CILASCI 5

5º CONGRESSO IBERO-LATINO-AMERICANO EM SEGURANÇA CONTRA INCÊNDIOS

5th IBERIAN-LATIN-AMERICAN CONGRESS ON FIRE SAFETY

15-17 /07/ 2019 - Porto, Portugal

Atas dos Artigos
Proceedings (full papers)

ipb INSTITUTO POLITÉCNICO DE BRAGANÇA
U.PORTO FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO
isep Instituto Superior de Engenharia do Porto
albrasci

CILASCI
5

5º CONGRESSO IBERO-LATINO-AMERICANO EM SEGURANÇA CONTRA INCÊNDIOS

5th IBERIAN-LATIN-AMERICAN CONGRESS ON FIRE SAFETY

15-17 /07/ 2019 - Porto, Portugal

Atas dos Artigos
Full Papers Proceedings

ipb INSTITUTO POLITÉCNICO DE BRAGANÇA
U.PORTO FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO
isep Instituto Superior de Engenharia do Porto
albrasci

TITLE:
Atas dos Artigos
5º Congresso IBERO-LATINO-AMERICANO EM SEGURANÇA CONTRA INCÊNDIOS

Full Papers Proceedings
5th IBERIAN-LATIN-AMERICAN CONGRESS ON FIRE SAFETY

PUBLISHER:
ALBRASCI - Associação Luso-Brasileira para a Segurança Contra Incêndio
ALBRASCI - Luso Brazilian Association for Fire Safety

EDITORS:
Paulo Piloto (IPB - DMA), Débora Ferreira (IPB - DMA), Elza Fonseca (ISEP - DEM), João Santos Baptista (FEUP-DEM), José Miguel Castro (FEUP – DEC), Luís Mesquita (IPB - DMA), Mário Vaz (FEUP-DEMec), Miguel Chichorro (FEUP – DEC), Rui Miranda Guedes (FEUP-DEMec) et al.

BOOK COVER DESIGN:
Soraia Maduro – Instituto Politécnico de Bragança

INTERNET WEB PAGE:
Pedro Oliveira – Instituto Politécnico de Bragança

EDITION:
1ª, Julho de 2019

ISBN:
978-989-97210-3-6

IMPRINT:
Tipografia Artegráfica Brigantina

PREFACE

The Iberian-Latin American Congress on Fire Safety (CILASCI) is held once every two years, with the aim of disseminating scientific and technical knowledge in the field of fire safety, integrating different players involved in this area of knowledge. The first edition of the Iberian-Latin American Congress on Fire Safety (CILASCI 1), was held in Natal (Brazil) between 10-12 March 2011. The second congress (CILASCI 2) was held in Coimbra (Portugal), between May 29 and June 1, 2013. The 3rd and 4th editions took place on the South American continent. The third congress (CILASCI 3) was held in Porto Alegre (Brazil) from November 3 to 6, 2015, while the fourth congress (CILASCI 4) was held in Recife (Brazil) from 9 to 11 October 2017. The CILASCI 5 will take place in the city of Porto (Portugal) from 15 to 17 July 2019, and presents 5 invited lectures and 78 manuscripts (full papers) from researchers around the world (Algeria, Australia, Belgium, Brazil, China, Czech Republic, France, Hong Kong, Italy, Mozambique, Portugal, Spain, United Kingdom and United States).

the 5th Iberian-Latin-American congress on fire safety reflects the new developments achieved on active and passive fire protection, on evacuation and human behaviour under fire, on computational modelling of structures and materials under fire, on explosion and risk management, on architectural issues for fire safety in buildings, on fire dynamics, on the experimental analysis of materials and structures under fire, on fires in special buildings and spaces, on fire-fighting operations and equipments, and on the behaviour of structures and materials under fire.

The Fire Safety is reaching new developments as a result of new research, development and innovation around the world, based on the excellence level of the research, the support of new skilled professionals and due to the existence of advanced training programmes in fire science technology. This development will increase the safety level of people, buildings, and products, but also is going to produce an impact in the economy of each country, with a positive impact on society.

The organizing committee believe that this congress will address to our delegates a wide forum of discussion about the recent developments in Fire Safety, promoting the exchange of ideas and international cooperation.

The organizing Committee would like to thanks to all authors and delegates.

On the behalf of the Organizing Committe
Paulo A. G. Piloto

ORGANIZING COMMITTEE

Paulo Piloto, Insituto Politécnico de Bragança - DMA
Débora Ferreira, Insituto Politécnico de Bragança - DMA
Elza Fonseca, Instituto Politécnico do Porto- ISEP - DEM
João Santos Baptista, Faculdade de Engenharia da Universidade do Porto - DEM
José Miguel Castro, Faculdade de Engenharia da Universidade do Porto – DEC
Luís Mesquita, Insituto Politécnico de Bragança - DMA
Mário Vaz, Faculdade de Engenharia da Universidade do Porto -DEMec
Miguel Chichorro, Faculdade de Engenharia da Universidade do Porto – DEC
Rui Miranda Guedes, Faculdade de Engenharia da Universidade do Porto -DEMec

SCIENTIFIC COMMITTEE

Aldina Maria Santiago – Universidade de Coimbra – Portugal
Ana Belén Ramos Gavilán - Universidade de Salamanca – Espanha
Ângela Gaio Graeff – Universidade Federal do Rio Grande do Sul – UFRGS - Brasil
André Teles – Corpo de Bombeiros Militar do Distrito Federal – CBMDF - Brasil
António Moura Correia – Instituto Politécnico de Coimbra – Portugal
Armando L. Moreno Júnior – Universidade Estadual de Campinas – UNICAMP - Brasil
Bernardo Tutikian – Universidade do Vale dos Sinos – Brasil
Carla Neves Costa – Universidade Estadual de Campinas – UNICAMP - Brasi
Carlos Balsa - – Instituto Politécnico de Bragança - Portugal
Carlos Pina dos Santos – Laboratório Nacional de Engenharia Civil – Portugal
Cristina Calmeiro dos Santos – Instituto Politécnico de Castelo Branco – Portugal
Daniel Alvear Portilla - Universidade de Santander - Espanha
Dayse Cavalcanti Duarte – Universidade Federal de Pernambuco – Brasil
Débora Rodrigues de Sousa Macanjo Ferreira - Instituto Politécnico de Bragança – Portugal
Domingues Xavier Viegas – Universidade de Coimbra - UC - Portugal
Edna Moura Pinto – Universidade Federal do Rio Grande do Norte – Brasil
Elza Maria Morais Fonseca - Instituto Superior de Engenharia do Porto – Portugal
Fabio Martin Rocha – Universidade de São Paulo – USP - Brasil
Francisco Carlos Rodrigues – Universidade Federal de Minas Gerais – Brasil
Gabriela B. de M. Lins de Albuquerque– Universidade de São Paulo – USP - Brasil
George Cajaty Braga – Corpo de Bombeiros Militar do Distrito Federal – CBMDF - Brasil
Geraldine Charreau – Instituto Nacional de Tecnologia Industrial – Argentina
João Santos Baptista - Universidade do Porto – FEUP - Portugal
João Godinho Viegas – Laboratório Nacional de Engenharia Civil – Portugal
João Paulo Correia Rodrigues – Universidade de Coimbra – Portugal (Coord.)
João Ramôa Correia - Universidade de Lisboa – IST – Portugal
Jorge Gil Saraiva – Laboratório Nacional de Engenharia Civil - Portugal
Jorge Munaiar Neto – Escola de Engenharia de São Carlos da Univ. de São Paulo – Brasil
Jorge Saul Suaznabar Velarde - IASU - Bolívia
José Carlos Lopes Ribeiro – Universidade Federal de Viçosa - Brasil
José Carlos Miranda Góis – Universidade de Coimbra - Portugal
José Jéferson do Rêgo Silva – Universidade Federal de Pernambuco – Brasil
Jose Luis Torero - Universidade de Maryland - Austrália
José Miguel Castro - Universidade do Porto – FEUP - Portugal
Larissa Kirchhof – Universidade Federal de Santa Maria – Brasil
Lino Forte Marques – Universidade de Coimbra – Portugal
Luiz Carlos Pinto da Silva Filho– Universidade Federal do Rio Grande do Sul – UFRGS
Luís Mesquita – Instituto Politécnico de Bragança – Portugal
Manuel Romero Garcia – Universidade Politécnica de Valencia – Espanha
Mariano Lázaro Urrutia - Universidade de Santander - Espanha
Mário Augusto Pires Vaz - Universidade do Porto – FEUP - Portugal
Miguel Chichorro Gonçalves – Universidade do Porto – FEUP - Portugal
Nuno Filipe Borges Lopes – Universidade de Aveiro – Portugal
Orlando V. Abreu Menéndez - Universidade de Santander – Espanha

INDEX

MECHANICAL ANALYSIS OF A PORTAL STEEL FRAME WHEN SUBJECTED TO A POST EARTHQUAKE FIRE

Mohammed Redha Merouani*
PhD Student, FGCA,
UHBC Chlef, Algeria

Belkacem Lamri
Professor
FGCA,
UHBC, Chlef, Algeria

Abdelhak Kada
Professor
FGCA,
UHBC, Chlef, Algeria

Paulo A. G. Piloto
Professor
IPB
Bragança, Portugal

Keywords: RPA99v2003*;* Post Earthquake Fire; Nonlinear Analysis; Fire resistance; ISO834.

1. INTRODUCTION

Fire or earthquake pose a significant threat to the human life, and can cause an enormous damage to the structures, moreover the dual effect of a Post-Earthquake Fire (PEF) is a major hassle to designers and rescuers alike. The experiments carried out by Petrina (2016) [1]; show that post-earthquake fire produces serious damage to the structural elements after their load resistance has been altered by a seismic action. Extensive research to study the behaviour of unprotected and protected steel structures [2-3] has been done, and yet there is still a great need for the understanding of the behaviour of structures damaged by earthquakes and exposed to fire.

The most PEF studies begin with a seismic study of the structure by applying the gravity loads, followed by a fire analysis, on the frames already damaged by the earthquake.

Work done by Zaharia et al. (2009) [4] illustrates PEF resistance through two different cases of unprotected steel frames damaged by an earthquake on two seismic regions with moderate and severe ground motions using a Pushover analysis according to the Eurocode8 [5]. It was

*Autor correspondente – Dep. Of Civil Engineering, Hassiba Benbouali University of Chlef. RN 19 Ouled Fares, Chlef.
Telef.: +213 551 309 440, E-mail: m.merouani@univ-chlef.dz

confirmed that the fire resistance of the structures considering their deformed state under earthquake is lower than the structures that do not have any early deformation prior to the application of the fire.

Behrouz and Hamid (2015) [6] conducted sequential analysis based on FEMA356 [7] to investigate the PEF resistance for two 5-storey portal frames, designed to meet the Life Safety (LS) and Immediate Occupancy (IO) level of performance, followed by a fire analysis, using both the ISO834 model and the natural fire model. The results for two fire scenarios, on the 1st and 5th floor, indicate that the majority of fires analysis resulted in the local collapse while all PEF analyses resulted in the global collapse.

Designers, when considering Algerian seismic rule (RPA99v2003) [8], ignore the possibility of a post-earthquake fire, whose effect can lead to the dramatic collapse of the structures [9]. This paper presents the evaluation of the fire resistance for a two-story steel portal frame, damaged by an earthquake simulated through spectrum response of Chlef scaled three in the Algerian Seismic Code [8]. First the design of the steel structure considers seismic actions by a static nonlinear analysis. Second a fire analysis using an ISO834 standard fire model is followed, considering that the structure is partially damaged. The finite element simulation and numerical analysis of the structure in post-earthquake fire condition yield the bilinear capacity curve at ambient temperature and the variation of local and global displacement at high temperature. A final comparison of the damaged (PEF) and undamaged (FIRE) frames subjected to the different fire scenarios is presented.

2. METHODOLOGY

Three step analysis procedure based on the framework was performed. The first stage of loading is the application of gravity loads, which are assumed to be static and uniform followed by a pushover analysis, while the displacement demand under the corresponding seismic event was determined using the N2 method according to the Eurocode 8 [5]. According to the N2 method, the seismic response spectrum is determined for a system with an equivalent single degree of freedom (SDOF). Pushover curve have been obtained for multi-degree of freedom systems (MDOF) and it is therefore necessary to determine the simplified force-displacement characteristic for the equivalent SDOF systems using the elastic response spectrum of the city of Chlef (Seismic Zone III with soft soil S3 and control period T_C = 0.5 sec) given by the Figure 1 [8].

The structure is pushed with a monotonically increasing lateral load to a different desired performance level. In this study four performance levels were considered, first performance point obtained by the N2 method, and then three other performance points depended of the story drifts.

For the seismic analysis a multi-linear stress-strain curve is used (Figure 2) for the European steel profiles of S235 steel grade.

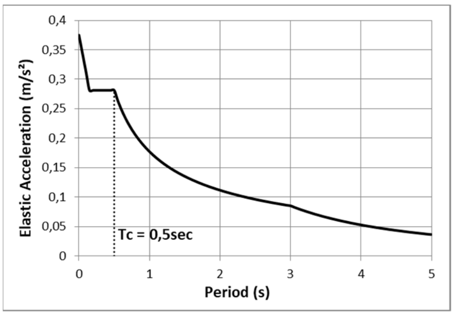


Figure 1: Elastic response spectrum for the city of Chlef.

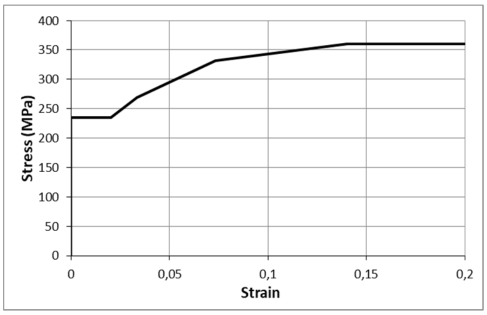


Figure 2: Stress-Strain Curve at ambient temperature (Earthquake).

Finally, the post-earthquake analysis (PEF) is applied in the form of fire load to the damaged structure under uniform temperature, simulated by the standard ISO 834 to understand the mechanical behaviour of solid unrestrained steel I-beams [10].

A comparative study is done with an identical unprotected portal frame considered undamaged by the earthquake (FIRE), with the same duration of fire exposure (60 min).

For the simulation of the behaviour of the steel frame, the finite element model based on structural analysis procedure in ANSYS [11] was developed, using a quadratic three-node finite beam element (Beam189), with six degrees of freedom at each node (Figure 3). The element is based on Timoshenko beam theory, which includes shear-deformation effects.

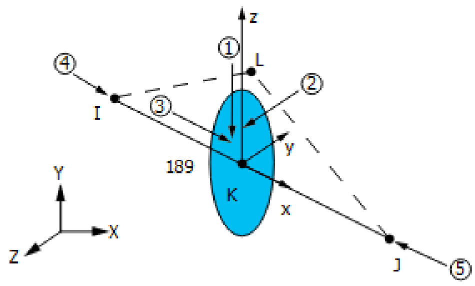


Figure 3: Beam189 geometry and loading directions [11]

3. EUROCODE TEMPERATURE ON PORTAL STEEL SECTIONS

In this study the standard ISO834 fire was applied on all four faces of the internal columns, the exterior side of external columns is not exposed to fire. Meanwhile, only three sides of beams are exposed to fire, because it is assumed that the top side is well protected by the concrete slab.

The standard ISO834 fire model is given by the following temperature-time relationship, where t represents the time in minutes:

$$\theta_g = 20 + 345\log_{10}(8t+1) \tag{1}$$

The increase of temperature leads to the reduction of the mechanical properties such as the Yield stress f_y and the Young's modulus E. The Reduction factors for the stress-strain relationship of steel at elevated temperatures, used for the analysis (Eurocode1) [12], are given by the figure 4. Stress Strain curve for the steel grade S235 at high temperature is given by the Figure 5.

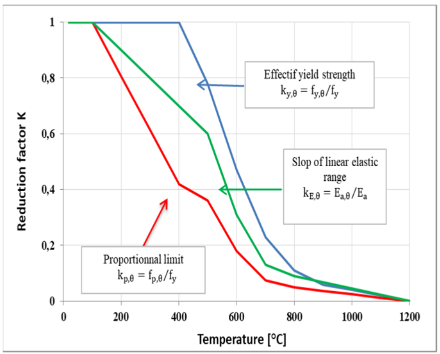


Figure 4: Reduction factors.

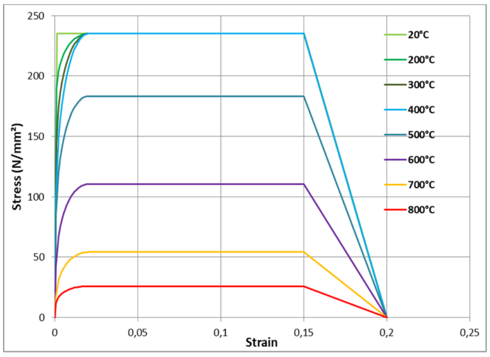


Figure 5: Stress-Strain at elevated temperature (S235).

Figure 6 shows the time temperature variation for ISO834 fire and the temperature for the IPE270 and HEA200 cross sections under ISO834 fire, considering a uniform temperature distribution, the temperature increase $\Delta\theta_{a,t}$ for the unprotected steel member during a time interval Δt should be obtained from:

$$\Delta\theta_{a,t} = k_{sh}\cdot\left(\frac{1}{C_a.\rho_a}\right)\cdot\left(\frac{A_m}{V}\right)\dot{h}_{net}\,\Delta_t \tag{2}$$

Where: k_{sh} is the correction factor for the shadow effect, A_m/V is the section factor for unprotected steel members [m^{-1}], C_a is the specific heat of steel [J/kgK], ρ_a is the unit mass of steel [kg/m^3], h_{net} is the design value of the net heat flux per unit area [W/m^2], Δ_t is the time step [seconds].

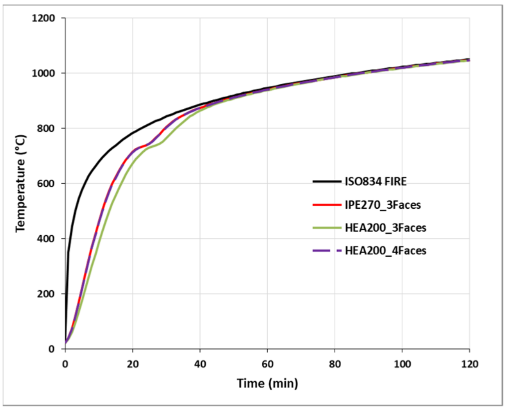


Figure 6: Time-Temperature curve for the columns and beams.

4. VALIDATION OF THE NUMERICAL MODEL

For the validation of the structural analysis model a simple portal frame shown in Figure 7 is taken from Chandra et al. (2016) [13]. The frame is of steel grade S235 having span and height of 3.5m each. The dead and live load considered in the analysis are 13.5 kN/m and 6 kN/m respectively. The simulations are done using the beam finite element model, Beam189, from ANSYS software [11].

The frame is statically analysed initially with gravity loads only. Subsequently it is pushed to the target displacement corresponding to the desired performance levels. For the validation study two performance levels considered were – Operational (O): δ/h = 1.0%; and Life Safe (LS): δ/h = 2.0%.

The result for the pushover analysis is presented in terms of capacity curve (Base Shear vs Story drift) as shown in Figure 8, and reveals a good agreement with the two-dimensional numerical study conducted by Chandra et al. (2016) [13].

In the second part of this validation, the ISO 834 fire was applied on all four faces of the beams and columns, considering a uniform temperature on all the cross sections.

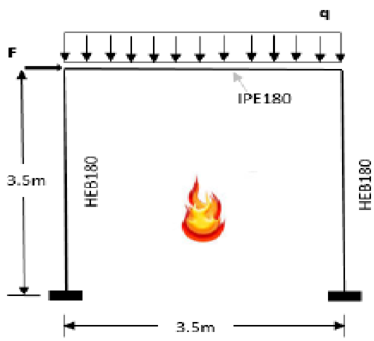


Figure 7: Portal Frame Configuration.

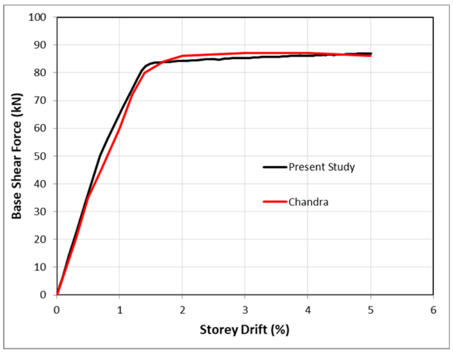


Figure 8: Pushover Curve.

The purpose of the fire structural analysis is to verify the fire resistance rating of the damaged structure and subsequently determine the effects of earthquake damage on the fire resistance rating.

The evolution of the vertical displacement in terms of fire exposure duration of the damaged frame for the two performance levels, Operational (Drift 1%) and Life Safe (Drift 2%) is given in Figure 9.

The variation of normalised fire resistance that is the ratio of the PEF fire resistance corresponding to a given performance level (drift) to the fire resistance of undamaged frame with the earthquake performance level for the frame is shown in Figure 10.

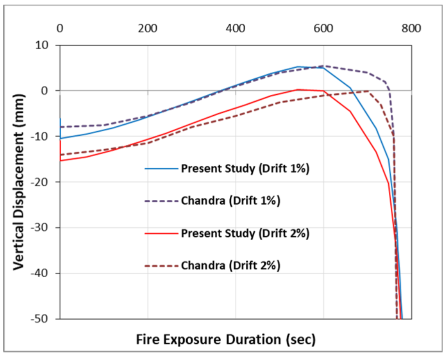


Figure 9: Vertical deformation of Beam mid-point vs Fire exposure duration.

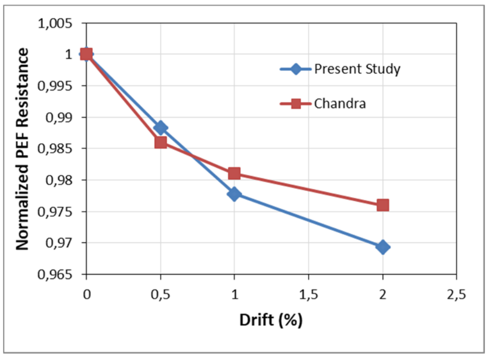


Figure 10: Variation of normalised PEF Resistance with performance level.

For the case of the vertical deformation of the beam at mid-span, the results presented in figure 9 show close similarities of curves from present study and Chandra's for both drifts. For the case of the variation of normalised PEF resistance with story drift, both curves show a sharp decrease in the resistance before 1% story drift ending by a small discrepancy of about 6% at a story drift of 2%.

5. CASE OF STUDY AND RESULTS

5.1. Model description

The building considered in this study is a 2-storey steel frame structure erected in the city of Chlef, Algeria, which is known for its high seismicity. The typical frame of the building, fire scenario and the loading applied is illustrated in Figure 11. The size of the beam finite elements is equal to 0.1m for all the columns and the beams. The numerical model and the mesh that is adopted are presented in Figure 12. The cross-section of the finite element used for the numerical modelling, is a user-defined solid numerically integrated.

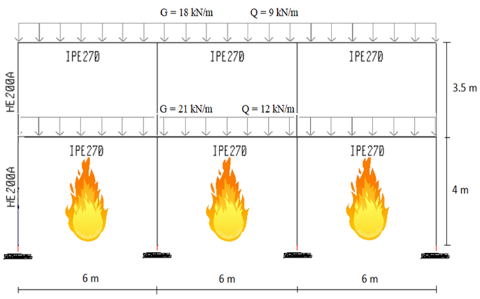


Figure 11: Frame characteristics and fire scenario.

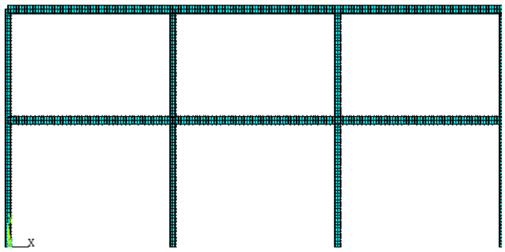


Figure 12: Numerical model.

For this study, the performance point of the structure is given by, the N2 method and three other performance levels, story drift 1%, 2% and 3% respectively.

In the analysis, the fire load is applied on the structure for both damaged and undamaged frames using the effect of ISO834. In case one the undamaged structure is exposed to the fire load (FIRE), while in case two, the deformed structure is exposed to the fire load (PEF). In both cases, when gravity load is alone or when gravity and earthquake loads are associated, the fire is applied as a subsequent load.

5.2. Results

The structure responded to the seismic motion in the elastic range, experiencing maximum story drift of 0.8% due to the Algerian Seismic Code, RPA99v2003 [5], is slightly larger than the 0.7% limit corresponding to "Immediate Occupancy" performance level according to the informative classification given by FEMA356 [7]. This means that the structure represents a minor local yielding at few places and no fractures.

Figure 13 illustrates the results of the Pushover curve. Figure 14 shows the performance point of the portal frame, obtained with N2 method according to the Eurocode 8 [5].

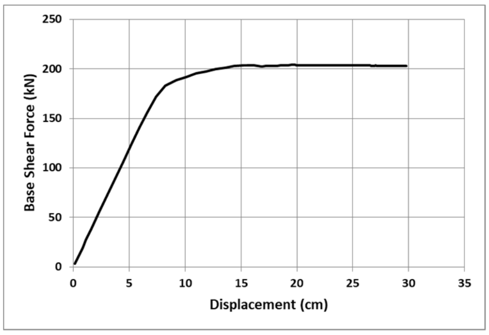


Figure 13: Pushover Curve.

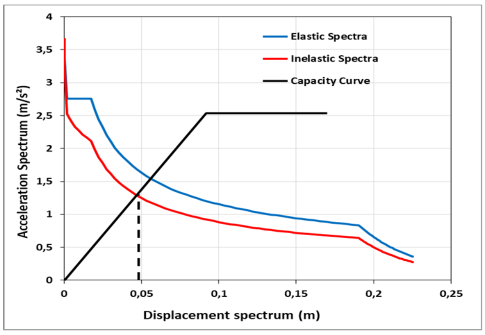
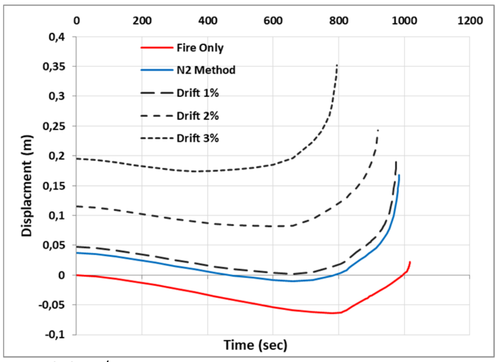
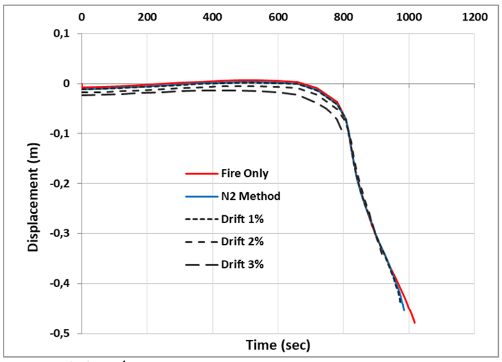


Figure 14: Capacity Curve vs Acceleration.

Figure 15 (a) shows the response of both undamaged frame (FIRE) and damaged frame (PEF) for the performance level corresponding to N2 Method and the three other performance levels considered 1%, 2% and 3% story drift, under ISO fire, in terms of horizontal displacement-time characteristics in the first floor. Figure 15 (b) illustrates the evolution of the vertical displacement at the beam midpoint at the first floor of the damaged and undamaged frame.



(a) 1st Floor horizontal displacement.

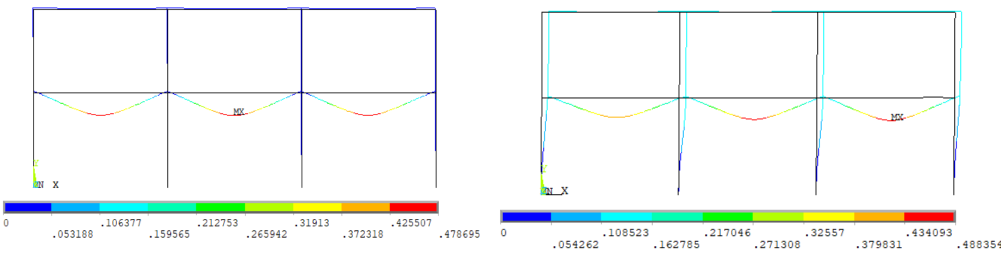


(b) 1st Floor vertical displacement.

Figure 15: Displacement-time characteristics.

The collapse time for the Post-earthquake Fire (PEF) in the case of the N2 method is around 16.20 minutes; it increases to about 17 minutes when submitted to fire only (FIRE), which signifies a 5% reduction in the fire resistance. For the other cases of performance level in the PEF, whenever the story drift is important, the displacement increases.

Figure 16 schematically show the deflected shape of the frames in two cases, the case of FIRE and the case of the PEF for the N2 method performance point.



(a) Undamaged Structure. (b) Damaged Structure.

Figure 16: Deformed shape mode.

Figure 17 shows the variation of normalised fire resistance which means the ratio of the PEF fire resistance corresponding to a given performance level (drift) to the fire resistance of undamaged frame with the earthquake.

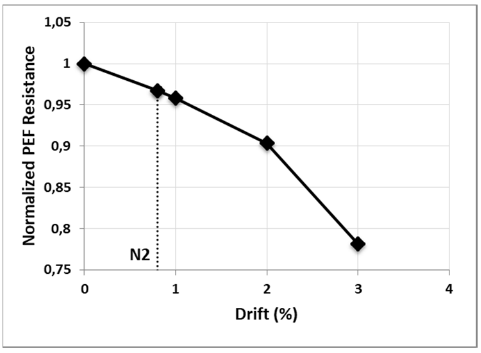


Figure 17: Variation of normalised PEF Resistance vs Story drift.

The post-earthquake fire resistance decreases with the increase in the earthquake damage. The difference in fire resistance is about 3.3% for the N2 Method, 4.2% for the story drift of 1%, 9.6% for the story drift of 2% and 21.9% for the story drift of 3%.

6. CONCLUSIONS

In this study, finite element models were used to predict the behaviour of steel portal frames in PEF condition. The results presented in this study show that the horizontal displacements given by the PEF analysis are significant different when compared to the fire analysis of an undamaged structure, unlike the vertical displacements. For the PEF loading, it is important to consider the maximum displacement values which depend on the 'damage level'. The later is induced in the structural system due to the residual displacement field after an earthquake, producing results with a difference between 3.3% and 21.9% in fire resistance situation for different performance levels.

7. REFERENCES

[1] Petrina, T., (2016). “Post–Earthquake Fire Tests – Part 1: Report”. World Multidisciplinary Earth Sciences Symposium.

[2] Łukomski, M., Turkowski, P., Roszkowski, P., Papis, B. (2017). “Fire Resistance of Unprotected Steel Beams – Comparison between Fire Tests and Calculation Models”. Procedia Engineering. Vol 172, p665-672.

[3] Lamri, B., Mesquita, L., Kada, A., Piloto., P. (2017). “Behavior of cellular beams protected with intumescent coatings”. Fire Research. Vol 1(27), p27-32.

[4] Zaharia, R. and Pintea D. (2009). “*Fire after Earthquake Analysis of Steel Moment Resisting Frames*”. International Journal of Steel Structures, Timisoara, Romania. Vol 9, No 4, pages 275-284.

[5] EN1998-1. Eurocode 8: Design of structures for earthquake resistance. Part 1: General rules, seismic actions and rules for buildings. European Committee for Standardization, Busseles, CEN, 2002.

[6] Behnam, B., & Ronagh, H. R. (2015). “*Post-Earthquake Fire Performance-based Behavior of Unprotected Moment Resisting 2D Steel Frames*”. KSCE Journal of Civil Engineering 19(1):274-284.

[7] FEMA356 (2000). Prestandard and commentary for the seismic rehabilitation of buildings rehabilitation requirements, American Society of Civil Engineers, Washington, DC.

[8] Règles Parasismiques Algériennes RPA99/Version 2003. Centre National De Recherche Appliquée En Génie Parasismique.

[9] Merouani, M.R., Lamri, B. Kada, A. (2018) “Etude post-sismique des structures métalliques sous l’effet d’un incendie”. 2ème Conférence Internationale de COnstruction Métallique et Mixte. Algiers.

[10] Kada, A., Lamri, B. (2018). “Numerical analysis of non-restrained long-span steel beams at high temperatures due to fire“. Asian Journal of Civil Engineering. Vol 20, issue 2, pp 261-267.

[11] ANSYS Academic Research. Release 16.2. Canonsburg: ANSYS. 2011.

[12] EN1991-1-2. Eurocode 1: Actions on structures - Part 1-2: General rules - Actions on structures exposed to fire, Brussels, CEN, 2002.

[13] Chandra, A., Bhowmick, A., Bagchi. A. (2016). “Nonlinear finite element model for post-earthquake fire performance evaluation of steel portal frames”. Resilient infrastructure, London, UK.

5º CONGRESSO IBERO-LATINO-AMERICANO EM SEGURANÇA CONTRA INCÊNDIOS

5th IBERIAN-LATIN-AMERICAN CONGRESS ON FIRE SAFETY

Sponsors

Media Partner

ISBN 978-989-97210-3-6


CIN
PROTECTIVE COATINGS
CILASCI
5