PhD title: Contributions to the study of MR steel frames with semi-rigid joints

PhD Thesis summary

PhD thesis investigates to behaviour of MR steel frames with semirigid joints, focusing mainly on the seismic behaviour of such structures and taking into account the real behaviour of beam-to-column joints. The seismic behavior investigates the local ductility demands in steel framed structurea, considering the effect of strain rate and accumulation of damage (low cycle fatigue). PhD thesis contains 7 chapters and 2 annexes.

Chapter 1 presents the most important research programs developed in the last years in the field of seismic behaviour of MR frames. Are presented also the contributions of the author to national and international research projects.

Chapter 2 presents a history of most important seismic events from the twentieth century (San Francisco 1906, Tokyo 1923, Northridge 1994, Kobe 1995). A major cause of failures was the lack of local and global ductility. Together with the description of the earthquakes are given the actions, which were taken after the event and the consequences on the development of the seismic design codes. The research needs and future trends in the field of seismic behavior of steel MR frames are presented.

Chapter 3 presents modern design methods for steel frames under static and dynamic conditions. New aspects incorporated in the Eurocodes, regarding the use of semirigid connections, both in seismic and non-seismic conditions are emphasized. The chapter also presents some comparisons with other design codes (Romania seismic design code P100/2003, North American code AISC 2002). Author highlights the importance of the local ductility on the global behaviour of MR steel frames and the insufficient prescriptions available in the actual codes for the determination of rotation capacity of connections.

Chapter 4 presents studies the local ductility and the main factors that affect it. Damages suffered by steel buildings were attributed to the deterioration of beam-to-column connections due to the insufficient ductility. Some building collapses were also attributed to the lack of ductility (insufficient available rotation capacity). Local ductility becomes, therefore, the key element for improving the seismic behaviour of MR steel frames. Although steel is considered as a very ductile material, the ductility of steel members may be affected by local buckling, strain rate, low cycle fatigue, etc. The influence of strain rate on the mechanical characteristics of connection details has been studied within an experimental program. A number of 54 welded specimens were tested at different strain rates until failure. Three welding procedures were used: fillet weld, double bevel butt weld and single bevel butt weld. Following parameters were considered:

- strain rate ($0.0001s_{-1}$; $0.03s_{-1}$; $0.06s_{-1}$)
- type of loading (monotonic, cyclic)
- yield stress (S235, S355)

Two failure types were observed for the welded specimens: fracture in the base metal and fracture in the weld. For monotonically loaded specimens, fracture occurred in the base metal. For cyclically loaded specimens, the increase of strain rate led to an increase of fractures in the welding, but for fillet and single bevel butt welds only. Fracture mode was not influenced by the strain rate for double bevel butt welds. It was also found that the strain rate does not influence the ductility of the specimens for cyclically loaded specimens. Experimental investigations on the influence of strain rate were followed by numerical studies using the finite element code NASTRAN 70.7. Numerical models were calibrated using the experimental values obtained from tests. Results obtained from the numerical analysis confirmed the experimental results, both in terms of mechanical characteristic variations and failure modes.

Influence of low cycle fatigue was the second factor affecting the local ductility considered in this study. A fatigue analysis is not required for steel building structures subjected to earthquakes. One reason is that from past experience steel structures were considered not particularly vulnerable to earthquakes. Another reason is that, despite the similarities to the usual fatigue mechanisms, there are differences to the fatigue due to the usual dynamic loading. A procedure for the fatigue assessment of steel building structures subjected to earthquakes was developed. The procedure constitutes an extension of the well-known high-cycle fatigue assessment methodology to the case of low-cycle fatigue. It may serve as a basis for the introduction of a fatigue limit state for the seismic design of steel structures as well as for the assessment of the damage occurred in buildings when subjected to specific earthquakes.

Chapter 5 presents the new concept of performance based design. Performance based design is a more general design philosophy in which the design criteria are expressed in terms of performance objectives, like lateral drifts or local ductility of elements and connections, when the structure is subjected to different levels of seismic hazard. In this chapter is presented a new design methodology using three performance levels:
- Serviceability limit state
- Damageability limit state
- Ultimate limit state

To be used in design, these performance levels are translated into seismic action, represented by magnitudes or accelerations. Actual codes are based on force-controlled design or capacity design, using the base shear concept. The parameter related to the degradation of the structure is the behaviour q-factor, based on the maximum capacity of structure to dissipate energy in the ultimate limit state (ULS). The ULS corresponding ductility cannot be attained, if higher levels of performance (i.e. less damage to the structure) are required. In that case, a reduced ductility corresponding to a partial q-factor characterizes the behaviour of structure. Finally, partial q-factor values are proposed for MR steel frames according with the three performance levels previously described.

Chapter 6 presents the application of the methodology presented in chapter 5 to determine the partial q factors for the three limit states. The methodology is used both for designing new structures and for verifying the existing ones. For study, frames with different geometric characteristics were designed according to actual design codes. Several parameters were considered in the study: different levels of rigidity for beam-to-column joints, different seismic motions, resulting in 36 different configurations. The results have shown a great influence of the seismic motion characteristics, especially the corner period, on the values of the q factor, which is not taken into account by actual seismic codes. Due to the very high rigidity demand, design of MR steel frames is mainly done according to the serviceability limit state. Therefore, a large value of strength and ductility is automatically incorporated into the structure. This may be explained by limiting the degradations in the structural and nonstructural elements. One important problem to be fulfilled in case of multi-level design is the optimization of solutions. It was observed that in case of DLS and ULS, a proper choice of limit characteristics (inter-storey drift and plastic rotation capacity) could lead to a similar level of input accelerations, which represents the optimal case. The difference exists in case of SLS. If the additional rigidity brought by interaction between structural and non-structural elements is considered, this difference could be reduced.

Chapter 7 presents the final conclusions and the contributions of the author.

Annex A1 presents the application of component method at determining the design characteristics of three beam-to-column connections.

Annex A2 presents details about the experimental program devoted to the strain rate influence, program described in chapter 4.