SEISMIC AND FIRE DESIGN OF COMPOSITE FRAMES

A multi-disciplinary approach for an integrated design

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1. Introduction

Seismic and fire design of a building structure may be two very demanding tasks especially if included in a performance-based design philosophy, so that a multi-disciplinary approach is needed; several problems still have to be solved:

- the harmonization on the regulations for these two design fields is almost missing
- while performance-based approach to seismic design has widely developed in last years, the same cannot be said for performance-based design of structures in fire (limited application)
- while many studies have been done on risk assessment for daily fires, there have been very few works on risk assessment and damage evaluation of a building after an earthquake

2. The proposed performance-based design methodology

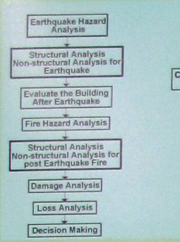

Fig.1: Lee et al.,2004 [1]

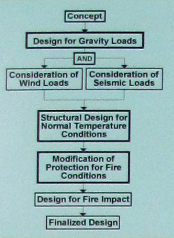

Fig.2: Johann et al.,2006 [2]

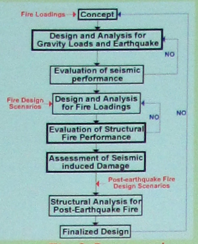

Fig.3:Proposed methodology

Only in last years, some design procedures have been developed ([1], [2]) accounting for the integration of structural fire safety into the design of framing systems and analyzing buildings subjected to an earthquake and to the subsequent fire (see Figs. 1 and 2). However, even if the evaluation of the state of the structure after the earthquake was posed as a fundamental step, no indication was given of means of quantifying the seismic-induced damage. Moreover, no attention was paid to the harmonization between seismic and fire design fields.

A comprehensive methodology for the assessment of fire performance of earthquake resistant frames including post-earthquake fire scenarios is presented (see Fig. 3).

The starting point is the conceptual design of the building (gathering information on the effectiveness of possible structural solutions). The obtained result is the definition of a set of composite frames to which the proposed methodology is applied in order to identify an optimized solution. Afterwards, the process is divided into two main macro-steps consisting in design and evaluation of the structural performance under seismic and fire loadings when these two are considered as independent hazards. Separating these two design/performance evaluation phases allows the identification of the most relevant structural parameters governing each design phase, in order to correlate them for the obtainment of an integrated design solution.

3. The composite frames: conceptual design

To choose the most suitable structural solution with respect to all design actions, several frames with the same geometric layout, but different members typologies as defined in the framework of a European Research Project [3] were investigated and summarized in Table 1.

Table.1: Analyzed structural solutions for beam and column elements

Frame Type	Main beams	Composite Columns
Type A1	IPE (bare steel)	HEB (partially encased)
Type A2	IPE (composite with ribbed steel sheeting)	HEB (partially encased)
Type B1	IPE (bare steel)	CHS (circular concrete filled)
Type B2	IPE (composite with ribbed steel sheeting)	CHS (circular concrete filled)

The main frame was made of two bays spanning 7,5 and 10 m, while the secondary beams, spanning 7,5 m each, were placed at a distance of 2,5 m (see Fig.4). An investigation on load bearing capacity at elevated temperature of the two kinds of composite columns showed that the concrete filled solution offered a more satisfactory result (see Fig.5)

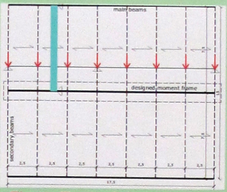

Fig.4: Typical floor layout

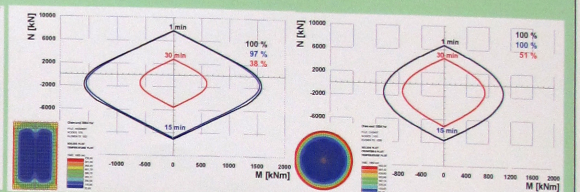

Fig.5: Load bearing capacity at elevated temperatures of columns

4. Design and performance for vertical and seismic loadings

Table.2: Analyzed structural solutions for beam and column elements

	Static combination of actions (EC3 / EC4)		Seismic combination of actions (EC8)	
Frame	Main beam	Composite Column	Main beam	Composite Column
Type A1	IPE450 (bare steel)	HEB340	IPE450 (bare steel)	HEB450
Type A2	IPE400 (composite)	HEB340	IPE400 (composite)	HEB400
Type B1	IPE450 (bare steel)	CHS355/10	IPE450 (bare steel)	CHS508/14 (not commercial)
Type B2	IPE400 (composite)	CHS355/10	IPE400 (composite)	CHS457/12

Gravity loads were applied and afterwards seismic design was developed according to the lateral force method of analysis considering q = 6. Obtained results are reported in [4,5,6].

The main findings in terms of members sizing are summarized in Table 2. When passing from static to seismic design, the size of beam cross sections was unchanged meaning that their sizing is governed by the static combination of actions. Moreover, severe limitations were imposed on the selection of column cross-sections, especially when coupled with bare steel beams (type A1, type B1) since the last do not add a significant contribution to the frame global lateral stiffness.

5. Design and performance for fire loadings

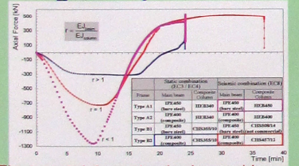

Fig.6: Axial force in the heated beams

Considering that in seismic design the importance of the relative stiffness between beam and column elements was outlined, three situations accounting for different values of the flexural stiffness ratio r were investigated to assess its influence in fire situation. The analyzed frames were Type B2 (r ~1) and Type A1 (r < 1) designed for the seismic combination of actions and Type B2 (r > 1) designed for the static combination of actions. Fire was applied at the second floor level; the obtained results were expressed in terms of evolution of the axial force in the longest span beam (see Fig.6). The performed analysis showed that the "seismic" Type B2 frame (r ~1) offer the best performance with respect to both seismic and fire actions when these are considered as independent hazards, since it offered near 40 minutes of fire resistance rating even if unprotected [8]. Therefore, such a solution was chosen as reference study case and thermo – mechanical analyses in the post-earthquake fire situation were developed.

6. Post-earthquake structural fire performance

A. Debonding of the steel sheeting from concrete slab

Neglecting the steel sheeting caused a reduction of the peak compressive force due to the limited expansion of the beam in the heating phase. The presence of steel sheeting can partly enhance the structural fire behaviour by adding a 7% to the surviving time. The Code assumption of considering the steel sheeting bonded to the concrete slab for all the duration of the fire is revealed to be not on the safe side in a post-earthquake fire situation.

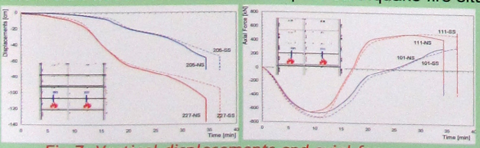

Fig.7: Vertical displacements and axial force

B. Simultaneous fire spreading in two adjacent compartments

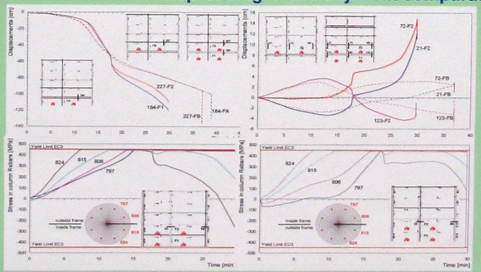

Fig.8: Displacements and stresses in column rebar

It was supposed that a fire could simultaneously start at the first (F1) and second (F2) floor levels; the obtained results were compared with two "undamaged" situations: FA - fire at first floor level only and FB - fire at second floor level only. Further investigation is needed, anyway it seems that for this design scenario, failure was due not only to extensive damage in the heated beams but in the heated columns as well, the frame global behaviour was satisfactory, this achieving a fire resistance rating of nearly 30 minutes and showing a time reduction of 23% with respect to FA and of 20% with respect to FB scenarios.

7. Summary and acknowledgment

The presented performance-based design methodology had two main goals. The first was integrating seismic and fire design issues since the early stages; the second was providing an assessment method for the evaluation of the post-earthquake fire performance. The application of such a methodology to a set of composite frames showed its effectiveness the resulting optimized solution showing a satisfactory behaviour with respect to seismic and fire loadings as independent hazards and in the post-earthquake fire situation, as well.

Results presented in this work were obtained in the framework of the following European research project: RFCS Steel RTD Programme, Contract n. RFSR-CR-03034 [3]. Nevertheless the opinions expressed in this paper are those of the writers and do not necessarily reflect those of the sponsors.

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