Robustness of steel structures - study of the applicability of innovative methods on real structures.

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1 Project objectives and goals

The request for robustness of structures is a recent topic aiming at ensuring the structural integrity of a structure in case of exceptional events. General design recommendations are provided in modern codes and standards but they are far from being satisfactory as it has been demonstrated that the respect of these recommendations do not necessarily allow to guarantee a sufficient robustness to a structure. It is the reason why research activities are still ongoing in this field in view of (i) mastering the response of structures when subjected to exceptional events and, on this basis, (ii) to derive rules for practitioners. This master thesis takes place in this context.

The objective of this master thesis is to study and apply methods for steel building structures allowing to reach an appropriate level of robustness. These research will be performed in the framework of an ongoing European RFCS project entitled "FailNoMore".

2 Description of method and results

During this work, a 3D steel structure (see Figure 1) with all connections hinged and an inner core that serves as a lateral force resisting system, initially designed by Feldman+Weynand, a German design office, for "classical" loading conditions, will be studied in view of (i) characterising its behaviour when subjected to a specific exceptional event, i.e. the loss of an internal column located at the ground floor, and of (ii) investigating the efficiency of existing design methods for robustness.

These objectives will be achieved using numerical and analytical approaches. The numerical investigations will be realised using the FINELG software which is a finite element software that allows to perform first order linear analysis, instability analysis, as well as nonlinear analysis.

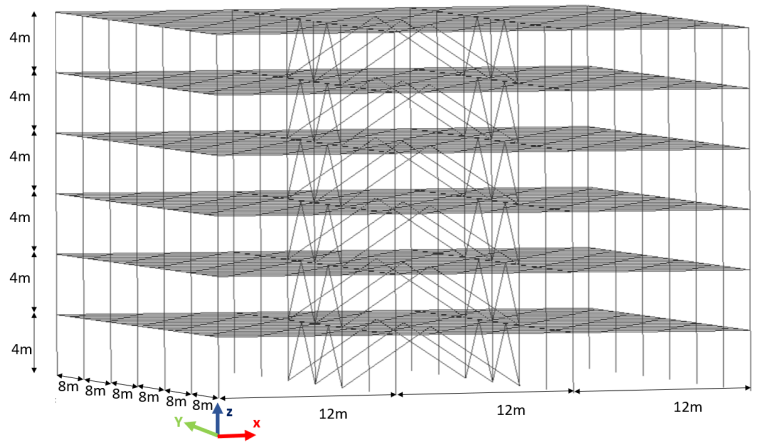

Figure 1: Studied steel structure.

The EN1991-1-7 code states that a minimum level of resistance, face to an exceptional event, can be provided to a structure by installing horizontal and vertical ties to ensure the robustness of a structure. But, this master thesis demonstrates that the tying method, such as it is present in the code, does not make it possible to ensure a sufficient robustness in the case of the scenario considered of the loss of a column.

It is also shown that, following a non-linear numerical study taking into account the loss of the column, the original structure designed classically at ULS and SLS doesn't reach a sufficient level of robustness due to the failure of the connections subjected to a too high tensile force. After some enhancements to the joints of the reference structure, it is shown that the structure with hinged joints whether with fin plate connection or header plate one, under the same scenario considered, cannot resist because of a too low tensile resistance of the connections. However, the steel structure can be robust face to the loss of the column if we accept to considerably increase the cross-section of the beams up to three times their weight in the case of fin plate connections and up to two times their weight for the structure with header plate connections. But, such changes considerably alter the reference structure, which is not conceivable.

Finally, the type of the beam to column connections of the structure is changed from hinged to partially resistant connections and the structure is studied by means of an innovative analytical approach. This approach consists in modelling a beam by two diagonal rods connecting each joint at the extremities of the beams. The connection is modelled by springs to take into account its behaviour and its resistance. A graphical representation is given in Figure 2.

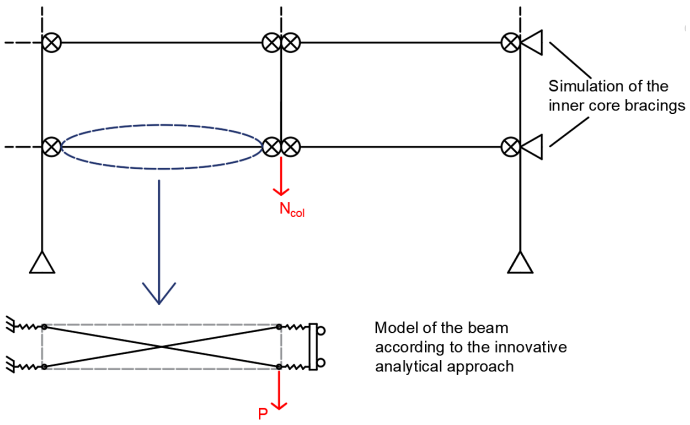

Figure 2: Model of the innovative analytical approach coming from the studied structure.

This model makes it possible to determine the force P, representing the loss of the column, which creates a mechanism and thus leads to the failure of the structure. Before reaching the plastic mechanism, the strength of three different contributions, i.e. the plastic moment of the connection, the arch effect of the two beams on either side of the lost column and the plastic mechanism of the concrete slab, must be reached. These three contributions are studied in detail in the work.
At the end, it is shown that the structure can be robust under the same exceptional scenario of column loss by using partially resistant connections and by slightly modifying the properties of the concrete slab.

The master thesis concludes with a critical analysis of the three different approaches studied throughout the work, in order to ensure the robustness of the steel structure subjected to a column loss, in view of making recommendations for practice.

3 Potential for application results

My master thesis allows to compare different methods to ensure the robustness of a given steel structure subjected to the loss of a column.

It has been shown in this work that the tying method prescribed by the Eurocode must be modified. This approach, as it is present in the code, is too insecure and does not provide sufficient resistance to the structure in case of a column loss. The case of application of the method should be clarified and it should take into account ductility aspects.

It was also shown that the structure with partially resistant beam to column connections could provide sufficient robustness to the structure under the studied scenario, in contrast to the reference structure, designed at ULS, with hinged connections.
The practitioner, when designing the steel structure, should choose partially resistant connections and should use a software that takes this type of connection into account to study the behaviour of the structure subjected to the loss of the column. If the practitioner does not have such a powerful program or if he wishes to carry out a first quick design, he can assess the robustness of the steel structure by using the analytical innovative method developed in the frame of this work.

4 Reference

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