FIRE ANALYSIS OF STRUCTURES IN SEISMIC AREAS

RAUL ZAHARIA, DAN PINTEA, DAN DUBINA

The "Politehnica" University of Timisoara, Romania

INTRODUCTION

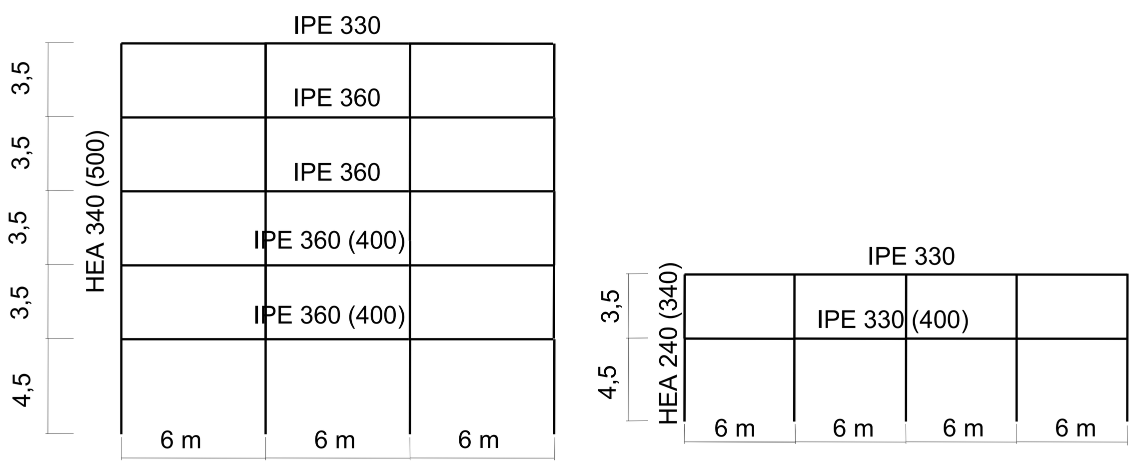
Fire following earthquake is the most concerning earthquake-related hazard. On another hand, even in the case no fire develops immediately after an earthquake, the possibility of later fires affecting the structure must be adequately taken into account, since the earthquake induced damages make the structure more vulnerable to fire effects than the un-damaged one.

The authors present a study on the influence of the damage induced by the earthquake and of the collapse mechanism of the damaged or undamaged structures under fire action, on the fire resistance. Both standard and natural fire scenarios are considered.

ANALYSED STRUCTURES

The moment resisting steel plane frames considered for the present study have the dimensions given in Fig. 1. The structures are made using S235 steel grade and all beam-to-column connections are rigid. Both frames were dimensioned for the same fundamental load combinations of actions. The frames were further verified for two seismic regions in Romania, with different ground motions: a near–field type (Banat region) and a far-field type (Vrancea region). The design was made according to the Romanian seismic code, adapted from EN1998. The elastic spectral analysis was applied considering the response spectrum for the Romanian Banat region (moderate seismic area), and for Vrancea region (severe seismic area).

The design of the Frame A - Banat structure was governed by the fundamental load combination (no changes in elements dimensions after the seismic design verification). For all other cases (Frame A – Vrancea and Frame B – Banat and Vrancea) the design of the structures was governed by the seismic combination. Fig. 1 shows the steel sections of both frames. The values in parenthesis represent the profiles used for Vrancea structures, which resulted with stronger beams for some levels and with stronger columns on the height of the building, due to the higher seismic demand.



a) Frame A b) Frame B

Figure 1. Steel frame dimensions

The seismic response of the structures was evaluated using a pushover analysis, while the displacement demand under the corresponding seismic event was determined using the N2 method. Figures 2-5 show the procedure used to determine the displacement demand (target displacement) of the equivalent SDOF systems.

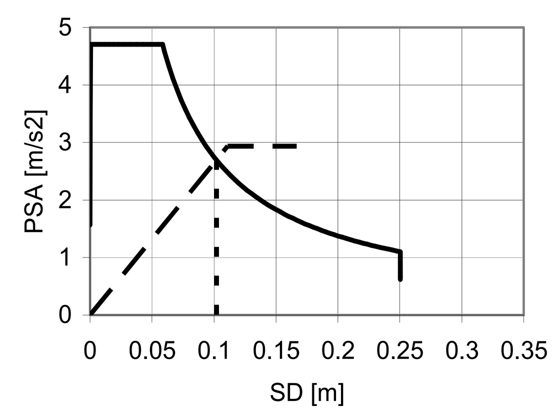


Figure 2. Seismic demand spectra vs. capacity diagram for Frame A - Banat

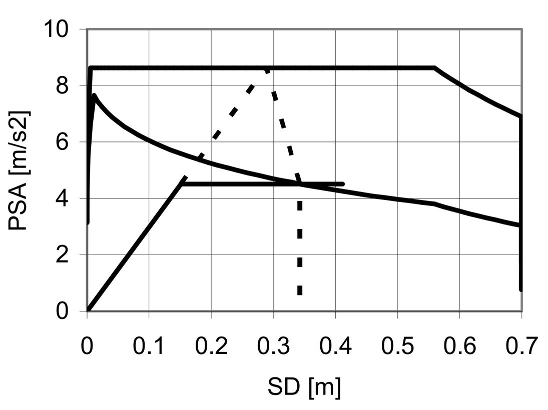


Figure 3. Seismic demand spectra vs. capacity diagram for Frame A - Vrancea

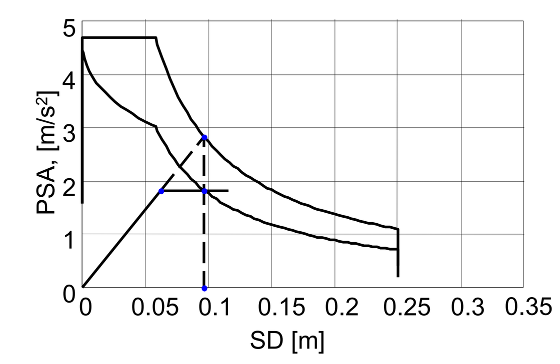


Figure 4. Seismic demand spectra vs. capacity diagram for Frame B - Banat

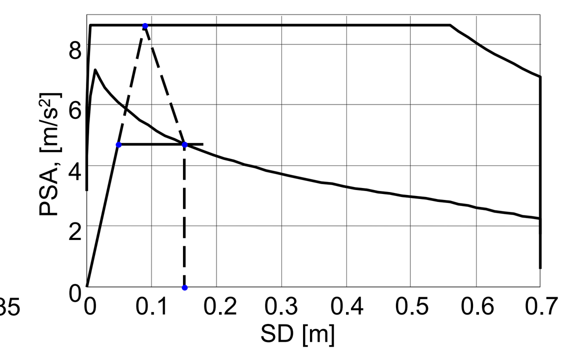


Figure 5. Seismic demand spectra vs. capacity diagram for Frame B - Vrancea

After earthquake, according to N2 procedure results, the Frame A - Banat remains undamaged, while for the other structures, which present a certain level of damage, two hypotheses are considered:

- a lower intensity earthquake occurs and the structure remains undamaged;
- an earthquake with the intensity given by the Romanian code for Banat and Vrancea regions occurs and the structures suffer the damage determined by the above procedure.

FIRE ANALYSIS

The standard ISO 834 fire and the natural fires were applied only for the columns and beams of the first storey, in the hypothesis that the ground floor represents a fire compartment. The steel elements have no fire protection. On the beams, the fire was applied on three sides (the top being protected by the concrete slab). In the mechanical analysis, the collaboration between the steel beam and the concrete slab was not considered.

The natural fire curves were obtained using OZone v2. The fire compartment is shown in Fig. 6. A linear variation of the openings was considered, i.e. the glass panes. At 300°C, 30% of the windows were considered broken, while at 500°C all the windows are broken, based on available research.

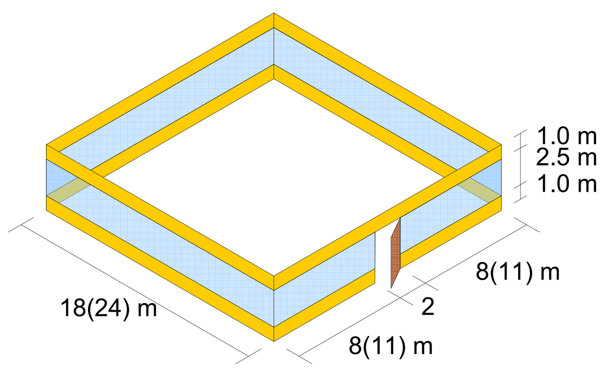


Figure 6. The fire compartment

Table 1 gives the values of the active fire fighting measure factors considered. Before the earthquake, the building being provided with sprinklers, the coefficient which takes into the account the existence of automatic water extinguishing system (δ_1) and the coefficient which takes into account the existence of the independent water supplies (δ_2) are both sub unitary. After the earthquake, considering the possible disruptions, the sprinkler system and the automatic fire detection are no more considered, and the corresponding coefficients are both 1.00. In relation with the prompt intervention of the fire brigades, which is no more possible due to the number of emergencies and traffic congestion, associated to the possible lack of the active fire measures, the coefficients δ_{5-9} are considered with the unit value.

Table 1. Fire fighting measures before and after the earthquake

Fire Scenarios	Autom. Water Exting.	Indep Water Supply	Auto Fire Detection	Alarm Fire Brigade	Fire Brigade	Access Routes	Fire Fight Devices	Smoke Exhaust	Total
	δ_1	δ_2	$\delta_{3/4}$	δ_5	$\delta_{6/7}$	δ_8	δ_9	δ_{10}	$\Pi\delta_n$
Before	0.61	0.87	0.73	0.87	0.78	1.0	1.0	1.0	0.26
After	1.0	1.0	1.0	1.0	1.0	1.5	1.5	1.0	2.25

Using these parameters and running Ozone, two fire curves were produced for each building (Fig.7). For both buildings, the "before earthquake" curves, for which no flashover occurs, are ventilation controlled. The "after earthquake" curves are fuel controlled. The peak temperatures for Frame B are higher than those of the Frame A, due to the higher design fire load density and to the size of the compartment

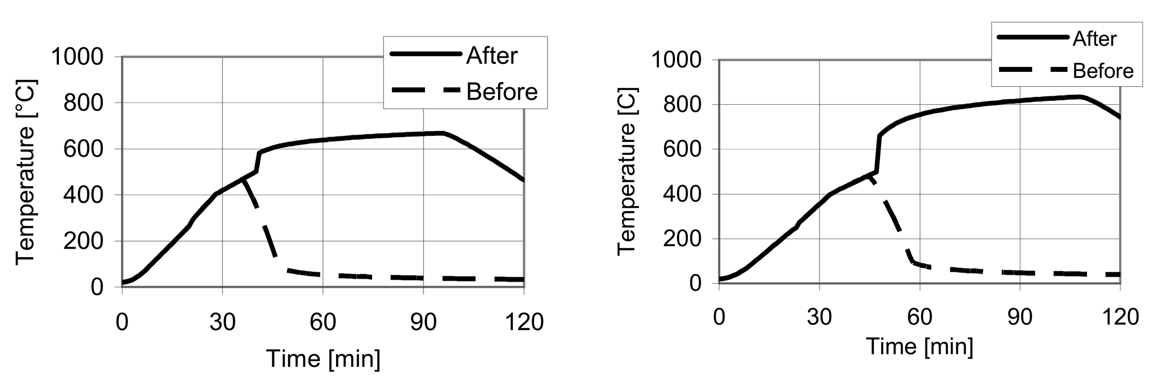
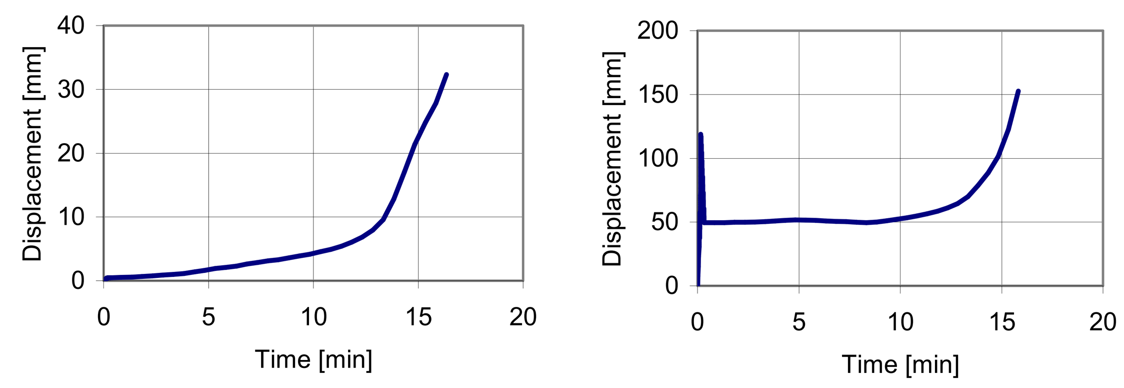


Figure 7. Temperature-time evolutions - Frame A (left), Frame B (right)

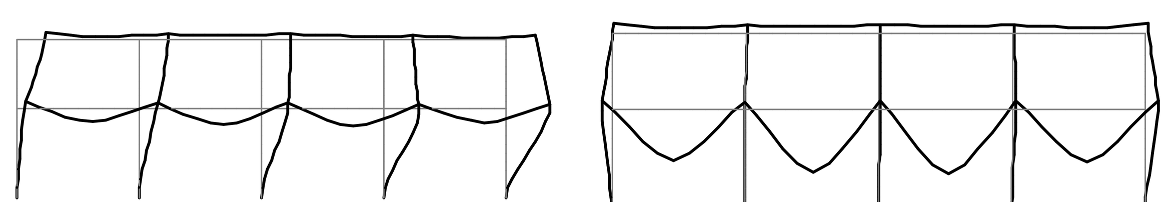
These curves were used in SAFIR to find the temperature evolutions on each of the exposed profiles, without fire protection. On the beams the fire was applied on three sides (the top being protected by the concrete slab). In the mechanical analysis, the collaboration between the steel beam and the concrete slab was not considered.

The analysis procedure for damaged structures is shown in figure 8b for the damaged Frame B – Banat under ISO fire. The structure subjected to vertical loads corresponding to the fire load combination is loaded with the lateral forces (push-over by applying an inverted triangular distribution of lateral forces, as described previously) up to the target displacement for the MDOF system, determined using the N2 method. The structure is then discarded of the lateral loads and, because the frame responded in the inelastic range, presents residual displacements. At this stage of structural damage, starts the fire analysis under vertical loads corresponding to the fire load combination. Figure 8 shows the response of both damaged and undamaged Frame-B Banat structure under ISO fire, in terms of displacement – time characteristics. Two types of collapse modes were observed during the fire analysis using standard or natural fire: a global mode and a mode characterized by the collapse of the beams. For all fire analyses, frame A presented a global collapse mechanism, while frame B presented both modes, as shown in figure 9. For all cases, considering all fire fighting measures active (before an earthquake) both frames, designed for the two seismic regions, resist to the fire action. Therefore, no collapse is produced for "before earthquake" natural fire scenario, for which no flashover occurs.



a) Undamaged structure b) Damaged structure

Figure 8. Displacement-time for Frame B – Banat under ISO fire



a) Global b) Beam

Figure 9. Collapse mechanisms for frame B - Banat

Table 2. Fire resistance times and collapse modes.

ISO fire	Frame A		Frame B	
	Banat	Vrancea	Banat	Vrancea
Undamaged	16' 10" global	26' 10" global	16' 30" global	26' 20" global
Damaged		20' 40" global	15' 40" global	23' 20" global
Natural fire (after earthquake)	Frame A		Frame B	
	Banat	Vrancea	Banat	Vrancea
Undamaged	74' 00" global	no collapse	56' 20" beam	71' 40" beam
Damaged		no collapse	54' 40" global	71' 20" beam

The differences in fire resistance times between the damaged and undamaged structures are affected by the damage level. Under ISO fire, the differences are ranging from around 5% for the Banat frame B (experiencing maximum inter-storey drifts of 1.8% in the inelastic range), 11% for the Vrancea frame B (experiencing maximum inter-storey drifts of 2.2% in the inelastic range), to around 21% for the Vrancea frame A (experiencing maximum inter-storey drifts of 2.7% in the inelastic range). In case of frame B for Banat region under natural fire, the difference is lower, but it is to be also taken into account that for the damaged and undamaged structures, the collapse mechanism is different. In case of frame B for Vrancea region under natural fire, for both damaged and undamaged structures, the collapse mechanism is local (beam) and the fire resistance time is not influenced in a significant way by the damage of the structure. Important differences in terms of fire resistance appear between the damaged and undamaged structures experiencing a global type of collapse mechanism.

For both structures and under both fire scenarios, the Vrancea frame, designed for stronger seismic action, presents higher fire resistance times than the corresponding structures designed for the Banat region. Moreover, in case of frame A, for a natural fire scenario after earthquake, the stronger Vrancea frame resists the fire, even if the structure is damaged after the seismic action, while the Banat frame collapses, even if its structure remains undamaged after the code earthquake.

Therefore, it must be underlined that the structures designed for seismic action (or for stronger seismic action) have an important reserve of resistance into a fire situation.