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Strategic Role of Research In Structural Engineering for High Performance and Reliable Devices

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Abstract

This paper provides some considerations about the strategic role of engineering research to predict structural strength and avoid damage. Even in the case of defects or after a break, scientific research allows understanding the causes through *Failure Analyses.*

All structural components can be manufactured with defects such as cracks. Cracks may or may not propagate and, in most applications, certain load values applied and below critical size do not propagate. However, the defect that today does not propagate if the component is subjected to normally applied loads can propagate later, perhaps years later, due to accidental exceptional loads that trigger propagation. This latter structural behavior is called "*causality*": defects present from the beginning that propagate later.[1] Non-destructive controls (remember magnetic methods and penetrating liquids in particular) are very important in order to control the size of defects. It is enough to give the example of the behavior and maintenance of aircraft structures to understand the importance of periodic checks: "*flying machines*" must have very high resistance/mass ratios (lightness is a fundamental requirement) and aircraft designers are aware that an aircraft can fly with damaged fuselage and wings, in which defects are always present. It might seem strange, but all the planes we use can contain damages, even those that have recently been in service. The aluminum alloy sheets with which the wings and the fuselage are made of are home to numerous defects whose position is known: the size of these defects is checked and the structure is intervened when the size exceeds the critical one (which would lead to the breakage of the sheet metal). Structures and components work even if they are damaged and need to be checked periodically. Clearly,

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this type of approach does not consider exceptional events: manoeuvres that cause overload or extremely aggressive environments.[2-7]

In light of these simple considerations, it is clear that safety depends on the responsibility of all the "actors" who contribute to the design, implementation, certification, use, and maintenance of the machine.

To accurately assess the reliability (probability of non-breaking) and the strength of components used in mechanical, civil, or aeronautical structures, it is necessary to consider which parameters most affect the damage. The most important aspects of this preliminary analysis are certainly those concerning materials, namely the mechanical strength of the individual components with and without surface treatments (i.e shot peening,[8] innovative manufacturing processes such as friction stir welding,[6] the operating loads, and possibly the exceptional ones. The variability of the above parameters sometimes makes it very difficult to predict the in-operation behavior of components whose reliability, moreover, can depend on interaction with the other components of the machine or structure. The estimate of the resistance in the deterministic field consists of the assessment of the safety coefficient that is the ratio of the average value of the resistance of the component to the average value of the operating load (the ratio of the limit load to the operating load). In the safety coefficient, the designer is aware that there are uncertainties about the loads applied, the dimensions, the calculation methods, the strength of the materials. International Standards for metal structures (for steel or aluminium alloys) currently in force report that, under conditions of static application of operating loads and in the absence of accidental or exceptional unforeseen events, the safety coefficient should be 1.5, i.e. the structure should be able to withstand 50% more load than the nominal one (in normal operating conditions). This way of dealing with the structural design is called the "deterministic approach". This approach does not directly consider the variability of the different factors that enter the verification formulas, but properly amplifies the safety factor. The subject becomes more and more complicated is we consider components subjected to innovative treatments, such as TiN or CrN PVD coatings,[4] or we want to take into account loads and resistance variability.

The deterministic approach can lead to consider safe some conditions that are very close to failure, and this is particularly true when using relatively low safety factors (as is the case in aircraft or motor racing). In general, the failure of a machine element, or a structure in general, is a function of both the material, as well as the actual geometric dimensions, and the loads; all these parameters may be subject to accidental variations due to processing imperfections (which may be limited through the assignment of appropriate processing tolerances) or effects due to the processes themselves (residual stresses induced by fusion processes, molding, machining) or, finally, variations in features not controllable by the designer. Think about the resistance to motion that, as we know, is regulated by friction between the contact bodies, friction of which is known as the strong dispersion. It can, therefore, be said that two components are nominally the same but their characteristics, both geometric and material, are subject to variability. Moreover, the design of mechanical components is conducted with theoretical and numerical procedures that are sometimes very approximate. The intrinsic nature of inaccuracy that occurs in the theoretical approach is systematic and cannot be taken into account in the design at the probabilistic level, which is currently possible concerning load variability and resistance.

In light of the results of probabilistic analyses relating to the strength of the individual machine component or structure, it will then be necessary to assess the importance of the component within the machine itself and possibly the interactions with other components. It is essential to indicate which kind of damage, at the catastrophic limit for the machine in terms of out of service, can lead to the out-of-service of the single component. There are two different approaches to design: *Fail-Safe* and *Safe-Life*. In *Fail-Safe* design a certain degree of defectiveness in accepted. With this latter approach the designer can assume lower safety factors than the ones used in *Safe-Life*, in which the out-of-service of the component causes the out-of-service of the whole device.

Conclusions

Structural damage during the life cycle of a mechanical device can be caused by:

- Lack of technical and scientific knowledge in the design phase (designers not adequately prepared);
- Use of insufficient safety factors;
- Errors of design and execution;
- Lack of non-destructive controls for important structures in terms of reliability and safety;
- Inadequate maintenance;
- Misuse;
- Accidental events that are not considered to be project-time or unexpected.

Damage during the life of mechanical systems can be avoided by means of:

- Good technical preparation and research;
- Implementation of the probalistic approach in design process;
- An adequate knowledge of the variability of applied loads and material resistance;
- Proper maintenance of the mechanical system and individual components;
- Accurate execution of non-destructive periodic checks.

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Conflict of Interest

The authors do not have any conflict of interest.

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