

1. INTRODUCTION

1.1. The corrugated metal sheets as roof panels: A bit of history

The metal sheets were first invented at the start of the XIX century, but was first after the Second World War when the developments in the car industry and the necessity to save material in construction, gave a big push on the development of the cold formed elements in the construction world.

The first norm that supported its development comes from the United States, where the American Iron and Steel Institute published in 1946 the “Cold formed Steel design manual”, based on the results of the campaign of experiments done by G. Winter.

From the United States this technology jumped into Europe, mainly thanks to the American companies installed in Europe after the Second World War. In this point of time, two main different building techniques were developed in Europe. On one side the English, who used cold-formed purlins as secondary structure, which is the support of low profile’s metal sheets and the insulation (fig 1.1). On the other side, in Germany and the Nordic countries, the use of the metal sheet itself, acting at the same time as secondary structure and support of the insulation (fig 2.2), would be highly spread.

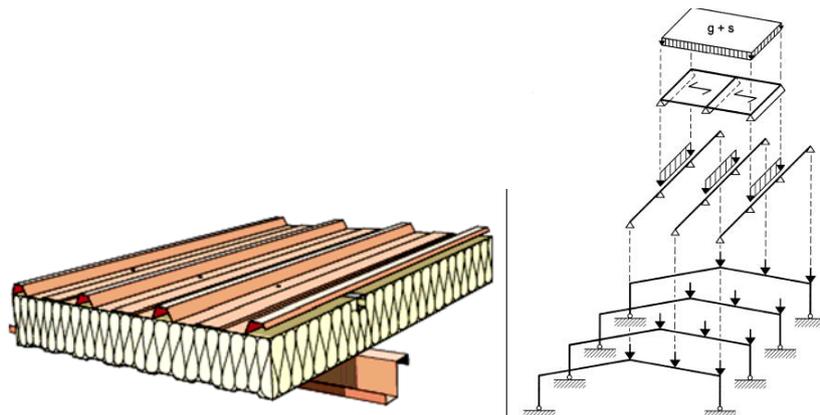


Fig 1.1: Roof with purlins (Z), which span from portal frame to portal frame. Next to it, distribution schema of vertical load flowing through the building to the foundations. Extracted from [1]; [2] respectively

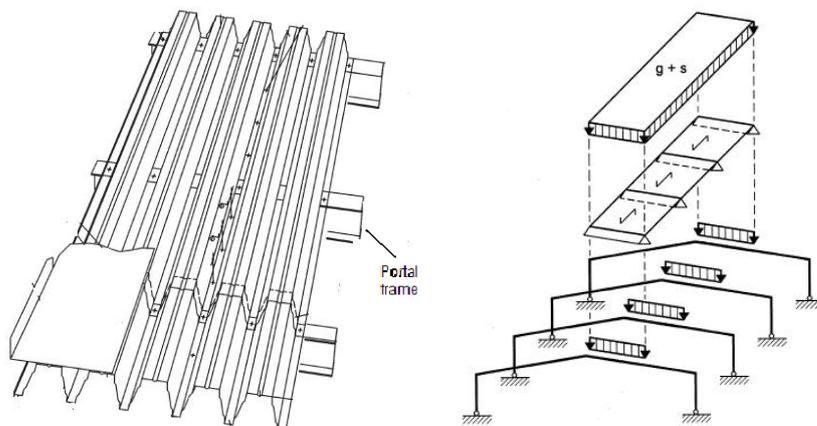


Fig 1.2: Metal sheet which span from portal frame to portal frame, next to it vertical load's distribution schema through the building to the foundations. [3]; [2] respectively

In Spain the main technique spread was the one with purlins, though it started later, in the seventies, probably as a substitution of the old method of hot rolled purlins and fibrocement plates, for the new cold formed technology, both in purlins and metal covering sheet. Just a look on the catalogues on the companies that offer metal sheets it can be appreciated that the maximum depth that can be seen is round 80 millimetre. The maximum spans range three to four meters.

1.2. Type of metal sheets

We can distinguish basically three different kinds of metal sheets depending on its structural performance and development:

1.2.1. **Metal sheets of the first generation**

The metal sheets of the first generation have normally depths between 30 to 80 mm, usually the webs and flanges are not stiffened, and their range of use goes from the two until three meters. This type of metal sheet is commonly used in case that we have a secondary structure with purlins, under it. This is the main type used in Spain, and is kind is the only type that is studied in the dissertation.

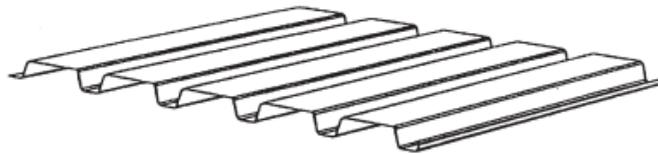


Fig 1.3: Metal sheet of the first generation. Extracted from [4]

1.2.2. **Metal sheets of the second generation**

The normally considered metal sheets of the second generation have depths ranging from 80 to 180 mm. These metal sheets have longitudinal stiffeners in the flanges (one or two) and longitudinal stiffeners in the web (one or two) (that follow the direction of the ribs). The allowed spans, for this kind of metal sheet and in normal cladding applications, range from 5 to 7 meter.

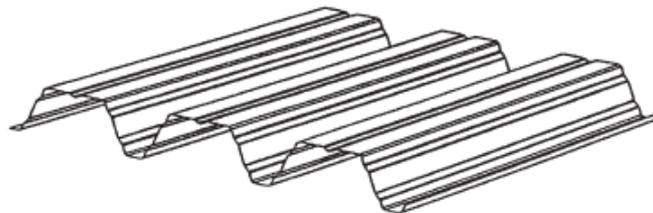


Fig 1.4: Metal sheet of the second generation Extracted from: [4]

1.2.3. Metal sheets of the third and fourth generation

The next evolution of these metal sheets was to provide stiffeners on the flanges of the metal sheets in the direction perpendicular to the direction of webs and crest. The metal sheets gained in stiffness in that direction with that. This new kind of metal sheets can be used for spans until 12 m, though in this case special support elements should be provided. The depth of the metal sheets of third generation (that are one ribbed) is from 200 mm. The metal sheets of the fourth generation are then a combination of the two previous (second and third)

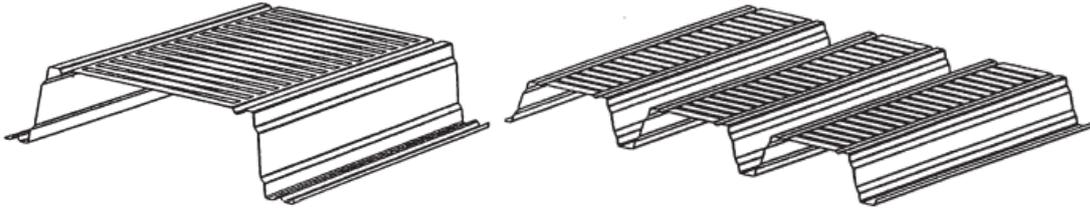


Fig 1.4: Metal sheet of the third and fourth generation respectively .Extracted from [4]

It can be seen in the following graphic the evolution between the recommended span (Spannweite) respect to the relationship weight (gewicht)/span (spannweite). It can be seen that each generation is much more effective in saved weight per meter.

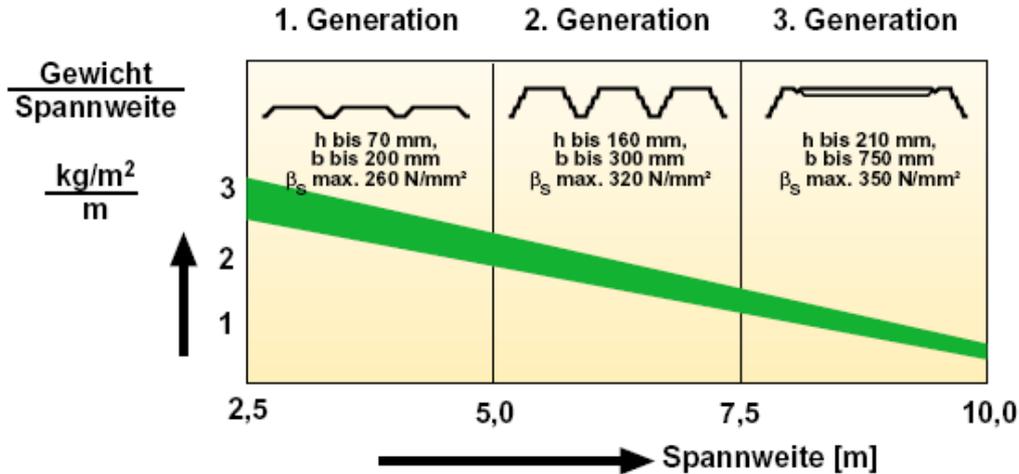


Fig 1.5: Graphic that relates the evolution from the relationship. Extracted from [5]

1.3. The stressed skin design

The stressed skin effect design takes into account, the stiffening that the roof's metal sheet provides to the stability of the building against lateral loads. This effect is always present, if this metal sheet covers the building. It is the option of the designer to consider its effect or not.

1.3.1. What is the diaphragm effect?

Let's consider on the first step a certain typology of building:

- One bay, and one storey rectangular building
- Portal frame as a main structure, which is repeated with certain spacing.
- The building has cold formed purlins that span between the portals
- There is an insulated roof over these purlins (either deck or sandwich "in situ").
- The metal sheet under the insulation is a first generation metal sheet, which overlaps in the valleys and that is screwed to the purlins
- The slope of the roof is lower than 10 degrees

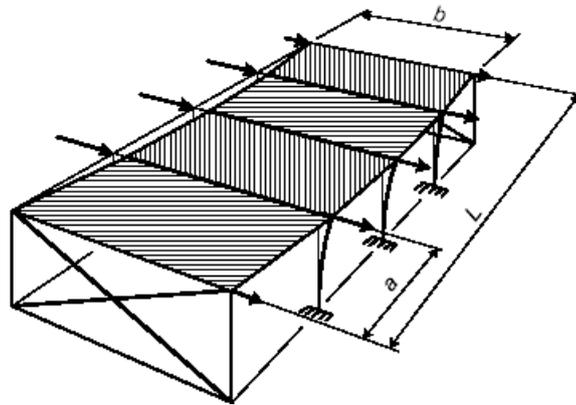


Fig 1.6: Building with wind on the side. Extracted from [6]

When the wind acts on the long side, the building's roof behaves like the web of a deep plate girder spanning between the stiffened portals. This beam absorbs part of the horizontal action and brings it to the stiffened portals. This forces absorbed by the diaphragm reduce the actions on the portals itself, which can be subsequently lighter.

The distribution of the lateral load on the figure 1.6 can be seen in the fig 1.7. The purlins act as the flanges of the beam, which absorb the normal efforts. And the metal sheet in the roof absorbs the shear forces, as the web on a beam.

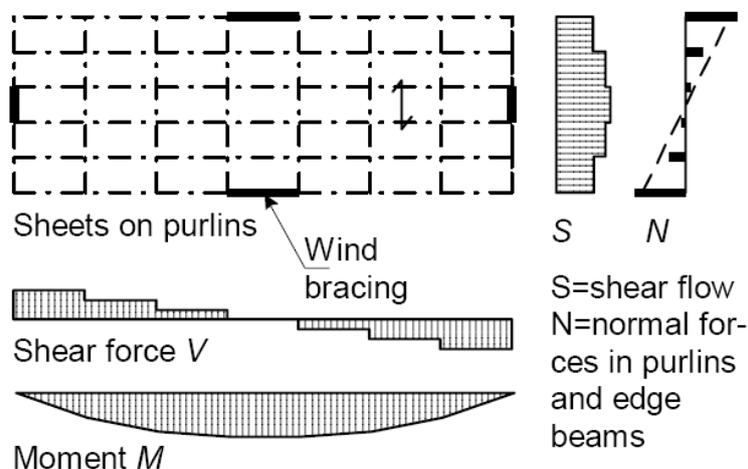


Fig 1.7: Shear force V and moment over the length of the building. Shear flow and normal force in each one of the shear cells. Extracted from [6]

The pieces of roof between the portals are the “shear cells”, whose calculation and behaviour is explained on the chapter IV of this dissertation.

1.3.2. Why it is useful to use stressed skin design?

The main two uses of the stressed skin design are:

- Reduce stresses and deflections in rigid-frame construction
- Provide lateral stability to nominally pin-jointed structures

Let’s extend these concepts a bit further. Industrial and logistic buildings are usually designed with portal frame structures, as it can be seen in the fig 1.8.

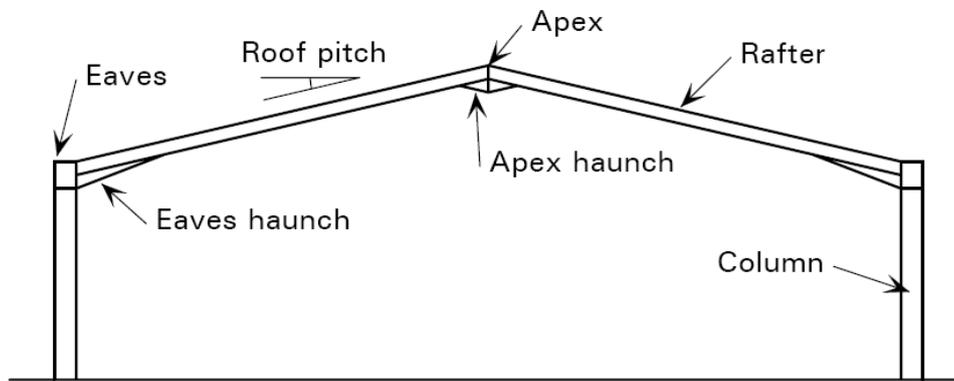


Fig 1.8: Typical portal frame with the name of its parts. Extracted from [7]

The instability effects are the ones that limit in the majority of cases the resistance of the portal frames. The columns and rafters, and sometimes the haunches will normally require intermediate restrains to the compression flanges. The outer flange is easily restrained by the purlins and the inner flange can be restrained by the flying bracing as seen in the figure 1.9

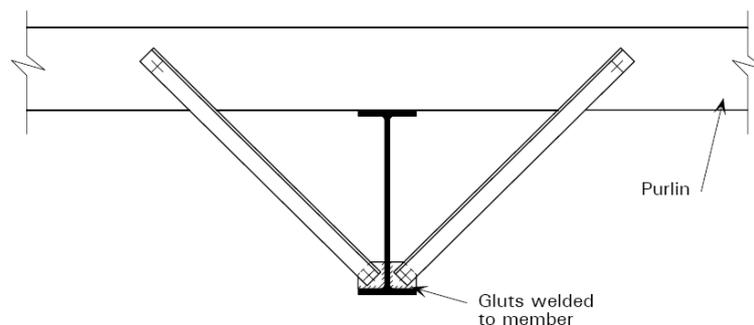


Fig 1.9: Flying bracing to restrain the compression flanges. Extracted from [7]

The restraint provided to the flanges is only effective when the structure as a whole is adequately restrained by appropriate overall bracing (plan bracing or other cross bracing) or diaphragm systems (stressed skin design of the roof)

In order to minimise the lateral movements between the portals, the in plane movement of the portals needs to be restrained and limited. There are two options:

- Design a rigid frame which is cantilevered in the basis, this is relatively difficult and expensive, as it requires special foundations,
- Design a rigid Eave, able to limit the lateral displacement.

In the figures 1.9 and 1.10 the moment distribution in the portal frames are shown. The function of the diaphragm is to reduce the lateral force acting on the frame, and consequently reduce the in-plane displacement and the moments in the frame. Which leads of course to lighter sections.

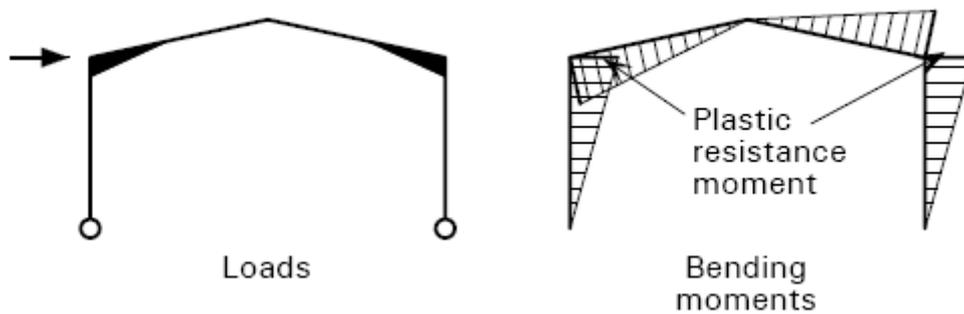


Fig 1.10: Moment distribution of a portal due to a “horizontal” force. Extracted from [7]

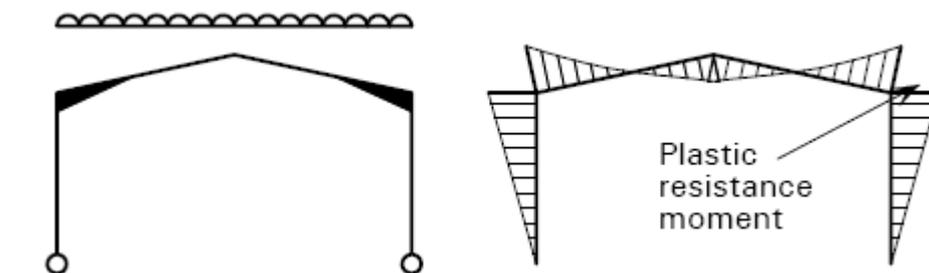


Fig 1.11: Moment distribution of a portal due to a “vertical” force. Extracted from [7]

On a second Stage the purlins can be also restrained by the sheeting. A calculation procedure is clearly explained in Eurocode 3 part 3.1 [8]. Usually the metal sheet is considered to be able to restrain the superior flange (in compression with down directed loads) but on the way up the compression flange, which lays on the down part, it is not stiffened.

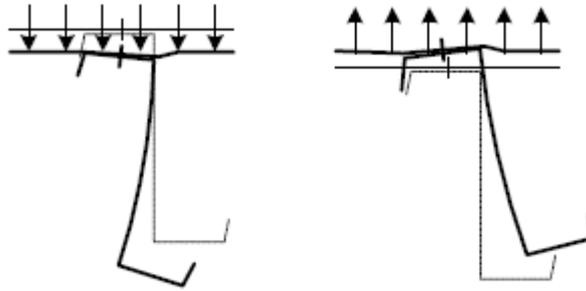


Fig 1.12: Purlin deformation in the two directions of vertically loaded Extracted from [8]

1.3.3. When is it useful to make use of the diaphragm effect?

- When in the construction period the use of few erection stabilisers, can avoid the use of permanent bracings (the diaphragm will do that paper)
- To provide stability to members to prevent flexural buckling, flexural torsional buckling and lateral torsional buckling or a combination of these.
- The number of openings in the roof is going to be small and will not prevent the use of the diaphragm
- The geometry of the building is easy and uniform.

1.3.4. Structural classification of the metal sheet

In the prEN 1993-1-3_[8] there is a classification of elements in three different groups:

Class I: The metal sheet it is contributing to the overall strength and stability of the structure. The metal sheet is absorbing the shear effort due to lateral loads, restraining the lateral deformation of the purlins and rafters where it is fastened, and at the same time supporting the vertical loads

Class II: The metal sheet is contributing to the stability of individual elements. The metal sheet restrains purlins or rafters and the vertical loads

Class III: The metal sheet is an element that transfers loads to the building, it is responsible to transmit the forces to the purlins or rafters, and other elements will be calculated to restrain the purlins or rafters and the building.

1.3.5. Diaphragm design in the USA

The use of the metal sheet as restrain for the whole building (class I) it is widely used in the USA. The metal sheets, which have a bigger grade of standardization, (type B, wide rib, and N are the mainly used) and the use of specific metal sheets (with interlocking

nesting) where the fastening between sheets, instead of being done with seam fasteners, equally distributed along, it is twisted as seen in the picture, what gives a much higher resistance in the long ends' union of the metal sheets. On the other hand the fastening done to the base structure it is done with puddle weld (round welds of the metal sheets to the bar joists (most used base material). In all this cases the maximum action it is going to be in shear in the fasteners and connections with the bar joists rather than the seams.



Fig 1.13: Fold on the connection of two sheets (seam connection) Extracted from [9]



Fig 1.14: Metal sheets laid on a bar joist frame. Extracted from [9]

1.3.6. Diaphragm design in Europe

In Europe its use is much more limited, maybe mainly for two factors:

- The lack of literature, or norms that regulate the use of the stressed skin
- The high complexity of the formulations in order to calculate the stressed skin

This dissertation will study the concrete problematic of the Spanish region: Loads, materials, ways of building, and give a whole spectrum of the possibilities and limitations that this technology can offer to the engineer designing steel one storey buildings.



Fig 1.15: Metal sheets laid on a the rafters Extracted from [10]



Fig 1.15: Framed building with purlins, before laying the roof and walls. Extracted from [11]

2. OBJECTIVES

The objectives of this dissertation are the following:

- 1) Explain the theoretical background of the stressed skin design
- 2) Analyse the different elements that contribute to the flexibility and strength of the shear cell and check its influence.
- 3) Analyse the real range of flexibilities and strength of the shear cells for the normal design conditions.
- 4) Analyse the interaction of the stressed skin with the building, both for symmetric and non symmetric buildings
- 5) Analyse the conditions for which the diaphragm design is a viable option of lateral stiffening.