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16 FIRE SAFETY ENGINEERING IN AN AIRCRAFT HANGAR (DEFINITION OF FIRE SCENARIOS AND DESIGN FIRES)

Summary

On the premises of the new airport of the city of Berlin, a line maintenance hangar for aircrafts was planned and will be finished until the second half of 2012. The fire safety consultants hhpberlin developed the relevant fire scenarios and defined design fires as a basis for CFD simulations. The possibility of successful fire fighting measures and the design of the load-bearing steel structure of the roof and the upper parts of the columns without protective coating were investigated on the basis of results of the simulations.

16.1 DESCRIPTION OF THE CONSTRUCTION

The hangar has the outer dimensions of 83.40 m width and 77.60 m depth and thus an inner area of approx. 6,472 square meters. The hangar has a horizontal orientated roof, which is supported by an external two truss girders on steel supports that are located on the outside. A secondary internal load-bearing system is attached below the main load-bearing elements. The hangar has a medium interior height of approx. 18.10 m, the height of the lower edge of the secondary load bearing structure is 15.25 m.

16.2 SAFETY OBJECTIVES

The building was designed on the basis of the German guidelines for industrial constructions. The first objective that has to be fulfilled is the sufficient structural safety in case of fire. The second objective for buildings that have an area of more than 1,600 square-metres is the proof of the possibility of successful fire-fighting.

In Germany this safety objective is achieved in case a smoke layer height of at least 2.5 m is verified for every level of the building.

In the present aircraft hangar this has to be differentiated more precisely, because for effective fire-fighting at least the fuselage of the aircraft parked and maintained in the hangar must be recognizable and must reside outside the smoke layer. The smoke-exhaust measures must be designed to keep the top edge of the highest aircraft out of the smoke layer.

The present case involves the Boing B747, which has a maximum height of approx. 10 m at the top of the cabin. The minimum height of the smoke layer to account for is thus 10 m.

The safety objective of ensuring a smoke layer height was fulfilled in a CFD simulation. As criteria to prove the safety objective the so-called optical smoke density is evaluated. It can be assumed that the safety objective is met when the optical smoke density does not exceed a value of 0.15 1/m (vfdb Leitfaden 2009).

In addition to the use of the results from the simulation for the design of the smoke exhaust systems, they are used for the structural fire design of the steel structure according to the simplified calculation procedures of (Eurocode 3) (columns and roof structure).

16.3 FIRE SCENARIOS

For the proof of the safety objectives all the relevant fire scenarios must be investigated.

Various aircrafts are to be serviced in the hangar. To demonstrate the stability of the load bearing structure of the roof, it is the worst case to assume that the fire occurs as high as possible in the building. To prove the effectiveness of the smoke exhaust measures for successful fire fighting operations, the amount of smoke gases produced by a fire at the lowest point in the building is relevant, because the longer the distance on which fresh air is entrained into the plume, the greater is the quantity of produced smoke gas.

Because of the wingspan of the aircrafts and the specified distance of the aircraft from the supporting structure there will not be high heat release rates from a fire close to the load bearing coloums. It cannot be excluded that a fire erupts directly near the supports of the roof structure, for example due to fires of technical equipment or temporarily positioned storage goods. For this reason another fire scenario 3 ("local fire") must be investigated in addition to fire scenarios 1 and 2 ("aircraft fires"). This fire is considered examplarily in the positions of relevant coloums of the main supporting structure.

The largest aircraft in the hangar and thus the potentially largest origin of a fire is the Boeing B747. The aircraft measures 71 metres in length and has a wing span of about 69 m, as well as a body diameter of around 7,30 m at the highest point, with a height above the floor of approx. 2.70 m.

In principle fire events have to be expected in the disadvantageous place in the building. If a fire occurs in a corner area of the building the temperatures it causes are typically higher due to accumulation effects. Due to the fact that the hangar doors at the front of the building are opened in the event of a fire, positions at the back of the building are viewed as disadvantagues.

The aircraft (B747), which is considered most relevant for assessment, has two levels. In the front section of the Boeing B747 an upper deck is located. It is therefore no longer apparent where a design fire will lead to higher temperatures in the building or at the bottom edge of the roof structure. Therefore two aircraft fire scenarios (see Fig. 16.1) were adopted, where the place of the fire was assumed at the back corner of the hangar in both cases.

- Scenario 1: fire in the cabin of a B747-400 with participation of part of the wings (plastics and kerosene fire), fire surface 100 m², fires in a height of approx. 6 m.
- Scenario 2: cabin fire in a B747-400 in the upper-deck (plastics) without participation of the wings, fire area 50 m², fires in a height of approx. 8 m.
- Scenario 3: local fire, for example larger car or a similar major technical device or storage good, fire area 10 m², fires at a height of 4.0 m.

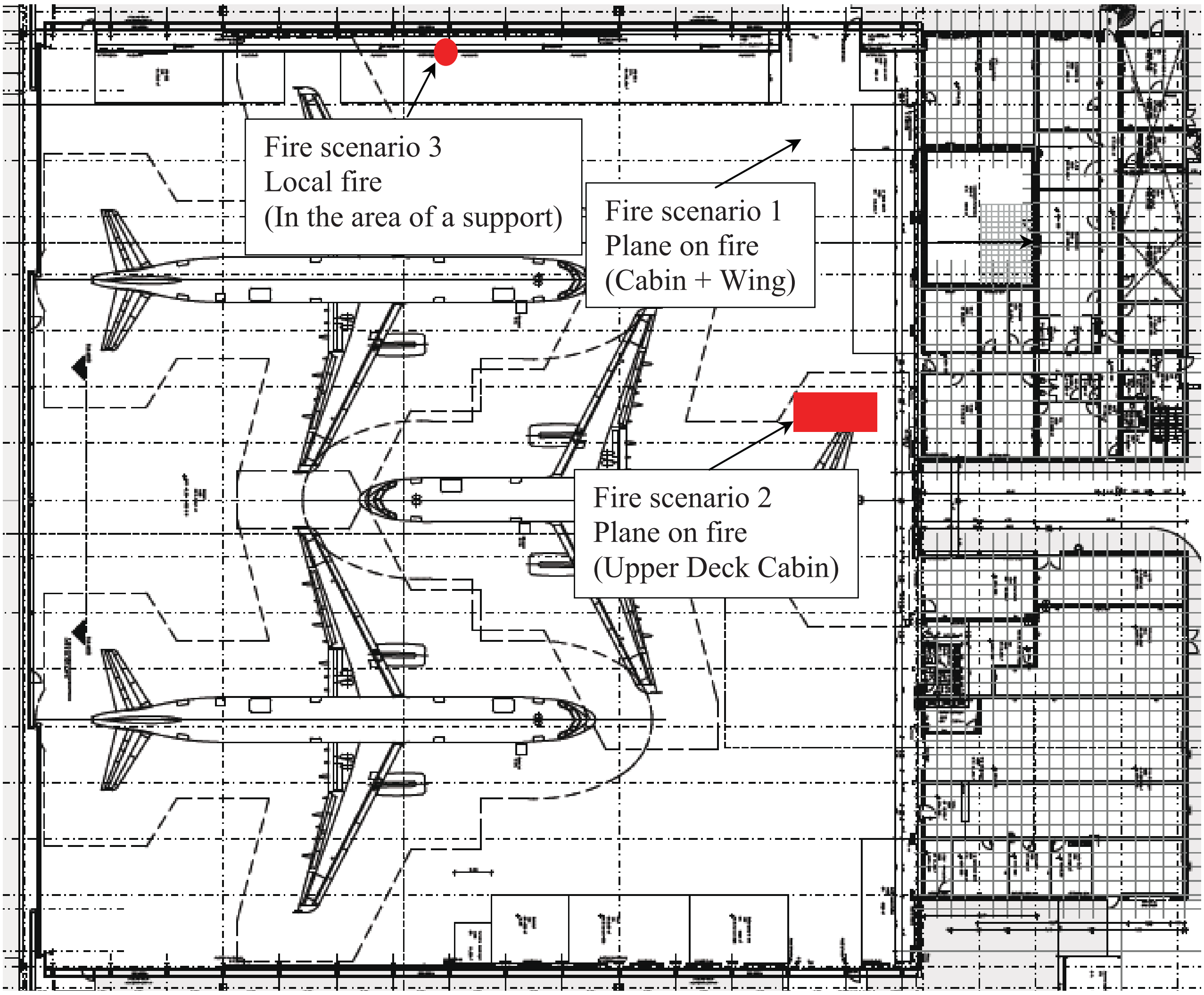

Fig. 16.1 Floor plan of the hangar with the position of the origin of the fire

16.4 DESIGN FIRES

To ensure design fires on the safe side, the relevant input parameters must be adopted conservatively, so that all relevant fire events are covered.

With regard to the course of the heat release rate, it is assumed that the fire does not extinguish after the depletion of the fire load but will remain at the maximum rate of the heat release. For that reason, only the nature of the fire load, but not the amount is significant the for the fire safety design.

The safety objectives in the building will be proven when a stationary state, i.e. a balance of the energy supplied by the fire and the energy dissipated by the smoke and heat exhaust measures is reached. In all fire scenarios extinguishing measures, for example, by the extinguishing system or the airport fire brigade, are not considered to have a direct effect on the heat release rate. They are accounted for conservatively by the partial factor $\gamma_{fi,HRR}$, according to (DIN EN 1991-1-2/NA).

Due to the fact that a fire develops higher temperatures if it burns with a high heat release rate concentrated in a small area and on the other hand a higher smoke gas production occurs in a larger fire area, the realistic fire areas mentioned above are chosen for the aircraft fire scenarios.

In the following the curve progressions of the heat release rates are defined for all 3 fire scenarios. The maximum of the heat release rate Q'_{max} is dependent on the speed of the fire development or the resulting fire area A_f , as well as the area-based heat release rate of q'. Additionally a partial safety factor to account for fire-fighting measures according to the safety concept of the Eurocode (DIN EN 1991-1-2) is considered.

$$Q'_{max}\,[kW] = q'[kW/m^2] * A_f\,[m^2] * \gamma_{fi,HRR} \tag{1}$$

According to the literature such as the (vfdb Leitfaden), area-specific heat release rates of between 150 kW/m^2 and 500 kW/m^2 are realistic. In individual cases also values over 600 kW/m^2 can occur especially in plastics and lubricants. This adds up to the following design fires for the defined fire scenarios (partial safety factors in accordance with DIN EN 1991-1-2 / NA):

- Scenario 1 (Fire in cabin + wing): q' = 600 kW/m²

  $$Q'_{max}\,[kW] = 600\,kW/m^2 * 100\,m^2 * 1{,}075 = 64500\,kW \text{ after approx. } 930\,s \tag{2}$$

- Scenario 2 (Fire in upper-deck cabin): q'=450 kW/m²

  $$Q'_{max}\,[kW] = 450\,kW/m^2 * 50\,m^2 * 1{,}075 = 24187.5\,kW \text{ after approx. } 720\,s \tag{3}$$

- Scenario 3 (Local fire at support): q'=500 kW/m²

  $$Q'_{max}\,[kW] = 500\,kW/m^2 * 10\,m^2 * 1{,}075 = 5375\,kW \tag{4}$$

The illustrations in Fig. 16.2, Fig. 16.3 and Fig. 16.4 show the curve progressions of the heat release over time.

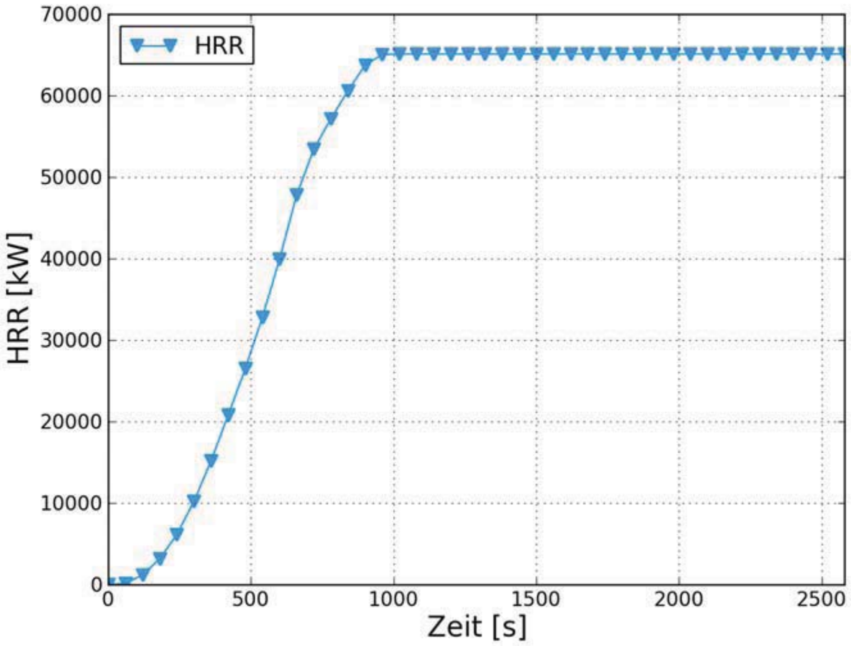

Fig. 16.2 Chronological sequence of heat release rate (HRR) in the fire scenario 1 ("aircraft fire")

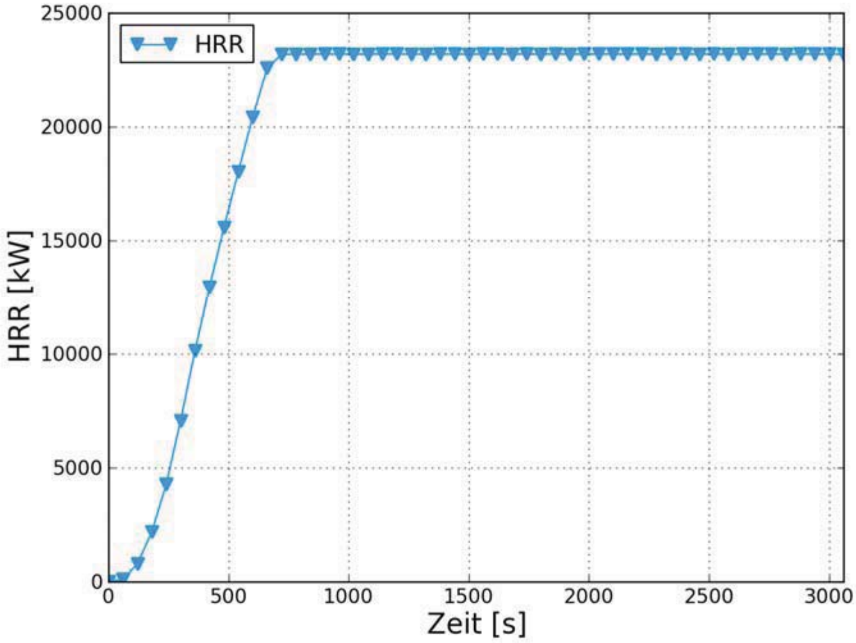

Fig. 16.3 Chronological sequence of heat release rate (HRR) in the fire scenario 2 ("Fire in upper deck cabin ")

A rapid fire propagation speed is assumed, so that a heat release rate of 1 MW is achieved after 150 s (see Fig. 1.4).

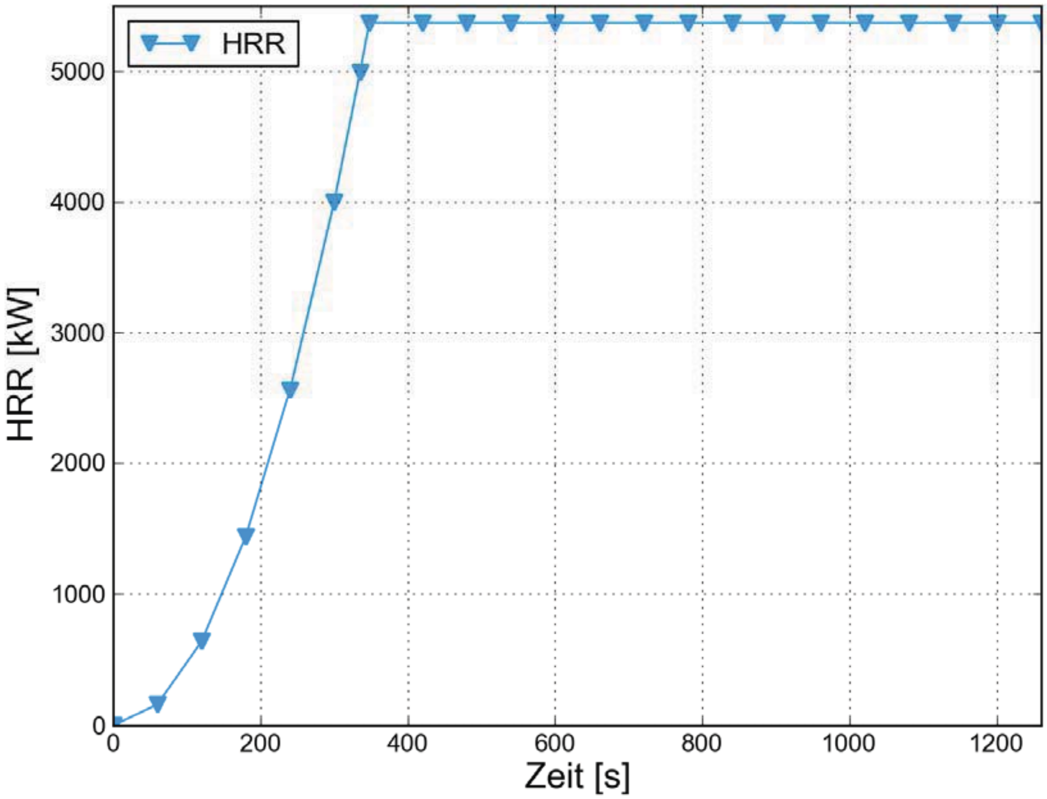

Fig. 16.4 Chronological sequence of heat release rate (HRR) in the fire scenario 3 ("Local fire ")

The specification of the source of a fire is required for fire simulations. The calculations are based on a mixed load of fire, which consists of 33% wood, 33% polystyrene, and 33% polyurethane and thus is based by 2/3 on plastics. In the light of the existing flammable substances in the hangar this is to be regarded as conservative.

The mean value of the heat of combustion of the fuel mixture was derived from the specific parameters of the individual substances to be approximately 27 MJ/kg.

Due to the relation between the heat release q‘, the mass flow m‘ and the heat of combustion H (m‘ = q‘/H) a higher heat of combustion leads to a lower mass flow in case a heat release rate was specified. Thus this leads to a lower production of smoke gas, so that this value specified is considered to be conservative.

The soot yield was set to an average value of 0.09 g / g. This definition of soot production was derived from the information in the (vfdb Leitfaden 2009) and is adopted conservatively.

16.5 CONCLUSIONS

The case study discusses the relevant design fires and fire scenarios for an appropriate design of structural fire protection measures of the load bearing structure of the aircraft hangar. The described design fires and fire scenarios were the basis of simulations carried out to derive a temporal and spatial temperature distribution in the hangar as input into the fire safety design methods of Eurocode 3 part 1-2.

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17 PRODUCTION AND STORAGE HALL OBJECT

Summary

The main objective of the case study is to examine fire resistance of steel structure of production and storage hall object located in Mnichovo Hradiště, Central Bohemia, Czech Republic. The investigated part of the object is of irregular ground plan. Its maximal dimensions are 90.0 x 114.0 m, 13.25 m height. Inside the hall there is the area for production of lemonade and area for storage of the product. The structure is composed of precast concrete columns and steel trusses of 22.5 m length. Roof deck is designed from trapezoidal sheet, vertical cladding from sandwich panels. The requirement for the fire resistance of the bearing structure is REI 15. The fire resistance of steel trusses, stiffeners and other members of roof deck and vertical cladding are investigated. Regarding large dimensions of the hall as one compartment localised fires of wooden pallets and high-lift truck are considered.

17.1 DESCRIPTION OF THE HALL

The object of production and storage hall of lemonade is located in Mnichovo Hradiště, Central Bohemia, Czech Republic. The subject of the study is only part of the object which is of irregular ground plan. Its maximal dimensions are 90.0 x 114.0 m, height of the attic is 13.25 m and roof declension of 2 %. The one floor hall includes an area of production of lemonade and area for storage of the product. The structure is composed of precast concrete columns and steel trusses of 22.5 and 20.0 m length, simply supported on the head of concrete columns, see Fig. 17.1. The span length between steel trusses is 19.0 m. Both, steel trusses and steel truss purlins consist of H-section upper chord and lower chord, diagonals are from square tubular section. In roof plane there are stiffeners of round tube section. Roof deck is designed from galvanized trapezoidal sheet S.A.B. 150/280/0.75 as two-span continuous beam 2 x 5.625 m. Vertical cladding of the hall consists of sandwich panels on intermediate columns from H-section and vertical beams of 5.625 m span length.

17.2 FIRE ENGINEERING APPROACH

17.2.1 Subject of examination of fire resistance

The objective of the case study is to investigate fire resistance of steel trusses (steel truss P1 is shown at Fig. 17.2), steel stiffeners and other members of the roof, bearing members of cladding as intermediate columns (see Fig. 17.3) and horizontal beam above the portal door. The fire resistance of concrete columns, roof cover and sandwich panels is not subject of the case study. The requirement for the fire resistance of the main bearing structure is REI 15.

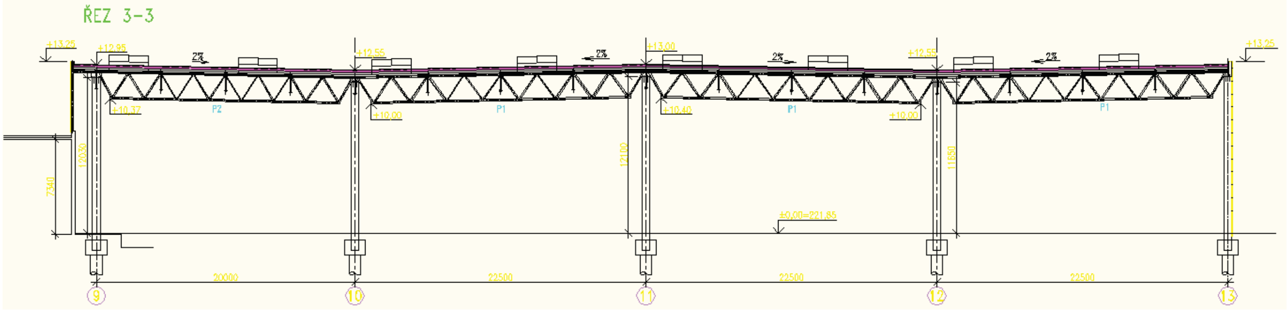

Fig. 17.1 Steel trusses of 22,5 m length

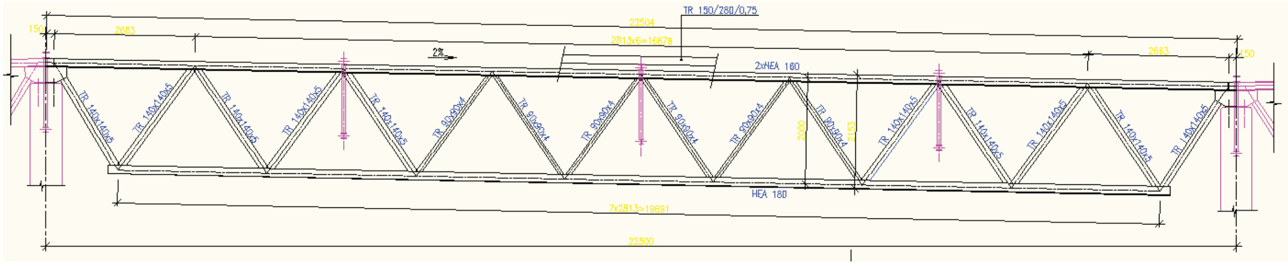

Fig. 17.2 Steel truss P1

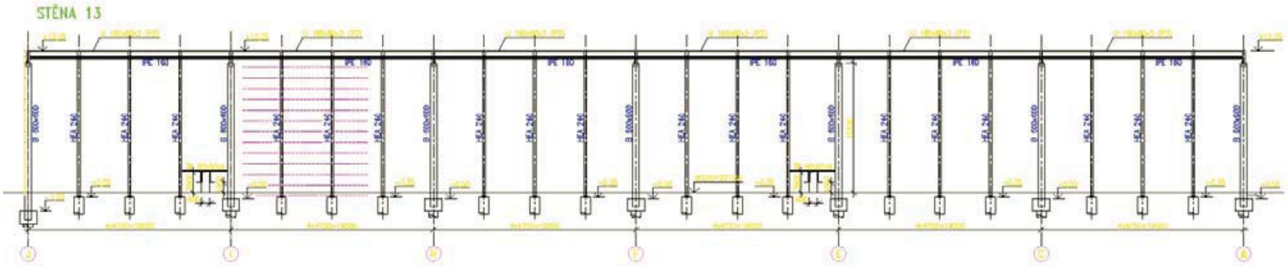

Fig. 17.3 Bearing members of cladding

17.2.2 Process of examination of fire resistance

The examination of fire resistance of steel structure covers several steps:

1. Selection of design fires
2. Description of design fires
3. Heat transfer analysis
4. Mechanical response analysis

17.3 DESIGN FIRE SCENARIOS

Regarding large dimensions of the hall as one compartment (area of 13 234 m^2) fully developed fire is not expected. Two localised fires are considered:

1. Localised fire of wooden pallets - product is stored on wooden pallets of weight 138 000 kg on area of 9 259 m^2. Fire load of 14.9 kg/m^2 is considered.
2. Localised fire of high-lift truck

Localised fire parameters are assessed by using the expressions given in EN 1991-1-2:2002 Annex C. By calculation of influence of localised fire to roof members it is assumed that the centre of fire is directly under the examined member. While by examination of intermediate cladding columns the method of heat transfer by radiation is used.

17.3.1 Localised fire of wooden pallets

The design value of the fire load is defined using EN 1991-1-2:2002 Annex E:

$$q_{f,d} = 577{,}2\, MJ / m^2$$

where characteristic fire load density per load area is $q_{f,k} = 260{,}8\, MJ / m^2$

factor $\delta_{q1} = 2{,}12$

factor $\delta_{q2} = 1{,}00$

sum of factors $\prod \delta_{n,i} = 1{,}305$ (no automatic water extinguishing system, no independent water supplies, installed automatic heat detection, no automatic smoke detection, no automatic alarm transmission to fire brigade, no work fire brigade, off site fire brigade, safe access routes are designed, fire fighting device are available, no smoke exhaust system)

To calculate time dependant rate of heat release RHR$_f$, the time needed to reach a rate of heat release of 1 MW is used as $t_{\alpha} = 300\, s$, RHR$_f$ = 1250 kW/m^2 (wooden pallets of 0.5 m height)and the fire diameter D = 3 m. The maximum heat release of wooden pallets is 8836 kW. The rising phase takes 14 min 52 s and stationary phase 28 s. Fuel burns out in 19 min 59 s, see Fig. 17.4. The length of the flame is calculated according to EN 1991-1-2:2002 Annex C. Fig. 17.5 shows the maximum length of the flame of 5.83 m (the flame is not impacting the ceiling).

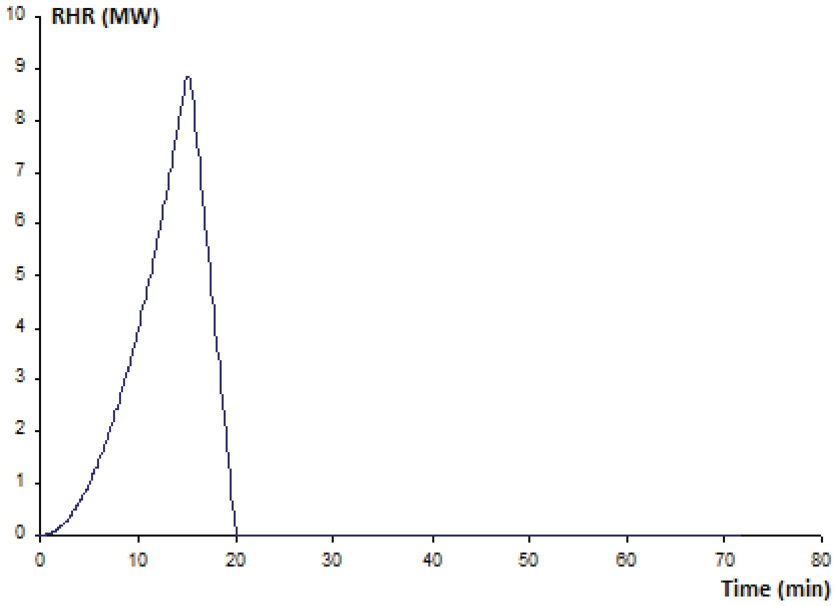

Fig. 17.4 Rate of heat release of wooden pallets fire

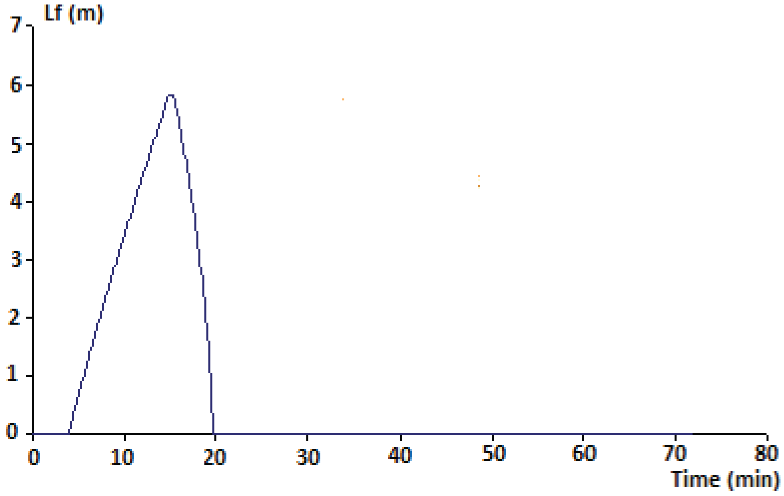

Fig. 17.5 Length of the flame of wooden pallets fire

17.3.2 Localised fire of high-lift truck

Rate of heat release of high-lift truck is taken as the value of fire of a car from project DIFISEK. The fire diameter D is 3.91 m. Fig. 17.6 shows time dependence of rate of heat release. The maximum heat release of the truck is 8300 kW. The fire takes 70 min. The maximum length of the flame is 4.68 m (the flame is not impacting the ceiling), see Fig. 17.7.

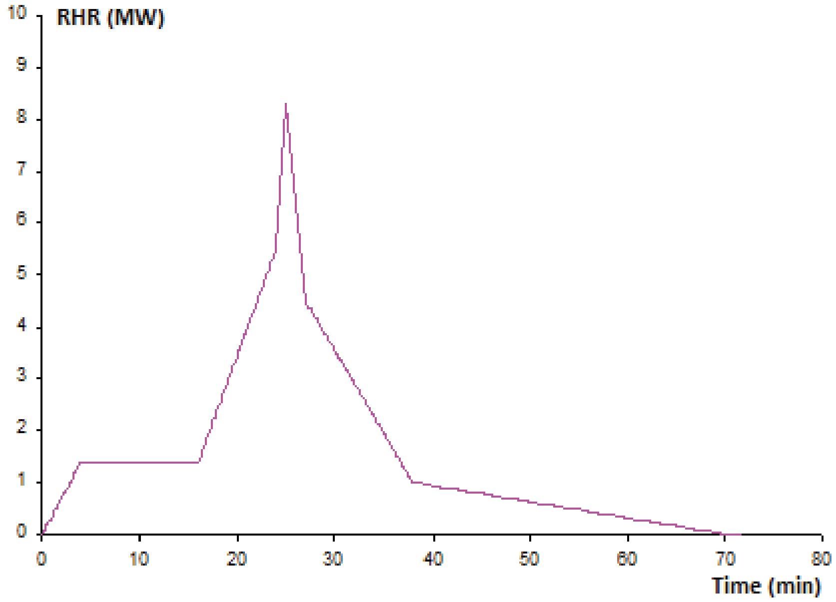

Fig. 17.6 Rate of heat release of high-lift truck fire

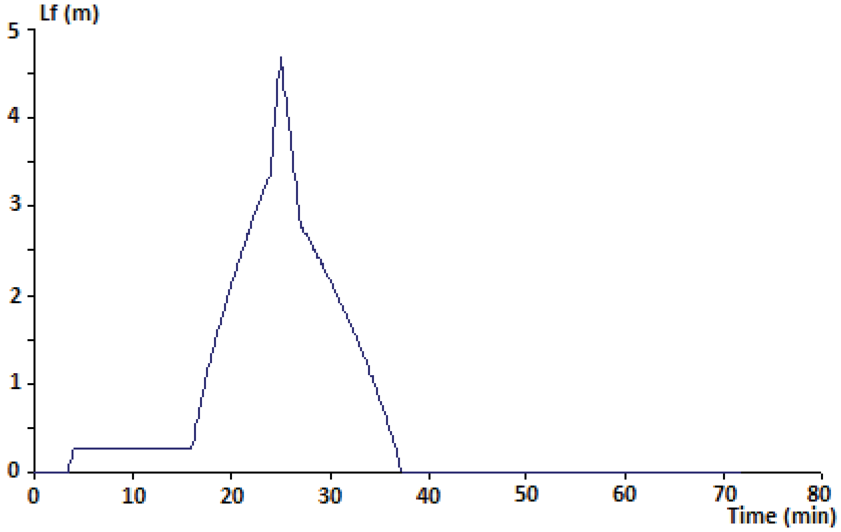

Fig. 17.7 Length of the flame of high-lift truck fire

17.4 HEAT TRANSFER ANALYSIS

17.4.1 Steel members of roof construction

The gas temperature in height of $z = 10$ m (height of lower chord of steel truss) is calculated using EN 1991-1-2:2002 Annex C. The maximum gas temperature during fire of wooden pallets is 221°C from 14 min 52s to 15 min 20 s. During the fire of high-lift truck the maximum gas temperature is 184°C in 25 min, see Fig. 17.8.

The temperature of unprotected steel structure is calculated using step-by-step method from EN 1993-1-2:2005. Fig. 17.9 shows the temperature of lower chord of steel truss P1 (cross section HE180A, $z = 10$ m, $A/V = 234$ m^{-1}, $k_{sh} = 0,62$) during considered fire of wooden pallets. The maximum temperature of the member is 122°C in 18 min. Temperature in time 15 min is 102°C. During fire of high-lift truck the maximum temperature of the member is 103 °C in 30 min, in 15 min the temperature is 49 °C, see Fig. 17.10. Temperatures of other members of roof structure are described in original report.

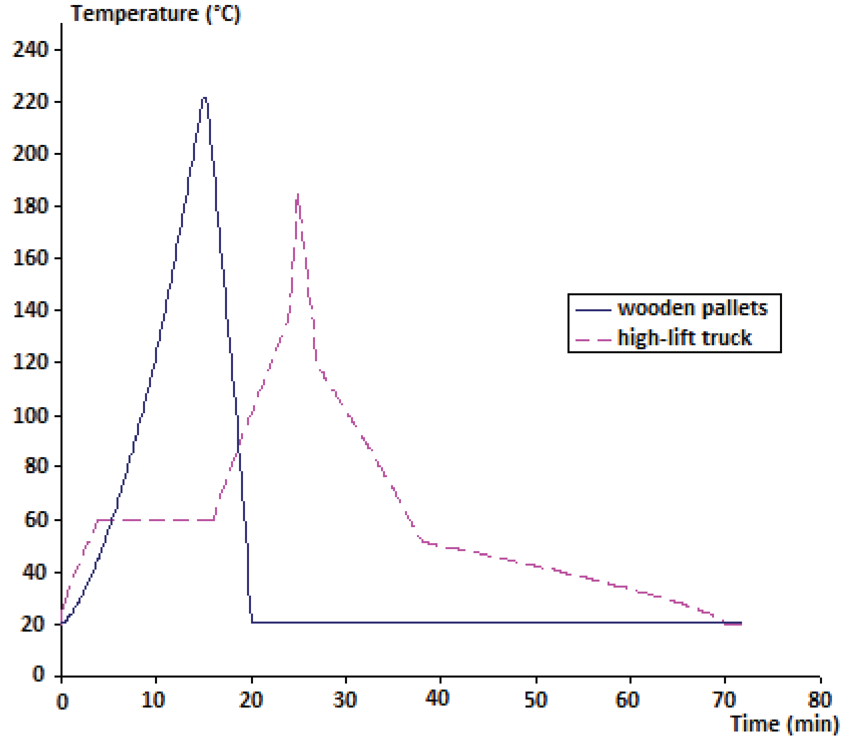

Fig. 17.8 Gas temperature in height of lower chord of steel truss

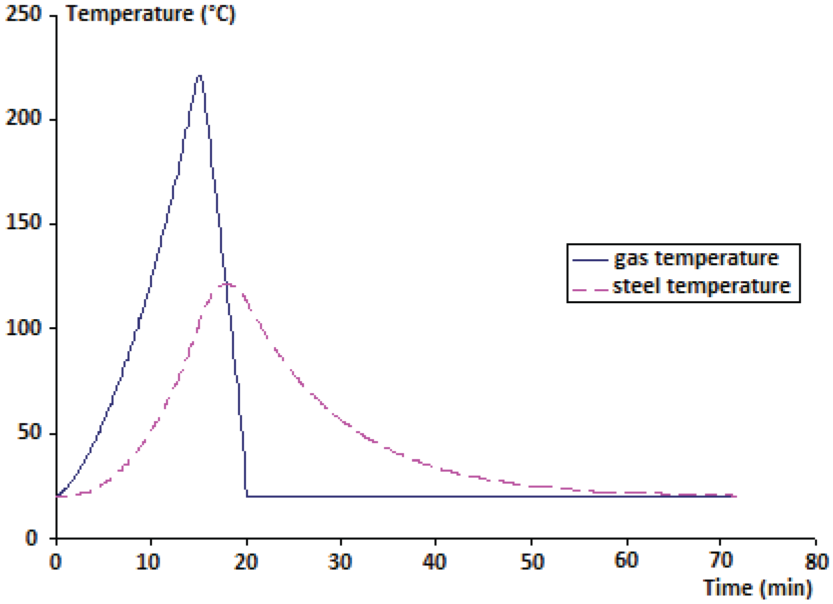

Fig. 17.9 Temperature of lower chord of steel truss P1 during fire of wooden pallets

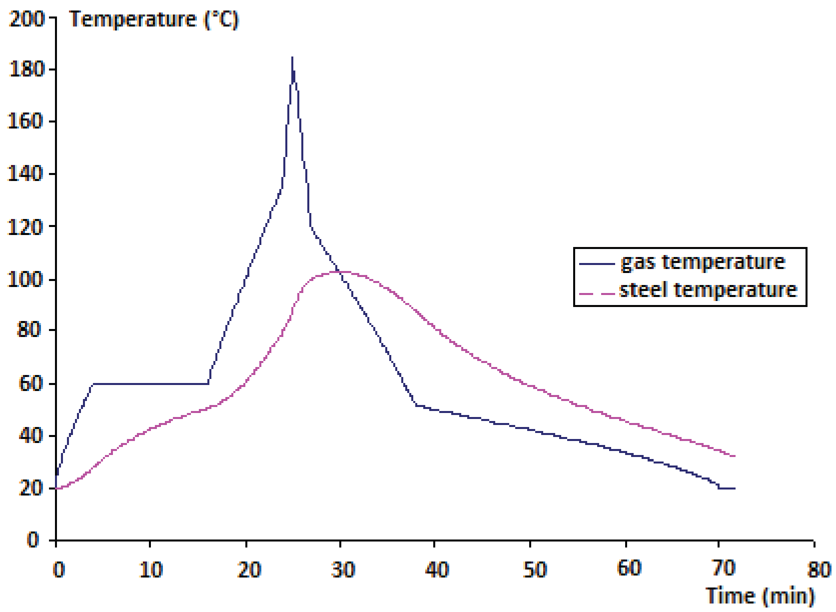

Fig. 17.10 Temperature of lower chord of steel truss P1 during fire of high-lift truck

17.4.2 Bearing members of cladding

The temperature of intermediate columns of the cladding during localised fire is derived using physics fundamentals and methods described in EN 1991-1-2 and EN 1993-1-2. Following assumptions are considered:

1. Flames of localised fire are substituted by cylindrical surface with diameter of the fire.
2. Columns of the cladding are not inside the cylinder. Heat transfer is realized due to radiation.
3. Temperature of column differs with its height. Heat conduction is neglected (assumption gives higher temperatures).
4. Non-uniform distribution of temperature is neglected.

Fig. 17.11 shows placing of localised fire and intermediate column of the cladding. Heat transfer due to radiation from cylindrical surface is calculated where temperature of radiant cylindrical surface depends on the height of flames z. The formula to calculate temperature of localised fire is used.

Due to temperature dependence of flames on the height cylindrical surface is divided into several rings with constant temperature. Temperature of selected column is calculated as sum of heat fluxes of all rings of cylindrical surface.

Surface of the column is affected by radiation from 3 sides. Using rules from EN 1991-1-2 Annex G a rectangular envelope is drawn around the cross-section of the member to describe shadow effects. In this case the configuration factor is defined numerically. The cylindrical surface is divided into rings with constant temperature. From each ring only a part which is directly visible from surface of the column is taken into account, see Fig. 17.11. The configuration factor is determined for flange and both sides of rectangular envelope parallel to column web. Final heat flux is defined as difference of heat profits and loss. The temperature in any point of the column is calculated by the aid of step-by-step method.

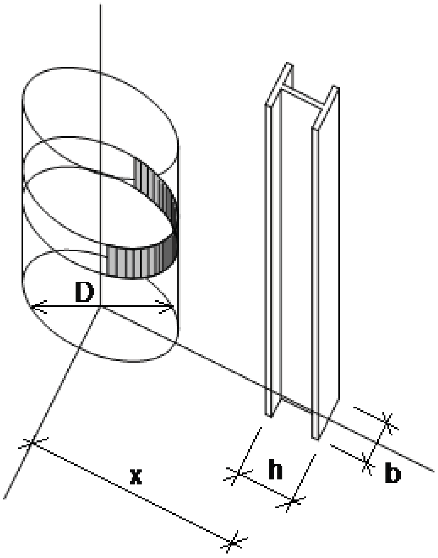

Fig. 17.11 Model of localised fire affecting intermediate column of the cladding

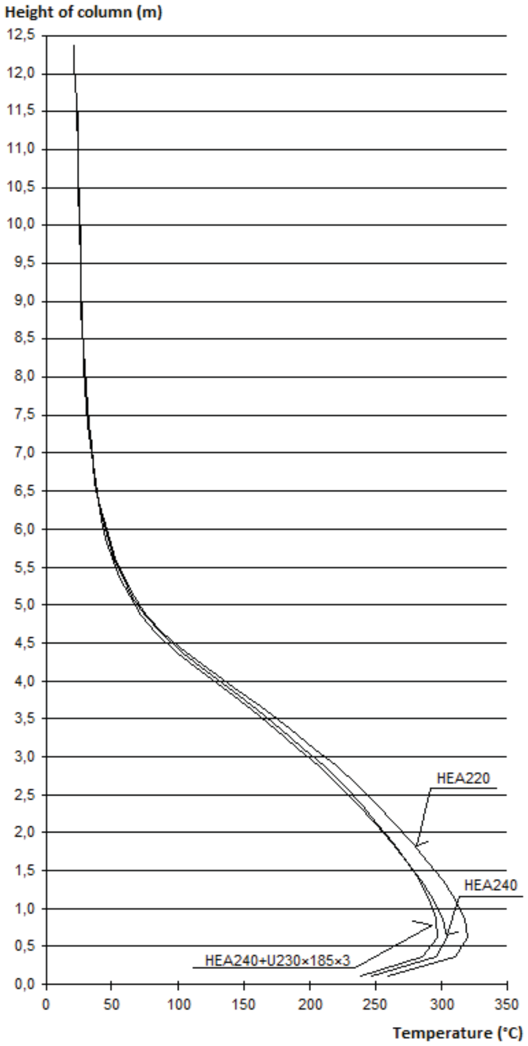

Fig. 17.12 Temperature-height dependence of column in 15 min

To calculate temperature of steel columns of cladding the fire of wooden pallets is used (the fire of high-lift truck gives lower temperature). Distance between the centre of the column and centre of the localised fire x = 1900 mm. Then face side of the column is from 285 to 295 mm from flames (depends on cross-section of the column). Columns of the cladding are of HE 220A, HE 240A, HE 240A+U230x185x3 cross-sections. Its height is 12.5 m. At Fig. 17.12 there is temperature-height dependence during the fire of wooden pallets.

Temperature of horizontal beam above the portal door is defined assuming that the fire of wooden pallets is situated under the member. Because of absence of pallets in this place the assumption is over-conservative. Temperatures of other members of cladding from hollow- square and rectangular sections are described in original report.

17.5 MECHANICAL RESPONSE OF THE STRUCTURE

17.5.1 Steel members of roof construction

Temperature in 15 min of members of roof construction does not exceed 140 °C. Reduction factor for effective yield strength $k_{y,\theta} = 1,00$. In this case resistance of the steel members is not influenced by fire. Considering lower load during the fire in comparison with load for limit state at normal temperature, the resistance of the members is satisfactory without next calculation.

17.5.2 Intermediate columns of cladding

The maximum temperature in 15 min of columns is 320 °C. Reduction factor for effective yield strength $k_{y,\theta} = 1,00$ (resistance of the steel members is not influenced by fire). Because of lower value of slope of the linear elastic range E_a the design buckling resistance is also lower. The column HE 240A is loaded by combination of compression (weight of the cladding) and bending (wind). Its length is 12.5 m, it is held because of buckling and lateral-torsional buckling by the aid of sandwich panels.

Normal force in column is $N_{E,k} = 8{,}50\,kN$ (load acts on the width of 5.625 m, sandwich panels Kingspan with PUR insulation of 70 mm, KS 1000 TF –M/MB, 11.44 kg/m^2 , 13.2 m high).

Bending moment is $M_{E,k} = 58{,}6\,kNm$ (wind speed is 26 m/s, c_e= 1,8 (III. category), c_{pe}= +0.7, $w_k = 3{,}00\,kN/m'$).

Load combination with normal force as permanent load ($\gamma_G = 1{,}00$) and wind load as variable load ($\gamma_Q = 1{,}00$, $\psi_1 = 0{,}2$) is used.

Resistance of the combination of compression and bending of the column during the fire can be calculated with following values:

slenderness at ambient temperature is $\lambda_y = 123{,}8$

non-dimensional slenderness for the temperature θ is $\overline{\lambda}_{y,\theta} = 1{,}479$

the ratio of imperfection for buckling curves is $\alpha = 0{,}65$

$\phi_0 = 4{,}149$

geometrical imperfection is $\chi_{y,fi} = 0{,}125$

Calculated column HE 240A uses up to 10 % of its resistance during the fire of wooden pallets. Regarding the same mechanical load of other columns of the cladding next calculation is not necessary.

17.6 SUMMARY

The chapter summarises the examination of fire resistance of steel structure of production and storage hall object. The fire resistance of steel trusses, stiffeners and other members of roof deck and vertical cladding are investigated. Regarding large dimensions of the hall as one compartment localised fires of wooden pallets and high-lift truck are considered. The requirement for the fire resistance of the bearing structure is REI 15. According to previous calculation all members of the steel structure satisfy the resistance requirement of 15 min without any fire protection materials. The project of examination of fire resistance of steel structure of production and storage hall object in Mnichovo Hradiště was approved without any problems by the stakeholder and authorities.

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18 REDUCING THE RISK OF TIMBER FIRES - A CASE STUDY

Summary

A case study of a ‘Serious fire’ in a Timber industry located in Northern Greece is presented. In this work summarized : ignition source, fire location, first and secondary ignited materials, fire behaviour as extracted from fire investigation report. Details from fire structure report have been given (number of occupants, product/equipment, total injuries or fatalities, economical losses information and property value at risk from the fire condition etc).

Also, it is described how existed fire safety measures behave during pre - flashover conditions. Methods to improve industry fire protection have been proposed in order to avoid spreading of fire and to minimize toxic emissions. This proposition has been validated by small and medium scale experimental work.

Fire Brigade intervention and the time taken to undertake its activities at a fire scene has been evaluated.

18.1 INTRODUCTION

This study examines a case of a ‘Serious fire’ in a Timber industry located in the industrial area of Thessaloniki. This Timber industry was complied with fire safety measures as predicted by the Greek Government Desicion (1589/104/2006) “Industrial Fire protection”. (so, it has been supplied with passive protection measures i.e means of escape, emergency lighting and signs , and active measures i.e. fire detection , permanent fire water supply network but with no sprinkler installation).The Timber industry was a 9.480 m^2 concrete building with 120 employees. Processed materials were raw wooden pine materials and final products were furniture and other wooden constructions.

18.2 INCIDENT ANALYSIS

The fire has been caused by spark friction originated in the production area below wooden pallets. First ignited materials were ‘unprotected’ wooden pallets and secondary materials were raw pine wooden material. These factors were leading to the rapid fire growth and flash over conditions. Fire almost immediately spread from first to second ignited materials. It was not contained to the room of origin and spread beyond to the whole building. Fire Compartments were inadequate to stop the fire and fire was not been be possible to be suppressed by permanent fire fighting hose reels by industrial fire staff.

Almost the whole wooden material and electro-mechanical equipment of industry has been destroyed by the fire. Estimated property loss 1,200,000 euro. On the other hand, the reinforced concrete, columns, beams performed very well in such a severe fire due to high fire resistance of reinforced concrete (above two hours). Estimated property value saved 1,000,000 euro.

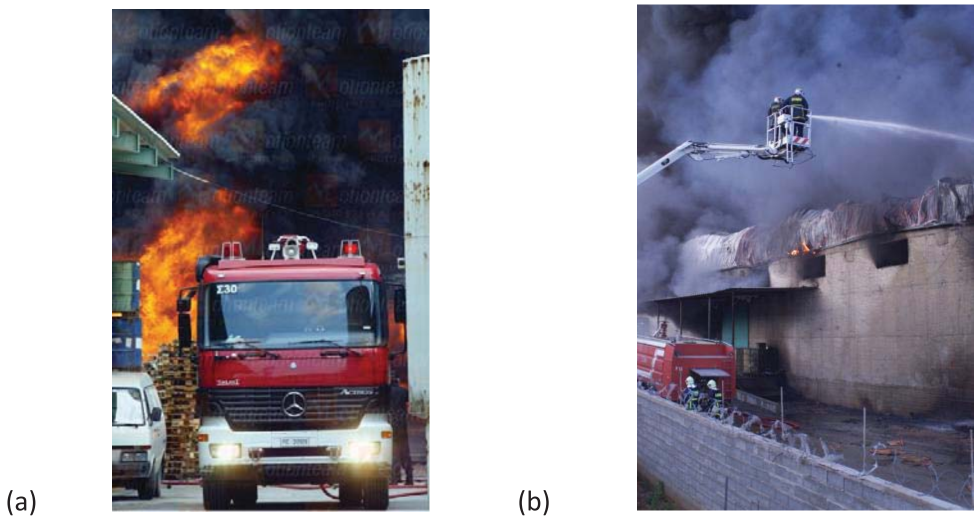

Fig. 18. 1 Fire incident during post-flashover period (a) production area , (b) storage area.

Because of the size of the fire, a site-wide evacuation was immediately initiated. Unfortunately, eight workers sustained minor injuries including scrapes and smoke inhalation.

18.3 EMERGENCY RESPONCE

The initial call reporting this incident was at 14.06 hours i.e in the middle of working day at 27-07-10. Timber complex had a trained and equipped Emergency Response Team (ERT) that included 20 members. On the day of the incident; 10 trained emergency responders were immediately available. Fire duration was eight (8) hours. Firefighters from the surrounding fire stations were in 'emergency alert' providing 25 fire vehicles with 60 fire fighters deployed at the scene of fire. Fire extinguished after eight (8) hours. In an effort to sustain firefighting operations while trying to establish a continuous water supply, tank water from multiple apparatus was transferred to the fire engines.

18.4 LESSONS LEARNED

It is clear from the above that prevention of fire spread behind the wooden first item ignited would have a significant impact on the reduction of fire losses.

In this case where the first material ignited is wood, it is considered that ignition and fire spread could be prevented or minimized by treating the timber surfaces with suitable flame retardants. Fire data on the effects of flame retardants on wooden surfaces is not available, since the relevant market is quite recent and not particularly widespread in Greece.

18.5 EXPERIMENTAL INVESTIGATIONS

Therefore, in order to investigate this possibility, commonly used timbers, untreated and treated were tested and compared using small scale (Cone Calorimeter) and medium scale (Enclosed Fire Rig) equipment combined with online effluent gas analysis equipment (FTIR). The most widely types of timber used in the Greek industry(Pine), were tested with bare samples, as well as using flame retardants (Small and Medium scale).

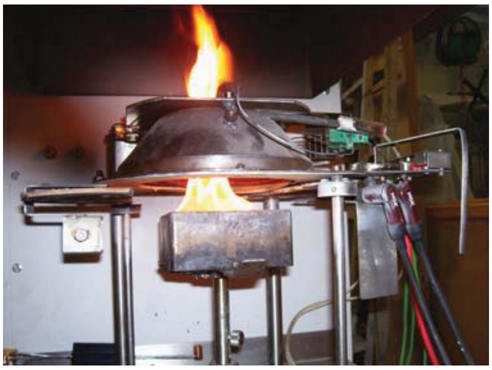

Fig. 18.2 Pine exposed at Heat flux 35kW/m2

Fig. 18.3 Untreated crib at 350sec into the test

Analysis involved thermal behavior and toxic species analysis of the samples:

- No ignition' and lower toxic emissions compared to untreated samples were observed at 35kW/m^2 (small scale).
- The same behavior was observed in those cases where wooden surfaces located next to ignition source had been treated (medium scale).
-

18.6 CONCLUSIONS

The main factors leading to the rapid fire growth and the fire spread to almost the whole building were:

- the lack of effective fire suppression measures close to ignition source,
- the untreated wooden first and secondary ignited materials

It is proposed that the application of intumescent flame retardants on wooden surfaces located close to ignition sources in the most probable areas for a fire to break out, could be a safe and effective approach in reducing fire loss in Timber industry.

Fig. 18.4 Flame retarded Pine exposed at heat flux 35kW/m2

Fig. 18.5 Flame retarded crib at 350sec into the test

18.7 SUGGESTIONS

Performing of more small- and medium – scale experiments, treated with the updated technology of the intumescent paints (different parts of wooden cribs or some other form of samples), and using various ventilation rates to achieve both establishing and documentation of the contribution of intumescent technology in fire suppression, are suggested.

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19 TO FIRE DESIGN OF 142 m HIGH BOILER HOUSE IN LEDVICE POWER PLANT

Summary

The building of the boiler house in Ledvice power plant is 81.6 x 88.5 m with clear height 139 m, see Fig. 19.1. The structure of unique power unit with output of 660 MW was built from 2009 to 2011. The underground part of construction is steel and concrete and above-ground structural steel with reinforced concrete floor slabs. The envelope of the building was created by light hooked sandwich surface in vertical part and as composed roof surface. The fire design is based on closed boiler technology and large open space inside the building with fire risk from oil medium in 49 locations.

Fig. 19.1 Erection of the boiler house building in power plant Ledvice with two concreted braced towers providing horizontal stiffness.

19.1 INTRODUCTION

The boiler house with connected two reinforced concrete towers creates production block of new source of power plant Ledvice with capacity 660 MW. The main load bearing construction forms four hollow columns with sizes 2.4 to 2.4 m with thickness of the wall 65 mm to height 51 m and the structure of the boiler itself. The thickness of the wall of the column up to 51 m height is 50 mm, see Fig. 19.2. Boiler house in terms of fire safety is building with one underground and one above-ground floor. The above-ground floor is divided in different height levels by technological footbridge.

19.2 ENGINEERING APPROACH

19.2.1 Fire safety concept

The fire safety solution, see (Bebčák 2009), covers all the asked requirements for fire hazard of industrial building. Due to atypical structural solution were asked, except of Czech National rules utilising simplified procedure, see (Reichl 2008 and 2011), also the performance based evaluation of fire resistance of the main bearing structure assuring the stability of the boiler, see (Rottschaefer 2011). The procedure was developed and the results approved at Czech Technical University in Prague, see (Sokol and Wald 2011). The building divided into eight small fire compartments, as cable, pump, and turn cocks rooms and one large with boil itself with area 6 064 m^2. In compartment of the boiler house are except of major fire load by coal in closed technology with its fire safety equipment installed the devices with oiling. Under devices with amount of oil 400 l were create the reservoirs. The major risk locations due to oil are summarized in Tab. 19.1.

Fig. 19.2 Erection of the main frame of the boiler house (29/10/2010).

Fig. 19.3 Finalised external structure on the building of the boiler house (13/2/2012).

Tab. 19.1 The major devices with amount of the oil

Technology	Number	Release oil volume (l)	Total oil volume (l)
Beater mills	8	450	3600
Air preheater	1	320	320
Force draft fan	1	400	400
Beater wheel carriage	1	300	300
Submerge scrape conveyor	1	120	120
Start up valves	2	300	600
HP bypass unit	4	200	800

The fire scenarios considered in evaluation of fire resistance are based on localised fire of installed machine equipment. The input data were derived from parameters of the installed equipment (diameter of the fire, area of the fire, fire load density, fire growth rate, rate of heat release). The fire scenario assumed for the localised fire is based on pool fire of hydraulic oil spilled on the floor because of failure of the oil pipes. It is assumed the initial amount of oil on the floor is supplied by leak of the oil to get steady burning during the period of required fire resistance, i.e. 45 min. In addition, burning of cables on cable trays is assumed to increase the rate of heat release. The fire is modelled based on rate of heat release given in (NUREG–1805). Model of localised fire according to EN 1991-1-2 Annex C is used to predict the gas and steel temperature.

19.2.2 Fire load by coal

The coal is the main fire load of boiler house even, if all the facilities are designed as closed system. Three model situation of fire of coal were taken into account, see (Bebčák 2009): the fire load by coal at level 0 m due to the accident of coal mill, at level 26 m due to conveyer belts, and at level 51 m due to coaling bunker. With automatic warning, camera systems, and the firemen's attack till 10 min it is expected free burning of coal at all three potential locations till 15 min. The required fire resistance of structures due to all installed active measures and automatic foam fire extinguishers was calculated to 30 min.

The design fire of coal mill is expected due to failure of surface structure of coal closed technology and burning all coal infilling 1000 kg. A mill is located on area of 50 m^2, which creates characteristic fire load density of timber equivalent 248 MJ/m^2 Note: According to Czech standard ČSN 73 0802: 2000 are combustible materials in checked space determined by variable and permanent fire actions, which is put out to the floor area and expressed by timber equivalent with heating value 16,5 MJ/kg. The fire load by coal on conveyer belts expect the fracture of surface structure and pour out of the material from belt. Due to automatic stop alarm it is expected to burn 500 kg of coal. The area under the longest bell is 26 m x 1,5 m, e.g. 39 m^2 which creates characteristic fire load density of 310 MJ/m^2. A coaling bunker has area 50 m^2, which allow of burning away of surface layer of about 2 100 kg of coal. This fire load creates characteristic fire load density of 193 MJ/m^2.

Due to closed system for transport of coal and the active fire measurements including gas detection it is not expected potential fire of coal combustible gases.

19.2.3 Fire load by oil

The parameters of hydraulic oil were taken from (Iqbal and Salley 2004). Parameters of hydraulic oil were modelled like more described parameters of transformer oil. Effective calorific value of transformer oil was expected as H = 46 400 MJ/kg, oil density as ρ = 760 kg/m^3, burning mass rate as m = 0,039 kg/m^2 and empirical constant – $k\beta = 0.7$ m^{-1}. The diameter D of the fire is derived from the equivalent area concept, i.e. the non-circular pool of oil is replaced by circular area of the same area.

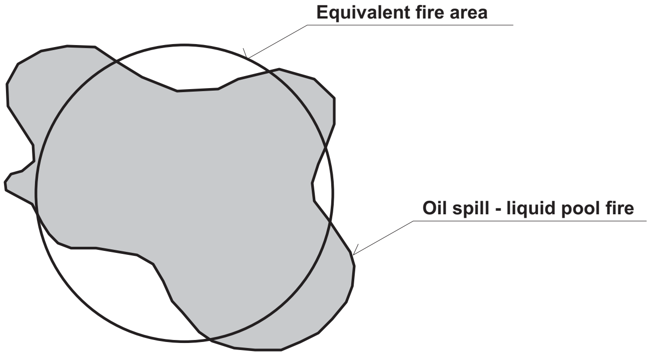

Fig. 19.4 Equivalent area of the fire

The rate of heat release of the liquid pool fire is given by

$$Q = m\,H\,A_f\left(1 - e^{-k\beta D}\right) \tag{1}$$

As the fire spreads quickly on the pool area after the ignition, the fire spreads at 10 cm/sec to 2m/sec, it is considered as simplification the rate of heat release is constant during the required fire resistance.

Duration of the fire can be evaluated according to

$$t = \frac{4\,V\,\rho}{\pi\,D^2\,m} \tag{2}$$

When necessary, the oil spill is supplied with additional oil to obtain duration of fire at least 15 min, i.e. the required fire resistance to get the maximum temperature of steel structure. The amount of oil supplied must be equal at least the amount of oil burned (the initial oil spill and increase of pool area is neglected). The amount of oil burned is given by $60mA_f\ \left(\mathrm{kg/min}\right)$ which is $60mA_f/\rho$ (l/min).

There are cables near which can be affected by the localised fire. The rate of heat release of the cable tray was evaluated from (NUREG–1805) and added to rate of heat release from the oil spill. The rate of heat release is given by

$$Q = 0.45Q_bA_f \tag{3}$$

where Q_b is rate of heat release obtained from bench tests and A_f is area of the cable tray affected by the fire. As the type of cables are not known, the PE/PVC type cables were used with $Q_b = 589$ kW/m^2. This is the most flammable cable type given in the references. It is assumed the rate of heat release from the cables is constant during the fire duration as the cables are ignited from the burning oil.

19.2.4 Temperature of steel structure

For columns in large and high compartments, the temperature of the upper part is low and the temperature of the lower part close to the heat source would be critical. The column temperature in the lower part can be calculated when the effect of heat gained from radiation and heat loses by convection and radiation to the surrounding space is taken into account. Standard step-by-step method as in EN 1993-1-2: 2005 was utilised, for the procedure see in (Sokol, 2011). The beams were fire unprotected and fire protected. The temperatures were evaluated based on EN 1993-1-2: 2005 procedure for localised fires and the transfer of heat by step by step procedure according to EN 1991-1-2: 2002.

19.3 EXAMPLE OF TEMPERATURE EVALUATION - THE COLUMN CLOSE TO THE BEATER WHEEL CARRIAGE

For the calculation it is assumed there is fire of oil leaking on the floor/reservoir. The oil spills on the surface creating a pool. After the fire starts, the pool is supplied with continuous oil leaking from broken tube or fault sealing in such amount the duration of fire is 15 mins to get maximum steel temperature. The total oil spill is 300 l, i.e. 0,300·760 = 228 kg. The diameter of the equivalent circular area of the fire is

$$D=\sqrt{\frac{4\,V\,\rho}{\pi\,t\,m}}=\sqrt{\frac{4\cdot 0{,}300\cdot 760}{\pi\cdot 15\cdot 60\cdot 0{,}039}}=2{,}88\,m \tag{4}$$

and the equivalent fire area is

$$A_f=\frac{\pi\,D^2}{4}=\frac{\pi\cdot 2.88^2}{4}=6.51\,m^2 \tag{5}$$

The rate of heat release of the liquid pool fire is given by

$$Q=m\,H\,A_f\left(1-e^{\;k\beta\,D}\right)=0.039\cdot 46\,400\cdot 6.51\cdot\left(1-\mathrm{e}^{-0.7\cdot 2.88}\right)=10\,218\,\mathrm{kW}\;. \tag{6}$$

The rate of heat release from cables is calculated for estimated fire area of the cable trays equal to the total fire area A_f.

$Q=0.45\cdot Q_b\cdot A_f$=0.45·589·6.51=1727 kW. (7)

The total rate of heat release (oil and cables) is

Q=10218+1727=11945 kW. (8)

The length of the flame, see Fig. 19.5, is

L_f=-1:,02D+0:,0148$Q^{2/5}$=-1.02·2.88·+0.148·11945000$^{2/5}$=7.09 m. (9)

The virtual origin z_0 is

z_0= -1,02·D+0,00524·$Q^{2/5}$=-1.02·2.88+0.00524·11945000$^{2/5}$= 0.612 m. (10)

and the temperature along the height of the flame is

θ_g=20+0.25$Q_c^{2/5}(z-z_0)^{-5/3}$=20+0.25·(0.8·11945000)$^{2/5}(z-0.612)^{-5/3}$=20+154.9·$(z-0.612)^{-5/3}$. (11)

but limited to 900°C.

The column centre is located at distance 2.4 m from the centre of the localised fire. If the distance from the fire to the column increases the column temperature would be smaller. The maximum column temperature at time 15 mins is reached 2.6 m above the floor, the temperature is 169°C, see Fig. 19.6. The calculation indicates the column temperature does not exceed 350°C even during 45 mins of fire exposure if the fire would continue to burn at the same rate.

19.4 SUMMARY

The contribution summarises the approach for evaluation of temperature of steel structure of the boiler house in the power plant Ledvice, which supports the Fire safety solution of the building.

Acknowledgement

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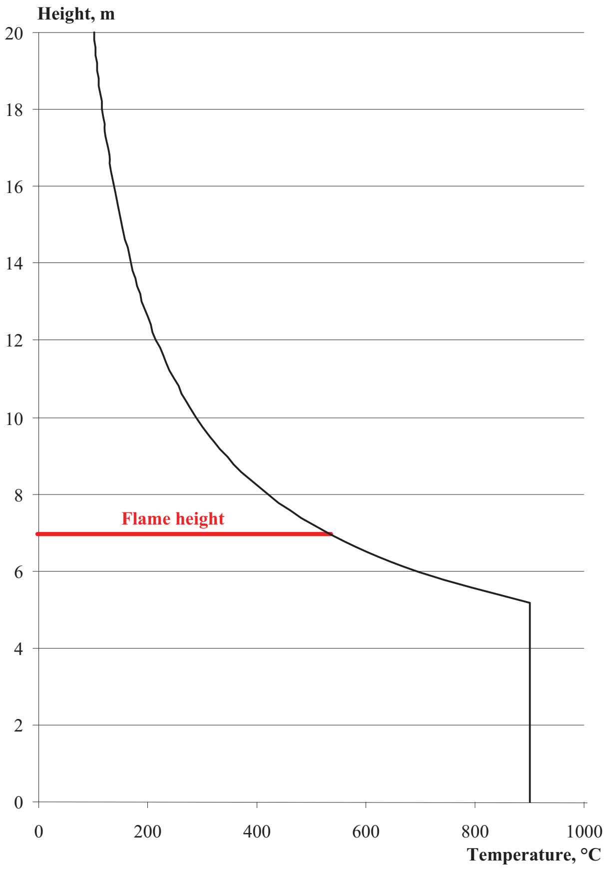

Fig. 19.5 Temperature along the flames, fire of beater wheel carriage

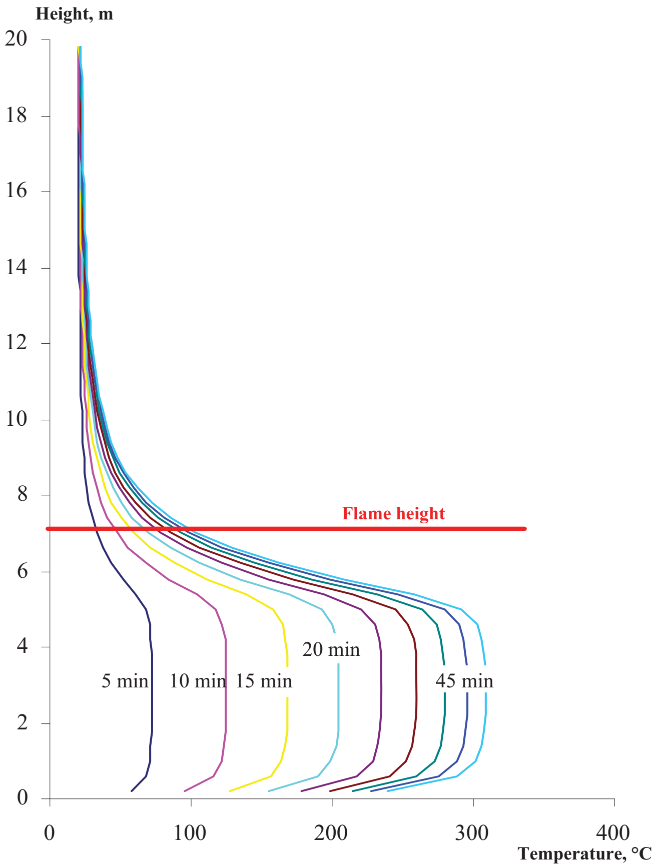

Fig. 19.6 Temperature of column RHS 1000×20, fire of beater wheel carriage

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20 A PRACTICAL APPROACH TO STUDY OF FIRE RESISTANCE OF A STEEL STRUCTURE WITH OPEN BUILT-UP MEMBERS AND COLUMNS

Summary

The case study exposes a practical evaluation of fire resistance of an old structure of Spanish industrial building composed of steel built-up members; the truss members are angles connected through packing plates and the columns are battened chords.

A simple calculation model was used element by element. First, heat is transferred to individual steel elements by convection and radiation in thermal study. The contributions of these two modes of heat transfer were treated by a practical approach. In mechanical study, the second order analysis was used with global imperfections. Finally, the fire resistance was evaluated R15 after some proposals.

20.1 PRECEDENTS OF THE CASE

The analyzed industrial building is a steel workshop that was erected more than 25 years ago. In the past, there were no specific mandatory rules in Spain to regulate this kind of industrial structures against fire, consequently the fire resistance *was* not taken into account in the structural design process.

In 2006, in order to renovate the activities permissions, the authorities requested the company to be in accordance with the current Spanish standard for industrial buildings (RSIEI, 2005). Following this standard, the requirement was to resist 15 minutes in an ISO 834 standard, R15. The Spanish standard (RSIEI, 2005) allows the use of Eurocode 3 (EN 1993-1-2, 2005) for checking structural fire resistance.

The company contacted the university in order to know if the current structure could be able to resist R15 without any specific fire protection.

20.2 BUILDING DESCRIPTION

The structure of this industrial building is made by several frames separated 5m between them. Each frame has 17,2m of span and the total length and total surface of the building are 76,2m and 1341,5m^2 respectively. The frame is symmetric about its centre. Fig. 20.1 below, shows a detail of geometry (Tekla, 2011).

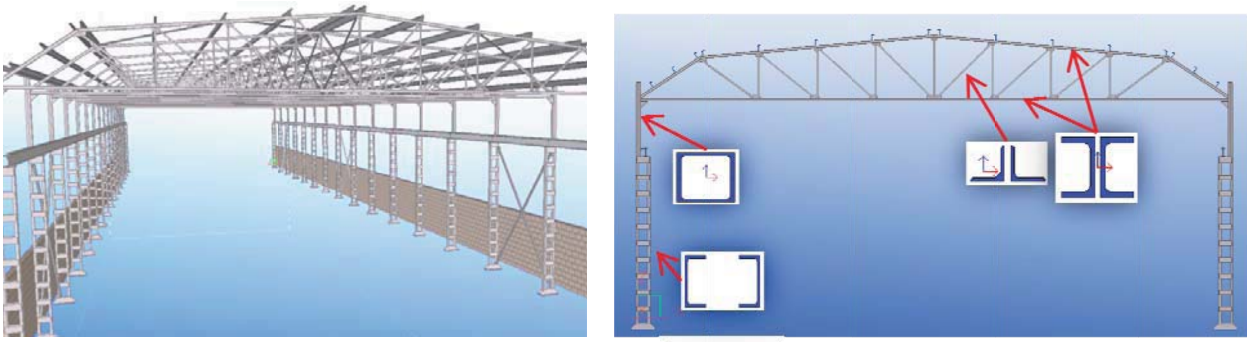


Fig. 20.1 Built-up members of the frame

Columns consist of battened built-up members of 7m height using two UPN 160 profiles, being separated at the part bellow the crane runway beam, and being a closed box above it. The column is fixed to the foundations and pinned to the truss. The upper and bottom chords of the truss are made by closely spaced built-up members using two UPN 80 profiles. They are connected through packing plates. The web members of the truss are spaced built-up members made up of battened equal angles L 40.4 or L 50.5.

Along the longitudinal direction, a resistant wall of 2,4m height offers a protection from the wind forces up to this height. As shown in Fig. 20.2, the longitudinal bracing systems in the walls and the roof provide fixed points to the frame; columns and truss. This construction results in a very light structure of 0,23 kN/m^2.

Fig. 20.2 Conventional bracing systems in the walls and rafter

20.3 ASSUMPTIONS FOR THE ANALYSIS AND REGULATORY REQUIREMENTS

The simple calculation model member by member was used to proceed in the resistance domain (EN 1993-1-2, 2005). This method is based on some appropriate hypotheses for their application to single structural members, for instance:

- No interaction between thermal and mechanical actions. Thermal and mechanical problems are solved independently.
- Effects of axial or in-plane thermal expansions may be neglected.

First, in thermal study, the uniform fire standard ISO834 was assumed for external temperature of the truss and columns in order verify R15 requirements (Fig. 20.3)

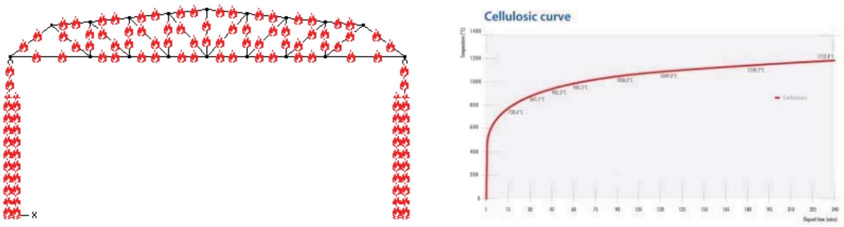
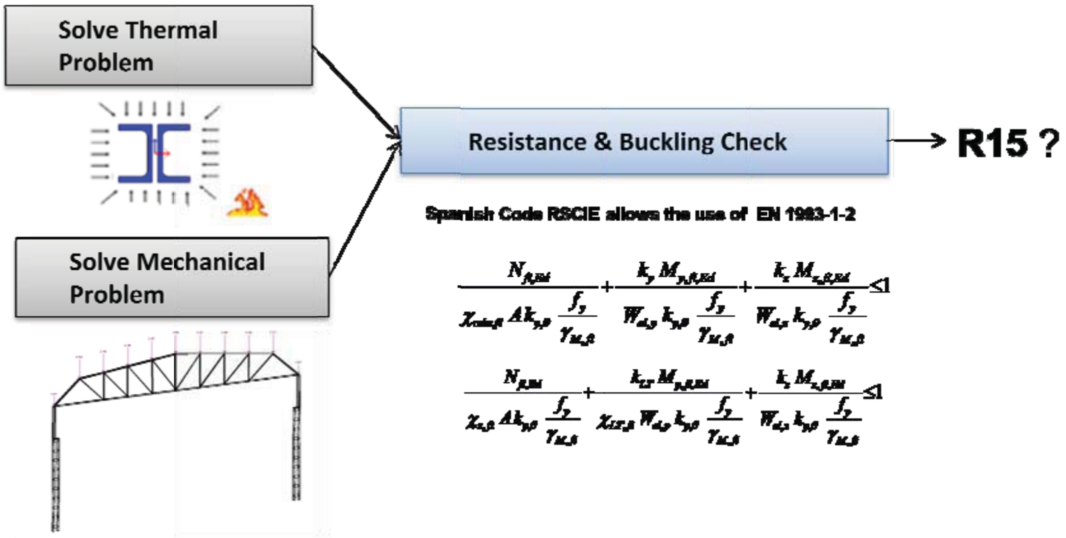


Fig. 20.3 Uniform fire standard ISO834 in the structure

Then, a global second order elastic analysis was carried out with constant elastic modulus for steel at normal temperature design, 20ºC. The boundary conditions at supports were assumed to remain unchanged throughout the fire exposure. Finally, the resistance and buckling were checked according to Eurocode 3 Part 1-2 (EN 1993-1-2, 2005). The Fig. 20.4 shows the procedure scheme.



$$\frac{N_{fi,Ed}}{\chi_{min,fi} A k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} + \frac{k_y M_{y,fi,Ed}}{W_{el,y} k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} + \frac{k_z M_{z,fi,Ed}}{W_{el,z} k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} \leq 1$$

$$\frac{N_{fi,Ed}}{\chi_{z,fi} A k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} + \frac{k_{LT} M_{y,fi,Ed}}{\chi_{LT,fi} W_{el,y} k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} + \frac{k_z M_{z,fi,Ed}}{W_{el,z} k_{y,\theta} \frac{f_y}{\gamma_{M,fi}}} \leq 1$$

Fig. 20.4 Scheme of simple calculation model in resistance domain

20.4 RESOLUTION OF THE THERMAL PROBLEM

To solve the thermal problem and to know how the temperature increases in the specific built-up sections, we have used commercial finite element software. It allows the simulation of transient heat transfer in 2D free-form objects (Brista-Physibel, 2011) where the view factor is based on non-linear radiation, and the empirical convection in enclosures and boundaries. In practice, the results were very similar as use the conventional concept of the correction factor for the shadow effect for sections under nominal fire actions (EN 1993-1-2, 2005). Other models based in partial heat radiation, limited inside of built-up sections, were not considered since lower temperatures were obtained. Finally, Fig. 20.5 shows the temperature results for each cross section type after ISO 834 fire curve.

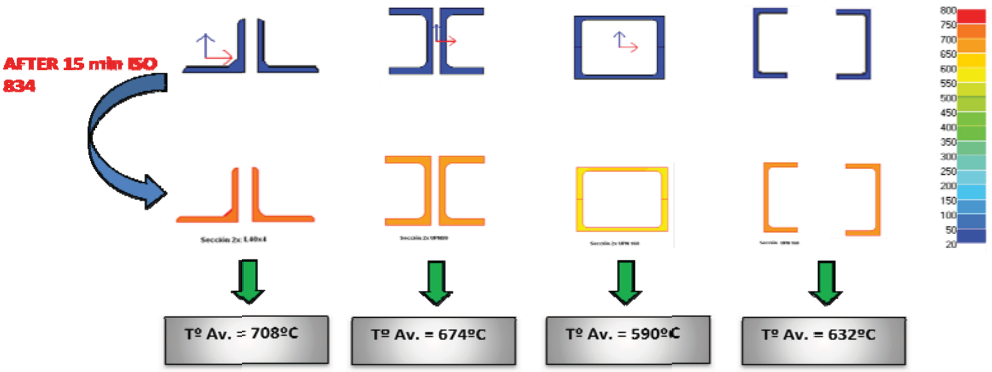


Fig. 20.5 Temperature distribution in built-up members after 15 minutes fire standard ISO 834

20.5 RESOLUTION OF THE MECHANICAL PROBLEM

A 2D model was used to solve global analysis and to know the internal mechanical efforts in a fire scenario, using the second order analysis by conventional structural software (PowerFrame, 2011). The frame is fixed in the longitudinal direction by the bracing systems. The next sub steps have been done:

20.5.1 Model

The truss beam members have modeled as their center of gravity axis lines with their respectives built-up sections in the software. In order to obtain more realistic efforts, the columns have been modeled as two different lines for each UPN chord connected by the battens in their real positions (see Fig. 20.6)

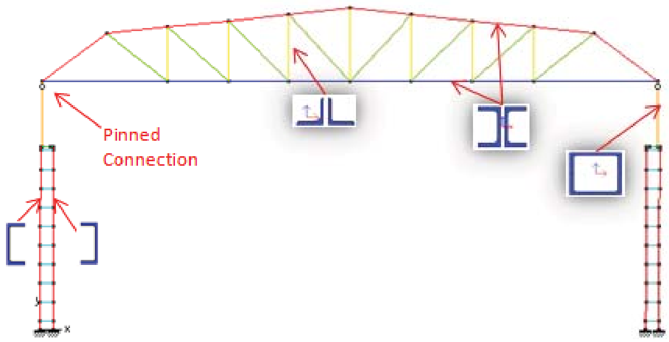


Fig. 20.6 The built-up columns were simulated by individual beams in a conventional global 2D model

Rigid links has been introduced in the model, as showed in Fig. 20.7, in order to take into account the eccentricities due to the change of section in battened columns and the exact position of the load from crane.

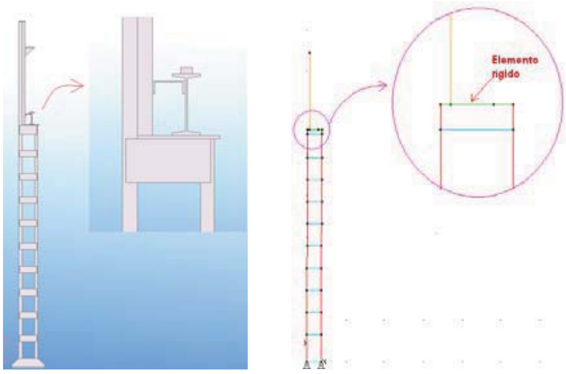


Fig. 20.7 Eccentricities of crane beam loads

20.5.2 Applied loads and relevant combinations

All loads taken into account are shown below. It must be said that loads for all kind of buildings have to be in accordance to the Spanish Technical Code (CTE, 2006), which describes climatic loads, majority factors and load combinations in fire scenario (see Fig. 20.8 and 20.9). Special considerations were done for the crane in fire scenario, only self weight of the crane and its accessories were used in two relevant positions (Fig. 20.10)

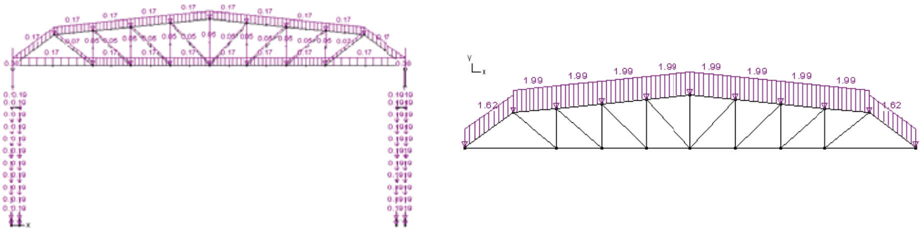


Fig. 20.8 Self weight, permanent loads and snow loads

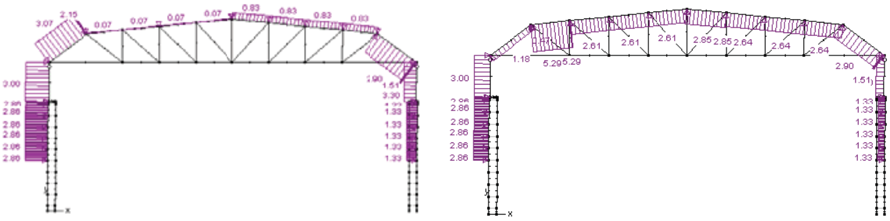


Fig. 20.9 Wind loads; two load cases from Spanish Technical Code (CTE, 2006)

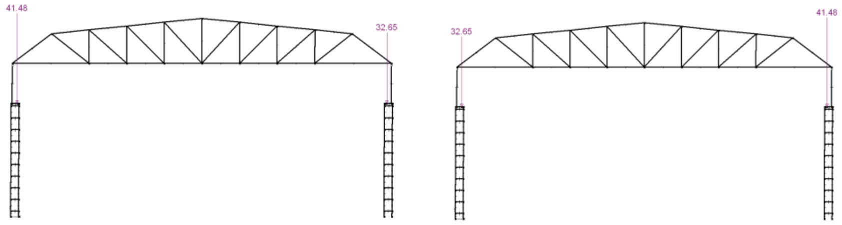


Fig. 10 Loads from the crane in fire scenario for two relevant positions

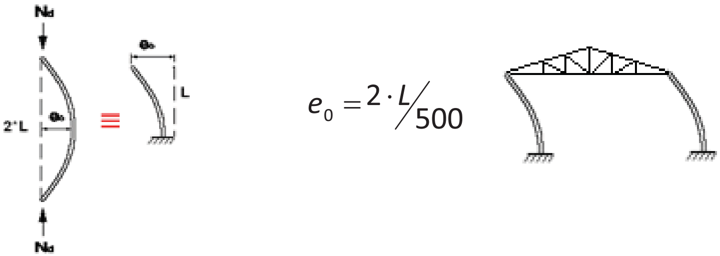
The effect of actions was determined using combinations factors $\psi_{1,1}$ and $\psi_{2,i}$ according the Spanish Technical Code (CTE, 2006):

$$\Sigma G_{k,j} + \psi_{1,1} Q_{k,1} + \Sigma \psi_{2,i} Q_{k,l} \tag{1}$$

These values have significant differences front the recommended national values of Eurocode. For instance, in case of wind action the factor $\psi_{1,1}$= 0,5 versus recommended national value $\psi_{1,1}$= 0,2 from Eurocode.

20.5.3 Analysis Type

A global second order elastic analysis, including global imperfections at the top of the columns, has been carried out. No information was found about special indications to apply global imperfection in battened columns under fire conditions; so, the common value L/500 for standard conditions was used.



$$e_0 = 2 \cdot L / 500$$

Fig. 20.11 Imperfection e_0 used in battened built-up columns

20.5.4 Flexural buckling critical length in members

The existence of two possible buckling planes shall be taken into account, requiring different checks. As long as the simplified method is used to solve the fire problem, the common buckling critical lengths used in non fire cases were implemented.

- Buckling lengths in upper chord of truss. The length of each split member for the buckling in the plane (β_y=1) was taken as buckling length. For the out of plane buckling, the original bracing system was modified to fix every node out plane (β_z=1). No considerations of diaphragm effect are considered.
- Buckling lengths in bottom chord of truss. There is no compression.

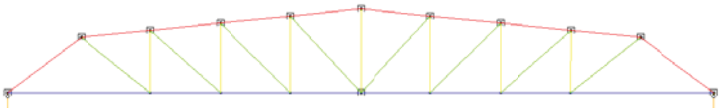


Fig. 20.12 Fixed points for out of plane flexural buckling of truss members

- Buckling lengths in battened columns. Plane buckling length of chords of columns is equal to the distance between two battens (β=1) because a second order analysis was carried out with global imperfection (see 20.5.3). In order to know the out of plane buckling length of the columns, a eigen buckling analysis was carried out using the commercial software (Consteel, 2011) (see Fig. 20.13). The second eigenvalue was used to calculate the out of plane buckling length. It was necessary a modification of original bracing system. No diaphragm effect was considered.

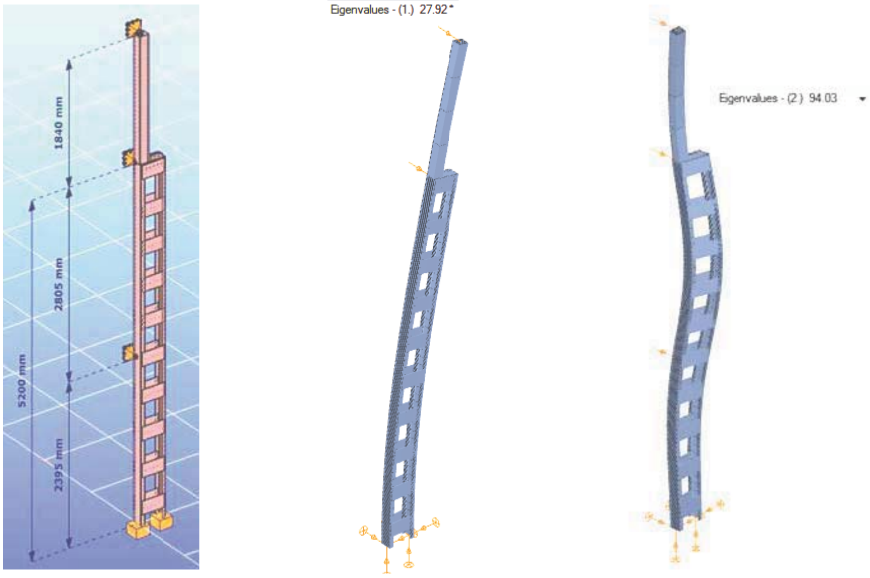


Fig. 20.13 Model with boundary restrictions and the first (in-plane) and second (out-plane) buckling modes

20.6 CHECKING ALL MEMBERS OF THE FRAME

For verifying standard fire resistance requirement, for instance R15, a member analysis is enough. Each member of the frame is checked at calculated temperature and compared with the efforts in fire scenario (EN 1993-1-2, 2005):

$$E_{fi,d} \leq R_{fi,d,t} \qquad (2)$$

20.7 CONCLUSIONS

Spanish standard for industrial buildings lets the engineer to apply modern concepts of fire engineering and allows the use of structural Eurocodes. A prescriptive requirement for structural resistance of old industrial Spanish building was verified. This building had a problematic light structure composed of steel built-up members. The thermal and mechanical study of these open members was treated by a practical approach using several commercial software. The simple calculation model in resistance domain was enough to verify the requirement of R15. Only the bracing system must be reconsidered.

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21 QUESTIONABLE FIRE SAFETY ASSESSMENT OF THE BAKERY PLANT BUILDING

Summary

The building broader presented in this paper is a bakery plant consisting of several premises of a different purpose and method of use, e.g.: technical facilities, production depot, distribution and storage spaces, long-term storage cool rooms, etc. The whole building that consists of single-storey technological (production and storage) part and (located on two storeys) office parts was approved as a singular fire zone with a total usable area of 6 280 m^2. The technological area includes production facilities, storage depots of raw materials, packages and finished products, as well as cold stores and a number of auxiliary function rooms. In the second (having two storeys)part of the building some social rooms, administrative areas and offices are localized.

The total height of the building (at the highest point) does not exceed 10.5 m. Due to the Polish regulations the parameters determining the fire-related requirements of individual structural elements of the building (especially in terms of their fire resistance) are the surface area, the average value of the fire-load density and the presence of the risk of possible explosion. The building was designed based on the assumption that the average fire-load density does not exceed the level of 1 000 MJ/m^2. The analysis and calculations carried out during the exploitation phase of the building confirmed the compatibilitywith the assumptions adopted, but the actual volume, estimated at the level of 974 MJ/m^2 proved to be very close to the limit value. Exceeding of the limit value of 1000 MJ/m^2 – due to provisions given in a state regulations - would automatically double the formal requirements for the resistance of the structural elements from R30 to R60. When assessing the real risk, especially in case of the large-surface-area buildings with varying ways of use of the premises, the average values of fire-load density may not properly reflect the real threat of fire. This is confirmed in the present facility, where in approximately 47% of the total area of the building the fire-load density doesn't exceed 100 MJ/m^2. Surfaces for which the fire load density exceeds 4000 MJ/m^2 (in extreme cases, it's 5644 MJ/m^2) represent only about 11% of the total area. It is worth mentioning that the fire-load density exceeding 4000 MJ/m^2 due to the national regulations and codes of design must meet the criterion of R240. A completely separate issue is the fact that the oldest part of the building was completed in violation of some basic technical and construction requirements, so that the structure of this part of the building currently does not meet any criteria for fire

resistance. This prompted the owner to implement some solutions that will not only lead the property to become fully consistent with the state regulations but also raise the level of security over the required standards, especially in the areas particularly vulnerable to fire. Presented case study shows that the method of determining the requirements for fire resistance, especially based on the average value of fire-load density, in selected cases can lead to significant underestimations and result in incorrect assessment of a building fire safety.

21.1 GENERAL BUILDING DESCRIPTION

The building presented in the paper is a free-standingbakery plant building, consisting of single-storey production hall with two mezzanines locatedin two separated zones of production part, and the internal patio as well as a two-storey part containing the staff rooms for employeesand office rooms.

Fig. 21.1 General view of the bakery plant building

In a production depothave beenlocalized some technological lines for bread production, storage spacesfor raw materials, packaging and finished products areas (including long-term storage cool rooms for storing bread at temperatures of about -25°C). In addition, in this part of the building designers also predicted other auxiliary facilities, such associal rooms for employees, and both electrical or repair shops, garage offorklift trucks, and a number of technical areas housingchillers, water treatment plant, electrical switching station, boiler room and air compressor operating a pneumatic transport of flour.

The ground-floor of the two-storey office part houses reception room, security agency office and hygienic rooms as well as restroom facilities for workers. On the second floor of the building a social and administrative area is located.

Functionally plant can be divided into *technological part* and the *social-administrative office part* (Fig. 21.2).

The technological part is consisting of:

✓ the storage-room of raw materials,
✓ silos for flour (2 external and three inside the building),
✓ two independent production lines,
✓ the packaging warehouse,
✓ a refrigerated warehouses and related technical areas,
✓ the storage of finished retail products with a distribution centre,
✓ the washing station for container boxes.

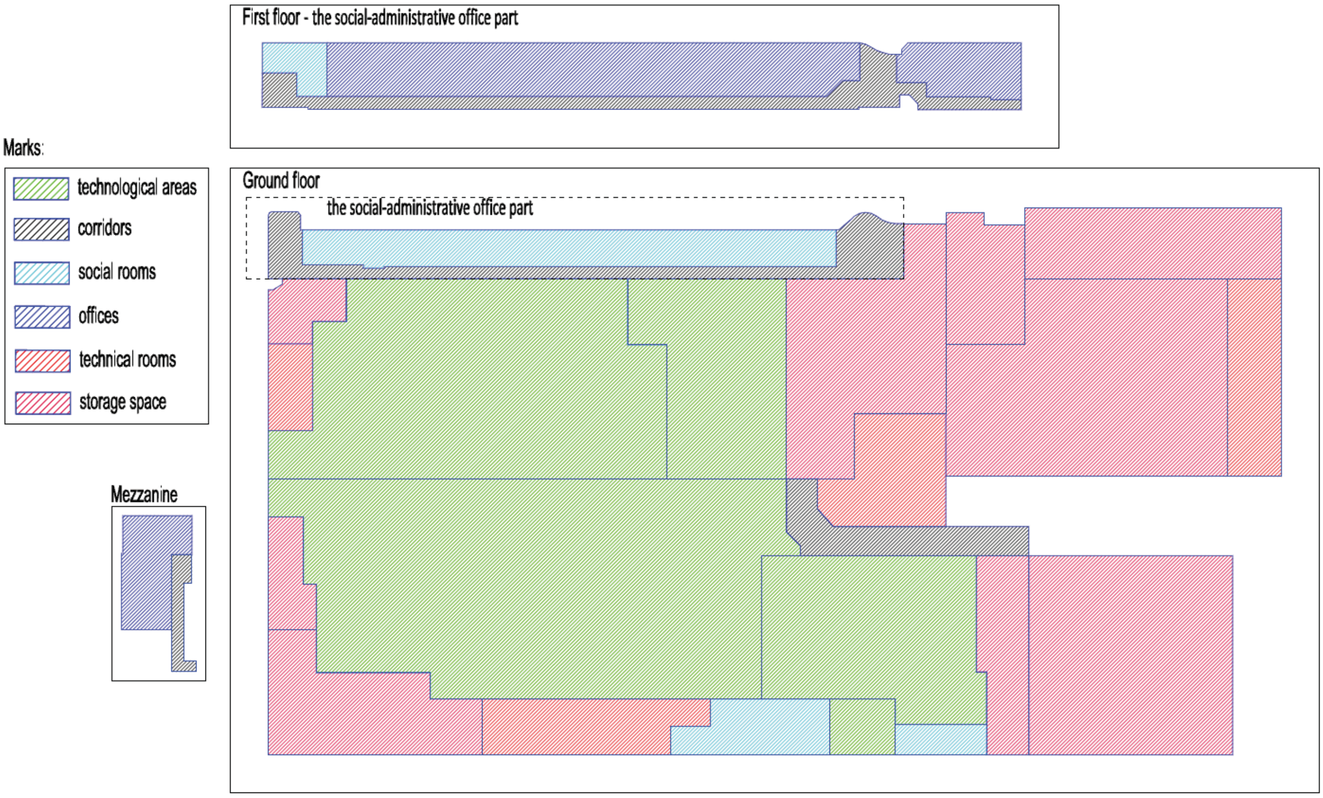

Fig. 21.2 Function of premises

The building in its present form was erected in three stages (Fig. 21.3). Initially, it was the production hall only, which was then extended to other facilities areas as the hall for the second production line and the social-administrative office part. Ultimately, in the last stage - the warehouse for retail products and a new washing station for container boxes were built.

The building was erected as of the steel structure object. Curtain walls and internal partitionshave beenmade of sandwich panels and the roof is finished with trapezoidalmetal sheets with appropriate thermal insulation layers. The social-administrative office part uses mixed steel and reinforced concrete structure, supported at the one end on the main structure of the technological (production) hall. Curtain walls have been designed as a multi-layered structure–built with clay brick tiles, insulated with polystyrene boards and finished with clinker. Partition walls are made of brick or plaster-cardboards. Roofing is finished with sandwich panels with trapezoid sheets located on both sides. The wall located between the office and technological partshave been made of sandwich panels.

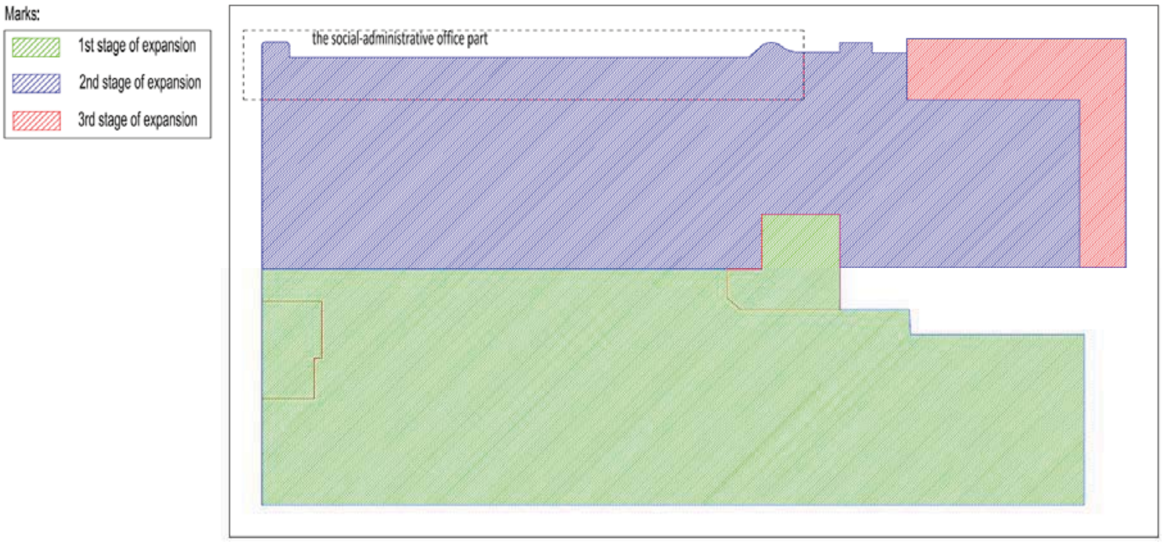

Fig. 21.3. Stages of expansion

The number of employees of the plant fluctuates around 189, while at the same time about 65 people may stay in the building.

The property now forms a vertical projection of the rectangle-like shape with external dimensions of 127m x 67m. As it was mentioned before building height does not exceed 10.5 m and the usable area is equal 6 280m^2.

21.2 FIRE SAFETY ENGINEERING SOLUTIONS USED

According to available documentation, despite the fact the building consists of premises of different functions, the object has been designed to function entirely as a wholein which it was assumed that:

- the fire load density does not exceed 1000 MJ/m^2, and
- does not contain any spaces and hazardous areas.

Due to Polish regulations and considering assumptions given above,it is allowed to assess the building as a singular fire zone. In the newest part of the property (storage and distribution of retail products area and washing station for container boxes) the structure was protected using the intumescent painting system to ensure designed flame resistance level.

The building is equipped with a fire plumbing system, which in the social-administrative office area and in the technological area located in the oldest part of the object, is finished with hydrants DN25. In the remainingparts of the building the fire hydrants type DN52 have been installed. The property is also equipped with an electric current fire breaker.

Important from the viewpoint of evacuation safety is the fact that the maintenance of refrigeration equipment in the facility uses ammonia system. For this reason, in the room where the chillersare located have been installed asystem of ammonia leak detection and signalling, as well as the mechanical ventilation. Some escape masks with ammonia absorbent filters were deployed in the building to ensure the emergency escape in case of ammonia system’s failure.

The emergency lighting lamps have been positioned along the emergency exit to facilitate the exit of the building by employees in case of emergency.

Evacuation of the building was planned by a number of emergency exits leading directly out of the technologicalpart of the propertyand through the two staircases in the social-administrative office area. In the walls between the staircases and corridors the fire doors of EI30 fire resistance were mounted. The corridor wasprotected with a smoke insulating door mounted in a halfway of its length.

In addition, in a close neighbourhood of the building four external fire hydrants were placed (powered by deep well which is the main source of water for technological purposes and the living), which provide a security source of water to extinguish the fire for the fire service.

21.3 REGULATORY REQUIREMENTS

Due to the Polish state legislative regulations the classification of buildings for fire safety is based on the *total height* and *the way, the building is used*.The buildingsin general are divided into five groups: *low* (no higher than 12m), *medium-high* (more than 12m to 25m), *high* (more than 25m to 55m) and *high-rise* buildings (over 55m).

After determining the *primary way of use* or *function of the building*, one can assign it to one of three categories: *risky to humans* (objects where the primary function is associated with at least temporary stay of people), *manufacturing* - *warehouse* (where the primary function is to produce and/or storage) and *livestock* (designed for plant growing and/or animal breeding).

Due to presented rules the object in question, described in the paper, should be classified as the“*low”* building (below 12m of height). Uncertainty may arise in assessing the primary function and qualifying it dependently on the way of usage. There are no special doubts about the fact, that part of the building serves as the technological production and warehouse zone. The question arises how about the social-administrative office area? This is the area which primary function is associated with its occupation by people for more than 4 hours/day. In such cases, the technical state regulations require the separation of different parts of building with various functions as a separate fire zones, unless they are linked functionally.

Except the two previously mentioned parameters there are two other ones that have a direct impact on fire protection requirements for production/storage buildings: the *presence of the risk of possible explosion* and the *average value of fire-load density*.

As mentioned earlier, the object wasdesigned and built to function entirely as a whole with the fire-load density less than 1000 MJ/m^{2}which do not contain any hazardous areas or spaces. In terms of height the building has been classified as a *"low"* category , due to way of use as the production/warehouse industrial object.

These are relatively comfortable assumptions, which allow the design and execution of the object as a singular fire zone (with no separate fire zoning for office and technological areas), while putting little demands in terms of fire resistance for the main construction of which will be discussed later.

Having information about a classification of a building, based on its height and the density of fire-load one can determine the so-called *"class of fire resistance"* (denoted by one of the five successive letters of the alphabet: A, which is the highest to E, which is the lowest). Assignments are made based on Tab. 21.1, below.

Tab. 21.1. The required global fire resistance class of a building

Maximum fire-load density in a fire zone of the building Q [MJ/m^2] *1*	Single-storey building (without limitations of height) *2*	Multi-storey building			
		low **(L)** *3*	Medium-high (MH) *4*	High (H) *5*	High-rise (HR) *6*
Q =< 500	"E"	"D"	"C"	"B"	"B"
500 < Q =< 1000	"D"	**"D"**	"C"	"B"	"B"
1000 < Q =< 2000	"C"	"C"	"C"	"B"	"B"
2000 < Q =< 4000	"B"	"B"	"B"	*	*
Q > 4000	"A"	"A"	"A"	*	*

The legislation contains a number of cases in which the required class of fire resistance can be lowered or when it should be increased. Directly from a determined class of the global fire resistance precise requirements for fire resistance of individual building components can be derived, as shown in Tab. 21.2, below.

Tab. 21.2. Requirements for the majorstructural elements regarding criteria for theglobal fire resistance class

Specified Fire Resistant Class of a Building	**Fire Protection Requirements for Major Structural Elements of Buildings (rates in minutes)**					
	Main supporting structural members (columns, walls)	Structure of the roof	Floor slab	External wall	Internal wall	Roof finishing layers
"A"	R 240	R 30	REI 120	EI 120 (o-i)	EI 60	R E 30
"B"	R 120	R 30	REI 60	EI 60 (o-i)	EI 30	R E 30
"C"	R 60	R 15	REI 60	EI 30 (o-i)	EI 15	R E 15

"D"	**R 30**	**(-)**	**REI 30**	**EI 30 (o-i)**	**(-)**	**(-)**
"E"	(-)	(-)	(-)	(-)	(-)	(-)

It should be noted that in this specific case no additional solutions that make it possible to reduce the required fire resistance class D were applied and thus the supporting structure must meet the criterion of R30 in case of fire.

On the basis of aclassification of a building, based on its height and the value offire-load density one can also set an acceptable fire zone area in the facility. The final value is dependent not only on the mentioned parameters but also on a number of storeys and the presence of zones with risk of possible explosion. These relationships are summarized in the Tab. 21.3, below.

Tab. 21.3. Allowablesize of a fire zone

Type of fire zone	Fire-load density Q [MJ/m^2]	Allowable size of a fire zone [m^2]		
		In a single-storey building (without any limitation of height)	**In a multi-storey building**	
			Low & Medium-high (L) and (MH)	High & High-rise (H) and (HR)
1	2	3	4	5
Fire zones with potentially explosive premises	Q > 4 000	1 000	*	*
	2 000 < Q ≤ 4 000	2 000	*	*
	1 000 < Q ≤ 2 000	4 000	1 000	*
	500 < Q ≤ 1 000	6 000	2 000	500
	Q ≤ 500	8 000	3 000	1 000
Remaining fire zones	Q > 4 000	2 000	1 000	*
	2 000 < Q ≤ 4 000	4 000	2 000	*
	1 000 < Q ≤ 2 000	8 000	4 000	1 000
	500 < Q ≤ 1 000	15 000	**8 000**	2 500
	Q ≤ 500	20 000	10 000	5 000

As seen above, allowable area of the fire zone in this building is equal 8 000m^2. As with the requirements for fire resistance, the surface can be changed using the appropriate solutions in terms of fire protection systems (e.g. smoke removers or permanent fire extinguishing devices).

21.3.1 Requirements for the evacuation

Polish regulations impose an obligation to ensure the evacuation of any room that may be occupied by people. By this it is meant to enable a safe emergency exit to leave the building, either directly or through channels of general communication to any safe place outside the building or to an adjacent fire zone. The law differentiates between the two parameters of the length of an escape route: *transition routes* and *access routes*.

The transition routes apply for rooms and spaces where there are no separate corridors. The length is measured from the farthest place where the individual human being can stay, to the exit on an escape route (corridor), or to another fire zone, or outside the building. Measurement should be made by the shortest possible route. In the case concerned, length of the transition route should not exceed 75 m. One can increase the permissible length of about 25% but only in areas with a height exceeding 5 m. It should be noted that if in a building there would be a room of potentially possible explosionit's permissible length of the evacuation passage is then reduced to 40m.The evacuation route must be of adequate width to be calculated in proportion to the number of persons for whom it is designed, taking at least 0.6 m per 100 people, but not less than 0.9 m. In the object in question the latter condition applies.

The access routes shall be measured in the axis of an escape route starting from the exit out of the room on this route up to the exit to another fire zone, or outside the building, or the enclosed stairway. The stairway should be then closed by the door of the fire resistance class EI30 at least, and equipped additionally with devices to prevent against smoke accumulation or used to smoke removal. In case of presented building, the length should be 30m when only one access route is provided (including no more than 20m of the horizontal escape route) or 60m with two or more routes designed. In the latter case it's allowed that the length of the second access route can be about 100% greater than the shortest one in the same fire zone. These access routes cannot overlap or cross with each other. With the presence of explosion endangered areas, what seems the crucial role in case of presented building, the length of access routes should be reduced to 10m when exists only one access route or to 40m with two or more routes designed.

Moreover, due to technical and building-related regulations:

- total width of the door, which exits from the room, should be calculated in proportion to the number of people who can reside inside at the same time, taking at least 0.6 m of width for 100 people, but not less than 0.9 m,
- minimum width of staircase should not be less than 1.2 m and the width of landing not less than 1.5 m - both values are measured in the most unfavourable location and finally the total required width is determined according to the rule providing of 0.6 m for every 100 people,
- an emergency exit door of a building designed for more than 50 people should open outwards,
- width of the outside door mounted on the emergency exit of the building (unless they are not the only exit from the separate room), and the width of the door to escape through the stairway leading outside the building or to another fire zone, should not be less than the required width of a staircase (in case of the concerned building - 1.2 m).

21.3.2 Requirements for fire equipment and other installations

Due to the fire requirements in the concerned building, fire equipment comprises of:

- fire plumbing equipped with hydrantstype DN52 (in the production part of the building) and DN25 (in the officezone),
- fire power switch.

The building is also equipped with a gas installation. The gas is used in a gas boiler with a capacity of 340 kW and in the process of baking. According to the state technical requirements - when the total nominal output of gas appliances installed is greater than 60 kW then such areas should be equipped with signalling installation and shut-off the gas supply devices. A valve shutting-off the gas supply, which is a component of signalling installation and shut-off devices should be located outside the building, between the main valve and the entrance of gas pipeinto the building. Additionally, the building concerned also requiressome water for fire protection provided, (in the volume of 40 dm^3/s), and convenient access for the fire-fighting brigades, i.e. the fire road.

21.4 ASSESSMENT STRATEGY

The basis for the verification of previously mentioned formal technical and fire requirements has become the idea to extent a building with a small storage space for baking molds. The room was to enlarge the existing fire zone which, according to Polish regulations means that a building must meet current fire safety requirements, regardless of legal status at different stages of reconstruction. Due to the owner's wish -next tothe review of existing current solutions for compliance with fire safety rules some assessment was made what level of safety all these solutions provide. Assessment for compliance of applied solutions with current fire safety rules and evaluation of security level of the building were based on the so-called *"Terms of fire protection"* given in form of fourteen key-points defining the main requirements for building fire safety, i.e.:

1. Size of floor area, height and number of storeys,
2. The distance from neighbouring objects,
3. Fuel/thermal parameters of present flammable substances,
4. Fire load density,
5. Category of building understood as the substitute of risk to people, estimated number of persons enable on each floor and/or individual rooms,
6. Assessment of explosion risk at rooms and outdoor spaces,
7. The way the object is divided onto separate fire zones,
8. Global fire resistance class of the building, fire resistance class of building components and the degree they spread the fire,
9. Conditions of evacuation, emergency (evacuation and backup) and obstacle lighting systems,
10. The applied methods of fire protection to protect the service installations,

11. Selection of fire-fighting equipment used in the building,
12. Number and type of fire extinguishers the building is equipped with,
13. Water supply for external fire-fighting,
14. Presence and quality/parameters of fire roads

21.5 DESCRIPTION OF THE APPROVAL PROCES

The investment process begins with the classification of the object in terms of the total height and the way, the building is used. Then, the designer assumes according to their knowledge the presence of a potentially explosive premises and the level of fire load density (average value in a whole fire zone).

The next stage of investment process is to obtain a building permit issued by an authorized body of territorial administration based on industry experts' agreement in relation to: fire protection, safety and hygiene of work and epidemiological-sanitaryas well. After obtaining a building permit an object is being erected under the supervision of a certified construction manager and supervising inspector. Supervising persons after completion the construction work shall declare that the execution of an object was done according to the project design, and the law, and the principles of technical expertise. This statement makes these people responsible for the correct execution of the property, even in case of some design errors. If any of them occur and are found out during the erection of the building it is the duty of the supervisor to stop ongoingwork and discuss with the designer what kind of alternative solution exists which is consistent with the rules and technical expertise.

Due to the Polish legislation, existing buildings should be adapted for current requirements of fire safety, such as: development, superstructure, reconstruction and changes of function (the way, the building is used) or when based on legal regulations [3]if it's considered threatening people's lives.

The building presented in this case study, as it was already mentioned, was expanded twice during its lifetime.

State authority empowered to control buildings in the meaning of fire safetybefore they are permitted to be exploited(which in Poland is the State Fire Service), during the reception after the third stage of development pointed out several inconsistencies which should be adapted to current requirements.

Inconsistencies with the provisions stated are listed below:

- DN25 hydrants used in the oldest part of the technological hall in contrary to required DN52 type,
- corridor (in the office part of the building) of a length exceeding 50 m not divided onto the shorter segments with the smoke-tight door,
- surgical stairs in the stairwells of the office part of the building.

In the first two cases, the necessary changes were done. Implementation of the third one would require demolition of the existing stairs. Polish regulations allow for the use of alternative solutions that would compensate the non-compliance. The recommended available solutions are defined by certified fire safety expert. However, they must be approved by the State Fire Service. In the presented building it was suggested to close the stairwells with doors satisfying the criterion EI30 of fire resistance. Finally, after applying the suggested solutions the property was considered compliant with the technical rules, but some doubts about the level of safety guaranteed by protection used were indicated.

21.5.1 Fire load density

In the analysed building the fire load density (due to the assumptions of project) does not exceed 1 000 MJ/m^2. Based on detailed analysis of the distribution of a fire load density it can be assumed that the design assumption is correct (Fig. 21.4). It should be noted that the presented value is the average one. When assessing the real risk, especially in case of the large-surface-area buildings with varying ways of use of the premises, the average values of fire-load density may not properly reflect the real threat of fire. This is confirmed in the present facility, where in approximately 47% of the total area of the building the fire-load density doesn't exceed 100 MJ/m^2. Surfaces for which the fire load density exceeds 4000 MJ/m2 (in extreme cases, it's 5644 MJ/m^2) represent only about 11% of the total area. In the lowest range of the fire load density which one can find in the technical regulations (i.e. of less than 500 MJ/m^2) falls to approximately 74% of the floor area of the analysed object.The estimated average fire load density [6] reached 974 MJ/m^2. Such a low value with such a large share of the floor area with relatively small or even negligible fire loadsuggests that there exist someareas where the small area accumulated large quantities of combustible materials. In these places the fire load density reaches a value that extends beyond the other end of the scale which we met earlier in regulations - over 4000 MJ/m^2 (compare Table X.1). Surfaces for which the fire load density exceeds 4000 MJ/m^2 (in extreme cases, it's 5644 MJ/m^2) represent only about 11% of the total area. In these areas, construction of a building designed and executed based on the assumption quoted at the beginning of the chapter is not adequately prepared for the likely fire conditions that may occur there.

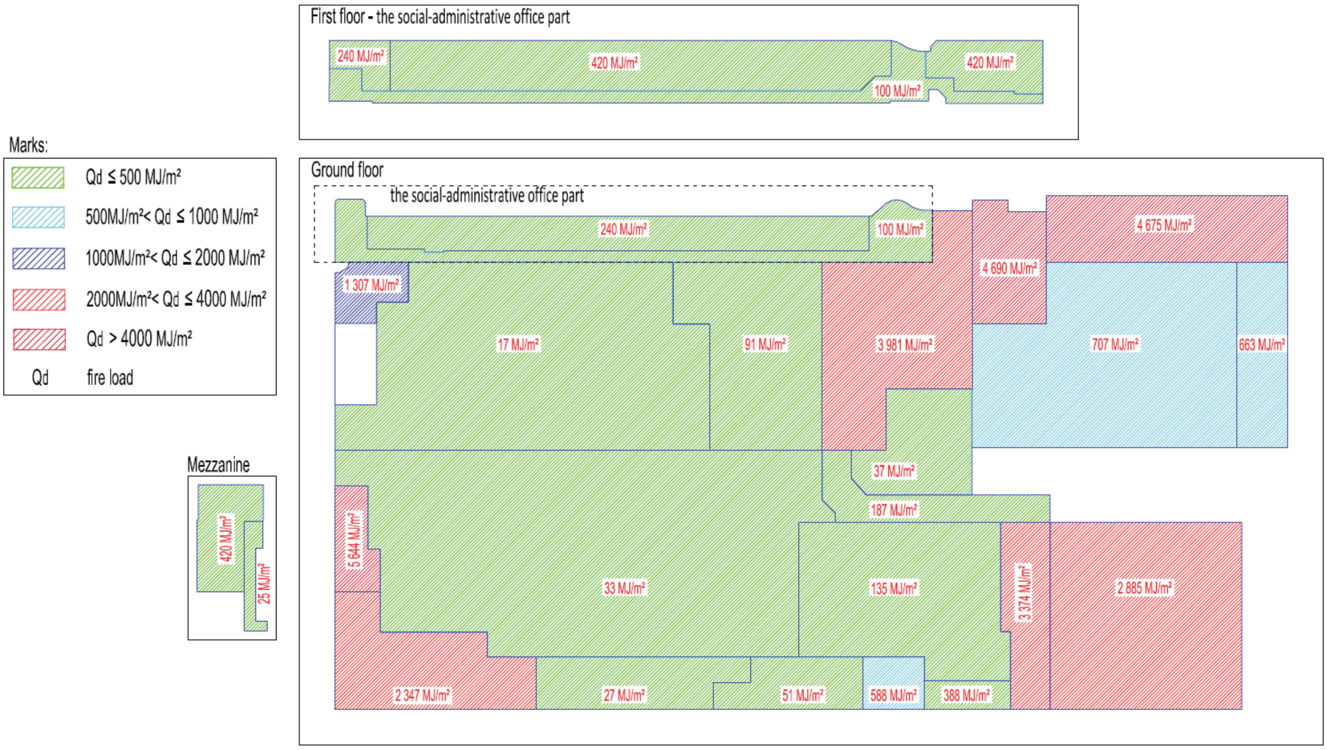

Fig. 21.4 Distribution of a fire load density

21.5.2 Fire zoning

Claiming that the office/administrative part of the building is linked functionally with the technological/production part (what was the main argument that made it unnecessary to divide the object onto the separate fire zones) seems rather questionable.

In addition, the allowed surface area of individual fire zone in a low multi-storey building, in which there are no potentially explosive areas, and the fire load density fits the range 500 <Q ≤ 1 000 is 8 000 m^2 (compare Tab. 21.3). Surface of the analysed object is now nearly 79% of the limit.

As already mentioned, the design assumptions have been positively verified with the amount of combustible materials taken for analysis on the basis of the state in May 2011, when a calculated fire load density was 97% of the assumed threshold, so very close to the limit value.

If – theoretically- the established threshold of 1000 MJ/m^2 would be exceeded(which in practice is possible when storing larger quantities of materials, raw materials or products) the requirements for the maximum fire zone area would increase, and the real floor area of the analysed facility would then reach 157% of the limit.

The existing building and its fire zoning is consistent with the current rules, but it cannot be regarded as beneficial in the meaning of safety reasons.

21.5.3 Assessment of explosion risk

Design assumptions imply that there are no rooms with potentially explosive atmospheres. A preliminary assessment confirmed this assumption. It does not mean that inside the building there is no risk of explosion. Factor posing a threat of explosion may be, for instance, the dust layer located on the floor, machines, or in inaccessible locations, which can be easily undermined, and mixed with air by a gust of wind. The inspection carried out in the building revealed that there are some surfaces permanently not cleaned, which were enveloped by the dust layer. In some cases, these were the areas of elevated temperatures: the electric motors or enclosures of bakery machines.

21.5.4 Fire resistance of building elements

The bakery plant was designed and built in class D of fire resistance. As mentioned before, the areas of the building where the average fire load density exceeds 4000 MJ/m^2 represent about 11% of the area. When the requirements would be imposed on the basis of local rather than average fire load density distribution - in these areas they would be the highest possible, (Class A of global fire resistance).

In addition, it should be also noted that in spaces executed during the first two phases of investment (the majority of the area of the plant) the main structure of on object is not protected to the required level of fire resistance equal R30.

21.5.5 Water for external fire-fighting

Water for external fire-fighting provide four external landline hydrants located on the property, supplied with its own water intake and one fire hydrant located in a neighbouring plant, water supply network powered. The owner of the neighbouring building, where this hydrant is localised has agreed to use it to protect the bakery plant concerned. These two fire hydrants located on the bakery site do not provide adequate amounts of water for fire-fighting purposes and do not meet proper efficiency requirements.

Analysing the technical capabilities of the water source used, which is the well with a capacity of 50 m^3/h it should be noted that this amount would only be sufficient to meet water demand for one outside hydrant only (13.9 dm^3/s at the required flow 10dm^3/s). Taking into consideration the fact, that the same source is also providing water for the internal water fire-plumbing system, it must be assumed that it is insufficient to power the external hydrants. Therefore it was necessary to ensure supply of water in a proper amount which results from a missing relative flow and the estimated duration of the fire, according to Polish Standard PN-B-02852:2001. In the presented case a missing amount of water is equal 30 dm^3/s and a relative duration of the fire is equal to 3600 seconds. So that it’s obligatory to guarantee reserve of water to extinguish a fire from the outside in the amount of 108 m^3.The solution that complies with the rules is the use of fire-fighting water tank complying with the requirements of Polish Standards.

21.6 RECOMMENDATIONS FOR THE FIRE ENGINEERED SOLUTIONS TO BE APPLIED AT THE SITE

Items below summarize some recommendations arising from the analysis carried out and the local considerations that allow to adapt the building for fire safety conditions:

1. It is reasonable to design additional protection in areas where a large fire load density occurs in tandem with the high threat of fire. The recommended solution is a permanent water or foam extinguishing equipment.
2. Some fire and explosion prevention recommendations were formed, aimed at minimizing the risk of explosion where it was indicated as a basic function the need of systematic cleaning of surfaces on which dust of flour and/or sugar can settle.
3. For fire zoning: It was recommended to separate the office part of the building from the technological part (as different fire zones) and to create completely new fire zone consisting of some storage areas with a highfire load density.
4. For the fire safety of structural system: The need to provide the required fire resistance R30 of the structure in the whole plant has been indicated. As the optimal solution it was suggested to separate the office part of the building from warehouses with a high level of fire load density as pretty individual fire zones. In all these areas structural elements (members and systems) should be protected to the level adequate for this type of fire zones.
5. For water supply: It was recommended to provide water to extinguish a fire from the outside by building a fire-fighting water tank.
6. For fire protection equipment: It was recommended to install inside the premises a fire alarm system that will protect the entire facility. Optional connection with the monitoring system will optimize, in case of emergency, the fire department rescue teams travel time.

21.7 CONSEQUENCES OF THE CHOSEN SOLUTION ON THE WHOLE LIFECYCLE OF THE BUILDING

Due to technical provisions the fire-fighting equipment should be maintained in accordance with the manufacturer’s instructions but not less frequently than once a year. Both the fire alarm system and fixed fire-fighting systems require regular controls exercised during specified periods of time and involving inspections and some specific activities weekly, monthly or every year. Water fire-fighting reservoir and related equipment are also subject to maintenance (every year) but also require to continuously monitor their technical condition. This generates additional costs that appear periodically.

21.8 CONCLUSIONS

The presented case demonstrates that during the whole investment process, there may occur some real problems when trying to obtain an administrative decision authorizing the use of the building, despite the seemingly simple and uncomplicated function of the building. Worrying is the fact that, despite the thoughtful and tight system of control and supervision at both the design and implementation phases, there are still problems with the successful completion of the investment which reconciles directly in the interest of the investor.

The authors of this study want to pay a particular attention to the trap that creates a building design based on the formal requirements conditioned by the fire-load density parameter.

The present case shows clearly, that the average fire-load density especially in fire zones and/or premises of large areas can lead to significant underestimations of building fire safety and result in incorrect assessment of the construction located in areas of high fire-load density levels.This problem is not generally discussed in the legal regulations.

There is also no need to prove that the fire load, which, paradoxically, is the greatest in areas with a high probability of fire determines the possibility of structure to survive in fire conditions.

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22 FIRE DESIGN OF A NEW FACTORY BUILDING IN ATHENS

Summary

The paper concerns the fire design of the new industrial building in Athens. It is a new, one storey steel building with a total area of about 50.000 m^2. The steel structure house the factory plant, customer services and warehouse. The building has been designed against fire, according to the current national regulations for the fire-protection of structures. All the active and passive protection measures are considered and the required fire-resistance of structural members is obtained through fire-protection materials.

In the present paper an alternative approach for the fire design of the structural members is also presented. New cross-sections of the steel members are calculated so that the required fire-resistance is achieved without any protection materials. This alternative fire design is based on the ISO-fire curve and to the regulations of Eurocode 3 – Part 1-2. The two solutions are compared with respect to the total costs.

22.1 DESCRIPTION OF THE BUILDING

This case study refers to a new industrial building. The aim of the project is the construction of a multi-area building, combining the production, the logistics centre and the customer service, in order to provide integrated services to the public. The building is going to be placed in Attiki, very near to the city of Athens in Greece. The total area of the one-storey steel structure is 56040.78 m^2 while the maximum height is 12 m. It is estimated that the industry will offer workspace for about 300 persons.

The usage of the building is multiple, as it combines an industrial part and an office area. The industrial sector can be divided to three different parts, the inbound, the production and the logistics area. The production zone, of total area equal to 14098.11 m^2, accommodates all the appropriate facilities for the manufacturing and the quality control of the products. The inbound zone, of total surface equal to 3482.52 m^2, is a part of the overall production area. The inbound building, of total area 10957.35 m^2, consists of two different halls that are used for the storage of the products. The customer service building, of total area equal to 3460.40 m^2, hosts offices, meeting rooms, storage place, workshop for the electronic devices, kitchen area, restaurants for the employees, sales department and reception hall for the customers. Finally, the Mechanical-Engineering building (M&E building) is a reinforced concrete structure, which houses all the mechanical equipment. It is the area the water tanks are installed. Fig. 22.1 illustrates the plan view of the industry.

The complex of the buildings has three access points from public roads. Two of them are dedicated to staff and visitors while the third one serves the heavy good traffic and it can be used by the fire-brigade vehicles.

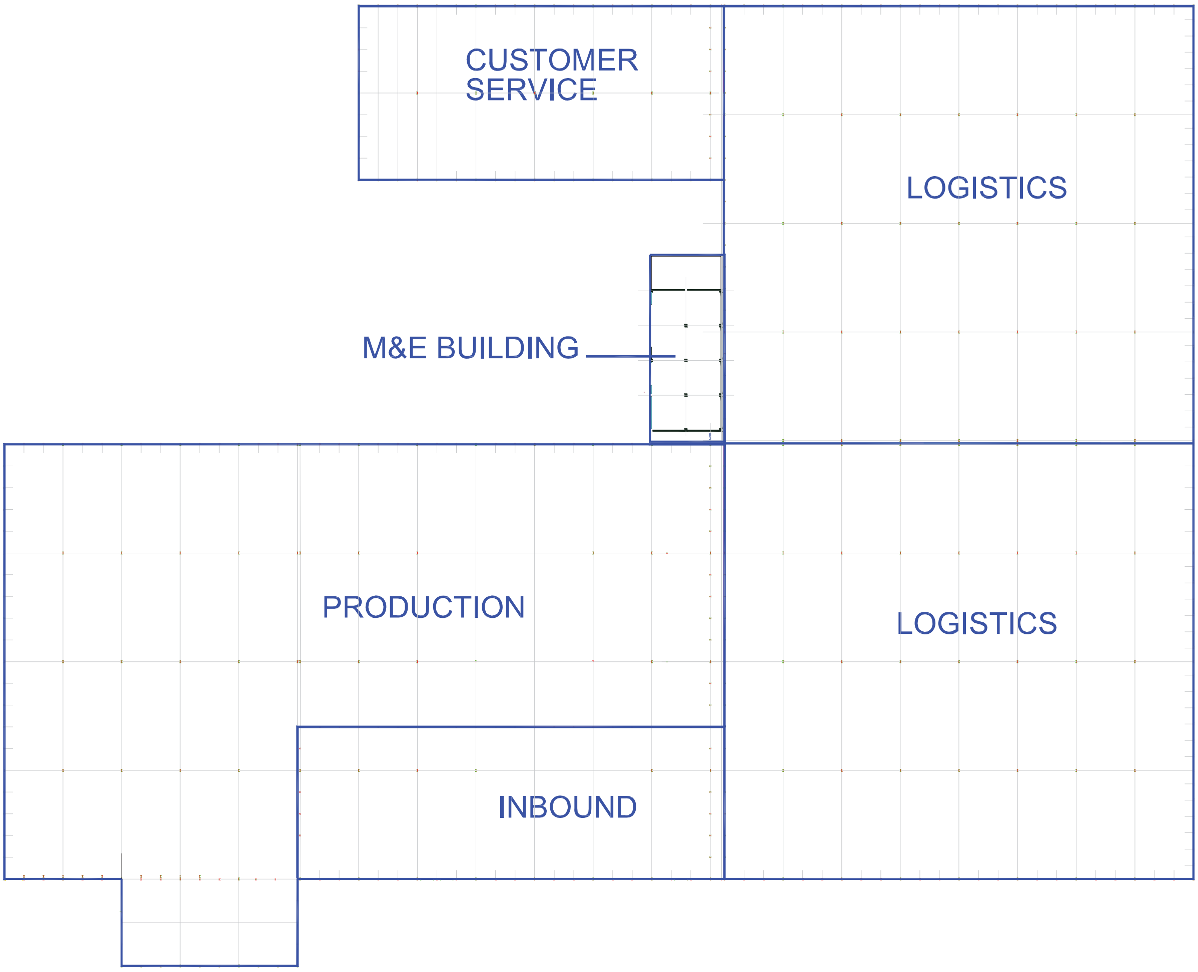

Fig. 22.1 Plan view of the building

22.2 FIRE PROTECTION REQUIREMENTS ACCORDING TO THE NATIONAL REGULATIONS

According to the national guidelines, the fire-protection design of the industrial building is based on the P.D. 71 “Regulations for the fire-protection of buildings” (FEK 32, issue A/17.2.1988) and specifically on article 11 which is referred to industry and storage buildings. The regulations specify that, the industrial and storage buildings should be classified according to the risk of the occurrence of the fire event or according to the fire load density. Specifically three categories are defined that are called Z1, Z2 and Z3. The previous are corresponding to small, medium and high risk buildings respectively. The fire-protection measures that are taken into account are strongly dependent on the category of the building. In this case study, the production building is coded as “Construction of home and professional appliances”, that is a Small Risk Industry which corresponds to Z1 category. The warehouse building fits to Z2 category due to high density of the fire load. The required fire-resistance time is dependent on the existence or not of sprinkler systems and on the number of storeys. Even though the industry is one-storey ground-level building, it is examined as multi-store due to the existence of mezzanines in the Production and the Warehouse area. Tab. 22.1 presents the required fire-resistance for the buildings.

Tab. 22.1 Required fire-resistance time

Building	Classification	Required Fire-resistance
Production	Z1	30 mins
Inbound	Z1	60 mins
Logistics	Z2	90 mins
Customer service	Z1	60 mins

Another important issue that is considered during the fire design of the building is the size of the fire compartments. Specifically, limitations should be taken into account considering the maximum area and the volume of the fire compartment as well as the length of the real and the direct escape roots. In this case study, difficulties are arising on the application of the previous limitations, due to the large size of the building and the specialities of its usage.

According to the regulations, the maximum area of the fire compartment is 5000 m^2 considering the case of the production area which is characterised as industry (category Z1). This area can be enlarged by the factor of 2.5, if the appropriate sprinkler system is going to be used. Also the permitted area can be scaled by the factor of 1.5, if the approach of the fire-fighting vehicles is assured by an access road on the perimeter of the building. Taking into account the increasing coefficients the maximum area of the fire compartment is calculated equal to 18750 m^2. If the building is considered as one-storey structure, which is the most convenient scenario, the maximum permitted volume of the fire compartment is equal to 28000m^3. According to the aforementioned, the height of the building should be 1.49 m, which is extremely paradox. Taking into account the expected height of the building (h=11m), the maximum allowed area of the fire compartment is calculated equal to 2545 m^2. This means that the production area, should be divided into 6, at least, different fire compartments, but this is not feasible for the function of the industry.

Moreover, following the corresponding guidelines for the warehouse, the maximum permitted area of the fire compartment is 15000 m^2 while the maximum permitted volume is defined equal to 15000 m^3. Taking into account the geometric characteristics of the building, the warehouse area should be divided into 16, at least, different fire compartments or the maximum height of the building should be 1.00 m. None of the previous is reasonable, taking into account the proper function of the logistics centre. Considering the customer service and the inbound area, the dimensions of the fire compartments are mainly defined from the limitations of the escape roots. Fig. 22.2 presents the arrangement of fire compartments according to the national regulations for the fire design of the industry.

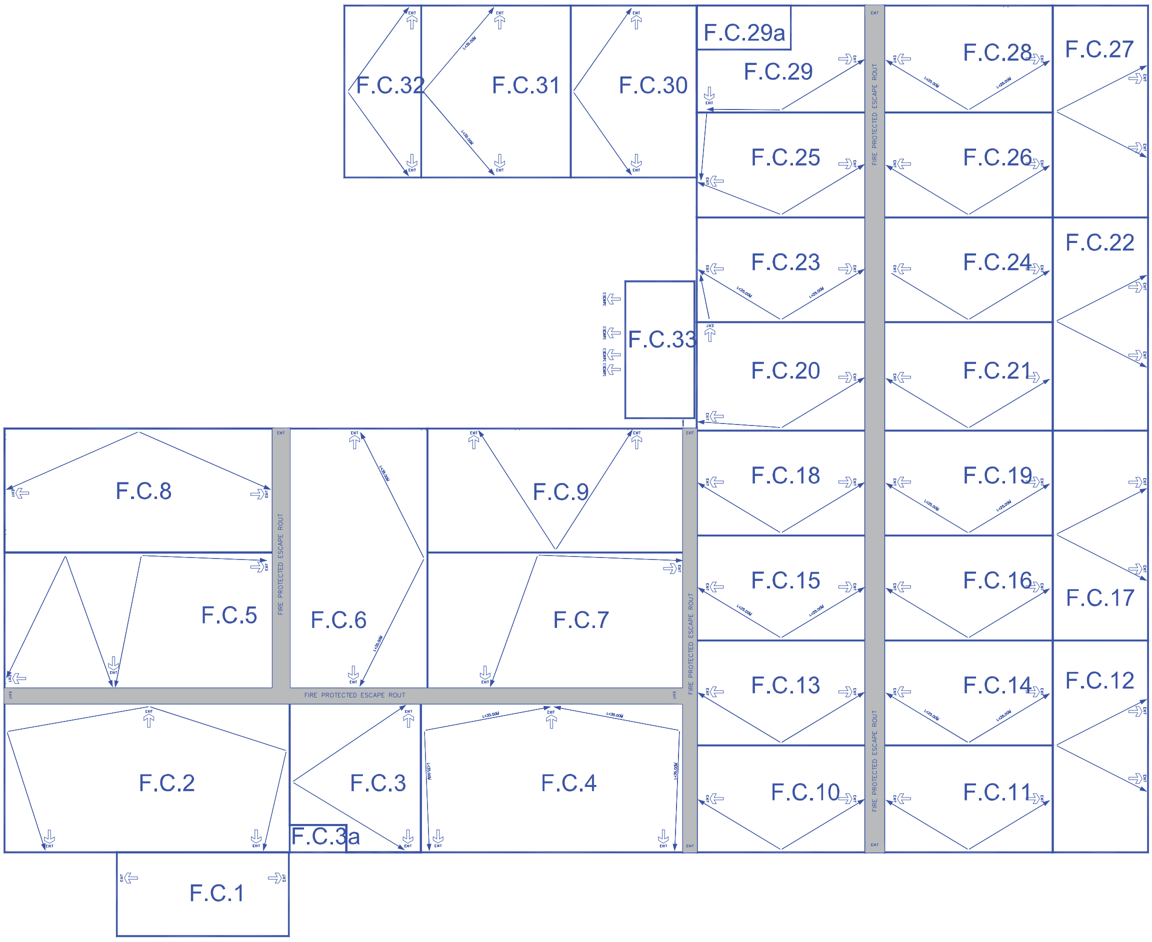

Fig. 22.2 Fire-compartments according to the national regulations for the fire-protection

Concluding, in this case study, the application of the national guidelines regarding the F.C. is impossible. Therefore deviation from the existing rules was asked from the authorities. Tab. 22.2 presents the characteristics of the final fire compartments while Fig.22.3 illustrates the new arrangement according to the deviation.

Tab. 22.2 Characteristics of the final fire compartments

Fire-Compartment	Use	Area (m^2)	Height (m)	Volume (m^3)
FC 1	Production	15133.6	11	155.079
FC 2	Inbound	3706.52	11	380307
FC 3	Logistics1	10957.35	11	120530
FC 4	Logistics2	10973.65	11	120710
FC 5	Customer service	4300	11	38064

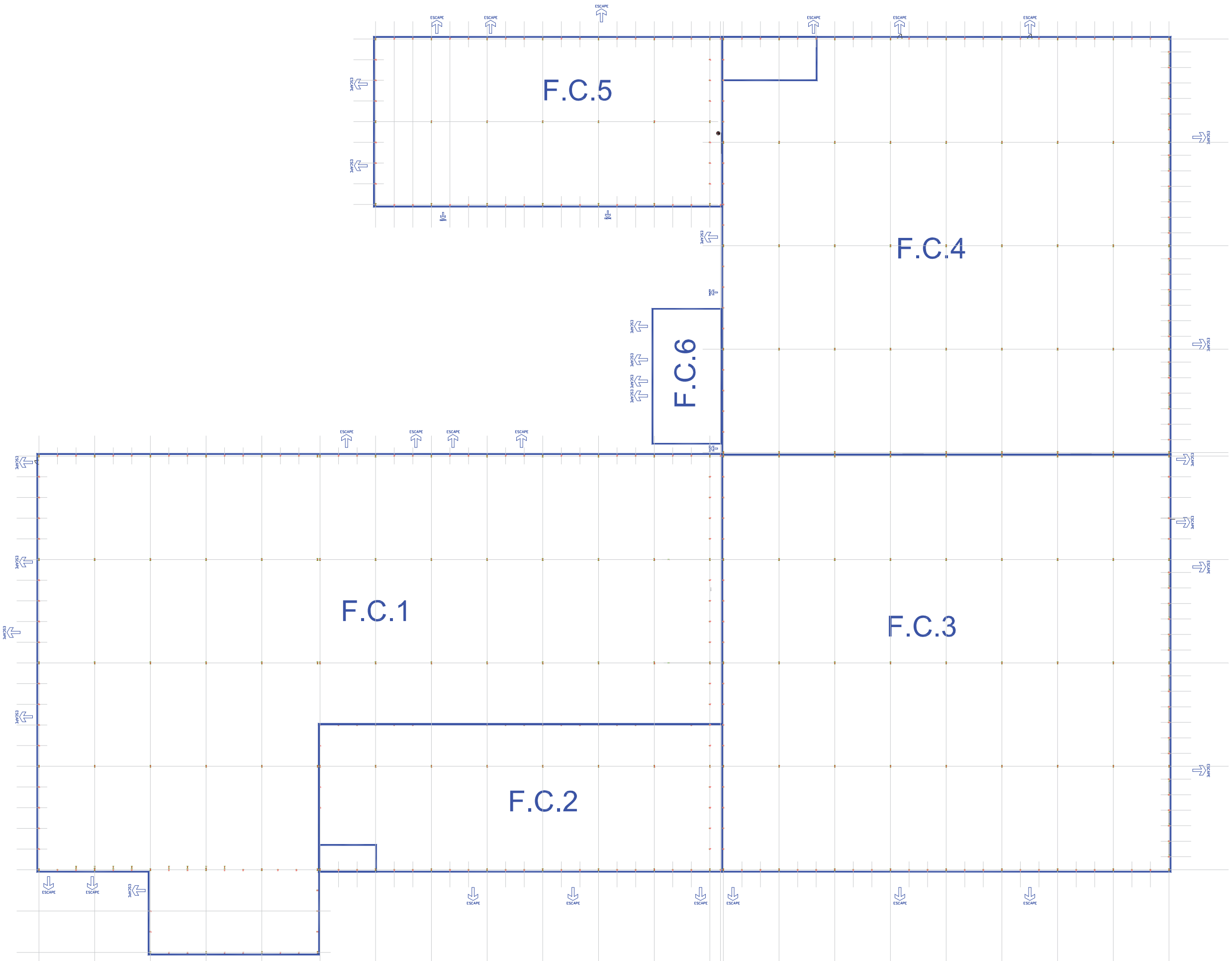

Fig. 22.3 Fire-compartments according to the deviation from the existing rules

22.3 STRUCTURAL FIRE DESIGN OF BUILDING

The required fire-resistance of the structure can be fulfilled either through fire-protection materials (fire-proof paintings, fire-resistant boards etc,) either by using the appropriate cross-sections of the members. Here, the study will be focused on the structural fire design of the Customer Service building. Specifically two different approaches are examined. The first approach is based on the use of the fire-protection materials in order to achieve the required fire-resistance. The second approach proposes alternative cross-sections and the fire-resistance is achieved without fire-protection materials. Finally, the effectiveness of the two different approaches is compared, in terms of financial cost.

Fig. 22.4a presents the plan view of the building and a typical frame of the steel structure is illustrated in Fig. 22.4b.The typical frame is repeated every 13.5 m.

It should be noted that the steel structure is primary designed against earthquake events and the fire design is the second step. The seismic design is performed according the national regulations [EAK 2000]. The cross-sections that are calculated during this stage are summarized in Table 3.

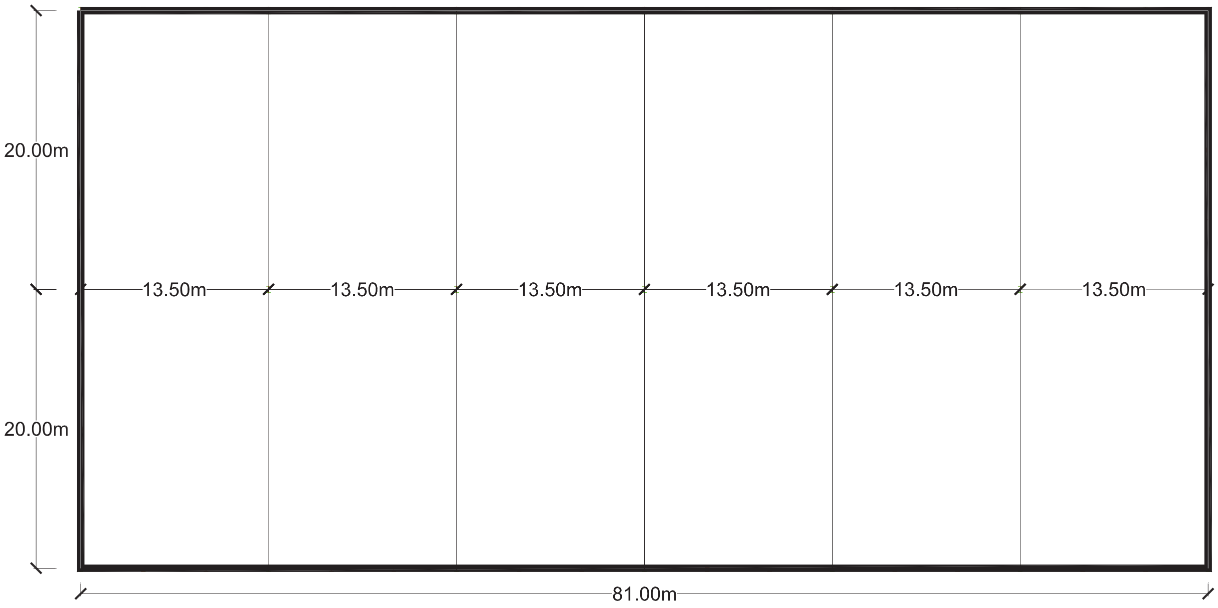

Fig. 22.4a Plan-view of the Customer Service building

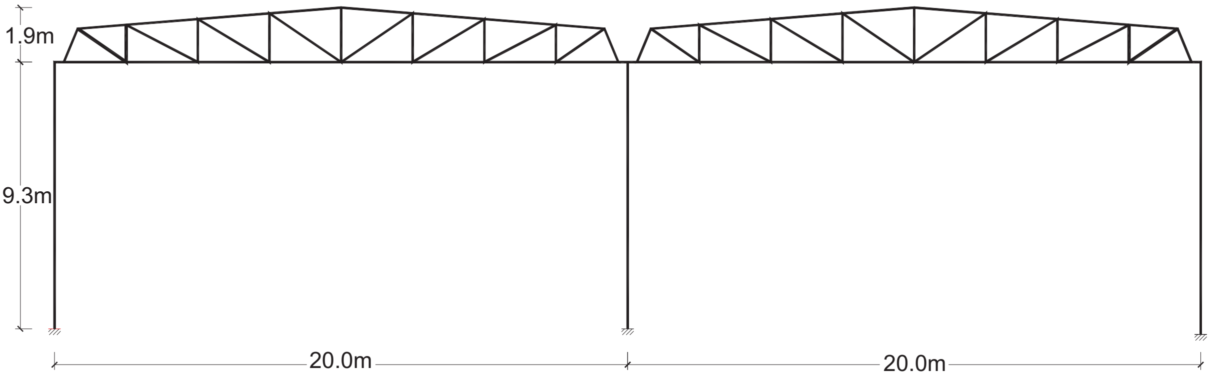

Fig. 22.4b The typical frame and the cross-sections coming from the seismic design

22.3.1 Structural fire design of building -First approach

According to the first approach, the required fire-resistance time, that is indicated equal to 60 minutes, is achieved through fire-proof painting. Specifically the seismic design is the first step and the second step is the estimation of the characteristics of the required fire-proof painting. The thickness of the painting and consequently the total financial cost is dependent on the fire-resistance time and on the dimensions of the cross-sections. Tab. 22.3 presents the required thickness of the painting for the structural members including the typical frame and the purlins. The calculations are conducted for fire-resistance time equal to 30 minutes and 60 minutes. It is noted that the total financial cost that is calculated includes the cost of the painting and the working cost for the application of the painting taking into account the Greek commercial market.

Tab. 22.3 Results of the first approach

Seismic design			Fire-design					
			R30			R60		
Section	Length (m)	Self-weight (kN)	Thickness of the painting (μm)	Weight of the painting (kg)	Cost (€)	Thickness of the painting (μm)	Weight of the painting (kg)	Cost (€)
HEB500	27.9	52.3	265	36.2	333	504	68.8	451
HEA220	81.9	41.3	330	78.2	634	1026	243.0	1227
HEA120	243.0	48.3	368	139.5	1951	1933	737.7	4086
RHS120/6.3	8.2	27.4	860	140.4	748	2000	326.5	79
RHS100/5	24.7	29.8	1135	157.6	833	3560	380.5	296
QHS80/3.6	315.2	27.2	1650	383.4	2269	5720	1329.2	5673
RHS80/5	6	0.7	1135	5.0	25	3560	15.7	63
RHS70/3	16.6	1.4	1150	15.6	73	5090	50.6	199
RHS60/4	23.8	1.7	1150	15.1	74	5090	66.9	260
QHS50/4	142.2	8.2	1150	75.4	522	5220	342.0	1482
QHS40/2.9	124.6	4.2	1600	73.5	440	2290	105.2	554
TOTAL		214.7		14006.3	6421		46033.3	14223

22.3.2 Structural fire design of building -Second approach

In this approach the required fire-resistance time is achieved without fire-protection materials and the calculation of the alternative cross-sections of the structural members is based on Eurocode 3 Part 1-2 using the ISO fire curve. It is indicated that no thermal analysis takes place and that the temperature is assumed to be uniform in the cross-sections and along the members. Specifically, the temperature of the structural members is calculated according to section 4.2.5 of EN 1993-1-2 and depends on the geometric characteristics of the cross-sections taking into account the corrections about the shadow effects. The target is to estimate the appropriate cross-sections of the structural members in order to resist in fire for 30 and 60 minutes respectively. The starting point of the calculation deals with the cross-sections that are coming from the seismic design. This calculation is actually an iterative procedure and the subsequent steps are the following:

Step 1: Calculation of the temperature of structural members of the typical sub-frame and the purlins, at the desired time t

Step 2: Static analysis for the fire combination $G+\psi_2 Q$

Step 3: Checking if the cross-sections are adequate for the fire combination at the desired time t. If they are adequate the calculation is finished. Otherwise step 4 follows.

Step 4: Calculation of the new cross-sections

Step 5: Repeat Step 2, 3 and 4 for the new cross-sections

The results of the iterative procedure are presented in Tab. 22.4, indicating the increase of the self-weight of the steel structure in relevance with the fire-resistance time. It is observed that in the case of 30 minutes required fire-resistance the self-weight of the structure is increased 34.75%, while the corresponding value for the R90 requirement is 76.33%.

Tab. 22.4 Variation of the self-weight of the structure according to the design requirements

	Seismic design	R30	R60
Self-weight of the structure	214.72 kN	289.33 kN	378.68 kN

22.4 COMPARISON OF THE ALTERNATIVE APPORCHES

The alternative approaches are compared in terms of financial cost. The comparison specifies that the most economical approach seems to be the first one which uses the fire-proof paintings (Tab. 22.5). The results of the second approach can be reconsidered if global elastic-plastic analysis of the steel structure is taken into account. It is expected that in this case the outcomes of the second approach would result to reduced financial cost, comparing with the results of the same approach in this study.

Another issue that should be noted is that the second approach is based on the ISO fire curve as it is indicated in the guidelines. Alternatively, this approach can be based on parametric fire curves, zone models or CFD temperature results. This is a critical parameter for the variation of the results of this approach.

Tab. 22.5 Comparison of the alternative approaches

		Self – weight	Financial cost	Fire-proof painting	Financial cost	Total financial cost
R30	Approach 1	21472 kg	34355 €	842 kg	6421 €	**40776 €**
	Approach 2	28933 kg	46293 €	-	-	**46293 €**
R60	Approach 1	21472 kg	34355 €	3011 kg	14229 €	**48584 €**
	Approach 2	37862 kg	60580 €	-	-	**60580 €**

22.5 SUMMARY

This paper presents the fire design of an industrial building that is going to be placed in Athens. Primary, the fire design requirements, according to the national regulations, are presented. It is concluded that in this case study, the guidelines concerning the fire compartment limitations are not applicable. Therefore, the final arrangement of the fire-compartments, according to the deviation from the existing rules, is presented. In the second part of the paper, two alternative approaches for the structural fire-design of the Customer service building are studied. The results indicate that the most economical approach is the one that is based on the use of fire-proof materials.

Acknowledgement

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