New advanced design methods for stainless steel structures

The Eurocodes and other international design specifications adopt design procedures that are comprised by two steps: (1) a structural analysis in which the internal forces of each element that comprises the structure are determined, and (2) the verification of the resistance of these elements using the design expressions codified in structural standards. In addition, these design methods are member-based, and assume that structures fail when the capacity of the critical element is reached. Member-based two-step methods are consolidated and they have been used for decades in the design of steel and stainless steel structures. However, they present some drawbacks, including that resistance checks are necessary for each structural component and multiple load combinations, resulting in long and tedious design processes, and that the redistribution of internal forces after the formation of the first hinge is usually not captured, which leads to a conservative prediction of the capacity of systems with significant load redistribution capacity. These drawbacks are especially relevant for materials with a significant initial cost, such as structural steel and stainless steel.

However, thanks to the recent advances in structural analysis tools based on finite element analysis and the capacity of desktop computers, it is now possible to predict the resistance and failure mode of complex stainless steel structures. This allows designing structures as entire systems instead of considering them as sets of individual members, changing the paradigm of structural design, and leading to the new system-based direct design methods that will be the basis for the new generation of international design specifications, including the Eurocodes.

These system-based direct design approaches simplify the design procedure significantly, and result in lighter and more economical structures since their redistribution capacity and redundancy is fully exploited, which is of paramount importance for the efficient design of stainless steel structures. The system-based direct design procedure can be summarized as follows:

1) create an advanced finite element model that accounts for all the features affecting the resistance of the structure (initial geometric imperfections, residual stresses, second-order effects, nonlinear material behaviour),

2) introduce the factored design loads Q_{Ed} in accordance with the prescribed load combinations (see Figure 1),

3) carry out a fully nonlinear analysis of the structure, as shown in Figure 2, and determine its characteristic resistance R_k, assumed as the ultimate resistance of the system F_u estimated from the system's load-displacement curve (see Figure 3),

4) check whether the characteristic resistance of the system R_k, divided by the corresponding (system) partial safety factor $\gamma_{M,s}$, is greater than the design loads Q_{Ed}, $R_k/\gamma_{M,s} \geq Q_{Ed}$.

It is important to note that, when adopting system-based direct design approaches, the partial safety factors that need to be considered in the resistance checks are those corresponding to systems (i.e., $\gamma_{M,s}$), which should account for the effect of the different associated uncertainties on the response of the whole structure. These system factors are different from the γ_{Mi} factors currently adopted in the Eurocode (i.e., γ_{M0}, γ_{M1}, γ_{M2}), and should be calibrated through independent reliability analyses based on systems to guarantee that the prescribed structural reliability requirements are met.

Although a few international design standards such as AISC 360, EN 1993-1-14 and AS/NZ 4100 already include preliminary versions of these system-based direct design methods, in general they do not prescribe values for the system factors that need to be adopted, and hence the reliability of the designed structures needs to be proven independently. Moreover, it should be noted that the current development of system-based direct design methods is not yet calibrated to account for the failure of connections; instead, it assumes that connections possess sufficient resistance and ductility for the ultimate state of the systems to be

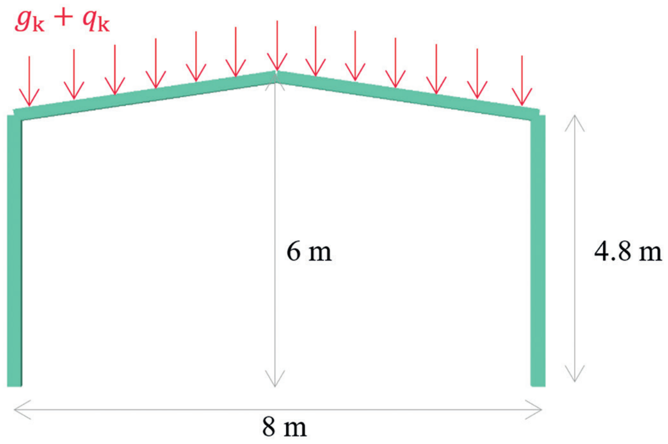

Figure 1. Finite element model of a stainless steel portal frame with design loads.

Figure 2. Deformed shape of the stainless steel portal frame after a fully nonlinear finite element analysis.

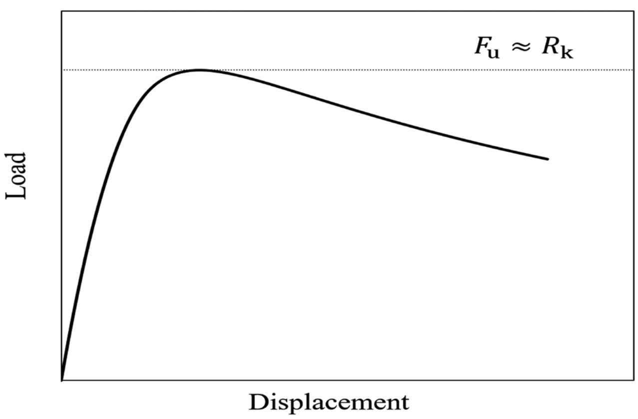

Figure 3. Load-displacement curve for a steel structure using advanced finite element analysis.

reached, and they should be checked independently using the traditional design equations for connections. Nevertheless, the upcoming developments on system-based direct design methods will hopefully allow for connection resistance checks to be also implemented.

Considering that the European design framework does not include provisions for the system-based direct design of stainless steel structures, the NewGeneSS research project (funded by the European Union under the Horizon 2020-MSCA programme and Grant Agreement No. 84239) has focussed on the calibration of suitable system factors for a more efficient design of stainless steel structures under different load scenarios, and to take further advantage of the features exhibited by this material in terms of durability and sustainability. The project has also developed and delivered a set of pre-normative design recommendations with the aim of contributing to the future implementation of system-based direct design approaches in international design specifications, which can be downloaded for free from the project website www.newgeness.com.

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