Chapter 1

Introduction and objectives

1.1 Introduction

During the last years the use of light-weight cold-formed steel structures is being widely spread for the construction of one or two storeys buildings. The reasons are a reduction on the costs, as well as, an improved versatility of the structure, being able to create very different houses with a few number of structural elements. And also having any desired outside aspect of the façade. Moreover, it is suitable for any kind of ground, since the foundation requirements are not very strict. But the most important factor in this development has been the quickness in the construction, reducing the time of this process to less than 5 months, with the actual technology and structural systems.

Figure 1.1 Steel structure of the single-storey building, Framehomes (2002) and Consul Steel (2003) after Valls (2002)
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Figure 1.2 Final aspect of the residential building, Framehomes (2002) after Valls (2002)

This new constructions developed from the building tradition in the centre and northern European countries, which was known as balloon framing when it was introduced in the USA. The main characteristic of this traditional building procedure is the existence of a structural skeleton, made of light-weight members, that is designed to provide the resistance and shape to the whole building. The beginning of the Framing can be dated about the year 1860, when a huge migration movement reached the US Pacific coast. In those years, the population increased in ten times, and so did the demand of houses. This problem was solved by using the materials available at the area, especially timber, and focusing in the speed and productivity of the building methods. This two facts put together can be considered as the origin of the Balloon Framing.

Figure 1.3 Application of the Balloon Framing, National Building Museum (1994) after Valls (2002)

The use of light-weight steel structures in commercial buildings and civil constructions started many years ago, but it was not until the end of the Second World War that it was also applied to residential buildings. Nowadays, steel is much more used in this last type of buildings than timber, its natural competitor. Some reasons are the ecological movements, steel is 100% recyclable whereas timber is more difficult to recover, the low fluctuations in its price and the quality of the material.
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The building tradition in the Mediterranean region has been always based in the use of rocky materials, such as stones, concrete and ceramics. But also this areas are now tending to the construction with light-weight systems and materials, since they are objectively more efficient.

When defining the Framing system it was remarked that it is the resistant part of the building, even though it is a light-weight structure. Moreover, there is another aspect of great importance, when comparing it to the traditional construction methods, the complete building is made of different elements or sub-systems that will work together. Some of this sub-systems are the steel structure, insulation elements, installations, etc. Therefore, the correct functioning of the building will depend on the way all these sub-systems are connected, and it is then when the light-weight structure has advantage in front of the traditional constructions. The structural system becomes almost transparent, creating no obstacles, so the house installations and services are very flexible in its design, which has more importance every day since the number of installations inside the houses increases.

Figure 1.4 Evolution of the steel price compared to other goods and services, Stevens (2000) after Valls (2002)

Figure 1.5 Installation of the floor heater, Consul Steel (2003) after Valls (2002)
Once the main advantages of this technology are mentioned, it is reasonable to predict that its use will surely increase in the next years, just slowed down by the existing building traditions in the different regions. Therefore, the builder or building companies will be a determining factor in the introduction of the *Steel Framing*.

From the structural point of view, the most characteristic feature of this kind of constructions is its lightness. It is achieved by making the structural elements from very thin steel sheets, about 1 mm. thickness, and joined by welding or bolts. The result is a set of beam profiles with very little cross-sectional area and moments of inertia. Therefore, high slenderness of the structural elements is another common characteristic in this type of buildings.

Moreover, the typically used beam sections have low ductility, because of local buckling phenomena in compressed members. Thus, it has to be mended by additional elements in the structure, such as x-bracings or shear walls.

These characteristics certainly yield to a different dynamic behaviour of the structure when compared to the most common residential buildings made with more usual technologies. Since earthquake actions can not be neglected in the design of light-weight steel structures, especially in areas with high risk of ground motions, it is important to analyse them in detail and reach a good understanding of this dynamic response. Another reason that justifies a special design for this particular kind of structures is that they are not included in the Eurocode’s building guidelines.

The main problem existing is that almost all the knowledge in light-weight structures comes from the performance of full-scale tests in laboratories. This tests, which might be very costly, are typically with static loads and not always satisfactory. Moreover, it is impossible to think in testing the complete structure of a building in a dynamic full-scale test, its cost would not be assumed by any company. Therefore, some cheaper and faster method has to be applied in the analysis of the behaviour of a whole structure when seismic excitations act on its foundation. The solution used in this thesis work is to model the structure with the finite element method (FEM). It has to be remarked that the FEM is not thought as a substitute of the full-scale test, their results are complementary.

The FEM has been proved to be a powerful technique in modelling and simulating many different physical problems, including the dynamic analysis of any...
kind of structures. The FEM software, in this case CASTEM 2000, provides the user total freedom in creating the geometry of the structure and also several options in the constitutive law of the material, boundary conditions and type of analysis. The discussion in the following chapters will be focused in the study of elastic structures by means of the response spectrum analysis, which is the quickest calculation procedure but also the most commonly used for seismic design, since it only computes the maximum structural response, displacements and stresses.

1.2 Objectives

The main goals of the thesis work can be summarized in:

- Seismic design of light-weight steel structures
- Numerical modelling, by means of the finite element method (FEM)
- Parametric studies
- Know-how studies

1.3 Outline of thesis

The linear dynamic analysis of structures is introduced in Chapter 2. First, the physical problem to be solved is explained, and next a brief description of the available numerical methods is done. Two main groups are discussed and compared, the direct time integration, also called step-by-step methods, and the mode superposition analysis.

Chapter 3 focuses in the particular case of earthquakes acting on the structure. It has some consequences in the equations to be solved and the way to introduce the loads in the calculations. But the most important is the discussion on the response spectrum analysis, a simplified dynamic analysis that can only be applied in seismic design.

The previously described numerical methods are applied to the analysis of a cantilever in Chapter 4. The aim of this example is to show the main characteristics of any dynamic analysis, such as the eigenmodes of vibration, the influence of the material and geometrical properties and the variation in the structural response for different seismic excitations.

Chapter 5 comprises the 2D analysis of a frame. It is carried out to complete the parametric study from the previous chapter, varying the damping properties of the structure, but mainly to achieve some conclusions in the numerical model and structural configuration of light-weight steel structures. It is proved that the mass of the roof can not be neglected and that the best horizontal stabilization method is the x-bracing.
Chapter 6 can be understood as an extension of Chapter 5, having a whole façade as the structural system instead of a single frame. It starts by checking if the results from the frame can also be applied to the façade. Then, the position of the x-bracing and the existence of openings in the façade is discussed, leading to the desired result that they are not significant in the dynamic response.

The last step in this thesis is to analyse the whole building, which is done in Chapter 7. For this purpose, a representative model of the structure has to be created in 3D. Next, the design of the bracing elements for a realistic loading case is performed and finally it is concluded that the 3D analysis cannot be reduced to a 2D one when two perpendicular ground motions act simultaneously.

Chapter 8 summarizes all the important concluding remarks derived during the thesis, and also future work in the seismic design of light-weight steel structures is proposed.