CHAPTER 10
Strength assessments

10.1 Introduction

Once the model has been validated, at least from the numerical point of view, as seen in Chapter 9, it is necessary to proceed to the strength assessment of the structure.

In essence, for each load condition, for each point considered critical, for each joint and/or connecting element, it is necessary to establish the "safety coefficient" or its homologous "safety margin"; we will see shortly that the difference between the two is not only numerical, but also conceptual, even though it indicates substantially the same thing, namely the ability or inability of the structure to survive the loads that stress it. Generally, the minimum values of these coefficients vary according to the experience of the structural engineer, the type of structure that is being designed, the level of uncertainty that affects the boundary conditions (for example, loads known only with little precision or based on estimates more or less reliable), the uncertainty of the mechanical behavior of the materials used; sometimes the minimum value may be imposed by a specification or by regulations, which depend very much on the sector in which we are working. Precisely for these reasons we cannot go into too much detail here, but we will try to give a general overview and some food for thought regarding the integrity of structures.

Normally the coefficient of safety (CS) is calculated as the ratio between the allowable value and the value applied to the component under investigation: in the case of structural parts it will usually be a ratio between stresses, while for rivets, for example, it could be a ratio between forces. In any case we will say:

$$CS = \frac{\text{Allowable}}{\text{Applied}}$$

Regarding the margin of safety (MS) it is calculated as follows:

$$MS = \frac{\text{Allowable}}{\text{Applied}} - 1$$

The relationship between CS and MS is also clear:

$$MS = CS - 1$$

The conceptual difference is less clear: especially in aerospace, the safety coefficient is applied with respect to the "limit" loads, i.e. the maximum forces that the structures should see during normal operations, while the safety margin is calculated for the so-called "ultimate" loads, i.e. the forces that occur under special and/or emergency conditions (out of the ordinary maneuvers, such as emergency landings) and that can take the structures beyond their elastic limit (see Chapter 13).

Due to the relationship between the two, there is often a tendency to use one or the other indifferently, and this can create some confusion, since the watershed for CS is 1.0 (< 1.0 it fails, > 1.0 it is fine) while for MS the discriminating number is 0. How much necessary it is to stay above these limits depends on the factors seen a few lines above. Perhaps in order to limit possible misunderstandings, the aerospace world has recently tended to use CS for both "limit" and "ultimate" conditions. In both cases, however, when we are above the lower limits, the two coefficients indicate what "reserve" the structure has at that point before reaching its limit, which can be yielding (limit loads), but also rupture (ultimate loads).

In the following paragraphs we will deal with static and fatigue assessments, assuming that the data used are those provided by finite element calculations.

10.2 Static assessment for homogeneous and isotropic materials

10.2.1 Continuous structure parts

On structures made of homogeneous and isotropic materials, the static assessment is nowadays rarely a problem, due to the use of strength criteria consolidated for a long time and repeatedly validated by experimental tests.

The most popular criterion for ductile materials is that based on the Von Mises equivalent stress σ_{VM}; this "number", as we saw in Chapter 9, is a combination of the principal stresses, but it can also, of course, be expressed as a function of all the components of the stress tensor. We can therefore have the following two valid relations for the calculation of the σ_{VM}:

$$\sigma_{VM} = \sqrt{\sigma_I^2 + \sigma_{II}^2 + \sigma_{III}^2 - \sigma_I \cdot \sigma_{II} - \sigma_{II} \cdot \sigma_{III} - \sigma_{III} \cdot \sigma_I}$$

$$\sigma_{VM} = \sqrt{\sigma_{xx}^2 + \sigma_{yy}^2 + \sigma_{zz}^2 + 3 \cdot \tau_{xy}^2 + 3 \cdot \tau_{yz}^2 + 3 \cdot \tau_{xz}^2 - \sigma_{xx} \cdot \sigma_{yy} - \sigma_{yy} \cdot \sigma_{zz} - \sigma_{zz} \cdot \sigma_{xx}}$$

Usually the computational codes determine the σ_{VM} directly, while at other times it is the post-processors that, from the stress tensor, evaluate the σ_{VM}.

In any case, once the σ_{VM} is known, it is possible to calculate the safety coefficient at all points of the structure. The σ_{VM} will constitute the applied stress, while the allowable stress will depend on the material: generally the yield value of the same is assumed since the residual deformations, due to more or less extensive plasticization, are not tolerated for the limit conditions. Only in exceptional cases we design to ultimate (more than anything else to assess the margin available with respect to the catastrophic collapse of the structure), and in this case the use of σ_{VM} may not be indicated as excessively conservative. However, in most cases this route is followed and the coefficient (or margin) of safety is calculated with respect to material failure by substituting