PROGETTO BASATO SULLE PRESTAZIONI DI UN EDIFICIO PILOTA

PERFORMANCE-BASED FIRE DESIGN OF A STEEL COMPOSITE PILOT BUILDING

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ABSTRACT

Tragic fires in the past decades have highlighted the importance of fire safety engineering and its application in the civil engineering field. The constant and significant growth of the research in the fire engineering field during the last few decades has suggested an alternative way in which the fire design may be approached. The classical approach based on a prescriptive time-temperature curve has been challenged by a performance-based one. Performance-based approach is aiming to determine how a structure respond to fire by considering performance criteria rather than achieving prescriptive requirements. The prescriptive approach requires strict compliance with established criteria, the lack of flexibility and optimisation are a drawback for a simplified implementation of the method. The performance-based approach is focused on ultimate goals to reach based on performance criteria, refined modelling techniques mixing engineering and science have to be used to gain in flexibility, design optimisation and cost reduction. In this work a comparison between design using a performance-based and a prescriptive approach will be provided for a medical lab compartment, which is part of a pilot building under development in the framework of a European demonstration project demonstration called DREAMERS.

SOMMARIO

Incendi tragici degli ultimi decenni hanno evidenziato l'importanza dell'ingegneria antincendio e le sue metodologie applicative. Negli ultimi decenni, la crescita costante e significativa della ricerca nel settore ha suggerito un modo alternativo di affrontare la progettazione antincendio. All'approccio classico basato sulla curva standard tempo-temperatura è stata affiancata la possibilità di rappresentare l'azione termica con un approccio basato sulle prestazioni. Questo approccio prestazionale mira a rappresentare il fuoco considerando più la fisica dell'incendio rispetto all'approccio

prescrittivo. L'approccio prescrittivo richiede una rigida osservanza di criteri prestabiliti, in questo caso la mancanza di flessibilità sono il prezzo da pagare per una più immediata implementazione della metodologia. L'approccio basato sulle prestazioni si concentra sul raggiungimento di obiettivi ben definiti quantificati da criteri prestazionali, l'uso di modelli più dettagliati permette una progettazione più flessibile e ottimizzata. In questo articolo verrà fornito un confronto tra l'approccio prestazionale e prescrittivo per un compartimento di un edificio pilota sviluppato nell'ambito del progetto di ricerca europeo DREAMERS.

1 BRIEF DESCRIPTION OF THE MEDICAL LAB

1.1. Compartment Geometry and main structural elements

The DREAMERS building will be built in the Campus of the University of Salerno with a total surface per floor of approximately 375 m^2. The main peculiarity of the building is the implementation of all the most advanced technologies for the construction of a sustainable and resilient structure considering all the risks, namely seismic, fire, or the loss of one of the main structural elements. The building is designed in steel and steel composite solutions, following a holistic design approach and foreseeing a lifetime monitoring of its behaviour. The DREAMERS building is made of three stories each one characterized by a different occupancy: the ground floor will be used as a car park, the first floor will be a medical laboratory and the last floor is devoted to offices. The total height of the building is 11.2 meters, whereas the car park is 3.5 m and the first and second floor measure 4.2 m in height. This work, for the sake of brevity focuses on the fire design of the medical laboratory even if the fire design has been performed for the whole building.

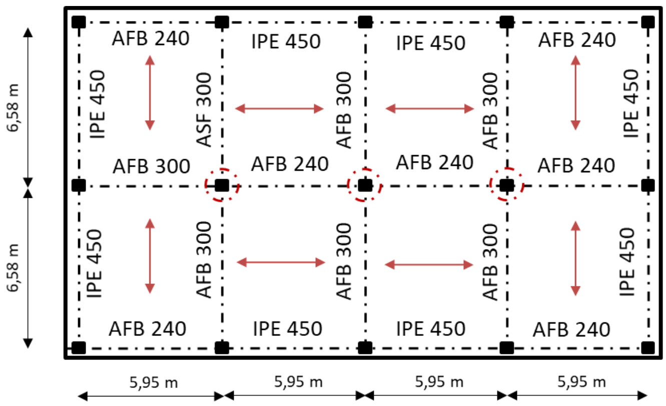
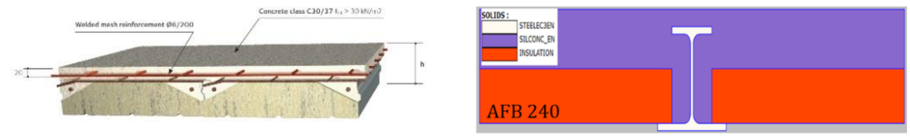


Fig. 1. Medical Lab plan view. Main structural elements, flooring direction and central columns (dashed in red)

In Fig. 1 are indicated the main structural elements, their structural framework and the three central columns resulting to be the most loaded. The steel sections are type S355, the composite steel concrete solution such as the slim floor beam are using a concrete class C30/35 a steel type S355 and rebars B500B. The flooring system is Cofradal260 and it is installed according to the direction of the red arrows. The connections between the beams are nominally pinned except for small cantilever beams of 0.82 m which are used to support the cladding (black continuous line) (AFB 240).



(a) *(b)*

Fig. 2. Cofradal 260 and Asymmetric floor beam

1.2. Openings and ventilation

A series of large openings are foreseen at the four sides of the façade of height equal to 3.65 m. The wall exposed to North has a total opening length of 9.1 m, the one to Est 5.95 m, the wall exposed to West side 3.7 m and 18.8 m for the opening oriented to South. The total area of openings is 137 m^2.

2 PERFOMANCE BASED APPROACH

2.1 Perfomance levels and requirements

According to the Italian fire standard D.M. 03/08/2015 [1] and its further updates, the definition of performance levels is a function of the determination of risk profiles linked with people's life, goods and environment. The specific risk related to the environment it is not evaluated since it has been considered negligible in view of the building typology. The risk related to the life of people has to be evaluated per each compartment (here medical lab) as a function of the fire growth rate of the fire and the familiarity of the occupants with the compartment. It has been assumed people not familiar with the building geometry and awaken in the building. This assumption is on the safe side of the design, thus possible visits by the students of the campus that are not fully aware of the building geometry have been considered. The life risk is evaluated as "B3" and the risk related to goods is equal to 1 (Tables G.3-3 and G.3-5 of D.M. 03/08/2015). Therefore, the performance level associated to the medical lab is to maintain the load-bearing capacity for the whole fire duration. At point S.2.4.8 of the Italian code [1] solutions to be adopted for a performance based approach are detailed.

2.2 Performance based approach: Fire scenarios:

The compartment has been characterised in terms of fuel load density at 80% fractile by means of statistical studies published in literature (International fire engineering guidelines) [2] and equal to 650 MJ/m^2. This fuel load density is a conservative choice. The design fuel load can be evaluated according to section S.2.9 of the Italian standard [1]:

$$q_{f,d} = \gamma_{q1} \cdot \gamma_{q2} \cdot \gamma_{ni} \cdot q_{f,80\%} = 1 \cdot 1.2 \cdot 0.9 \cdot 0.85 \cdot 650 = 596\ [MJ/m^2] \quad (1)$$

γ_{q1} , γ_{q2} are parameters related to the size of the compartment and ignition probability, γ_{ni} are coefficients accounting for the fire risk related to the size of the compartment and eventual active fire protection measures. It has been assumed at least an internal fire hydrant pipe system and fire detection systems.

2.3 Determination of rate of heat release curves

The medical laboratory is not among the standard class occupancies defined at European and national levels [1],[3]. Therefore, the determination of the fire growth rate and rate of heat release density (RHR_f) were made according to section M.2.7 of the Italian standard. Consequently, the fire growth rate is set equal to 150 seconds and RHR_f equal to 500 kW/m^2. Fig. 3 shows the rate of heat release associated either to a possible generalised fire scenario or localised one. The two of them have been used for the fire design. However, for the sake of brevity, only the generalised fire scenario is shown.

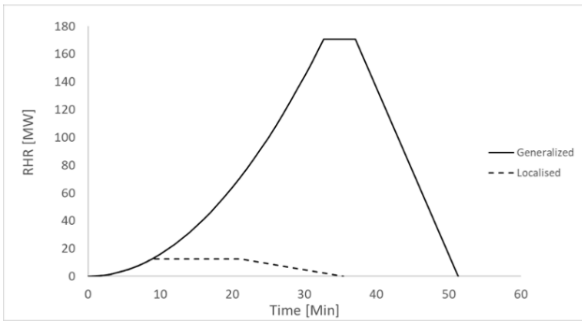


Fig. 3. Rate of heat release: generalised fire (continuous) and localised fire scenario(dashed)

2.4 Determination of the thermal action

Ozone, a zone model developed at University of Liege [4], has been used to determine the gas temperature in the compartment, assumed to be uniform for a generalised fire scenario. Zone models are defined in EN1991-1-2 Annex D (advanced fire models) [3].These models are evaluating the fire evolution by making each time step a mass and energy balance in the compartment. Main inputs are given in terms of RHR, compartment geometry and material thermal proprieties. To choose the most unfavourable thermal attack to the compartment a parametrical analysis on the effects of windows breakage has been done by considering the study conducted by Babrauskas [5].

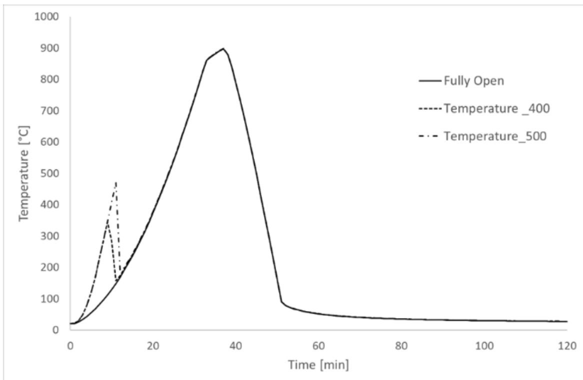


Fig. 4. Gas Temperature in the compartment. Fully opened (continuous line), breakage of windows set to 400°C (dashed line) and breakage set to 500°C (dot-dashed line)

Fig. 4 shows different outcomes of gas temperature in the compartment by considering, fully opened scenario and other two scenarios in which by default 10% of the total opening area is assumed “open” and the rest it will open when the glass of the windows it is going to break. The worst-case scenario has been considered to be the one with breakage of windows set at temperature of 500°C due to a pre-heating effect given the accumulation of hot gasses before the windows breakage.

3 PERFORMANCE BASED APPROACH: THERMAL AND MECHANICAL ANALYSIS

The thermal and mechanical analysis have been done with the finite element software SAFIR [6], developed at the University of Liege. SAFIR does a decoupled analysis, first a thermal analysis with the input gas temperature of the compartment must be done and only thereafter the mechanical analysis is performed. The materials properties are a function of the temperature (computed accounting for the detrimental effects of temperature). SAFIR version 2020c2 has been used.

3.1 Thermal analysis

The thermal action on the structural elements is evaluated with a 2D thermal analysis, considering the elements exposed on one side except the columns that are considered on 4 sides. The convective parameter is taken as 35 W/m^{2}K as suggested in EN1991-1-2. In Fig. 5a and Fig. 5b the temperature distribution for AFB 300 and AFB 240 is shown. In Fig. 5c the temperature evolution curve for each structural element is plotted in time, for AFB, the temperature refers to the bottom flange.

a)
b)
c)

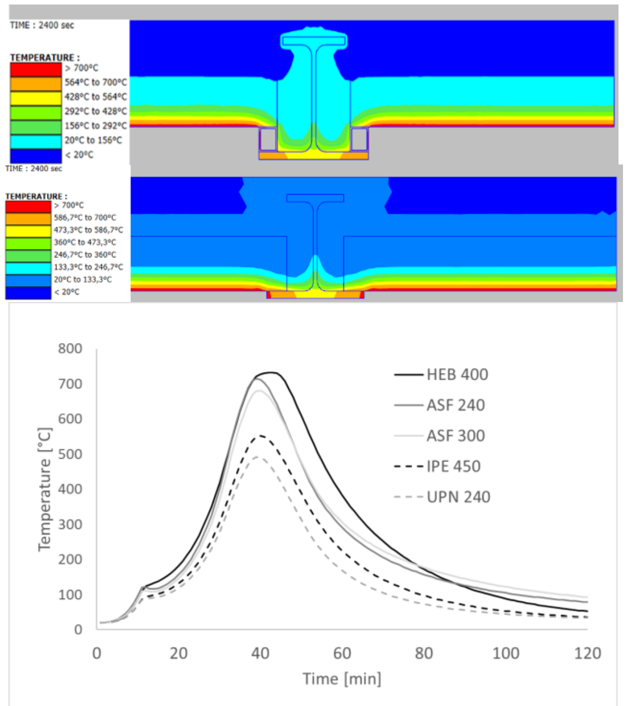
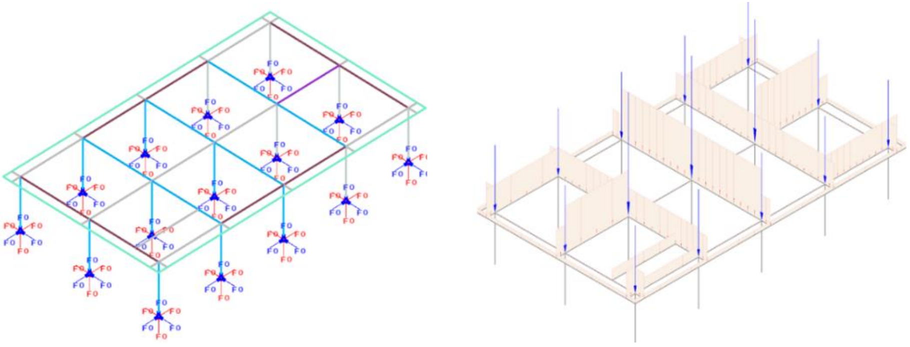


Fig. 5. Temperature of structural elements: a) Temperature map AFB 300 at peak; b) Temperature map AFB 240 at peak; c) Temperature evolution of all elements.

In Fig. 5c the column temperature is the highest one, possibly because it is the only element exposed on all sides. The slim floor beam solutions have a heterogeneous temperature distribution. At the level of the concrete slab and dowels the temperature is 100 °C. The synergy between the ASF and the Cofradal solution shows an excellent fire behaviour. For all the section profiles it is possible to notice a sort of preheating of the element in the first 10 minutes, this is an effect of the windows breakage.

3.2 Mechanical analysis

The mechanical analysis is performed using a solving scheme based on a pure Newton-Raphson procedure, commonly suggested when the model is composed mostly of beam objects [7]. The precision is set equal to 10e-03 and the come back to 10e-4. The time step used is of 1 seconds, while the time print is 30 seconds. The steel yield strength has been set equal to 345 MPa.



a) *b)*

Fig. 6. Compartment model: a) Restraints; b) Loads

In Fig. 6a the compartment model is presented, the columns are considered fully restrained at their base whereas the beam-to-beam connections are considered pinned, imposing stiffness equal to 0 with “relaxation” command. The cantilever connection is considered fully rigid. Fig. 6b shows the loads applied on the building, which have been evaluated according to the exceptional fire combination suggested by the national standard (NTC18) [8].Two load typologies have been applied as a on the structure linearly as a function of time. At time 20 seconds of the simulation the point loads on the columns and distributed load on the beams are fully applied.

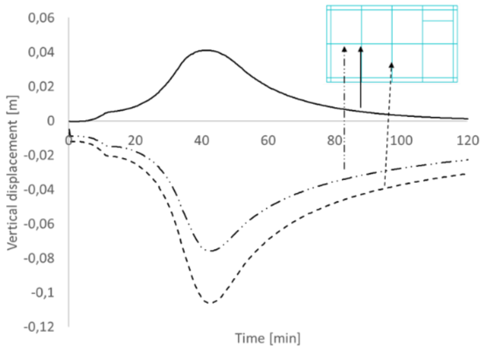


Fig. 7. Vertical displacements evolution

The vertical displacement evolution from the mechanical analysis is depicted in Fig. 7. The central column (continuous line) is among one of the most loaded, it is possible to see how due to the thermal action it elongates up to almost 4 cm. On the contrary the displacement evolutions of the

AFBs are pointing downward, the most loaded beam (dashed line) experiences a maximum displacement of 10.6 cm. When the fire cools down the displacement for the column is going to 0, whereas for the beams a plastic deformation might develop since the displacement after the cooling phase are not fully recovered. SAFIR automatically performs a check on the elements, thus when the analysis converges the structure is assumed to withstand the fire. In this particular case after analyzing bending moments, deformed shape and horizontal displacements, clues that can indicate a failure such as vertical sway of beams or vertical asymptotes in the displacement evolution, were not found. Therefore, the structure can withstand the fire. Moreover, a simple check on the shear resistance of the most loaded beam has been performed (Table 1, $V_{rd,fi}>V_{ed,fi}$). The temperature of the web has been assumed uniform (conservative) equal to 452°C (see Fig. 5a).

Table 1. Shear verification

fy [MPa]	345
T,web [°C]	452
ky,teta	0.88
Ved,fi [kN]	158
Vrd,fi [kN]	504

4 COMPARISON WITH STANDARD APPROACH

The standard or prescriptive approach is a method to check the fire resistance by analysing structural members under a standard fire curve ISO 834 (time temperature). The minimum fire resistance for the medical lab has been evaluated according to the Italian standard as a function of the design fuel load (Table S.2-3 of D.M. 3-08-2015 since the class is III) and it is equal to R45. The composite elements AFB 300 and AFB 240 have been verified according to numerical methods and a methodology in the new version of EN1994-1-2 Annex H which get his root on the studies performed by Duma et al.[9]. Whereas the steel elements have been verified according to EN1993-1-2.

Table 2. Steel elements verification

Element	Section	Critical Temperature	Resistance class
Central Column	HEB 400	837	<R45
Perimetral Column	HEB 400	898	>R45

Table 2 presents the verification of the steel columns in a temperature domain, where an iterative methodology has been used, accounting also for instability. The central row of columns cannot withstand the prescribed resistance class. Therefore the verification with a prescriptive approach is not fulfilled. At this point generally the structure is reviewed, or protection applied to the most critical elements. This is the main reason why the design has been done with a performance-based approach (Section 2).

CONCLUSIONS

The structural fire resistance of a compartment of a building in the framework of a European project (DREAMERS) has been studied. The structural fire verification adopting a prescriptive approach was not satisfied with regards to the central columns of the compartment. A layer of protection or an increase in section size must be considered. Therefore, an approach focused on the global performance has been adopted (Section 2) leading to the structural verification without any fire protection or increase in section size. It is important to remark how in this approach, more physics is considered accounting for several factors, that cannot be considered by simply applying a temperature time curve on a structural element (forces redistribution, structural overstrength…).

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KEYWORDS

composite floors, fire safety, performance-based approach