



# SAFETY AND SECURITY ENGINEERING

## V

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# SAFETY AND SECURITY ENGINEERING V

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# Preface

SAFE 2013 is the fifth international conference on Safety & Security Engineering after those held very successfully in Rome (2005), Malta (2007), Rome (2009), and Antwerp (2011).

Safety & Security Engineering, due to its special nature, represents an interdisciplinary area of research and applications that brings together, in a systemic view, many disciplines of engineering, from the most traditional to the most advanced and novel.

Safety & Security Engineering is characterized by a totally new approach since it first analyzes the hazard context not only by means of traditional tools but also applying risk analysis techniques and then manage the context through technical solutions, installations, systems, human resources and procedures to prevent and mitigate natural or man-made events that could damage people or property.

This means that Safety & Security Engineering uses a systemic and multidisciplinary approach to the safety and security problems needing to be solved, decomposing them into elementary problems, studying their reciprocal relations and interactions and finding a final optimal solution that takes into consideration all the multiple aspects in their singularity and in their belonging to a complex system.

Nowadays, every context needs a safe approach that must be, from the beginning, integrated in any process to ensure the desired safety and security standards within given costs.

The International Conference on Safety and Security Engineering continues to provide a forum for the presentation and discussion of the most recent developments in the theoretical and practical aspects of these important topics.

This Volume contains papers presented at the Conference, and is widely distributed throughout the world in paper and digital format. The articles are also permanently

archived in the eLibrary of the Institute (<http://library.witpress.com>) where they are permanently available to the International Scientific Community.

The Editors are grateful to the members of the International Scientific Advisory Committee and other colleagues who helped to review the papers included in this book. They are also indebted to all authors for their contributions.

F. Garzia

C.A. Brebbia

M. Guarascio

Editors, Rome 2013

# Contents

## Section 1: Risk analysis, assessment and management

A tool for intelligent budget allocation of prevention measures related to major accidents <i>T. Brijs &amp; G. Reniers</i> .....	3
General approach to risk optimisation of road bridges exposed to accidental situations <i>M. Sykora, M. Holicky &amp; P. Mañas</i> .....	11
Conceptual design of a crime regulatory system for Mexico <i>D. E. Santos-Reyes</i> .....	21
Flood risk assessment and management: a case study in Rio de Janeiro <i>M. G. Miguez, A. P. Veról &amp; L. Bianchini</i> .....	29
A new knowledge-based risk control method for risk sensitive devices <i>S. Plogmann, A. Janß, A. Jansen-Troy &amp; K. Radermacher</i> .....	43
Risk assessment: workers operating in loading/unloading (shipping/receiving) areas <i>E. Salvador &amp; M. Forte</i> .....	55
A unified framework for safety and security assessment in critical infrastructures <i>T. Aoyama, M. Koike, I. Koshijima &amp; Y. Hashimoto</i> .....	67
A model to facilitate the development of an appropriate risk assessment methodology and instrument for crowd safety at outdoor music festivals <i>A. Raineri</i> .....	79
Flood hazard: planning approach to risk mitigation <i>F. D. Moccia &amp; A. Sgobbo</i> .....	89

Evaluation of coefficients for an energy security indicators system <i>J. Augutis, R. Krikštolaitis, A. E. Lutynska, S. Pečiulytė &amp; I. Žitautaitė</i> .....	101
Unmanned aerial vehicle for post seismic and other hazard scenarios <i>V. Baiocchi, D. Dominici &amp; M. Mormile</i> .....	113
Informing the population in case of extraordinary events by means of digital video broadcasting – terrestrial <i>P. Senovsky &amp; D. Rehak</i> .....	123
Limits and opportunities of risk analysis application in railway systems <i>R. Licciardello, A. Baldassarra, P. Vitali, A. Tieri, M. Cruciani &amp; A. N. Vasile</i> .....	133
Nitrogen gas spillage in a confined space located in the Gran Sasso Underground Nuclear Physics Laboratory: an outstanding oxygen deficiency hazard case study <i>G. Bonfini, F. Gabriele, M. Tobia, R. Tartaglia &amp; A. Giampaoli</i> .....	145
Risk management and its methodological support in the performance economy <i>W. E. Schroeder</i> .....	155
Processing of large amounts of data on a credit scoring example using neural network technology <i>K. K. Nurlybayeva &amp; G. T. Balakayeva</i> .....	165
Toxic greens: a preliminary study on pesticide usage on golf courses in Northern Ireland and potential risks to golfers and the environment <i>C. A. Kearns &amp; L. Prior</i> .....	173
Revision of town planning in the Pioverna basin by the use of a multidisciplinary study to identify flood-prone areas: Valsassina, Lombardy Region, Northern Italy <i>F. Luino, J. V. De Graff &amp; P. Fassi</i> .....	183

## **Section 2: Human factors**

Stereoscopic displays for air traffic control: conflict judgement performance as a function of visualisation, task characteristics and expertise <i>A. Baier, A. Zimmer, C. Vernaleken &amp; H. Neujahr</i> .....	199
--	-----

A statistical look at gender and age differences as related to the injury crash type on low-volume roads  
*F. Russo, S. A. Biancardo, M. Busiello, M. De Luca & G. Dell'Acqua*..... 213

The analysis of unconscious action as a dangerous factor and the promotion of risk aversion action  
*G. Hotta, M. Fukunaga, Y. Ohbuchi & H. Sakamoto* ..... 225

Risk perception in emergency planning environments  
*A. Pratelli* ..... 233

### **Section 3: Incident management**

Support system for the training of crisis management group members  
*M. Drozdova, P. Rapant & L. Malerova*..... 247

Sustainable safety management:  
incident management as a cornerstone for a successful safety culture  
*B. Freibott*..... 257

### **Section 4: Infrastructure protection**

Optical fiber sensors as the primary element in the protection of critical infrastructure especially in optoelectronic transmission lines  
*M. Życzkowski, M. Szustakowski, W. Ciurapiński, P. Markowski, M. Karol & M. Kowalski* ..... 273

Multispectral solutions in surveillance systems: the need for data fusion  
*M. Życzkowski, M. Szustakowski, W. Ciurapiński, M. Kastek, R. Dulski, M. Karol, M. Kowalski & P. Markowski* ..... 285

Multisensor system for the protection of a critical harbour infrastructure  
*M. Kastek, R. Dulski, M. Życzkowski, M. Szustakowski, P. Trzaskawka, W. Ciurapiński, G. Grelowska, I. Gloza, S. Milewski & K. Listewnik*..... 295

Analyzing the impacts of explosions on dams and levees  
*J. Parkes, H. Kelly, G. Munfakh & S. Choi* ..... 307

Assessment of retaining levels of safety barriers  
*K. Jung & J. Markova*..... 319

Anti-terrorism protection and protective design measures for hotels  
*M. Zineddin & L. Sherwood* ..... 331

Cost-effectiveness of protection measures to mitigate terrorist attacks on bridges and tunnels <i>C. A. Andersen, K. C. Jørgensen &amp; E. K. Lauritzen</i> .....	341
A new blast-mitigation solution for building facade protection with a laminated polycarbonate based system <i>V. Benz, J. Lorenzo, R. Pyles, R. Rumer &amp; K. Wiecking</i> .....	353
Concentration system for volatile compounds detection <i>B. Rutecka, J. Wojtas, J. Mikolajczyk, Z. Bielecki &amp; T. Stacewicz</i> .....	365
Improved solutions for dangerous liquid containment <i>G. Janszen, A. M. Grande, P. Bettini &amp; L. Di Landro</i> .....	379

### **Section 5: Construction safety and security**

Archaeological safety considerations on construction sites <i>E. S. Patterson</i> .....	391
Structural integrity assurance of casing pipes in the oil and gas industry <i>M. Rakin, M. Arsić, B. Medjo, Ž. Šarkoćević &amp; A. Sedmak</i> .....	401
A world sea safety system using second generation WIG <i>E. A. Aframeev &amp; Y. Yoshida</i> .....	411

### **Section 6: Traffic safety and security**

Case study: driving safety culture in small enterprises – an industry-led initiative <i>K. Oldham, G. Bermingham, I. King &amp; J. Sinclair</i> .....	425
Analyzing risk factors for highway theft in Mexico <i>E. de la Torre, C. Martner, J. Martínez, E. Olivares &amp; E. Moreno</i> .....	437
Performance improvements for calculations of third party risk around airports <i>R. Aalmoes, R. Erkamp, Y. S. Cheung &amp; R. van Nieuwpoort</i> .....	447
Security procedures and devices for road transportation of high consequence dangerous goods <i>A. Accettura, R. Bubbico, F. Garzia &amp; B. Mazzarotta</i> .....	459

Fatal crashes in GCC countries: comparative analysis with EU countries for three decades <i>H. M. N. Al-Madani</i> .....	471
Optimization methods for system track data securing using digital signatures <i>G. Icriverzi</i> .....	483
Analysis of pedestrian accidents using a geographical information system (GIS) in Konya city, Turkey <i>C. Avci &amp; S. S. Durduran</i> .....	495
Joint efforts needed to prevent traffic accidents, injuries and fatalities <i>M. Mikusova</i> .....	503

**Section 7: Safety in the design of road networks in ordinary and emergency conditions (Special session organised by A. Vitetta)**

Impacts of accidents involving shopping and restocking vehicles on an urban road network <i>F. Russo &amp; A. Comi</i> .....	517
Risk occurrence measures for dangerous goods transport on a road network <i>F. Russo &amp; C. Rindone</i> .....	529
A day-to-day experiment on an urban road network in ordinary and emergency scenarios <i>M. L. De Maio, G. Musolino &amp; A. Vitetta</i> .....	541
A before–after analysis for the design problem on an urban road network <i>G. Pavone, A. Polimeni &amp; A. Vitetta</i> .....	553
Planning instruments in Italy and the UK: private and public spaces for emergency events in urban areas <i>G. Musolino &amp; P. Panuccio</i> .....	565

**Section 8: Modelling and experiments**

Fire safety in perforated wooden slabs: a numerical approach <i>E. M. M. Fonseca, D. Couto &amp; P. A. G. Piloto</i> .....	577
---	-----

Investigation of the safety of seawalls against scouring <i>S. A. Lashteh Neshaei &amp; F. Ghanbarpour</i> .....	585
Effect of temperature on the concentration explosion limits of combustible liquids <i>P. Lepik, J. Serafin, M. Mynarz &amp; J. Drgáčová</i> .....	597
Understanding ignition of natural fuels by heated particles <i>C. D. Zak, D. C. Murphy &amp; A. C. Fernandez-Pello</i> .....	607
Experimental evaluation of floor slab contribution in mitigating progressive collapse of steel structures <i>M. Hadjioannou, S. Donahue, E. B. Williamson, M. D. Engelhardt, B. Izzuddin, D. Nethercot, H. Zolghadrzadehjahromi, D. Stevens, K. Marchand &amp; M. Waggoner</i> .....	615
Estimate modelling for assessing the safety performance of occupant restraint systems <i>H. Horii</i> .....	627

## **Section 9: Modelling studies**

Automatic human signature recognition system <i>E. Da Sacco, F. Garzia &amp; R. Cusani</i> .....	639
Learning from failures through feedback to design <i>A. Labib</i> .....	651
Assessment of safety evacuation of persons in the design of assembly areas <i>P. Kucera &amp; E. Strakosova</i> .....	661

## **Section 10: Soil and food contamination**

Analysis of natural radioactivity and artificial radionuclides in soil samples in the Najran region of Saudi Arabia <i>A. Al-Zahrany &amp; K. S. Al-Mogabes</i> .....	675
Acetanilide herbicide degradation using indigenous soil microorganisms <i>S. Farooq, I. Hashmi, M. Arshad &amp; I. A. Qazi</i> .....	685

Mitigation of pathogens and marine biotoxins contamination in shellfish <i>P. Fajardo, M. Atanassova, J. Cotterill, T. Wontner-Smith, J. Vieites &amp; A. Cabado</i> .....	691
---	-----

## Section 11: Air pollution issues

Occupational health risk assessment of benzene and toluene at a landfill site in Johannesburg, South Africa <i>R. Moolla, S. K. Valsamakis, C. J. Curtis &amp; S. J. Piketh</i> .....	701
---	-----

Prevalence of respiratory symptoms associated with outdoor and indoor air pollution in Bogota 2012 <i>R. Sarmiento-Suárez &amp; K. Medina</i> .....	713
---	-----

Influence of fine particulate matter (PM <sub>2.5</sub> ) on the function of human immune cells <i>T. Brzicová, I. Lochman, P. Danihelka, A. Lochmanová, K. Lach &amp; V. Mička</i> .....	725
---	-----

Air quality in a hospital environment <i>J. I. Macedo, T. H. Kubota, L. S. Matsumoto, A. T. Giordani, A. M. M. Takayanagui, A. A. Mendes &amp; D. A. Bertolini</i> .....	737
---	-----

Indoor air quality in a bus <i>A. Gajewski</i> .....	749
---	-----

Mathematical simulation of ammonia gas release in a complex urban terrain using CFD and a statistical approach <i>M. Kozubková, M. Bojko, O. Zavila, P. Danihelka &amp; L. Malěřová</i> .....	759
---	-----

## Section 12: Air quality

Volatile organic compounds in normal human exhaled breath: a long neglected pollutant source <i>X. Sun &amp; X. Yang</i> .....	773
--	-----

Occupational exposure to PCDD/PCDF from industrial boilers at a whisky factory and vegetable oil factory in Samutsakorn Province, Thailand <i>S. Pongpiachan, T. Wiriwutikorn, C. Rungruang, K. Yodden, A. Sbrilli, M. Gobbi &amp; C. Centeno</i> .....	785
---	-----

**Section 13: Earthquake issues**

3D motion capture application to seismic tests at ENEA Casaccia  
Research Center: 3D Vision System and DySCo Virtual Lab  
*G. De Canio, M. Mongelli & I. Roselli*..... 803

Seismic behavior of a precast hollow core wall under biaxial lateral  
cyclic loading  
*N. H. Hamid & K. D. Ghani* ..... 815

Experimental investigation on a non-seismic precast RC beam-column  
exterior joint under quasi-static lateral cyclic loading  
*K. D. Ghani & N. H. Hamid* ..... 827

Earthquake induced interaction between RC frame and  
steel frame structures  
*M. J. Favvata, M. C. Naoum & C. G. Karayannis*..... 839

Improvement of the seismic retrofit performance of damaged  
reinforcement concrete piers using a fiber steel composite plate  
*K.-B. Han, P.-Y. Song, H.-S. Yang, J.-H. Lee, J.-M. Kang & H.-J. Kim* ..... 853

Design and analysis of base isolated structures  
*M. Amroyini Farissi & R. Bambang Budiono*..... 863

**Author index** ..... 875

# Fire safety in perforated wooden slabs: a numerical approach

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## Abstract

The main goal of this work is to present a numerical model to assess the fire safety of wooden slabs with rectangular perforations on a ceiling. These typical constructions have good sound absorption, heat insulation and relevant architectonic characteristics. They are used in many civil applications: concert and conference halls, classrooms, nurseries, airports, hotels, shopping, universities, and many other public buildings. These panels are normally installed at a lower level in building constructions to facilitate essential maintenance. Depending on the installation requirement, the perforated wooden slabs could have insulation material inside the cavities. In this work the proposed numerical model could be used for different design constructive solutions. In order to guarantee the fire rating in a typical used perforated wooden slab, a transient thermal analysis with nonlinear material behaviour will be solved using ANSYS program. This study allows for verifying the evolution of the temperature and the char-layer throughout a wooden slab with different rectangular perforations and considering the insulation effect inside the cavities. The developed numerical model allows future studies and simultaneously characterizes the effect of rectangular perforations in wooden slabs to minimize the fire risk. The numerical model can easily be adjusted for other constructive solutions, to facilitate fire safety validation, in buildings with several wooden slab assemblies used in floors or in ceiling applications.

*Keywords: perforated wooden slab, fire, numerical study.*



## 1 Introduction

In this work a perforated wooden slab was exposed to fire. Different types of perforations were considered, simultaneously using an internal fibreboard insulation material. Figure 1 shows applications in floors or ceilings used in buildings.



Figure 1: Wooden applications.

Wood is a natural material and presents advantages due its high strength and stiffness when compared with other materials. The main advantages of wood, relatively to the use of other materials, are: ease of construction and maintenance, pleasant appearance, renewable material and lightweight. The main disadvantage is the high level of combustion when exposed to fire conditions

The fire safety of this type of structures involves prevention, inhibition and detection. This involves appropriate design rules, installation, construction and maintenance of the wood in different applications. If wood is submitted to a sufficient heat flux, a degradation thermal process (pyrolysis) occurs, producing gases accompanied by loss in serviceable cross-section and its mass. The factors which affect the burning behaviour of wood determine the charring rate. These types of factors include: level of radiant heat exposure, char layer formation, moisture content, species and dimensions, as reported by Poon and England [1].

The authors of this work have published different articles in conferences and journals related to this theme [2–6]. They studied different wood species and their behaviour, the evolution of charring rate, using experimental and numerical techniques. In their research activity they usually consider standard fire conditions to improve new design solutions or develop new safety design rules [7–8].

The main objectives of this work are:

- To present a numerical model to predict the evolution of the charring layer during a fire scenario using a finite element method with appropriate material properties and boundary conditions;
- To evaluate the fire performance in a perforated wooden slab, when subjected to nominal ISO834 fire [9];
- To determine the charring layer of two different constructive solutions using a slab with and without insulation material;
- To determine the fire resistance in such way that contributes for a safety design in perforated wooden slab.

## 2 Perforated wooden slab

Figure 2 shows the geometric model considered in this work. The model considers a wooden perforated slab (920x1000mm) with three different cellular zones and homogenous thickness (25mm). Different types of rectangular perforations were considered in the bottom layer (4 slots with 250x20mm and six slots with 20x20mm). The top wooden surface is solid (1150x1232mm) with homogenous thickness (18mm). The same geometric model was considered with internal insulation material (MDF) near side by side with perforations, with one overlapping plate (20mm).

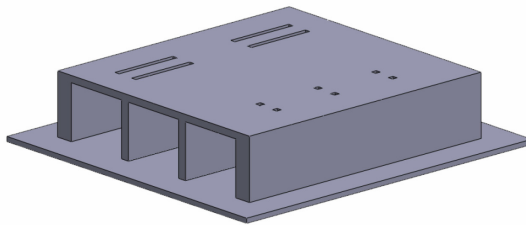


Figure 2: Geometric model.

### 2.1 Wood thermal properties and numerical model

A 3D finite element (Solid70) with 8 nodes was used for thermal and nonlinear transient analysis. The non-linearity due to the thermal properties dependence will be taken into account in the numerical simulation. The wooden slab (with or without MDF insulation) was exposed to standard fire condition during 1800s at the bottom surface. The temperature of compartment follows the standard fire ISO 834 curve, as represented according the following equation [9]:

$$T = 20 + 345 \log_{10} (8t+1) \quad (1)$$

where  $T$  is the gas temperature in the fire compartment in °C and  $t$  is the time in min.

Wood material when exposed to fire presents a thermal physical degradation. The interface between charred and noncharred wood is the transition phase between black and brown material [10] and is characterized by a threshold value of 300°C, according Eurocode 5 [11]. Also the thermal properties of wood vary considerably with temperature and should be defined according Annex B of Eurocode 5 [11]. This standard code provides the design values for density, thermal conductivity and specific heat of wood. The density of the spruce wood material was considered equal to 450kg/m<sup>3</sup> at room temperature. Figure 3 shows the thermal material properties used in this work.

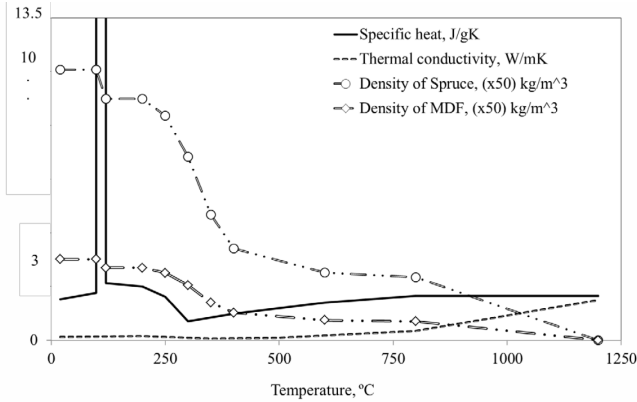


Figure 3: Thermal properties.

Medium density fibreboard (MDF) was applied in the wooden slab using the properties of ISO 10456 [12]. Two MDF panels were used in the numerical model. The density was considered equal to 151.2 kg/m<sup>3</sup> and for this reason (below 550 kg/m<sup>3</sup>) is considered ultra-light MDF [13]. The thermal conductivity was considered equal to 0.05 W/mK and the specific heat equal to 1700 J/kgK, at room temperature and at elevated temperature.

The effect of fire in building structures [14] is considered using the appropriate boundary conditions due to convective heat flux ( $\alpha c=25\text{W/m}^2\text{K}$  in exposed surface and  $\alpha c=9\text{W/m}^2\text{K}$  in perforated zone) and radiative heat flux ( $\epsilon=1$ ).

Figure 4 represents the finite element model used for the numerical approach and all applied boundary conditions.

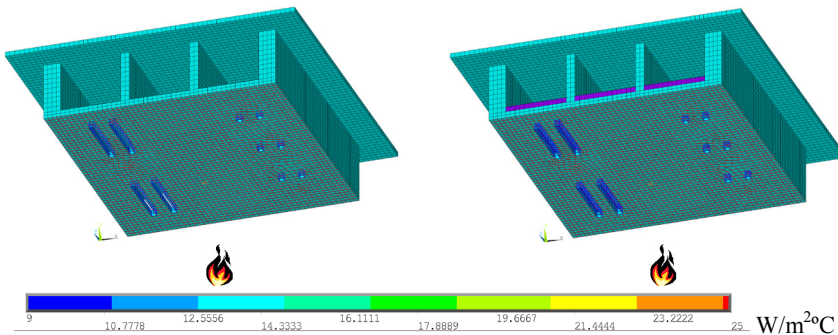


Figure 4: Numerical model and boundary conditions.

## 2.2 Numerical results

The numerical results for different time instants are represented in figure 5. Different images represent the temperatures in wooden slab with and without

insulation material (MDF). Also a residual cross-section with the charring layer formation is presented with incidence of the perforated slab zones. This effect is presented with a grey colour. The charring depth depends on the time of fire exposure and also depends of the insulation material. The charring depth is the distance between the outer surface of the initial member and the position of the char-line, defined by the threshold value of 300°C isotherm [11]. The calculation of the charring rate under standard fire exposure is the relation between the charring depth in mm and the time of fire exposure in min. This relation ( $\beta$ ) is calculated for each model when bottom surface is carbonized and is presented in mm/min near of the slab models. Eurocode 5 [11] proposes a value equal to 0.9 mm/min as a design value for wood panelling.

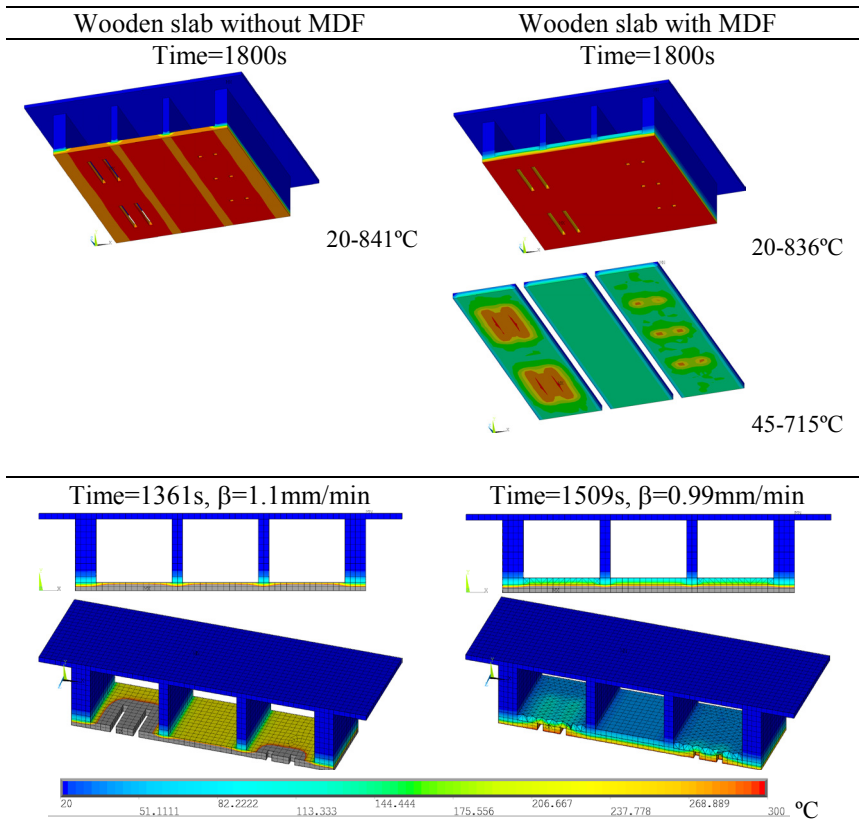


Figure 5: Results of temperature and charring rate.

As represented in figure 5, the damage effect of fire is higher in the wooden slab with higher perforated zones. The rectangular perforation facilitates the heating process when compared with the squared perforation. The cellular zone without perforations presents less damage. The charring rate is higher in wooden slab without MDF and for a time equal to 1361s reaches the start of

carbonization. When the wooden slab has a MDF panel the carbonization has a delay equal to 148s.

The time temperature evolution was also compared, in particular different nodal positions during 30 minutes, as represented in figure 6. All positions are compared between the two different models in different curves, figure 7. The standard fire ISO 834 curve is represented [9].

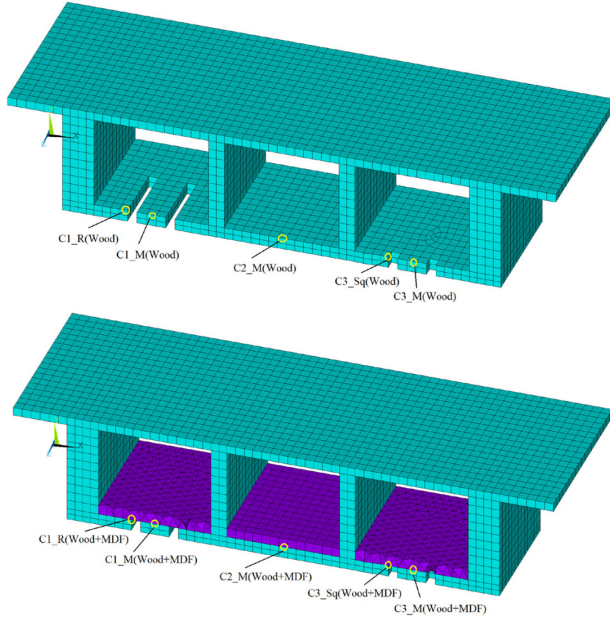


Figure 6: Nodal positions for time history.

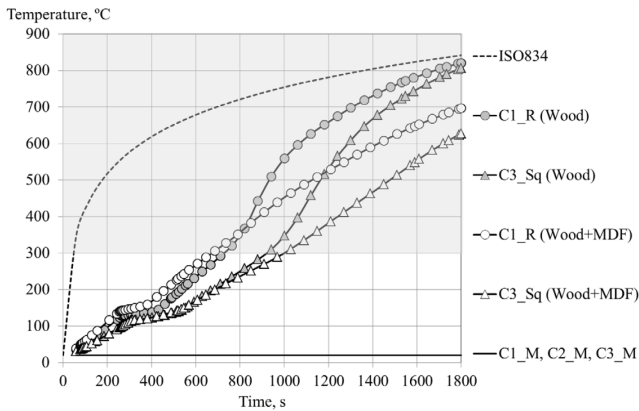


Figure 7: Time-temperature history in nodal positions.

The nodal positions in the border of the rectangular and square slots have higher values of temperatures when compared with all other nodal positions which remain at lower temperatures. The rectangle perforation facilitates a faster heating process with higher temperatures compared to the square perforation. Comparing the rectangular perforation in two different wooden slabs it is notorious a delay during all fire exposure when the cellular zone has a plate of MDF insulation. The same conclusion is obtained for squared perforation. At the end of simulation, 1800s, a difference of 100°C exists for rectangular perforation slots and a difference of 200°C for squared perforation slots.

### 3 Conclusions

In wooden slab with perforations, the type and the size of perforation can limit the use of these constructive elements in terms of fire resistance. The constructive elements should be chosen before, to prevent and delay the damage effect, allowing that the slab could remain in service during more time. This study allows verifying the evolution of the temperature and the char-layer throughout a wooden slab and verifying the influence of the use of MDF. In the future developments in this area should consider the experimental validation in typical wooden slab with perforations using a fire resistance furnace with imposed standard and natural fire conditions.

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