| Moderate | Min | 717 | -60.37 | -80.12 | -73.29 | 1413 | -60.37 | 64.06 | -72.59 |
| Moderate | Min | 719 | -75.96 | -80.45 | -70.38 | 1414 | -75.96 | 64.46 | -75.04 |
| Moderate | Min | 721 | -106.81 | -78.71 | -66.44 | 1415 | -106.80 | 63.14 | -77.50 |
| Moderate | Min | 723 | -90.41 | -61.03 | -62.60 | 1416 | -90.42 | 47.93 | -79.35 |
| Moderate | Min | 725 | -8.31 | -2.88 | -4.41 | 1417 | -8.30 | -29.25 | -6.34 |

Table 4.23 summarizes the maximum and minimum value of force in the "fusible links" stated in the previous tables taking into account the single force, P, $V_2$ and $V_3$ and the design forces, maximum tensile and resultant shear force, to evaluate the number of bolts in the "fusible link".

In Table 4.23, the following convention is used: P corresponds to axial forces in fusible links while V2 and V3 corresponds to shear forces. In addition, the negative value of P represents a compression stress, while a positive value represents a tension stress. It is clear that the compression forces for the detail shown in Figure 4.11 do not affect the bolts but the fire wall and they were shown for sake of completeness. Moreover, in the last column the design force variation is stated comparing the building with and without roof.

For each configuration and level of seismicity, the required number of bolts to withstand the forces obtained from the analyses were computed with and without roof. In particular, with the roof and for the detail shown in Figure 4.11, a maximum of 10 and 15 M16 aluminium bolts were required for low and moderate seismicity, respectively, as reported in Table 4.23.

When the roof effect was not considered, the maximum number of bolts became 5 and 8 M16 aluminium bolts for low and moderate seismicity, respectively (see Table 4.23). The fire wall orthogonal to the portal frames caused a significant increase in the number of bolts. In particular, the tension force increases remarkably. This is mainly determined by a lower number of elements modelled as fusible links in comparison with the configuration parallel to the fire wall.

Table 4.23: Forces in the fusible links considering detail shown in Figure 4.11

| Force | | With roof | | | Without roof | | | Design Force Variation (%) |
|---|---|---|---|---|---|---|---|---|
| **Single** | **Design** | **Value (kN)** | | **N of M16 bolts** | **Value (kN)** | | **N of M16 bolts** | |
| **Low seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | -282.75 | ***321.41*** | **Combined actions** | -48.24 | ***90.08*** | **Combined actions** | ***-71.97%*** |
| P | | 321.41 | | | 90.08 | | | |
| V2 | $V_{Ed}$ | 53.10 | ***70.55*** | **10** | 74.69 | ***80.04*** | **5** | ***13.46%*** |
| V3 | | 46.45 | | | 28.77 | | | |
| **Low seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -290.83 | ***225.63*** | **Combined actions** | -69.21 | ***44.76*** | **Combined actions** | **-** |
| P | | 225.63 | | | 44.76 | | | |
| V2 | $V_{Ed}$ | 53.05 | ***70.50*** | **8** | 74.64 | ***79.99*** | **4** | ***13.46%*** |
| V3 | | 46.42 | | | 28.75 | | | |
| **Moderate seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | -273.82 | ***440.14*** | **Combined actions** | -39.09 | ***146.29*** | **Combined actions** | ***-66.76%*** |
| P | | 440.14 | | | 146.29 | | | |
| V2 | $V_{Ed}$ | 57.84 | ***119.03*** | **15** | 80.50 | ***113.33*** | **8** | ***-4.79%*** |
| V3 | | 104.03 | | | 79.76 | | | |
| **Moderate seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -299.77 | ***106.91*** | **Combined actions** | -124.14 | **-** | **Combined actions** | **-** |
| P | | 106.91 | | | -8.30 | | | |
| V2 | $V_{Ed}$ | 57.80 | ***118.97*** | **7** | 80.45 | ***113.31*** | **4** | ***-4.76%*** |
| V3 | | 103.99 | | | 79.80 | | | |

In this configuration, reducing the in-plane stiffness of the roof determines in the fusible links a general increasing of the resultant shear action, around 14%, in low seismicity case, while there is a decreasing of 5% in moderate seismicity case. However it can be noted a general decreasing of the tensile forces around 70%.

## 4.2 Reference case n°2: Montreuil

The second case study is another building composed of two steel structures made of hot-rolled sections and separated by a fire wall. It was analysed according to three configurations: i) the fire wall parallel to the portal frames, ii) the fire wall parallel to the portal frames but with the bracing system close to them and iii) finally the fire wall orthogonal to the portal frames.

The horizontal design response spectra used for these analyses are shown in Figure 4.13: the low seismicity is represented by the Carcassone spectrum, while the moderate seismicity is represented by the Riva del Garda response spectrum. In this case, the response spectrum of the building site was also considered.

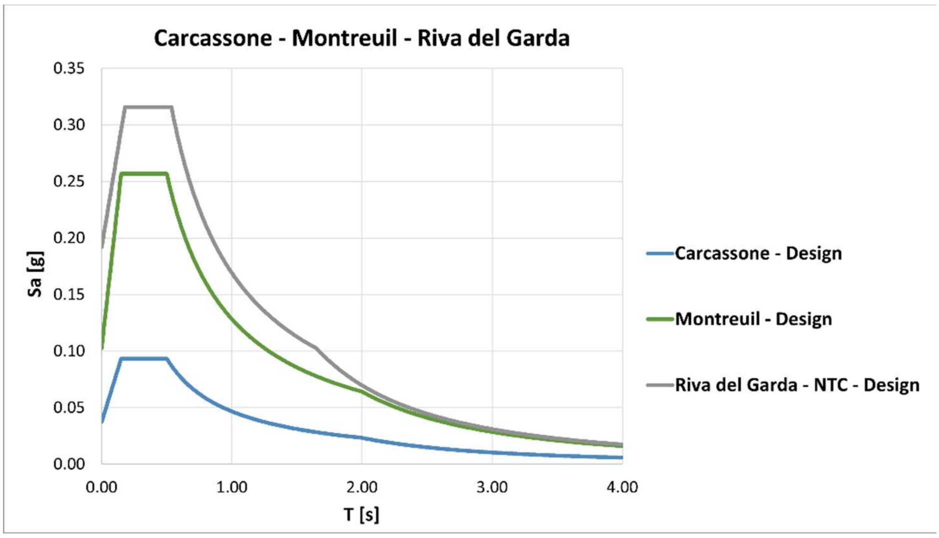



Figure 4.13: Horizontal design response spectra at the ULS used for Montreuil case study

### 4.2.1 Parallel fire wall and bracing system in the actual position

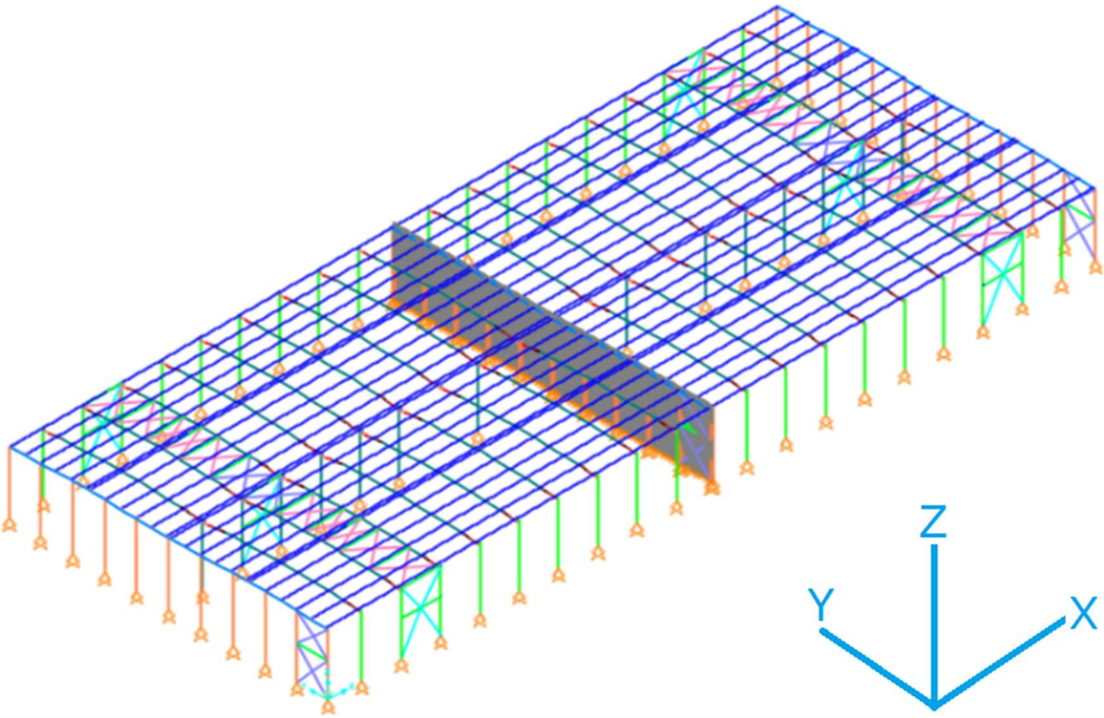



Figure 4.14: Fire wall parallel to portal frames

The first analysed configuration is shown in Figure 4.14, with the fire wall parallel to the portal frames.

From the analyses performed, the dynamic properties of the model are summarized in Table 4.24 and Table 4.25. The first period of the structure was in both cases around 1 s, with a purely translational mode along X direction.

Table 4.24: Dynamic properties of the model with roof

| With Roof | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| **Mode 1** | **0.94** | **0.89** | 0.00 | 0.00 |
| **Mode 2** | **0.67** | 0.89 | 0.00 | **0.97** |
| Mode 3 | 0.63 | 0.89 | 0.00 | 0.97 |
| Mode 4 | 0.63 | 0.89 | 0.00 | 0.97 |
| Mode 5 | 0.62 | 0.89 | 0.00 | 0.97 |
| Mode 6 | 0.62 | 0.89 | 0.00 | 0.97 |
| Mode 7 | 0.62 | 0.89 | 0.00 | 0.97 |
| Mode 8 | 0.62 | 0.89 | 0.00 | 0.97 |
| Mode 9 | 0.62 | 0.89 | 0.00 | 0.97 |
| Mode 10 | 0.62 | 0.89 | 0.00 | 0.97 |
| Mode 11 | 0.60 | 0.89 | 0.00 | 0.97 |
| **Mode 25** | **0.46** | 0.89 | **0.51** | 0.98 |

Table 4.25: Dynamic properties of the model without roof

| Without Roof | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| **Mode 1** | **0.96** | **0.89** | 0.00 | 0.00 |
| Mode 2 | 0.80 | 0.89 | 0.00 | 0.05 |
| Mode 3 | 0.80 | 0.89 | 0.00 | 0.05 |
| Mode 4 | 0.77 | 0.89 | 0.00 | 0.08 |
| Mode 5 | 0.77 | 0.89 | 0.00 | 0.08 |
| **Mode 6** | **0.75** | 0.89 | 0.00 | **0.93** |
| Mode 7 | 0.69 | 0.89 | 0.02 | 0.93 |
| Mode 8 | 0.69 | 0.89 | 0.02 | 0.96 |
| Mode 9 | 0.63 | 0.89 | 0.02 | 0.96 |
| Mode 10 | 0.63 | 0.89 | 0.02 | 0.96 |
| Mode 11 | 0.63 | 0.89 | 0.02 | 0.96 |
| **Mode 31** | **0.55** | 0.89 | **0.59** | 0.96 |

As can be noticed from Table 4.24 and Table 4.25, the fire wall presence changed the building dynamic properties in the direction parallel to the fire wall. This is the reason why the translational global mode parallel to the fire wall decreased its period with respect to the single case studies without fire wall.

For this preliminary estimation of forces, it was considered that the fire wall solution associated to fusible links placed between the two steel structures could be that given in Figure 4.15.

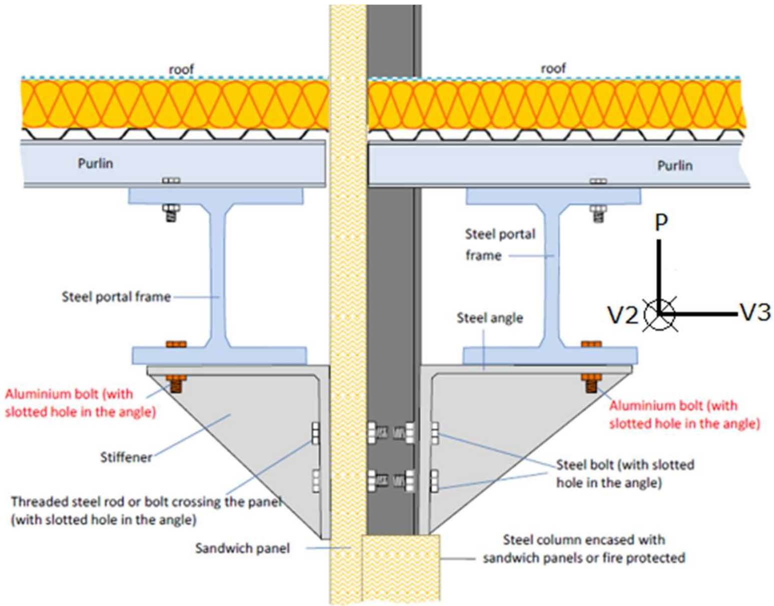



Figure 4.15: Possible fusible link detail assumed in the modelling

In Table 4.26 the following convention is used: P corresponds to axial forces in fusible links while V2 and V3 corresponds to shear forces. In addition, the negative value of P represents a compression stress, while a positive value represents a tension stress. It is clear that the compression forces for the details shown in Figure 4.15 do not affect the bolts and they were shown for sake of completeness.

For each configuration and level of seismicity, the required number of bolts to withstand the forces obtained were computed with and without roof. In particular, with the roof a maximum of 2, 5 and 3 M16 aluminium bolts were required for low, moderate and local seismicity, respectively, as reported in Table 4.26.

When the roof effect was not considered, the maximum number of bolts became 2, 4 and 3 M16 aluminium bolts for low, moderate and local seismicity respectively (see Table 4.26).

Table 4.26: forces in the fusible links shown in Figure 4.15

| Force | | With roof | | | Without roof | | | Design Force Variation (%) |
|---|---|---|---|---|---|---|---|---|
| **Single** | **Design** | **Value (kN)** | | **N of M16 bolts** | **Value (kN)** | | **N of M16 bolts** | |
| **Low seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | -28.57 | ***12.76*** | **Combined actions** | -13.66 | ***13.52*** | **Combined actions** | ***5.99%*** |
| P | | 12.76 | | | 13.52 | | | |
| V2 | $V_{Ed}$ | 35.34 | ***36.37*** | **2** | 42.63 | ***43.53*** | **2** | ***19.67%*** |
| V3 | | 8.60 | | | 8.79 | | | |
| **Low seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -31.13 | ***0.00*** | **Combined actions** | -23.03 | ***0.00*** | **Combined actions** | **-** |
| P | | 0.00 | | | 0.00 | | | |
| V2 | $V_{Ed}$ | 35.65 | ***35.96*** | **2** | 42.73 | ***43.00*** | **2** | ***19.59%*** |
| V3 | | 4.69 | | | 4.85 | | | |
| **Moderate seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | -25.87 | ***51.40*** | **Combined actions** | -9.69 | ***53.84*** | **Combined actions** | ***4.76%*** |
| P | | 51.40 | | | 53.84 | | | |
| V2 | $V_{Ed}$ | 99.54 | ***100.98*** | **5** | 76.71 | ***79.07*** | **4** | ***-21.69%*** |
| V3 | | 16.99 | | | 19.17 | | | |
| **Moderate seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -56.62 | ***-*** | **Combined actions** | -59.30 | ***-*** | **Combined actions** | **-** |
| P | | 0.00 | | | 0.00 | | | |
| V2 | $V_{Ed}$ | 99.83 | ***100.62*** | **4** | 76.91 | ***78.19*** | **3** | ***-22.29%*** |
| V3 | | 12.63 | | | 14.07 | | | |
| **Local seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | -27.66 | ***20.65*** | **Combined actions** | -11.86 | ***21.90*** | **Combined actions** | ***6.05%*** |
| P | | 20.65 | | | 21.90 | | | |
| V2 | $V_{Ed}$ | 55.67 | ***56.79*** | **3** | 50.29 | ***51.51*** | **3** | ***-9.30%*** |
| V3 | | 11.24 | | | 11.13 | | | |
| **Local seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -33.66 | ***-*** | **Combined actions** | -28.16 | ***-*** | **Combined actions** | **-** |
| P | | 0.00 | | | 0.00 | | | |
| V2 | $V_{Ed}$ | 55.97 | ***56.41*** | **2** | 50.42 | ***50.80*** | **2** | ***-9.95%*** |
| V3 | | 7.05 | | | 6.26 | | | |

In this configuration, reducing the in-plane stiffness of the roof determines in the fusible links a general decreasing of the resultant shear action, from 10% to 20%, for the moderate and local seismicity cases, whereas there is an increasing of the 20% in low seismicity case. However it can be noted a general increasing of the tensile force around 5÷6%.

### 4.2.2 Parallel fire wall and bracing system close to the fire wall

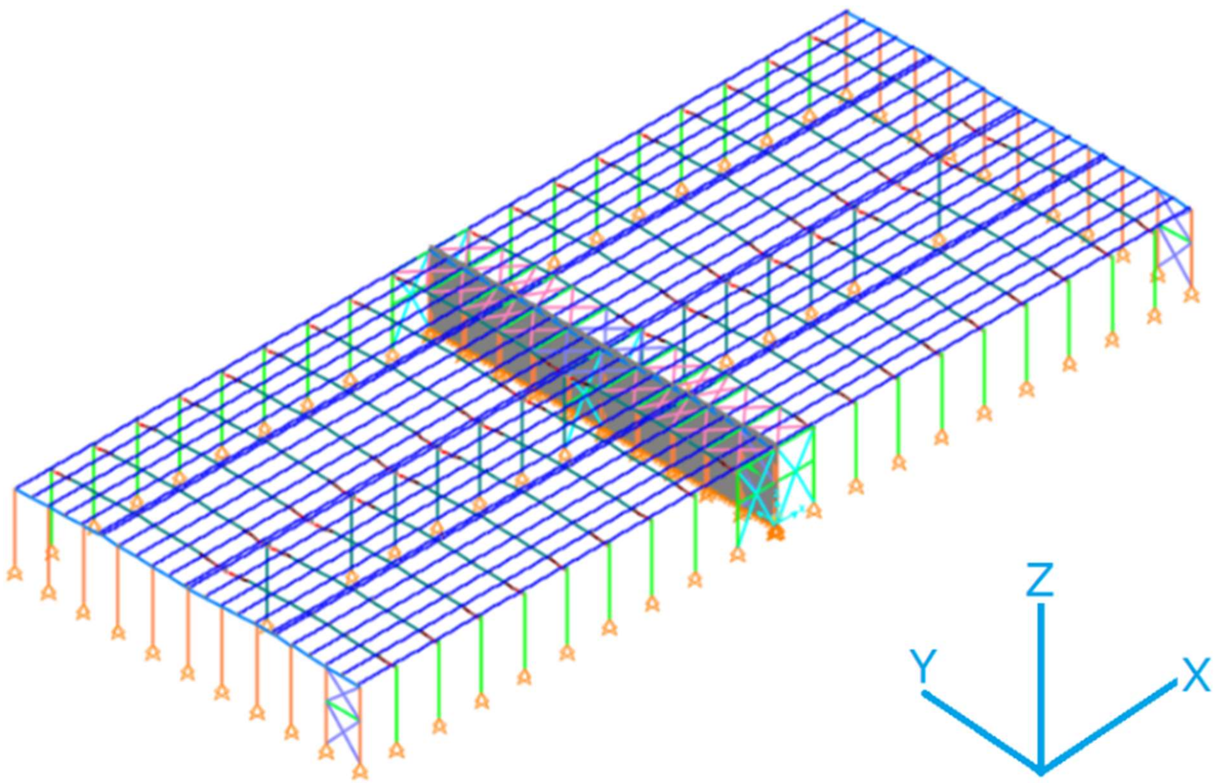



Figure 4.16: Fire wall parallel to portal frames with bracing system close to it

The second configuration analysed is shown in Figure 4.16, with the fire wall parallel to portal frames and the bracing system moved close to it.

The dynamic properties of the structure with and without the roof effect are reported in Table 4.27 and Table 4.28, where the first period of the structure was in both cases a purely translational mode in the X direction. It is evident from Table 4.27 and Table 4.28 that the effect of the roof stiffens the structure by decreasing the first period of about 4%.

Table 4.27: Dynamic properties of the model

| With Roof | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| **Mode 1** | **0.99** | **0.88** | 0.00 | 0.02 |
| **Mode 2** | **0.66** | 0.89 | 0.00 | **0.97** |
| Mode 3 | 0.53 | 0.89 | 0.00 | 0.97 |
| Mode 4 | 0.53 | 0.89 | 0.00 | 0.97 |
| Mode 5 | 0.53 | 0.89 | 0.01 | 0.97 |
| Mode 6 | 0.52 | 0.89 | 0.01 | 0.97 |
| Mode 7 | 0.52 | 0.89 | 0.01 | 0.97 |
| Mode 8 | 0.52 | 0.89 | 0.01 | 0.97 |
| Mode 9 | 0.52 | 0.89 | 0.01 | 0.97 |
| Mode 10 | 0.52 | 0.89 | 0.01 | 0.97 |
| Mode 11 | 0.52 | 0.89 | 0.01 | 0.98 |
| **Mode 17** | **0.46** | 0.89 | **0.49** | 0.98 |

Table 4.28: Dynamic properties of the model

| Without Roof | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| **Mode 1** | **1.03** | **0.87** | 0.00 | 0.02 |
| Mode 2 | 0.80 | 0.87 | 0.00 | 0.05 |
| Mode 3 | 0.80 | 0.87 | 0.00 | 0.05 |
| Mode 4 | 0.76 | 0.87 | 0.00 | 0.05 |
| Mode 5 | 0.76 | 0.87 | 0.00 | 0.05 |
| Mode 6 | 0.71 | 0.88 | 0.00 | 0.81 |
| Mode 7 | 0.70 | 0.88 | 0.01 | 0.81 |
| **Mode 8** | **0.69** | 0.89 | 0.01 | **0.97** |
| Mode 9 | 0.63 | 0.89 | 0.01 | 0.97 |
| Mode 10 | 0.63 | 0.89 | 0.01 | 0.97 |
| Mode 11 | 0.60 | 0.89 | 0.05 | 0.97 |
| **Mode 17** | **0.56** | 0.89 | **0.53** | 0.97 |

As can be noticed from Table 4.27and Table 4.28, the fire wall presence changed the building dynamic properties in the direction parallel to the fire wall. This is the reason why the translational global mode parallel to the fire wall decreased its period with respect to the single case studies without fire wall.

The fire wall solution with fusible links considered in this configuration is the same of the previous one shown in Figure 4.15 because the main difference between these two models is only the position of the bracing system. In this case the forces obtained are summarized in Table 4.29.

For each configuration and level of seismicity, the required number of bolts to withstand the forces obtained from the analyses were computed with and without roof. In particular, with the roof and for the detail shown in Figure 4.15, a maximum of 2, 6 and 3 M16 aluminium bolts were required for low, moderate and local seismicity, respectively, as reported in Table 4.29.

When the roof effect was not considered, the maximum number of bolts remain 3, 6 and 3 M16 aluminium bolts for low, moderate and local seismicity, respectively (Table 4.29). For the bracing system close to the fire wall there is an increase of the number of bolts with respect the solution with the bracing system far from the fire wall.

Table 4.29: forces in the fusible links shown in Figure 4.15

| **Force** | | **With roof** | | | **Without roof** | | | **Variation Resultant Force (%)** |
|---|---|---|---|---|---|---|---|---|
| **Single** | **Resultant** | **Value (kN)** | | **N of M16 bolts** | **Value (kN)** | | **N of M16 bolts** | |
| **Low seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | -22.85 | ***22.20*** | **Combined actions** | -9.47 | ***25.67*** | **Combined actions** | ***15.65%*** |
| P | | 22.20 | | | 25.67 | | | |
| V2 | $V_{Ed}$ | 30.56 | ***36.09*** | **2** | 42.52 | ***51.49*** | **3** | ***42.67%*** |
| V3 | | 19.20 | | | 29.03 | | | |
| **Low seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -25.01 | ***4.23*** | **Combined actions** | -22.38 | ***8.72*** | **Combined actions** | ***106.17%*** |
| P | | 4.23 | | | 8.72 | | | |
| V2 | $V_{Ed}$ | 31.04 | ***39.75*** | **2** | 43.42 | ***57.89*** | **3** | ***45.64%*** |
| V3 | | 24.83 | | | 38.29 | | | |
| **Moderate seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | -20.24 | ***73.29*** | **Combined actions** | -6.20 | ***74.01*** | **Combined actions** | ***0.98%*** |
| P | | 73.29 | | | 74.01 | | | |
| V2 | $V_{Ed}$ | 96.33 | ***102.12*** | **6** | 99.46 | ***107.96*** | **6** | ***5.72%*** |
| V3 | | 33.90 | | | 41.98 | | | |
| **Moderate seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -67.24 | ***-*** | **Combined actions** | -65.04 | ***-*** | **Combined actions** | ***-*** |
| P | | -3.81 | | | -0.31 | | | |
| V2 | $V_{Ed}$ | 96.72 | ***106.24*** | **4** | 101.02 | ***117.50*** | **4** | ***10.59%*** |
| V3 | | 43.97 | | | 60.01 | | | |
| **Local seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | -21.90 | ***32.93*** | **Combined actions** | -8.59 | ***36.09*** | **Combined actions** | ***9.60%*** |
| P | | 32.93 | | | 36.09 | | | |
| V2 | $V_{Ed}$ | 51.21 | ***56.51*** | **3** | 55.87 | ***64.42*** | **3** | ***13.99%*** |
| V3 | | 23.90 | | | 32.07 | | | |
| **Local seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -28.94 | ***-*** | **Combined actions** | -31.59 | ***4.29*** | **Combined actions** | ***-*** |
| P | | -0.70 | | | 4.29 | | | |
| V2 | $V_{Ed}$ | 51.96 | ***60.47*** | **2** | 56.92 | ***71.33*** | **3** | ***17.97%*** |
| V3 | | 30.93 | | | 42.99 | | | |

In this configuration, reducing the in-plane stiffness determines in the fusible links a general increasing of the shear action, from 5 to 45 %, however it can be noted a general increasing of the tensile action up to 106 %.

Comparing the two configurations above, it can be noticed that, in this case, moving the bracing system close to the fire wall always increases the forces in the fusible links, with a maximum of about 17%, from 100.98 kN to 117.50 kN as a shear force and with a maximum of 36%, from 53.84 kN to 74.01 kN considering the tensile action.

### 4.2.3 Orthogonal fire wall

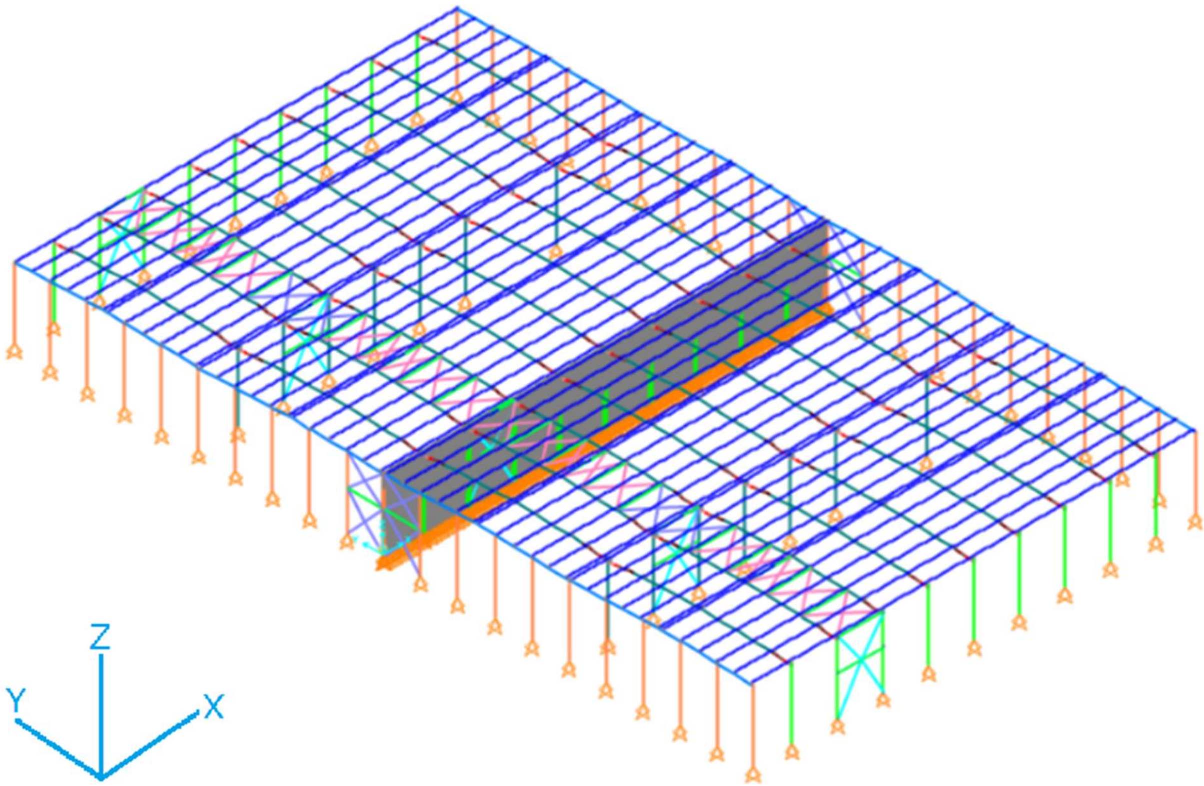



Figure 4.17: fire wall orthogonal to portal frames

The third configuration analysed is shown in Figure 4.17, with the fire wall orthogonal to portal frames. The dynamic properties of the structure are reported in Table 4.30 and in Table 4.31. The effect of the in-plane stiffness of the roof is to decrease the first period of about 10% with respect to the solution without the roof.

Table 4.30: Dynamic properties of the model

| **With Roof** | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| **Mode 1** | **0.98** | 0.00 | **0.94** | 0.00 |
| **Mode 2** | **0.81** | 0.10 | 0.94 | **0.85** |
| Mode 3 | 0.69 | 0.10 | 0.94 | 0.85 |
| Mode 4 | 0.63 | 0.10 | 0.94 | 0.85 |
| Mode 5 | 0.63 | 0.10 | 0.94 | 0.85 |
| Mode 6 | 0.62 | 0.10 | 0.94 | 0.85 |
| Mode 7 | 0.62 | 0.10 | 0.94 | 0.85 |
| Mode 8 | 0.62 | 0.10 | 0.94 | 0.85 |
| Mode 9 | 0.62 | 0.10 | 0.94 | 0.85 |
| Mode 10 | 0.62 | 0.10 | 0.94 | 0.85 |
| Mode 11 | 0.62 | 0.10 | 0.94 | 0.85 |
| **Mode 21** | **0.53** | **0.55** | 0.94 | 0.96 |

Table 4.31: Dynamic properties of the model

| Without Roof | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| **Mode 1** | **1.08** | 0.00 | **0.69** | 0.00 |
| Mode 2 | 1.03 | 0.00 | 0.93 | 0.00 |
| Mode 3 | 1.00 | 0.01 | 0.93 | 0.01 |
| Mode 4 | 0.90 | 0.01 | 0.93 | 0.01 |
| **Mode 5** | **0.86** | 0.14 | 0.93 | **0.75** |
| Mode 6 | 0.82 | 0.14 | 0.93 | 0.77 |
| Mode 7 | 0.80 | 0.14 | 0.93 | 0.77 |
| Mode 8 | 0.77 | 0.14 | 0.93 | 0.78 |
| Mode 9 | 0.77 | 0.15 | 0.94 | 0.78 |
| Mode 10 | 0.76 | 0.15 | 0.94 | 0.80 |
| Mode 11 | 0.74 | 0.15 | 0.94 | 0.82 |
| **Mode 31** | **0.56** | **0.61** | 0.94 | 0.96 |

As can be noticed from Table 4.30 and Table 4.31, the fire wall presence changed the building dynamic properties in the direction parallel to the fire wall. This is the reason why the translational global mode parallel to the fire wall decreased its period with respect to the single case studies without fire wall.

For this preliminary estimation of forces, it was considered that the fire wall solution associated to fusible links placed between the two steel structures could be that given in in Figure 4.18.

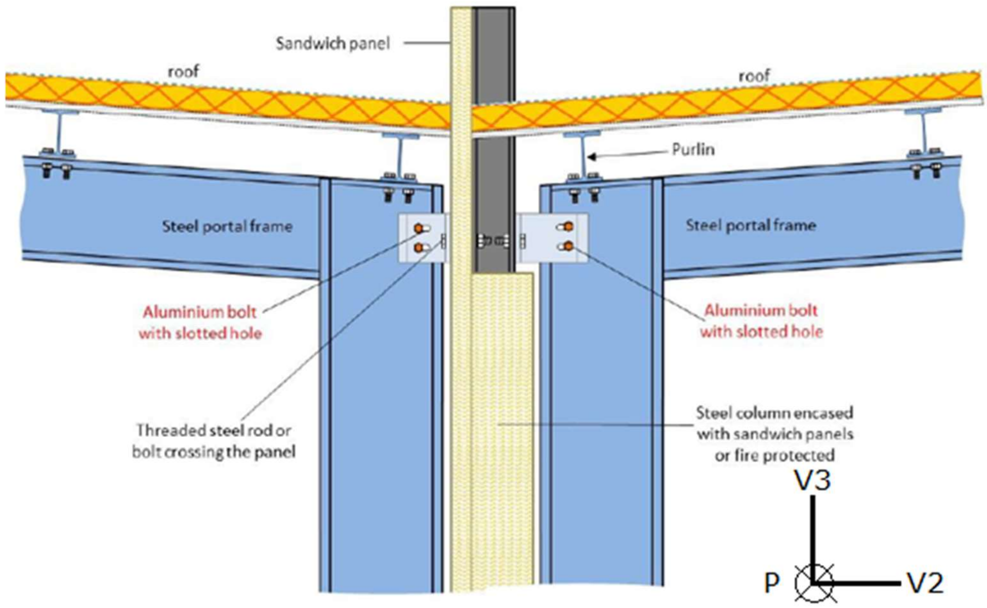



Figure 4.18: Possible fusible link details assumed in the modelling

In
Table 4.32 the following convention is used: P corresponds to axial forces in bolts while V2 and V3 corresponds to shear forces. In addition, the negative value of P represents a compression stress, while a positive value represents a tension stress.

For each configuration and level of seismicity, the required number of bolts to withstand the forces obtained from the analyses were computed with and without roof. In particular, with the roof and for the detail shown in Figure 4.18, a maximum of 3, 8 and 4 M16 aluminium bolts were required for low, moderate and local seismicity, respectively, as reported in Table 4.32.

When the roof effect was not considered, the maximum number of bolts became 4, 8 and 5 M16 aluminium bolts for low, moderate and local seismicity, respectively (see Table 4.32).

Table 4.32: Forces in the fusible links shown in Figure 4.18

| Force | | With roof | | | Without roof | | | Design Force Variation (%) |
|---|---|---|---|---|---|---|---|---|
| **Single** | **Design** | **Value (kN)** | | **N of M16 bolts** | **Value (kN)** | | **N of M16 bolts** | |
| **Low seismicity - max combination** | | | | | | | | |
| P | ***$P_{Ed}$*** | 3.88 | ***32.48*** | **Combined actions** | 4.70 | ***36.17*** | **Combined actions** | ***11.36%*** |
| P | | 32.48 | | | 36.17 | | | |
| V2 | **$V_{Ed}$** | 24.66 | ***45.99*** | **3** | 28.53 | ***74.17*** | **4** | ***61.28%*** |
| V3 | | 38.82 | | | 68.46 | | | |
| **Low seismicity - min combination** | | | | | | | | |
| P | ***$P_{Ed}$*** | -28.27 | ***0.34*** | **Combined actions** | -23.89 | ***1.76*** | **Combined actions** | ***421.07%*** |
| P | | 0.34 | | | 1.76 | | | |
| V2 | **$V_{Ed}$** | 23.69 | ***44.34*** | **2** | 26.87 | ***72.16*** | **3** | ***62.74%*** |
| V3 | | 37.48 | | | 66.97 | | | |
| **Moderate seismicity - max combination** | | | | | | | | |
| P | ***$P_{Ed}$*** | 8.71 | ***100.90*** | **Combined actions** | 10.71 | ***98.05*** | **Combined actions** | ***-2.82%*** |
| P | | 100.90 | | | 98.05 | | | |
| V2 | **$V_{Ed}$** | 79.46 | ***152.46*** | **8** | 74.90 | ***145.56*** | **8** | ***-4.52%*** |
| V3 | | 130.12 | | | 124.81 | | | |
| **Moderate seismicity - min combination** | | | | | | | | |
| P | ***$P_{Ed}$*** | -97.63 | ***-*** | **Combined actions** | -84.79 | ***-*** | **Combined actions** | ***-*** |
| P | | -4.53 | | | -3.35 | | | |
| V2 | **$V_{Ed}$** | 77.49 | ***151.63*** | **5** | 73.46 | ***140.18*** | **5** | ***-7.55%*** |
| V3 | | 130.33 | | | 119.39 | | | |
| **Local seismicity - max combination** | | | | | | | | |
| P | ***$P_{Ed}$*** | 5.07 | ***49.23*** | **Combined actions** | 6.73 | 49.85 | **Combined actions** | ***1.27%*** |
| P | | 49.23 | | | 49.85 | | | |
| V2 | **$V_{Ed}$** | 36.24 | ***70.54*** | **4** | 38.45 | 89.76 | **5** | ***27.24%*** |
| V3 | | 60.52 | | | 81.11 | | | |
| **Local seismicity - min combination** | | | | | | | | |
| P | ***$P_{Ed}$*** | -45.23 | ***-*** | **Combined actions** | -37.33 | ***0.63*** | **Combined actions** | ***-*** |
| P | | -0.88 | | | 0.63 | | | |
| V2 | **$V_{Ed}$** | 35.07 | ***68.83*** | **3** | 36.84 | ***86.91*** | **3** | ***26.26%*** |
| V3 | | 59.23 | | | 78.72 | | | |

In this configuration, reducing the in-plane stiffness determines in the fusible links a general increasing of the shear action, around between 25% and 65% for low and local seismicity cases, whereas there is a decreasing between 4.5% and 7.5% in moderate seismicity case.
However it can be noted a general increasing of the tension action up to 11%, with the exception of one case.

## 4.3 Reference case n°3: Pibrac

The third case study is a building consisting of two steel structures made of welded sections, separated by a fire wall. It was analysed according to two configurations: i) the fire wall parallel to portal frames and ii) the fire wall orthogonal to portal frames.

The horizontal design response spectra used for these analyses are shown in Figure 4.19. The low seismicity is represented by the Pibrac spectrum, while the moderate seismicity is represented by the Riva del Garda response spectrum.

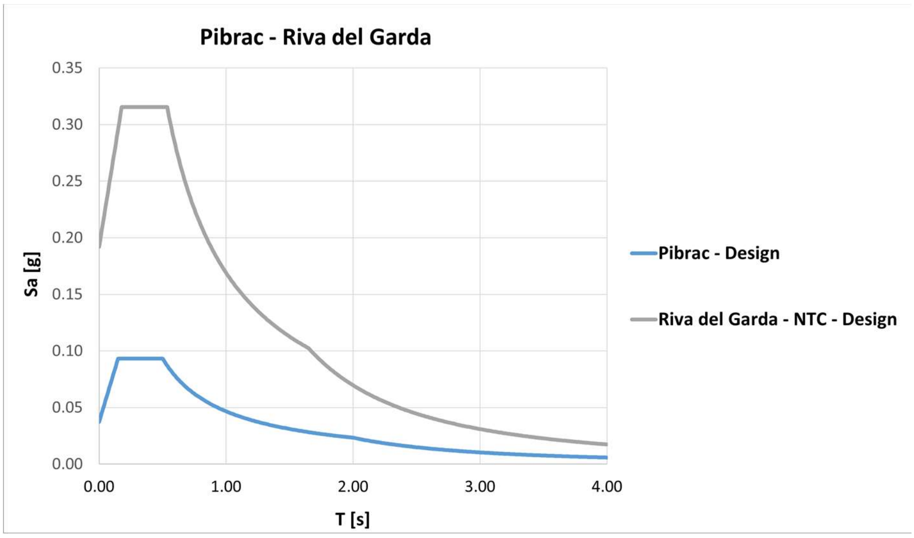



Figure 4.19: Horizontal design response spectra at ULS used for the Pibrac case study

### 4.3.1 Parallel fire wall

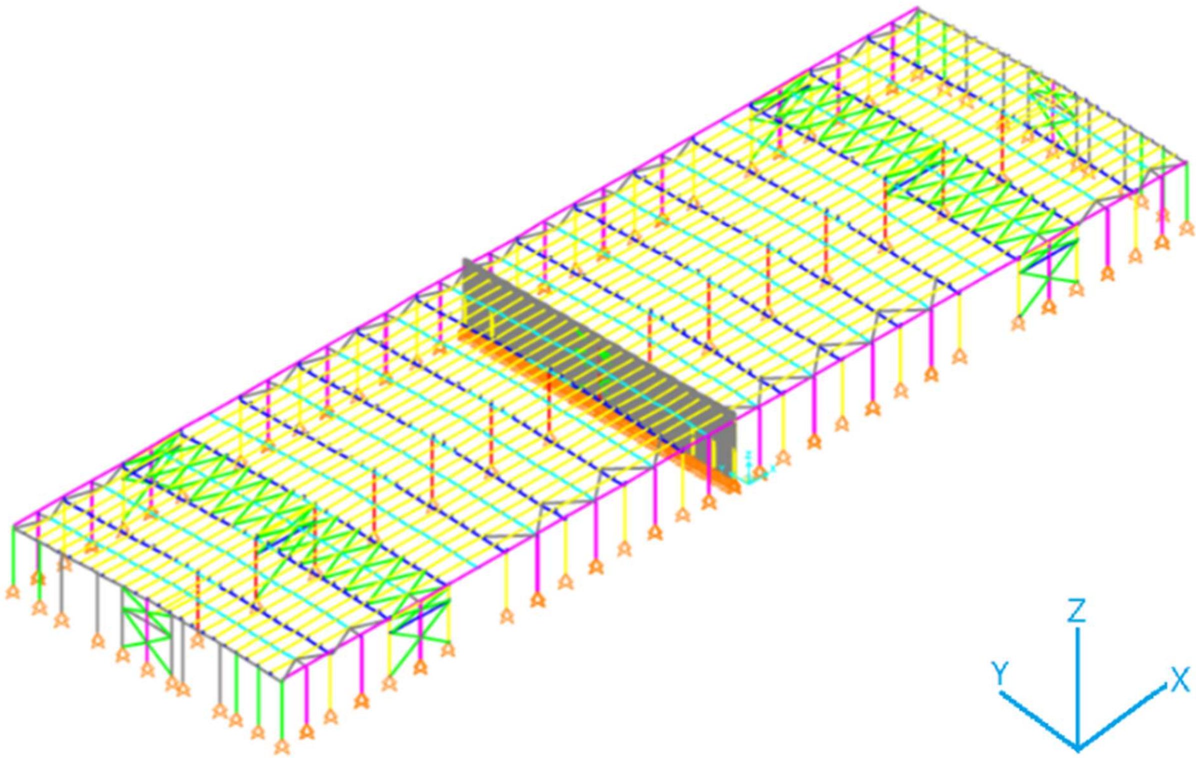



Figure 4.20: fire wall parallel to portal frames

The first analysed configuration is shown in Figure 4.20, with the fire wall parallel to the portal frames.

From the analyses, the dynamic properties of the model with and without effect of in-plane stiffness of the roof are summarized in Table 4.33 and in Table 4.34. The first global modes of the structure were characterised by periods equal to 1.10 s (with roof) and 1.17 s (without roof), respectively. As in the previous cases, the effect of the in-plane stiffness of the roof determines a decrease in the first period.

Table 4.33: Dynamic properties of the model with roof

| With Roof | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| Mode 1 | 1.62 | 0.00 | 0.00 | 0.00 |
| Mode 2 | 1.62 | 0.00 | 0.00 | 0.00 |
| Mode 3 | 1.22 | 0.00 | 0.00 | 0.00 |
| Mode 4 | 1.22 | 0.00 | 0.00 | 0.00 |
| **Mode 5** | **1.10** | **0.93** | 0.00 | 0.00 |
| **Mode 6** | **0.63** | 0.93 | 0.00 | **0.96** |
| Mode 7 | 0.59 | 0.93 | 0.01 | 0.97 |
| Mode 8 | 0.59 | 0.93 | 0.01 | 0.98 |
| Mode 9 | 0.56 | 0.93 | 0.02 | 0.98 |
| Mode 10 | 0.56 | 0.93 | 0.02 | 0.99 |
| **Mode 11** | **0.52** | 0.93 | **0.44** | 0.99 |
| Mode 12 | 0.47 | 0.93 | 0.44 | 0.99 |

Table 4.34: Dynamic properties of the model without roof

| Without Roof | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| Mode 1 | 1.62 | 0.00 | 0.00 | 0.00 |
| Mode 2 | 1.62 | 0.00 | 0.00 | 0.00 |
| Mode 3 | 1.22 | 0.00 | 0.00 | 0.00 |
| Mode 4 | 1.22 | 0.00 | 0.00 | 0.00 |
| **Mode 5** | **1.17** | **0.92** | 0.00 | 0.00 |
| **Mode 6** | **0.68** | 0.92 | 0.00 | **0.97** |
| Mode 7 | 0.60 | 0.92 | 0.21 | 0.98 |
| Mode 8 | 0.59 | 0.92 | 0.22 | 0.98 |
| Mode 9 | 0.58 | 0.92 | 0.46 | 0.98 |
| Mode 10 | 0.56 | 0.92 | 0.46 | 0.98 |
| **Mode 11** | **0.56** | 0.92 | **0.48** | 0.98 |
| Mode 12 | 0.48 | 0.92 | 0.48 | 0.98 |

As can be noticed from Table 4.33 and Table 4.34, the fire wall presence changed the building dynamic properties in the direction parallel to the fire wall. This is the reason why the translational global mode parallel to the fire wall decreased its period with respect to the single case studies without fire wall.

For this preliminary estimation of forces, it was considered that the fire wall solutions associated to fusible links placed between the two steel structures could be that given in Figure 4.21.

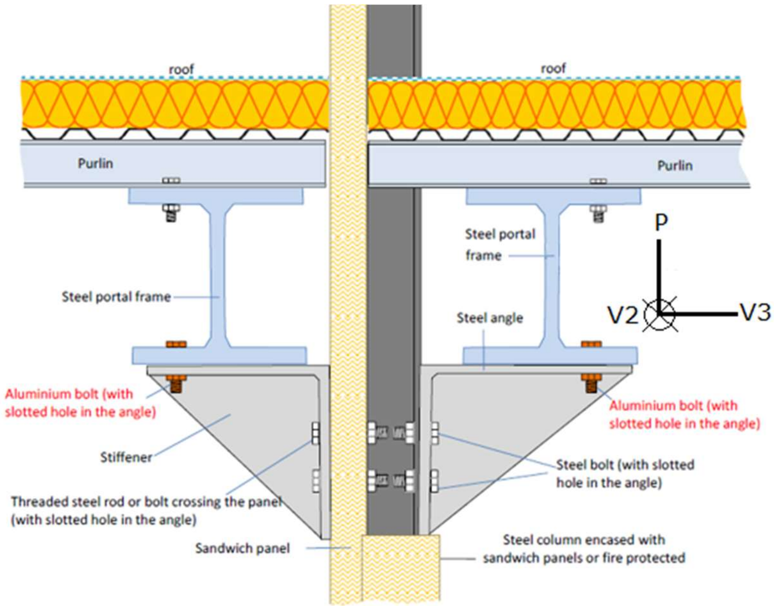



Figure 4.21: Possible fusible link detail assumed in the modelling.

In Table 4.35 the following convention is used: P corresponds to axial forces in bolts while V2 and V3 corresponds to shear forces. In addition the negative value of P represents a compression stress, while a positive value represents a tension stress.

For each configuration and level of seismicity, the required number of bolts to withstand the forces obtained were computed with and without roof. In particular, with the roof a maximum of 2 and 3 M16 aluminium bolts were required for low and moderate seismicity, respectively, as reported in Table 4.35.

When the roof effect was not considered, the maximum number of bolts became 2 and 3 M16 aluminium bolts for low and moderate seismicity respectively (see Table 4.35).

Table 4.35: Forces in the fusible links shown in Figure 4.21

| Force | | With roof | | | Without roof | | | Design Force Variation (%) |
|---|---|---|---|---|---|---|---|---|
| **Single** | **Design** | **Value (kN)** | | **N of M16 bolts** | **Value (kN)** | | **N of M16 bolts** | |
| **Low seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | -7.46 | ***12.49*** | **Combined actions** | -9.69 | ***13.24*** | **Combined actions** | ***6.01%*** |
| P | | 12.49 | | | 13.24 | | | |
| V2 | $V_{Ed}$ | 21.46 | ***21.96*** | **2** | 24.62 | ***24.92*** | **2** | ***13.48%*** |
| V3 | | 4.64 | | | 3.83 | | | |
| **Low seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -17.29 | ***5.56*** | **Combined actions** | -20.27 | ***8.38*** | **Combined actions** | ***50.73%*** |
| P | | 5.56 | | | 8.38 | | | |
| V2 | $V_{Ed}$ | 21.50 | ***21.85*** | **1** | 24.60 | ***24.72*** | **1** | ***13.15%*** |
| V3 | | 3.88 | | | 2.44 | | | |
| **Moderate seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | -4.83 | ***25.51*** | **Combined actions** | -6.68 | ***19.42*** | **Combined actions** | ***-23.86%*** |
| P | | 25.51 | | | 19.42 | | | |
| V2 | $V_{Ed}$ | 69.25 | ***70.32*** | **3** | 59.48 | ***60.53*** | **3** | ***-13.93%*** |
| V3 | | 12.27 | | | 11.24 | | | |
| **Moderate seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -30.51 | ***-0.89*** | **Combined actions** | -34.45 | **-** | **Combined actions** | **-** |
| P | | -0.89 | | | 2.20 | | | |
| V2 | $V_{Ed}$ | 68.98 | ***69.95*** | **3** | 59.37 | ***60.19*** | **2** | ***-13.95%*** |
| V3 | | 11.64 | | | 9.88 | | | |

In this configuration, reducing the in-plane stiffness of the roof determines in the fusible links an increase of the resultant shear action of about 13% and the axial force up to 50% in the case of low seismicity, whereas a decreasing of the shear action of about 13% is observed in the case of moderate seismicity and a 23% decrease in the axial force.

## 4.3.2 Orthogonal fire wall

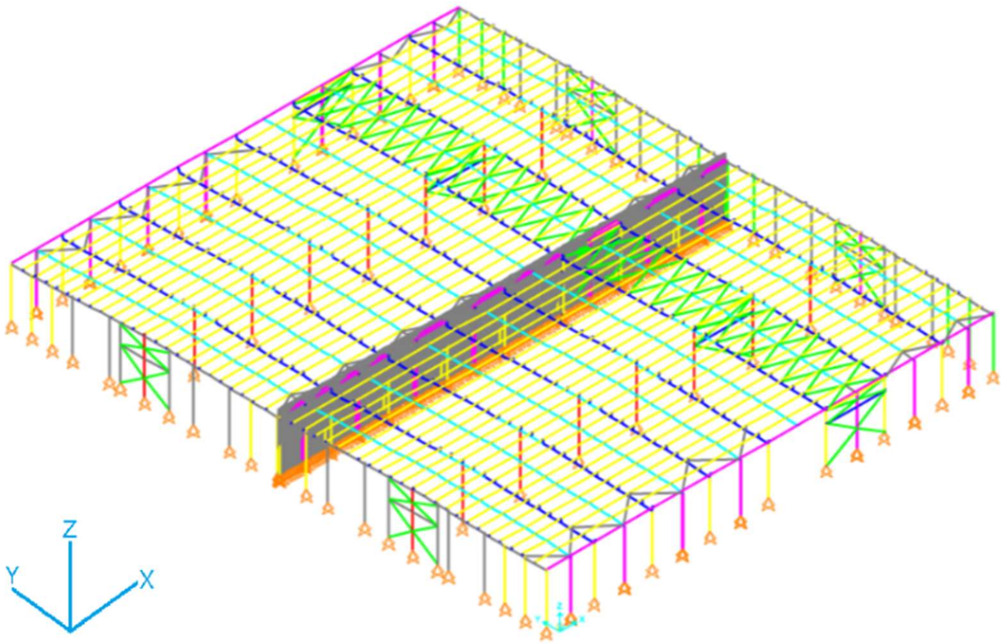



Figure 4.22: fire wall orthogonal to portal frames

The second configuration analysed is shown in Figure 4.22 with the fire wall parallel to portal frames.

The dynamic properties of the structure are reported in Table 4.36 and in Table 4.37. The first global modes of the structure were characterised by periods equal to 0.82 s (with roof) and 0.88 s (without roof), respectively.

Table 4.36: Dynamic properties of the model with the roof

| With Roof | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| Mode 1 | 1.62 | 0.00 | 0.00 | 0.00 |
| Mode 2 | 1.62 | 0.00 | 0.00 | 0.00 |
| Mode 3 | 1.22 | 0.00 | 0.00 | 0.00 |
| Mode 4 | 1.22 | 0.00 | 0.00 | 0.00 |
| **Mode 5** | **0.82** | 0.00 | **0.92** | 0.00 |
| **Mode 6** | **0.71** | 0.00 | 0.92 | **0.96** |
| Mode 7 | 0.59 | 0.00 | 0.92 | 0.96 |
| Mode 8 | 0.59 | 0.00 | 0.92 | 0.96 |
| Mode 9 | 0.50 | 0.00 | 0.92 | 0.96 |
| Mode 10 | 0.46 | 0.00 | 0.92 | 0.96 |
| Mode 11 | 0.46 | 0.00 | 0.92 | 0.96 |
| **Mode 50** | **0.28** | **0.33** | 0.95 | 0.97 |

Table 4.37: Dynamic properties of the model without roof.

| Without Roof | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| Mode 1 | 1.62 | 0.00 | 0.00 | 0.00 |
| Mode 2 | 1.62 | 0.00 | 0.00 | 0.00 |
| Mode 3 | 1.22 | 0.00 | 0.00 | 0.00 |
| Mode 4 | 1.22 | 0.00 | 0.00 | 0.00 |
| **Mode 5** | **0.88** | 0.00 | **0.91** | 0.00 |
| **Mode 6** | **0.75** | 0.00 | 0.91 | **0.95** |
| Mode 7 | 0.59 | 0.00 | 0.91 | 0.95 |
| Mode 8 | 0.59 | 0.00 | 0.91 | 0.95 |
| Mode 9 | 0.50 | 0.00 | 0.91 | 0.95 |
| Mode 10 | 0.47 | 0.01 | 0.91 | 0.95 |
| Mode 11 | 0.47 | 0.01 | 0.91 | 0.95 |
| **Mode 24** | **0.41** | **0.41** | 0.91 | 0.95 |

As can be noticed from Table 4.36 and Table 4.37, the fire wall presence changed the building dynamic properties in the direction parallel to the fire wall. This is the reason why the translational global mode parallel to the fire wall decreased its period with respect to the single case studies without fire wall.

For this first estimation of forces, it was considered that the fire wall solution associated to fusible links placed between the two steel structures could be that given in Figure 4.23.

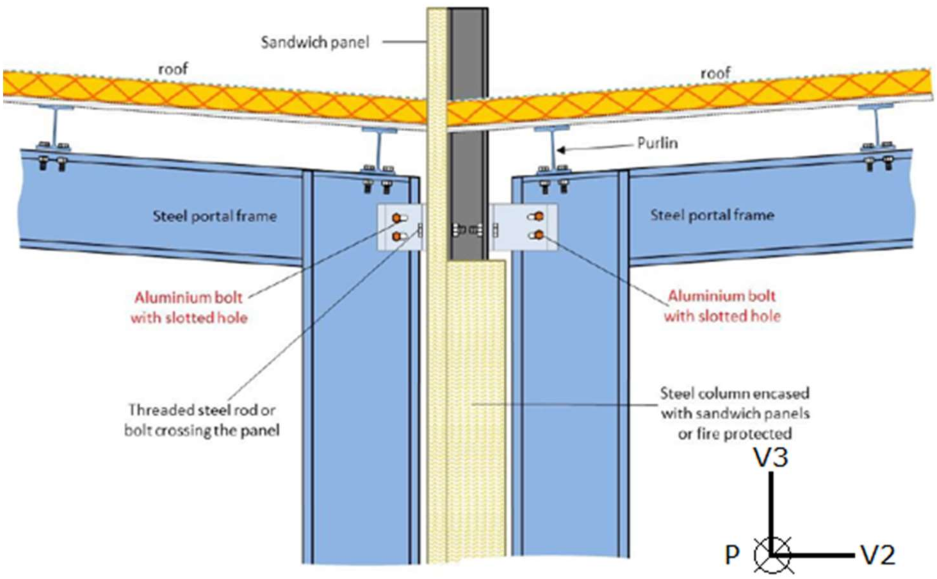



Figure 4.23: Possible fusible link detail assumed in the modelling

In Table 4.38 the negative value of P represents a compression stress, while a positive value represents a tension stress. It is clear that the compression forces for the details shown in Figure 4.23 do not affect the bolts and they were shown for sake of completeness.

For each configuration and level of seismicity, the required number of bolts to withstand the forces obtained were computed with and without roof. In particular, with the roof a maximum of 3 and 7 M16 aluminium bolts were required for low and moderate seismicity, respectively, as reported in Table 4.38.

When the roof effect was not considered, the maximum number of bolts remains 3 and 8 M16 aluminium bolts for low and moderate seismicity, respectively (see Table 4.38).

Table 4.38: Forces in the fusible links shown in Figure 4.23

| Force | | With roof | | | Without roof | | | Design Force Variation (%) |
|---|---|---|---|---|---|---|---|---|
| **Single** | **Design** | **Value (kN)** | | **N of M16 bolts** | **Value (kN)** | | **N of M16 bolts** | |
| **Low seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | 0.09 | ***38.72*** | **Combined actions** | 0.04 | ***39.11*** | **Combined actions** | ***1.01%*** |
| P | | 38.72 | | | 39.11 | | | |
| V2 | $V_{Ed}$ | 11.69 | ***39.36*** | **3** | 13.36 | ***35.33*** | **3** | ***-10.22%*** |
| V3 | | 37.58 | | | 32.71 | | | |
| **Low seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -35.92 | ***0.53*** | **Combined actions** | -34.40 | **-** | **Combined actions** | **-** |
| P | | 0.53 | | | -0.02 | | | |
| V2 | $V_{Ed}$ | 2.57 | ***37.64*** | **2** | 2.45 | **32.80** | **2** | ***-12.86%*** |
| V3 | | 37.56 | | | 32.71 | | | |
| **Moderate seismicity - max combination** | | | | | | | | |
| P | $P_{Ed}$ | 0.30 | ***130.86*** | **Combined actions** | 0.14 | ***129.73*** | **Combined actions** | ***-0.86%*** |
| P | | 130.86 | | | 129.73 | | | |
| V2 | $V_{Ed}$ | 23.74 | ***100.23*** | **7** | 27.93 | ***102.32*** | **7** | ***2.09%*** |
| V3 | | 97.38 | | | 98.44 | | | |
| **Moderate seismicity - min combination** | | | | | | | | |
| P | $P_{Ed}$ | -128.11 | **-** | **Combined actions** | -125.07 | **-** | **Combined actions** | **-** |
| P | | -0.27 | | | -0.12 | | | |
| V2 | $V_{Ed}$ | 9.98 | ***97.85*** | **4** | 12.84 | ***99.28*** | **4** | ***1.47%*** |
| V3 | | 97.34 | | | 98.45 | | | |

In this configuration, reducing the in-plane stiffness of the roof determines in the fusible links an increasing of about 10% and a decreasing of about 2% on the shear action in the case of low and moderate seismicity, respectively. However, it can be noted a small increasing and decreasing in the axial forces, in the low and moderate seismicity case, respectively.

## 4.4 Reference case n°4: Bressuire

The fourth case study is a building composed of two steel structures made of welded sections, separated by a fire wall. It was analysed according to two configurations: i) the fire wall parallel to portal frames and ii) the fire wall orthogonal to portal frames.

The design response spectra used for these analyses are shown in Figure 4.24. The low seismicity is represented by the Carcassone spectrum, while the moderate seismicity is represented by the Riva del Garda response spectrum. Moreover, the response spectrum of the building site was also considered.

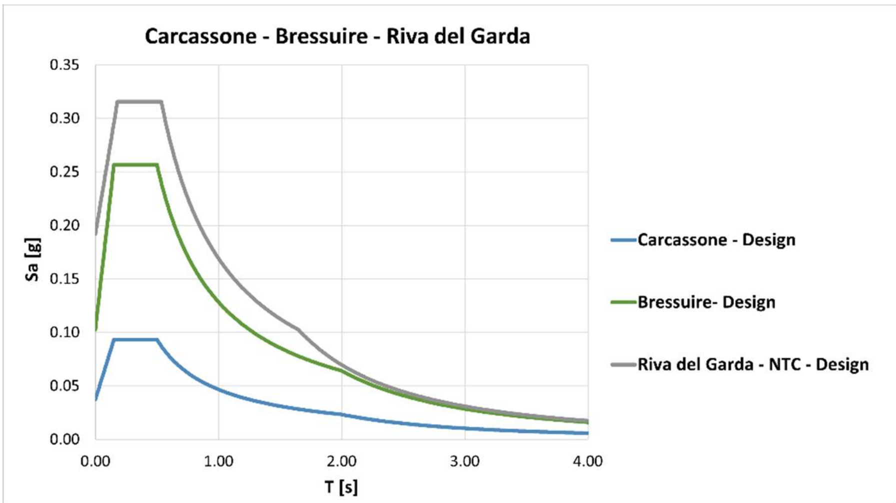



Figure 4.24: Horizontal design response spectra at ULS used for Bressuire case study

### 4.4.1 Parallel fire wall

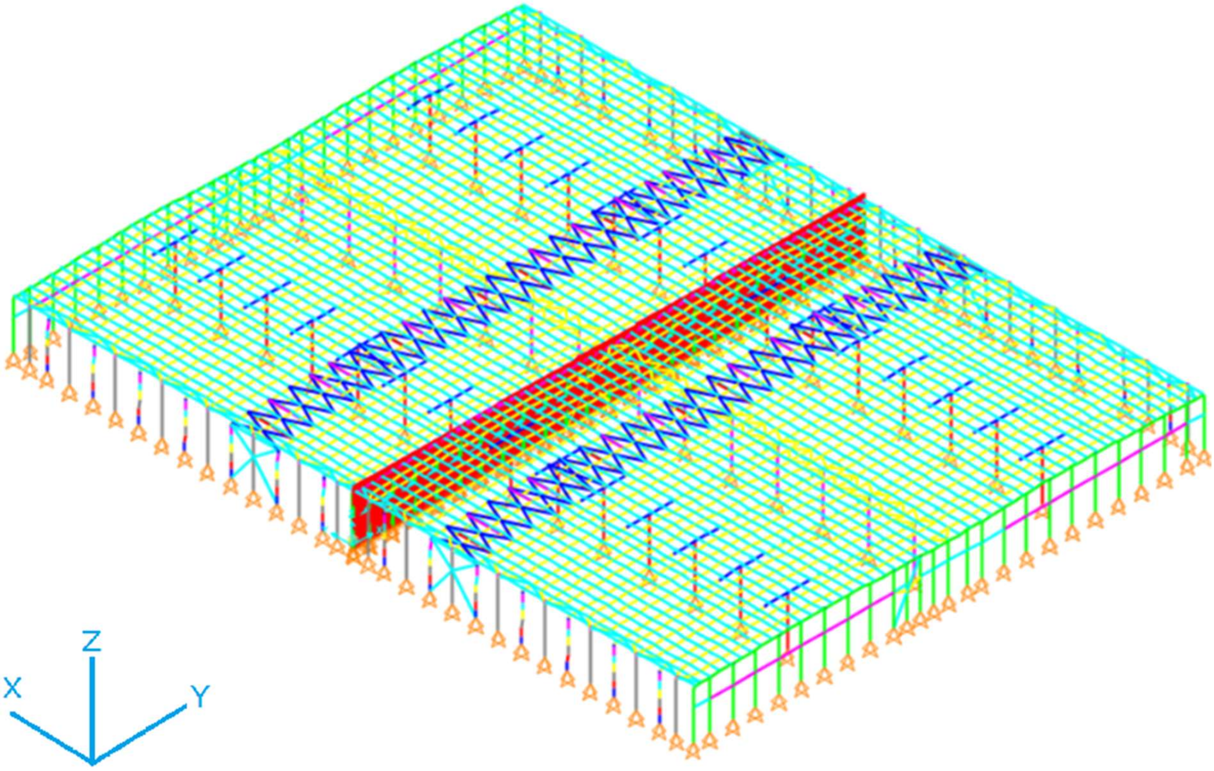



Figure 4.25: fire wall parallel to portal frame

The first configuration analysed is shown in Figure 4.25, with the fire wall parallel to portal frames.

From the analyses, the dynamic properties of the model are summarized in Table 4.39 and in Table 4.40. The effect of the in-plane stiffness of the roof is to decrease the first period of about 4% with respect to the solution without the roof. The first period is about 2 s, which is the longest one among the analysed case studies.

Table 4.39: Dynamic properties of the model with roof

| With Roof | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| Mode 1 | 2.00 | 0 | 0.06 | 0.28 |
| **Mode 2** | **1.98** | 0 | **0.65** | 0.31 |
| Mode 3 | 1.70 | 0 | 0.65 | 0.31 |
| Mode 4 | 1.64 | 0 | 0.65 | 0.31 |
| **Mode 5** | **1.57** | **0.93** | 0.65 | 0.31 |
| Mode 6 | 1.49 | 0.93 | 0.65 | 0.31 |
| Mode 7 | 1.43 | 0.93 | 0.65 | 0.31 |
| **Mode 8** | **1.01** | 0.93 | 0.65 | **0.89** |
| Mode 9 | 0.99 | 0.93 | 0.67 | 0.89 |
| Mode 10 | 0.99 | 0.93 | 0.67 | 0.95 |
| Mode 11 | 0.90 | 0.93 | 0.67 | 0.95 |
| Mode 12 | 0.89 | 0.93 | 0.67 | 0.95 |

Table 4.40: Dynamic properties of the model without roof

| Without Roof | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| Mode 1 | 2.10 | 0.00 | 0.05 | 0.27 |
| **Mode 2** | **2.07** | 0.00 | **0.65** | 0.29 |
| Mode 3 | 1.70 | 0.00 | 0.65 | 0.29 |
| **Mode 4** | **1.69** | **0.93** | 0.65 | 0.29 |
| Mode 5 | 1.64 | 0.93 | 0.65 | 0.29 |
| Mode 6 | 1.49 | 0.93 | 0.65 | 0.29 |
| Mode 7 | 1.43 | 0.93 | 0.65 | 0.29 |
| **Mode 8** | **1.04** | 0.93 | 0.65 | **0.94** |
| Mode 9 | 1.02 | 0.93 | 0.67 | 0.94 |
| Mode 10 | 1.02 | 0.93 | 0.67 | 0.94 |
| Mode 11 | 0.95 | 0.93 | 0.67 | 0.94 |
| Mode 12 | 0.95 | 0.93 | 0.67 | 0.94 |

As can be noticed from Table 4.39 and Table 4.40, the fire wall presence changed the building dynamic properties in the direction parallel to the fire wall. This is the reason why the translational global mode parallel to the fire wall decreased its period with respect to the single case studies without fire wall.

For this first estimation of forces, it was considered that the fire wall solution associated to fusible links placed between the two steel structures could be that given in the following image (Figure 4.26):

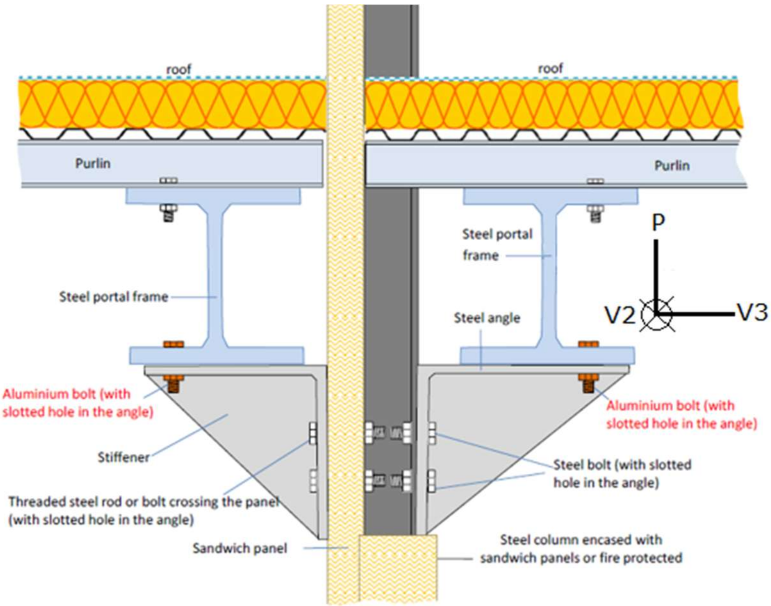



Figure 4.26: Possible fusible link assumed in the modelling

In Table 4.41 the negative value of P represents a compression stress, while a positive value represents a tension stress. It is clear that the compression forces for the details shown in Figure 4.26 do not affect the bolts and they were shown for sake of completeness.

For each configuration and level of seismicity, the required number of bolts to withstand the forces obtained were computed with and without roof. In particular, with the roof a maximum of 1, 3 and 3 M16 aluminium bolts were required for low, moderate and local seismicity, respectively, as reported Table 4.41.

When the roof effect was not considered, the maximum number of bolts became 1, 3 and 2 M16 aluminium bolts for low, moderate and local seismicity, respectively (see Table 4.41).

Table 4.41: forces in the fusible links shown in Figure 4.26

| Force | | With roof | | | Without roof | | | Design Force Variation (%) |
|---|---|---|---|---|---|---|---|---|
| **Single** | **Design** | **Value (kN)** | | **N of M16 bolts** | **Value (kN)** | | **N of M16 bolts** | |
| **Low seismicity - max combination** | | | | | | | | |
| P | P | -7.02 | ***19.48*** | **Combined actions** | -6.94 | ***11.22*** | **Combined actions** | ***-42.39%*** |
| P | | 19.48 | | | 11.22 | | | |
| V2 | $V_{Ed}$ | 2.07 | ***2.92*** | **1** | 1.99 | ***10.89*** | **1** | ***272.28%*** |
| V3 | | 2.07 | | | 10.70 | | | |
| **Low seismicity - min combination** | | | | | | | | |
| P | P | -30.25 | ***0.56*** | **Combined actions** | -32.11 | ***0.40*** | **Combined actions** | ***-29.11%*** |
| P | | 0.56 | | | 0.40 | | | |
| V2 | $V_{Ed}$ | 1.74 | ***14.03*** | **1** | 1.73 | ***11.07*** | **1** | ***-21.13%*** |
| V3 | | 13.92 | | | 10.93 | | | |
| **Moderate seismicity - max combination** | | | | | | | | |
| P | P | -6.15 | ***70.82*** | **Combined actions** | -6.07 | ***60.85*** | **Combined actions** | ***-14.07%*** |
| P | | 70.82 | | | 60.85 | | | |
| V2 | $V_{Ed}$ | 4.79 | ***24.92*** | **3** | 2.70 | ***21.48*** | **3** | ***-13.79%*** |
| V3 | | 24.46 | | | 21.31 | | | |
| **Moderate seismicity - min combination** | | | | | | | | |
| P | **P** | -73.61 | ***0.02*** | **Combined actions** | -79.89 | ***0.00*** | **Combined actions** | ***-99.22%*** |
| P | | 0.02 | | | 0.00 | | | |
| V2 | $V_{Ed}$ | 3.92 | ***30.68*** | **1** | 1.97 | ***22.46*** | **1** | ***-26.78%*** |
| V3 | | 30.43 | | | 22.38 | | | |
| **Local seismicity - max combination** | | | | | | | | |
| P | P | -6.44 | ***70.82*** | **Combined actions** | -6.33 | ***34.13*** | **Combined actions** | ***-51.80%*** |
| P | | 70.82 | | | 34.13 | | | |
| V2 | $V_{Ed}$ | 4.79 | ***24.92*** | **3** | 2.70 | ***21.48*** | **2** | ***-13.79%*** |
| V3 | | 24.46 | | | 21.31 | | | |
| **Local seismicity - min combination** | | | | | | | | |
| P | P | -73.61 | ***0.08*** | **Combined actions** | -45.19 | ***0.20*** | **Combined actions** | ***136.90%*** |
| P | | 0.08 | | | 0.20 | | | |
| V2 | $V_{Ed}$ | 3.92 | ***30.68*** | **1** | 1.97 | ***22.46*** | **1** | ***-26.78%*** |
| V3 | | 30.43 | | | 22.38 | | | |

In this configuration, reducing the in-plane stiffness determines in the fusible links a general decreasing of the shear action higher than  from 14% to 27%, except for one case. Similarly, it can be noted a general decreasing of the tension action, from 15% to 99%, apart from one case.

## 4.4.2 Orthogonal fire wall

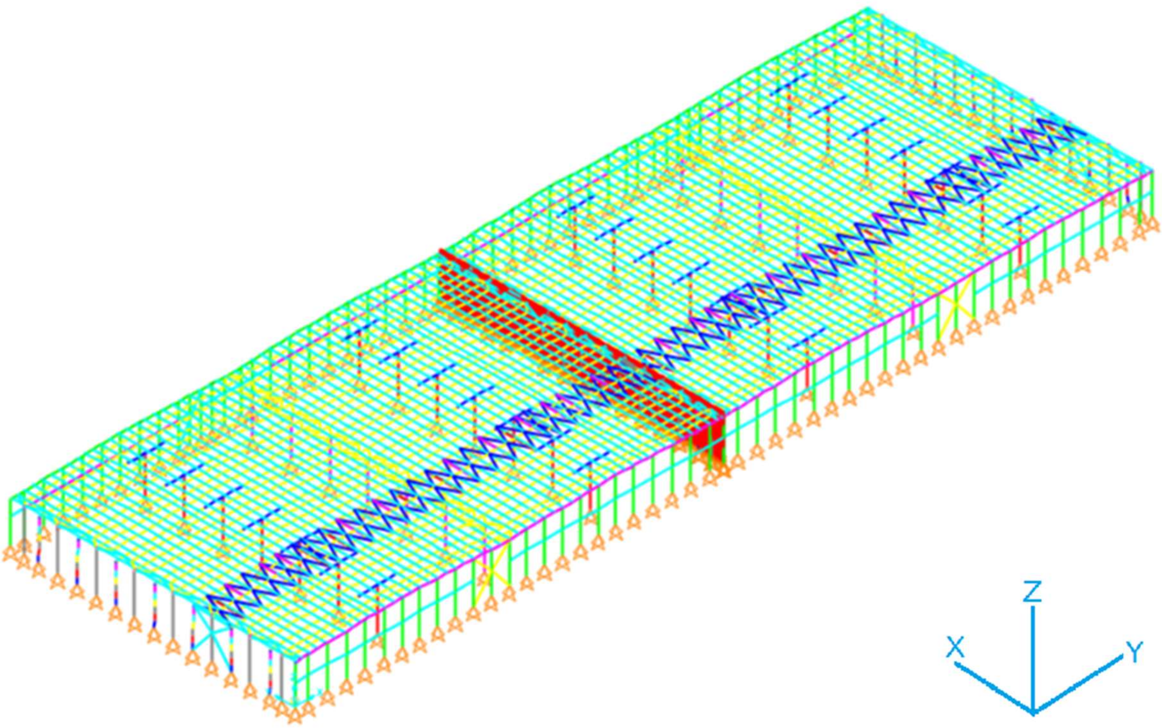



Figure 4.27: Wall orthogonal to portal frames

The second configuration analysed is shown in Figure 4.27, with the fire wall orthogonal to the portal frames.

The dynamic properties of the structure are reported in
Table 4.42 and in Table 4.43. The first period of the structure was in both cases around 1.8 s, with a purely translational model along X direction.

Table 4.42: Dynamic properties of the model with roof

| With Roof | | | | |
|---|---|---|---|---|
| **N. Mode** | **Period (s)** | **Relative modal participation mass UX (-)** | **Relative modal participation mass UY (-)** | **Relative modal participation mass RZ (-)** |
| **Mode 1** | **1.82** | 0.00 | **0.86** | 0.01 |
| Mode 2 | 1.70 | 0.00 | 0.86 | 0.01 |
| Mode 3 | 1.64 | 0.00 | 0.86 | 0.01 |
| Mode 4 | 1.49 | 0.00 | 0.86 | 0.01 |
| Mode 5 | 1.43 | 0.00 | 0.86 | 0.01 |
| **Mode 6** | **1.20** | 0.00 | 0.87 | **0.97** |
| **Mode 7** | **1.03** | **0.56** | 0.87 | 0.97 |
| Mode 8 | 0.91 | 0.56 | 0.87 | 0.97 |
| Mode 9 | 0.76 | 0.56 | 0.87 | 0.97 |
| Mode 10 | 0.71 | 0.56 | 0.87 | 0.97 |
| Mode 11 | 0.69 | 0.56 | 0.87 | 0.97 |
| Mode 12 | 0.69 | 0.56 | 0.87 | 0.97 |

Table 4.43: Dynamic properties of the model without roof

| Without Roof | | | | | |
|---|---|---|---|---|---|
| N. Mode | Period (s) | Relative modal participation mass UX (-) | Relative modal participation mass UY (-) | Relative modal participation mass RZ (-) |
| **Mode 1** | **1.86** | 0 | **0.85** | 0.01 |
| Mode 2 | 1.70 | 0 | 0.85 | 0.01 |
| Mode 3 | 1.64 | 0 | 0.85 | 0.01 |
| Mode 4 | 1.49 | 0 | 0.85 | 0.01 |
| Mode 5 | 1.43 | 0 | 0.85 | 0.01 |
| **Mode 6** | **1.30** | 0 | 0.86 | **0.96** |
| **Mode 7** | **1.14** | **0.61** | 0.86 | 0.96 |
| Mode 8 | 0.94 | 0.61 | 0.87 | 0.96 |
| Mode 9 | 0.78 | 0.61 | 0.87 | 0.96 |
| Mode 10 | 0.71 | 0.61 | 0.87 | 0.96 |
| Mode 11 | 0.71 | 0.61 | 0.87 | 0.96 |
| Mode 12 | 0.70 | 0.61 | 0.87 | 0.96 |

As can be noticed from Table 4.42

Table 4.42 and Table 4.43, the fire wall presence changed the building dynamic properties in the direction parallel to the fire wall. This is the reason why the translational global mode parallel to the fire wall decreased its period with respect to the single case studies without fire wall.

For this first estimation of forces, it was considered that the fire wall solution associated to fusible links placed between the two steel structures could be that given in the Figure 4.28.

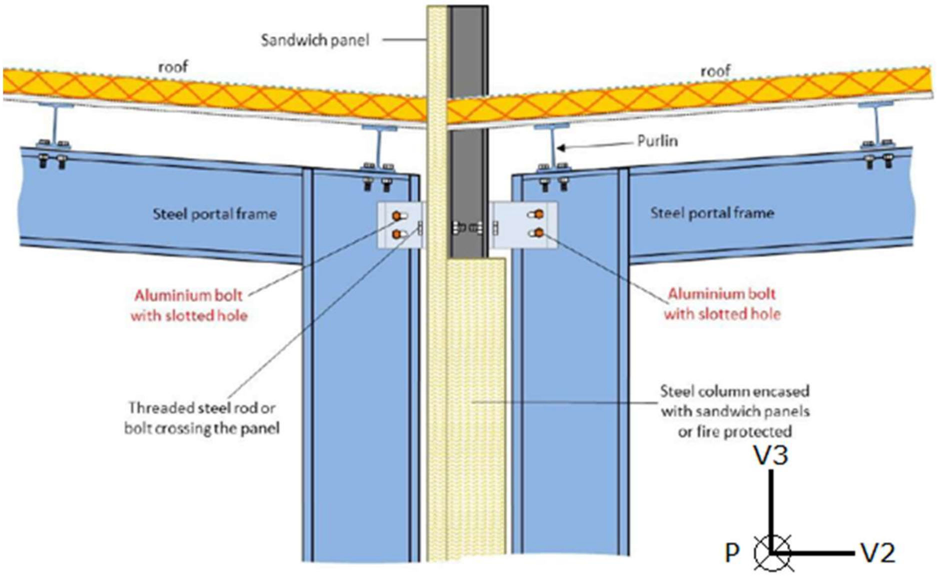



Figure 4.28: Possible fusible link assumed detail in the modelling

In Table 4.44 the negative value of P represents a compression stress, while a positive value represents a tension stress. It is clear that the compression forces for the details shown in Figure 4.28 do not affect the bolts and they were shown for sake of completeness.

For each configuration and level of seismicity, the required number of bolts to withstand the forces obtained were computed with and without roof. In particular, with the roof a maximum of 2, 8 and 5 M16 aluminium bolts were required for low, moderate and local seismicity, respectively, as reported Table 4.44.

When the roof effect was not considered, the maximum number of bolts became 3, 8 and 5 M16 aluminium bolts for low, moderate and local seismicity respectively (see Table 4.44).

Table 4.44: forces in the fusible links shown in Figure 4.28

| Force | | With roof | | | Without roof | | | Design Force Variation (%) |
|---|---|---|---|---|---|---|---|---|
| Single | Design | Value (kN) | | N of M16 bolts | Value (kN) | | N of M16 bolts | |
| **Low seismicity - max combination** | | | | | | | | |
| P | P | 0.11 | ***27.38*** | **Combined actions** | 1.47 | ***29.95*** | **Combined actions** | ***9.41%*** |
| P | | 27.38 | | | 29.95 | | | |
| V2 | $V_{Ed}$ | 15.03 | ***21.25*** | **2** | 15.28 | ***48.82*** | **3** | ***129.71%*** |
| V3 | | 15.03 | | | 46.37 | | | |
| **Low seismicity - min combination** | | | | | | | | |
| P | P | -25.03 | ***1.86*** | **Combined actions** | -26.65 | ***-*** | **Combined actions** | ***-*** |
| P | | 1.86 | | | -0.18 | | | |
| V2 | $V_{Ed}$ | 5.65 | ***56.72*** | **2** | 5.63 | ***46.71*** | **2** | ***-17.65%*** |
| V3 | | 56.44 | | | 46.37 | | | |
| **Moderate seismicity - max combination** | | | | | | | | |
| P | P | 4.07 | ***78.13*** | **Combined actions** | 4.86 | ***100.62*** | **Combined actions** | ***28.79%*** |
| P | | 78.13 | | | 100.62 | | | |
| V2 | $V_{Ed}$ | 41.45 | ***179.37*** | **8** | 41.73 | ***153.67*** | **8** | ***-14.32%*** |
| V3 | | 174.51 | | | 147.90 | | | |
| **Moderate seismicity - min combination** | | | | | | | | |
| P | P | -71.44 | ***-*** | **Combined actions** | -98.47 | ***-*** | **Combined actions** | ***-*** |
| P | | -2.29 | | | -4.42 | | | |
| V2 | $V_{Ed}$ | 31.60 | ***177.31*** | **6** | 31.70 | ***151.27*** | **5** | ***-14.69%*** |
| V3 | | 174.47 | | | 147.91 | | | |
| **Local seismicity - max combination** | | | | | | | | |
| P | P | 3.41 | ***38.31*** | **Combined actions** | 3.52 | ***48.46*** | **Combined actions** | ***26.50%*** |
| P | | 38.31 | | | 48.46 | | | |
| V2 | $V_{Ed}$ | 41.45 | ***117.68*** | **5** | 41.73 | ***111.77*** | **5** | ***-5.03%*** |
| V3 | | 110.14 | | | 103.68 | | | |
| **Local seismicity - min combination** | | | | | | | | |
| P | P | -35.03 | ***-*** | **Combined actions** | -45.86 | ***-*** | **Combined actions** | ***-*** |
| P | | -1.47 | | | -2.01 | | | |
| V2 | $V_{Ed}$ | 31.60 | ***114.56*** | **4** | 31.70 | ***108.53*** | **4** | ***-5.26%*** |
| V3 | | 110.11 | | | 103.79 | | | |

In this configuration, reducing the in-plane stiffness determines in the fusible links a general decreasing of the shear action, from 5% to 20%, apart from one case. However, it can be noted a general increasing of the tension action, from 10% to 30%.

# 5 CONCLUSIONS

This report described the seismic analyses performed on four different single-storey steel-framed buildings based on the reference ones described in detail in the deliverable D1.1, by considering two levels of seismicity: low and moderate. The main objective was to estimate conservatively the forces that could act in the fusible links (using aluminium bolts) connecting the fire walls to steel structures. Conservative modelling assumptions were made in order to obtain, as far as possible at this state of the project upper bound estimations.

All investigated case studies are characterised from different stiffness along the two principal directions due to the inherent difference in lateral-resisting systems used in most of single-storey steel-framed building, i.e., portal frames in one principal direction and bracing systems in the other one. Despite this stiffness difference, analyses indicated that both the damage limitation (DL) state, i.e. interstorey drift limitation, and the ultimate limit state (ULS) were satisfied.

As expected, the presence of the fire wall with the fusible links that connect it to the structures affected the dynamic properties of the single case studies. In particular, in the direction parallel to the fire wall, the translational global mode clearly stiffened.

From the results obtained in simulations, it has been shown that:

- The configuration with fire walls parallel to portal frames entailed a maximum number of 3 and 6 M16 aluminium bolts for low and moderate seismicity, respectively to withstand seismic actions. . The effect of the in-plane stiffness of roof was analysed and it led, as expected, to shorter periods and in most cases to a slightly higher number of bolts. The configuration with the bracing system close to the portal frame can increase also the number of bolts in comparison with the same building but with the bracing system in its original position. However, it depends on the building configuration considered.
- The configuration with the fire wall perpendicular to the portal frames requires a higher number of bolts with respect to the parallel direction, due to a lower number of fusible links. In the worst case, represented from the case Reference case 1 with limited number of portal frames, the estimated number of bolts for fusible link was 10 and 15 for low and moderate seismicity, respectively. This building configuration implied short periods in the direction parallel to the fire wall, characterised by high modes.
- The in-plane stiffness of the roof changes the force in the fusible links. In general, the assumption of roof without in-plane stiffness increases the tensile force in the bolts and reduces the shear force due to their arrangement near the roof.

Simulation results will be used to define the range of seismic actions to consider in the tests foreseen on fusible links in Work Package 4 as well as in the design of test specimens made in Task 1.5.

The numerical work undertaken in the Task 1.4 was only a preliminary work. In the scope of the Task 4.3, it is planned to develop for each reference building a 3D FE modelling taking account more accurately the detailing of investigated fusible link solutions and their connection to the fire wall selected in the project. In addition, the influence of the arrangement of bracing systems in buildings, the soil type, the wall stiffness or any other parameters considered as relevant may be investigated in more detail. Moreover, the seismic design of the case study buildings could be also revisited at that time, if needed.

# 6 REFERENCES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