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7 RELIABILITY OF STEEL ROOF STRUCTURES OF THE SPALADIUM SPORTS HALL IN CASE OF FIRE

Summary

In this paper a method for analyzing fire resistance of load bearing structures in big indoor spaces, based on Eurocode, is presented through case study of the steel roof structure of the Spaladium Sports Hall in Split, Republic of Croatia. The temperature-time relationships for indoor space are obtained by the zone model numerical calculation which is applied for two characteristic fire situations: fire in the arena, and fire on the grandstand. The reliability of the roof structure is analysed through the temperature-time curves in load-bearing elements of the steel structure. Parallel to zone model calculation mentioned above, CFD numerical modelling of smoke propagation and determination of temperature fields under the roof structure is performed, which gives additional and more accurate input data for analysing roof structure reliability as well as enable the reduction of costs for passive measures of fire protection.

7.1 GENERAL BUILDING DESCRIPTION

Spaladium Centre, sports and business complex (Fig.7.1) is located on the northern part of the Split peninsula and it was prompted by the Men's World Handball Championship in January 2009 when Split was one of the host cities. The centre is designed by “Studio 3LHD” from Zagreb, Croatia and consists of a multifunctional handball arena with 12,000 seating capacity, sports, recreation and wellness centre, a shopping center of 30,000 m^2, a parking garage with 1,500 parking spaces, a 100m high office tower, and a sky bar withan exclusive restaurant on the top floor.

Construction of the complex is planned through phases. The first phase has been carried out in 12/2008 and implied a Spaladium Arena while other facilities are planned to be constructed through the second phase.

Fig. 7.1 Plan of Spaladium Centre

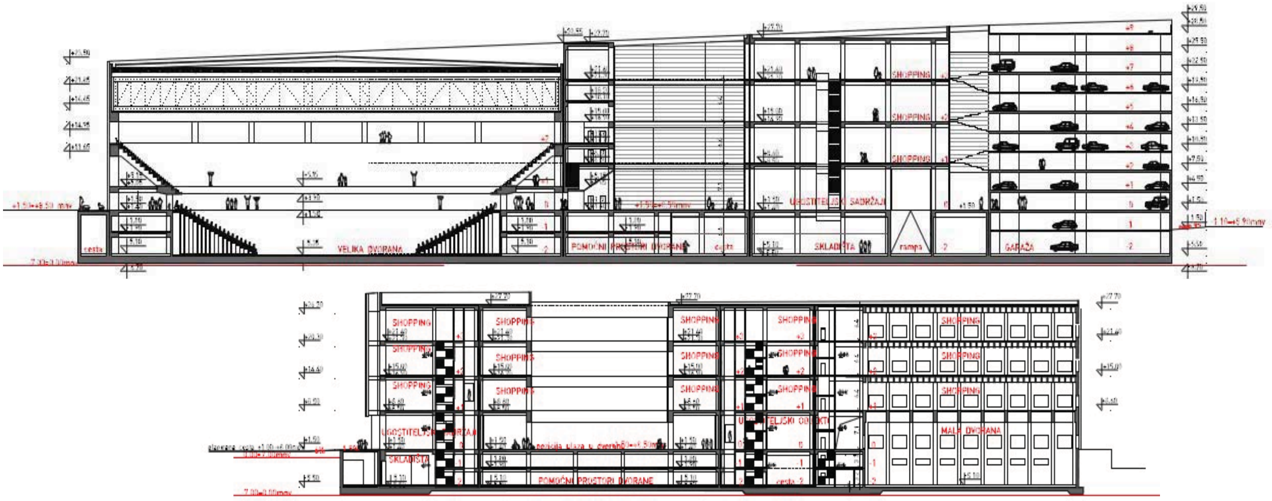


Fig. 7.2 Cross sections of Spaladium sports hall

SPALADIUM ARENA (Fig. 7.2 and Fig. 7.3) is a multi-purpose hall with a gross surface area of 28.500 m^2 and a 12,000 seating capacity. It has squared plan with dimensions of 80,3 x 100,3 m and height of 30,25 m. Clear span from the ground floor to the bottom chord of lattice girder is 24, 57 m. On the rooftop of the sports hall there are 30 smoke air vents, used for emergency venting of the smoke in case of fire. Fire protection study (Bezic, 2007) indicated that the estimated fire load would be approximately 300.0 MJ/m2 in the fire compartment located on the grandstand and the fighting arena. Approaches of the viewers, access control and evacuation has been simplified by placing the main processions around the hall, which is also used as a fire access. On the main processions are 14 stairs which viewers access to the upper stands.

Fig. 7.3 Interior of Spaladium sports hall during sport event

7.2 REGULATORY REQUIREMENTS FOR FIRE SAFETY OF HALL

For assessing adequate fire safety of object, the combination of prescriptive measures, requirements of fire authorities and performance based approach was applied. As Croatia has no regulatory fire safety requirements for sports hall, it is allowed to use foreign regulatory requirements as “recognized rule of technical practice” (as described in Croatian regulation). That is the reason why NFPA 101 was used. According to NFPA 101 fire resistance rating for building structure was type II (222). Based on investor’s request, fire authority accepted the fire resistance rating for steel roof of 1 hour due to closed distance of professional fire brigade (500 m) and large number of evacuation stairs (14).

According to Croatian regulation at the time when Spaladium sport hall was designed (2008.), the usage of performance based design was not clearly defined yet. From 2010 year on the performance based design could be used in accordance to new Fire protection law. Despite these facts, fire engineering methods was used for the roof structure thermal response of Spaladium arena and for the smoke movement prediction in the evacuation phase (generally for the entire building).

7.3 GENERAL ASSESSMENT STRATEGY

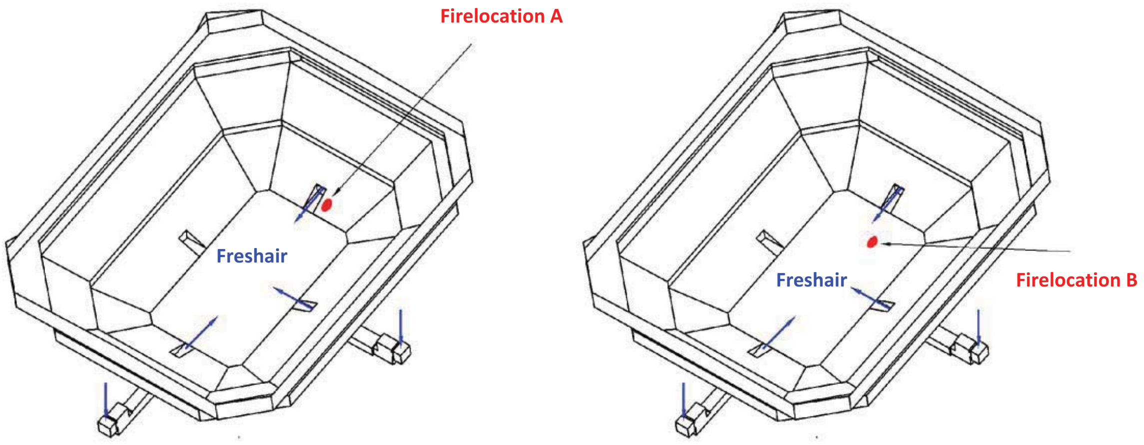
The concept for the truss girders of steel roof structure was as follows. The first step was to determine the fire load for particular sport building (300.0 MJ/m^2). Using the t^2-method, the fire was simulated in a two locations using zone-model software JET. Finally, the compartment temperatures were used as thermal action in several thermal finite-element-simulations including steel cross sections and intumescent coatings to predict the steel temperatures. The load bearing capacity at t=60 min was calculated using the method of the critical temperature and where necessary using methods of simplified mechanical calculations. The efficiency of natural smoke exhaust system by air vents was proved using the CFD-model FLUENT.

7.4 COMPUTATIONAL FLUID DYNAMICS

In order to predict the smoke propagation during the entire period of evacuation, proving that the smoke layer will not endanger the evacuation routes (minimum height of non-smoke zone at the highest point of stand of 1,83 m) the computational fluid dynamics (CFD) was used.

For the Spaladium Arena sport hall fire scenario for two locations was used:

a) grandstands
b) ground floor (playground)



a) b)

Fig. 7.4 Fire scenario locations with main fresh air intakes

In the case b) it is presumed that fire risk is pretty low (almost no combustible materials), but in the case of fire possible smoke production is large because of the height of predefined "non smoke" zone. This fire scenario can be also applied for the central positioned stage. In the case a) it is presumed that fire risk is higher (main combustible materials are seats) and consequences are more serious because of the presences of visitors. In the both cases "axisymetric plume model" is used according NFPA 92B with "volumetric" fire source.

Selected design fire for the smoke propagation calculation by CFD modelling is represented by the “t-square” fire curve, described as:

$$Q(t) = \alpha \cdot t^2 \tag{1}$$

Choosing the growth coefficient of fire α = 0,045 kW/s^2, fast fire scenario is predefined [Hu, 2006]. Time period for firemen intervention (input data from the Fire Protection Study) is defined in 300 seconds, so the resulting heat release rate (HRR) peak is 4,05 MW (Fig. 7.5).

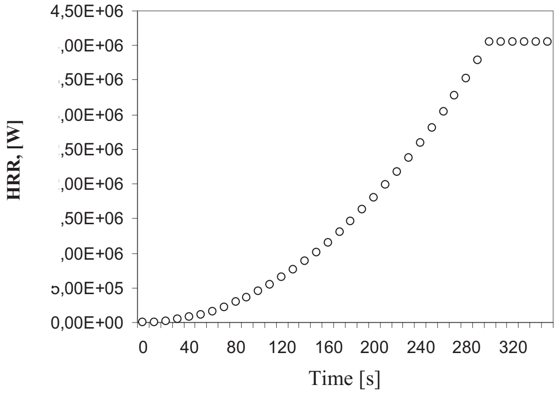


Fig. 7.5 Time-HRR curve for design fire (max. HRR=4,05 MW)

From our point of view, selected "t-squared fast fire" peaking at 4.05 MW is applicable for this project because it is based on full-scale experiment results, but probably more conservative in our case, using the fast fire growth (experimental fire growth is reported "to be fluctuated between slow and medium").

7.5 STRUCTURAL FIRE ENGINEERING

For the calculation of the fire resistance of the structure, the two most extreme fire design scenarios were also considered (Fig. 7.6):

- Fire occuring at the centre of ground floor (playground)
- Fire occuring at the edge of the grandstand.

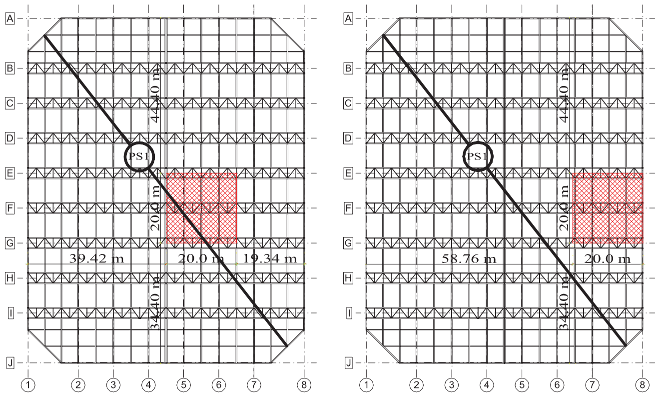


Fig. 7.6 Two considered fire design scenarios

Fire occurring in an enclosure such as a sport hall goes through three distinctive phases: the growth phase, the phase of fully developed fire and the decay phase. HRR curves are used to describe the time dependent release of heat caused by a fire source inside the compartment. These curves were calculated under the assumption that 70% of the original fire load would be consumed in the growth and development phase of fire, while the remaining 30% of the fire load will be consumed in the decay phase of fire. The calculated HRR curve was used as an input parameter for a fire model JET (Davis, 1999) and its graphical presentation is given in Fig. 7.7. JET is a two zones, single compartment model designed to predict the plume centerline temperature, the ceiling jet temperature and the ceiling jet velocity produced by a single fire plume. The impact on the upper layer due to the presence of draft curtains, ceiling vents and thermal losses to the ceiling are included in the model. The unique feature of this model lies in the fact that the characteristics of the ceiling jet depend on the depth of the hot layer.

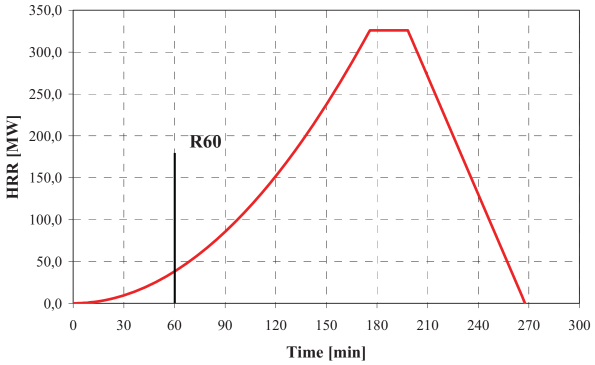
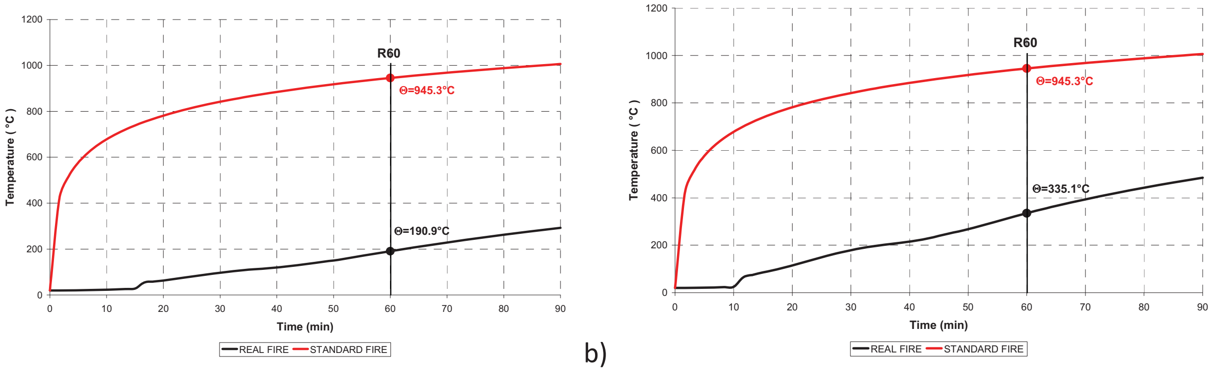


Fig. 7.7 Input HRR curve

Fig. 7.7 shows that the growth phase occurs during the first 170 minutes, which is a characteristic of a slow burning fire. It is also evident that the required fire resistance of roof structure is within that period, which makes the growth phase of the fire the most relevant one.

Fig. 7.8 (a and b) presents the obtained parametric temperature-time curves in the area of the structure ceiling, just below the origin of fire.



a)

b)

Fig. 7.8 Parametric temperature-time curve a) H = 11.0 m – upper chord of lattice girder
b) H = 6.5 m – lower chord of lattice girder

7.5.1 Description of the heat transfer analysis

In order to analyze the distribution of the temperature inside the structural elements, a heat transfer model was used. The transfer of heat through the structural elements was modeled by a two dimensional transient, non-linear heat transfer model TASEF (Temperature Analysis of Structures Exposed to Fire) (Sterner, Wickstrőm, 1999). Derived temperature-time curves (Fig. 7.9) were used as boundary conditions to solve the heat transfer equation. Results of the heat transfer analysis for the selected steel elements are given in Fig. 7.9 – 7.10.

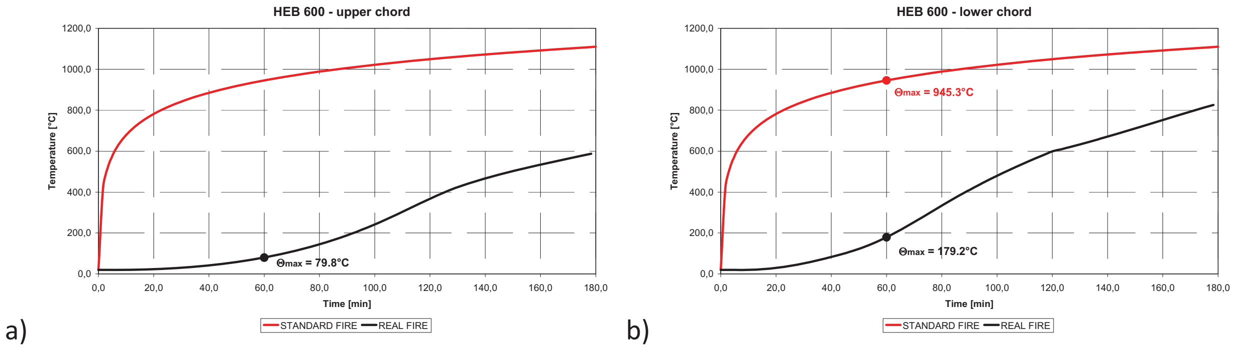


Fig. 7.9 Derived temperature-time curves in cross section: a) in the upper chord of the lattice girder (GP); b) the lower chord of the lattice girder (DP)

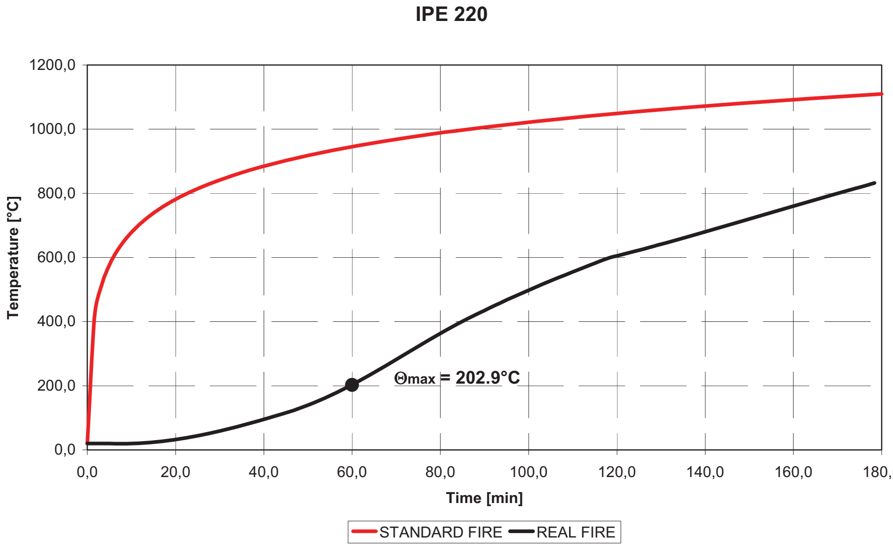


Fig. 7.10 Derived temperature-time curves in cross section in the diagonal element of lower chord of the lattice girder (H2)

7.5.2 Thermal response of the structure

Thermal response of the roof structure was analyzed on a segment, while the rest of the structure was replaced by a system of elastic springs with adequate stiffness representing the neighbouring lattice girders (Fig. 7.11).

In addition to the external forces that act as a load on a roof structure, temperatures occuring during fire were added as a load on a part of the lattice girder, depending on the fire scenario, which causes additional internal forces in the elements of the lattice girder.

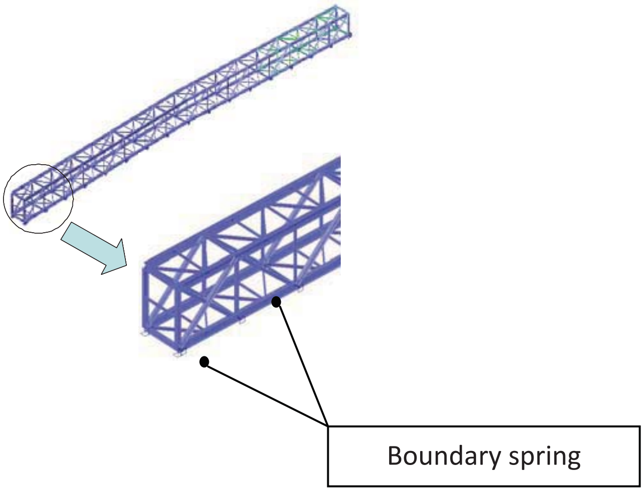


Fig. 7.11 Derived temperature-time curves in cross section in the diagonal element of lower chord of the lattice girder (H2)

7.5.3 Mechanical response of the structure

In order to determine the reliability of the structure, two parameters must be defined: structure resistance R (expressed as the ultimate force which causes structural failure) and action on structure S (forces resulting from the structure loads). The steel structure resistance is defined by a series of parameters, the most important being: yield strength of steel, modulus of elasticity, cross-sectional area of the structural element and the moments of the resistance of the cross-sectional area. The action upon the structure can be classified into several load types, the most relevant being: permanent load, variable load, snow load, wind load, earthquake load and fire.

Generally, parameters R and S are characterized by a different number of variables which are mainly non-deterministic. In that case, the probability of structural failure can be expressed as the probability of the event (Milčić, Peroš, 2002):

$$p_f = P\big(G(X) \le 0\big) = \int \ldots \int_{G(X)\le 0} f_X(X_1 \ldots X_n) dX_1 dX_2 \ldots dX_n \tag{2}$$

in which *G(X)* is the limit state function which depends on the type of structural failure (failure of cross section or structural element), f_X is the joint probability density function of variables $X_1,\ldots,X_n$. The probability of the structural failure p_f can be determined, depending upon the safety index β:

$$p_f = \Phi(-\beta) \tag{3}$$

where Φ is the Standard normal cumulative distribution function.

The integral defined by expression (2) can be solved only by applying complex probabilistic models. The probabilistic model STRUREL was used in this paper for the determination of the safety index β for a ‘’Spaladium’’ sports hall for specific cases of the fire load.

Eurocode 1 defines only one limit state wherein the structural failure is supposed to have occurred:

- Ultimate limit state – a state wherein the structure should have sufficient load capacity (resistance) to whitstand the given static load.

The safety proof in case of fire for the ultimate limit state can be defined by the expression:

$$p_{f,fi} \cdot p_{fi} \leq p_t \tag{4}$$

where p_{fi} is the probability of fire action, $p_{f,fi}$ the probability of structural failure resulting from fire action, and p_t the normed probability of the structural failure. Consequently, it can be concluded that the codified value of the safety index $\beta_{fi,norm}$ can be determined from expression (4) for the fire action (ultimate limit state):

$$\beta_{fi,norm} = \Phi^{-1}\left(p_{f,fi}\right) = \Phi^{-1}\left(\frac{p_t}{p_{fi}}\right) \tag{5}$$

Codified probability for structural failure during the period of exploitation, in the case of fire action, depends upon the conditions of evacuation for the structure under study; for normal conditions of the evacuation this amounts to p_t=1.3·10-4. Probabilistic variables for resistance R and action S are presented in the Tab. 7.1

Tab. 7.1 Basic resistance variables X

Basic resistance variables [X]				
Variable	**Mean value**	**Variation**	**Distribution**	**Type of variable**
X1	$k_{y,\theta}$* 41.9 kN/cm2	0.054	Lognormal	Yield strength
X2	$k_{E,\theta}$* 21000 kN/cm2	0.0645	Weibull	Modulus of elasticity
X3	Depends on the cross section	0.05	Normal	Cross section area
X4	Depends on the cross section	0.05	Normal	Resistance moments Wy and Wz

where:

$k_{y,\theta}$- reduction coefficient for the yield strength,

$k_{E,\theta}$ – reduction coefficient for the modulus of elasticity.

Tab. 7.2 Basic action variables Y

Basic action variables [Y]				
Variable	**Mean value**	**Variation**	**Distribution**	**Type of variable**
Y1	$\overline{T}_S, \overline{T}_1, \ldots, \overline{T}_n$	0.30	Gumbel	Fire action expressed as mean temperature in a cross section

Fig. 7.12 presents the longitudinal and transverse cross section of the segment of the roof lattice girder with the position of the steel elements.

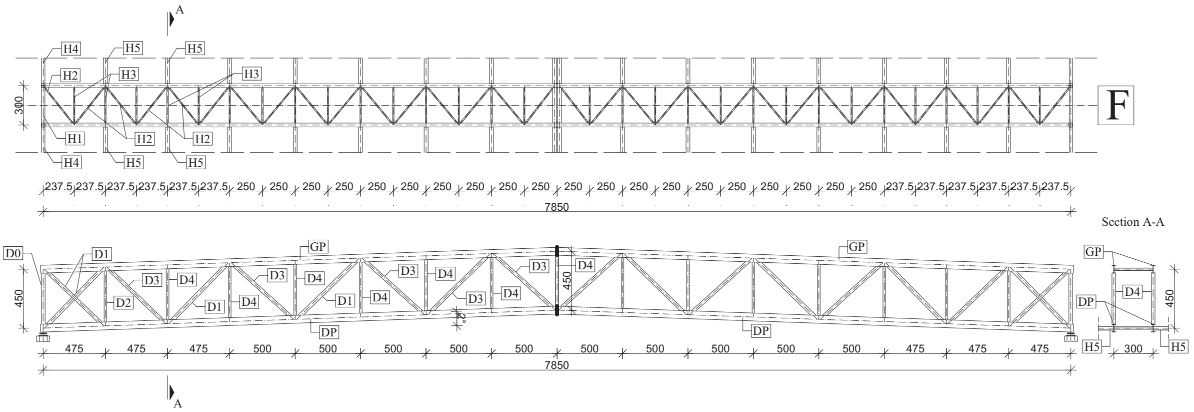


Fig. 7.12 Longitudinal and transverse cross section of the lattice girder section

Tab. 7.3 Position of the basic steel section of the lattice girder

Position	Profile
GP	HE 600B
DP	HE 600B
D0	HE 300B
D1	HE 280B
D2	HE 200A
D3	HE 260A
D4	IPE 200
H1	HE 300B
H2	IPE220
H3	IPE 180
H4	HE 260A
H5	HE 300A

Tab. 7.4 presents the results of the calculated safety index β and the codified value β_{fi} for the characteristic elements of the lattice girder structure.

Tab. 7.4 Position of the basic steel section of the lattice girder

Position	β	β_{fi}
GP	4.2	2.0
DP	4.0	2.0
H2	2.2	2.0

Calculated values of the safety index β show that the elements of the load bearing roof structure are higher than the codified values of the safety index β_{fi} in case of fire, thus the reliability of the designed structure is proved.

7.6 CONCLUSIONS

The main goal of this paper was to describe the challenges which designers were faced with in the situation when national fire regulations are pretty poor and inadequate for particular building. Combination of prescriptive and performance based design was used for the roof structure thermal response and for the smoke movement prediction in the evacuation phase of Spaladium arena, with the aim to optimise the construction costs and to prove important input presumptions regarding the evacuation process. Combination of mentioned methods with extensive usage of numerical modelling didn't reduce the fire safety level; even more it enables cost effective solutions for the roof structure construction and provides safe conditions for the visitor evacuation.

The complete design in the fire safety area was the compromise between the investor, the fire authorities and the entire project team. This compromise request the big efforts from the fire engineering designers during the process of project development, because of the fact that actual Croatian Fire law at that time didn't recognize the performance based methods as the valuable alternative of the prescriptive design approach.

Acknowledgement

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8 REDEVELOPMENT OF ASCOT RACE COURSE - APPROACH TO FIRE SAFETY ENGINEERING

Summary

The redeveloped Ascot Racecourse opened in 2006. The creation of a stadium and an adjacent multilevel space to accommodate larger numbers of people are at the heart of the redevelopment. The varied activities associated with a modern major horse racing facility requires an holistic approach to fire safety including structural performance, smoke management and means of escape. To support this requirement a fire engineering approach was fundamental to deliver the essential safety and viability of densely populated spaces of this nature. The strategy to deliver an adequate standard of safety, background to the risk assessments and supporting analyses are explained to demonstrate what an engineered approach can deliver.

8.1 APPROACH TO PERFORMANCE BASED FIRE SAFETY ENGINEERING

There are two primary ways of achieving an adequate standard of fire safety in a building. One is the simple application of building codes and standards, which require limited engineering as the majority of solutions, are prescribed. There is little flexibility. Alternatively, a fire safety engineering approach gives greater design flexibility to achieve a particular performance but requires greater skills involving analysis, risk assessment and engineering judgement. There is often an opportunity to improve value and or performance by selecting the most appropriate combination of fire protection measures with each building requiring its own consideration and its own solutions. Engineered solutions can also be used to demonstrate an equivalent level of fire safety where there is a variation from prescribed guidance. As the complexity and analytical techniques advance the engineer is well positioned to lead this process.

The fire engineering design of the new Ascot Race Course facility is an example where an holistic engineering approach was adopted to deliver the benefits, the value and to eliminate the fragmentation between disciplines that manifests itself on many projects. It is the combination of the built provision, the operational procedures, the fire service response and the identification of realistic fire scenarios that delivers the most appropriate cost effective solution. In the case of Ascot this was effectively co-ordinated by the fire safety team which consists of all the main stake holders.

The basic approach involved making sure that there was sufficient time to evacuate the many occupants of varying age and ability at any stage in the racing cycle throughout the day. This involved assessing that the spread of smoke and the performance of the fire protection measures were sufficient to establish that the means of escape was reasonable. However the built provision alone was not sufficient and fire safety management was equally important.

8.2 DESCRIPTION OF THE PROJECT

Ascot Authority (Holdings) Ltd is responsible for running Ascot, the UK's premier racecourse. The largest event is the Royal Meeting which is a five day event, with up to 80,000 spectators of all ages across the social spectrum visiting each day. The previous facilities were becoming dated in terms of the need to meet the demands of a modern busy racecourse. The decision was therefore taken to re-align the track and build a new facility to reduce congestion and create an exceptional facility fit for many years of racing, hospitality and entertainment. The design comprises a series of facilities facing the course, to the front, and parade ring, to the back, with a Galleria running throughout. All the boxes, balconies and facilities make maximum use of the track side of the Galleria, which means that stairs and other facilities are positioned away from the track side, which bring their own fire and circulation challenges.

Fig. 8.1 Grandstand

8.3 METHODOLOGY FOR MANAGING THE FIRE SAFETY TEAM

In major complex projects, like Ascot Race Course where the normal national codes have little real relevance a performance based engineering approach is essential. This required the designers, the operators and all the relevant authorities to come together early on in the process to define the technical approach and processes. It was only in this way that viable safe quality spaces could be achieved. Advanced engineering methods were used as typical available design codes were unlikely to deliver the same flexibility or consider the essential levels of safety. The main participants in the fire safety team were: -

- Client
- Fire and rescue services
- Project managers
- Building control
- Structural engineers
- Crown property representation
- Architects
- Sports grounds authority
- Building Services engineers Third party checkers
- Fire engineers

With this number of parties involved, the sequential development of the engineering in parallel with a progressively advancing approval was the key to successful understanding and risk reduction. The fire engineering approach adopted was exemplified by the following steps as part of the overall engineering methodology.

1. Initiation and development of fire
2. Smoke management
3. Structural response and fire spread
4. Detection and alarm
5. Fire service intervention
6. Means of escape

Steps 1, 2, 3 and 6, which are the most significant in engineering terms, are dealt with in this paper.

8.4 INITIATION AND DEVELOPMENT OF FIRE

Determination of the size of fire and its speed of development has an impact on all aspects of fire safety. Therefore early agreement was essential as it has an impact on all of the following.

- Structural fire performance requirements
- The need for added fire protection to steelwork
- Spread of smoke and smoke management
- Means of escape
- The requirement for sprinklers
- The extent of compartmentation
- The degree of management to control the fire load content

- Fire service response and provisions

All of these issues were very interactive and thus the agreement of fire size was a fundamental precursor to the engineering, the risk assessment and the expert opinion, which was managed via the fire safety team process.

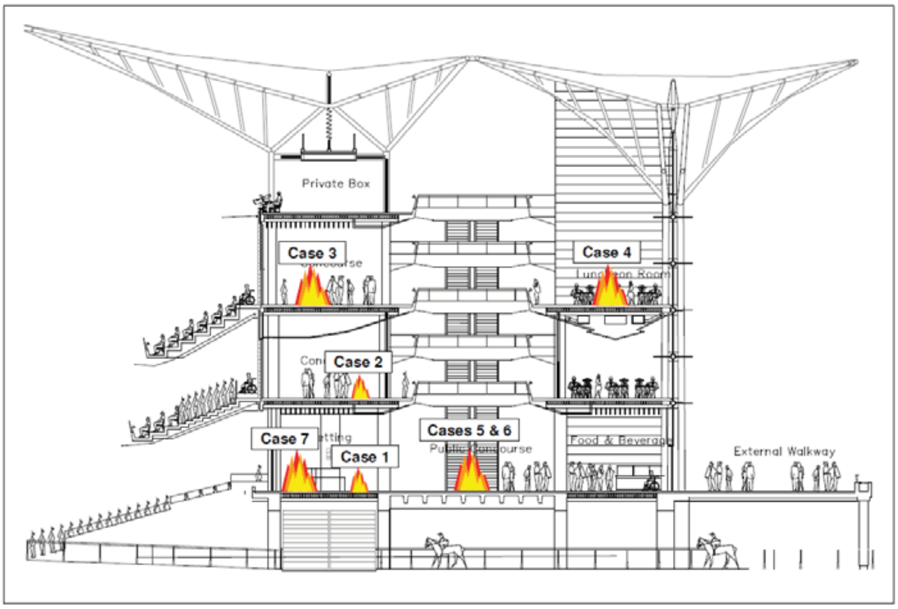


Fig. 8.2 Fire scenarios – indicated on section through Galleria

The range of principal fire scenarios identified in consultation with the fire safety team is illustrated in Fig. 8. 2.

- Sprinklered fires in retail and exhibition areas from 1.25 to 2.5MW with medium to fast growth rate fires. The main influence was on means of escape with little impact on structural performance although integrity (spread of smoke through small cracks) of structural walls and floors remains a relevant performance requirement. (Cases 1 & 2).
- Full developed non-sprinklered fires in high risk areas (e.g. storage) contained by compartmentation so mainly impacts on structure and compartmentation. (Case 7).
- Fires on open decks with no sprinklers, managed fire load and medium to fast growth rate fires from 3MW to 6MW. The primary impact was on means of escape but local temperature checks required on the structure to make sure that a relatively small fire does not have a disproportionate impact on structural performance. (Case 4).
- Separately compartmented tunnel access under the stand with sprinklers, fire resistance and smoke control to reduce risk of fire affecting the business of a major race event.
- Christmas tree. (Case 5)

8.5 SMOKE MANAGEMENT

The development of the form of the roof and the integrated design of the smoke vent layout (Fig. 8.3) was very important in the strategy for limiting smoke spread and maximising smoke extraction to allow the longer means of escape time required for the large populations. Account was taken of the wind effects and the microclimate that dominate the flows of cooler low buoyancy smoke. The wind regime around the building, including the impact of dominant low level openings was investigated by wind tunnel testing to establish that there were no significant inflows through the vents, which would prevent venting of the smoke (Fig. 8.6). Also different seasons were considered to test a range of micro climates before the fire scenarios were imposed on the analysis.

For fires on high level floors (Case 3and 4) the smoke calculations show that there is a clear layer above the highest occupied level of about 5m to 7m thus allowing means of escape. The CFD analysis (figure 5) showed that there is sufficient buoyancy to enable this approach.

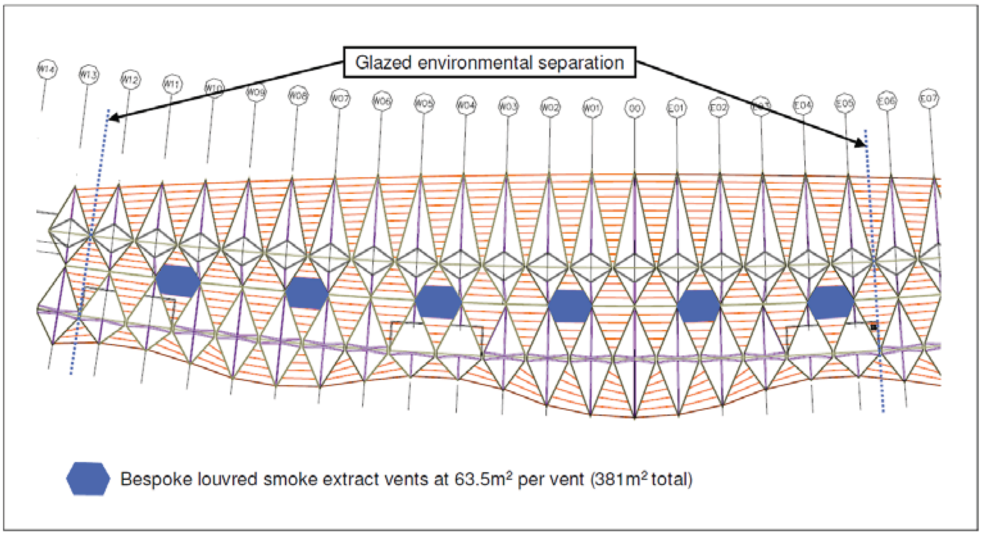


Fig. 8.3 Roof plan - showing layout of vents at natural high points in roof

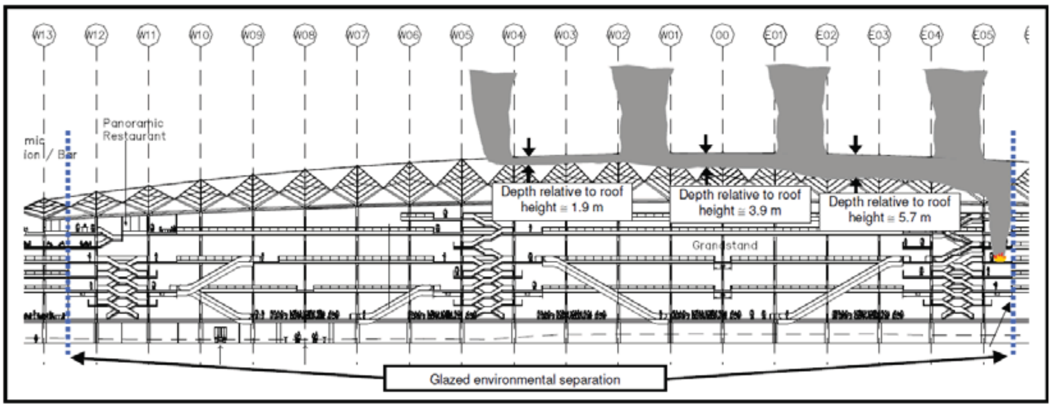


Fig. 8.4 Long section through Galleria - showing plug-holing effect of vents preventing lateral spread of smoke

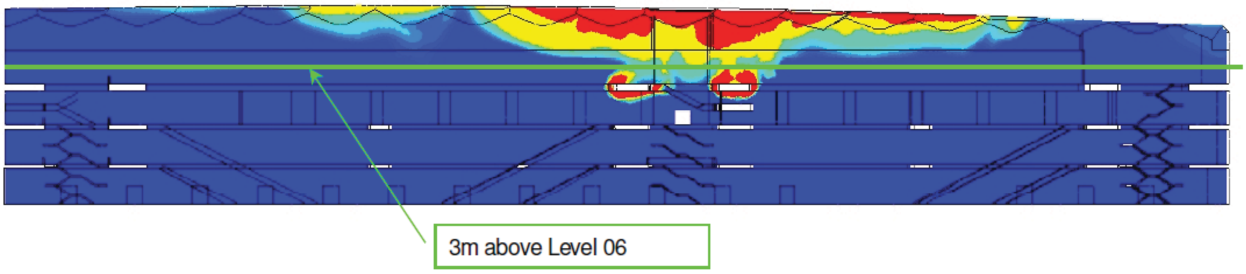


Fig. 8.5 CFD output - demonstrating effectiveness of vent system accounting for microclimate and wind effects

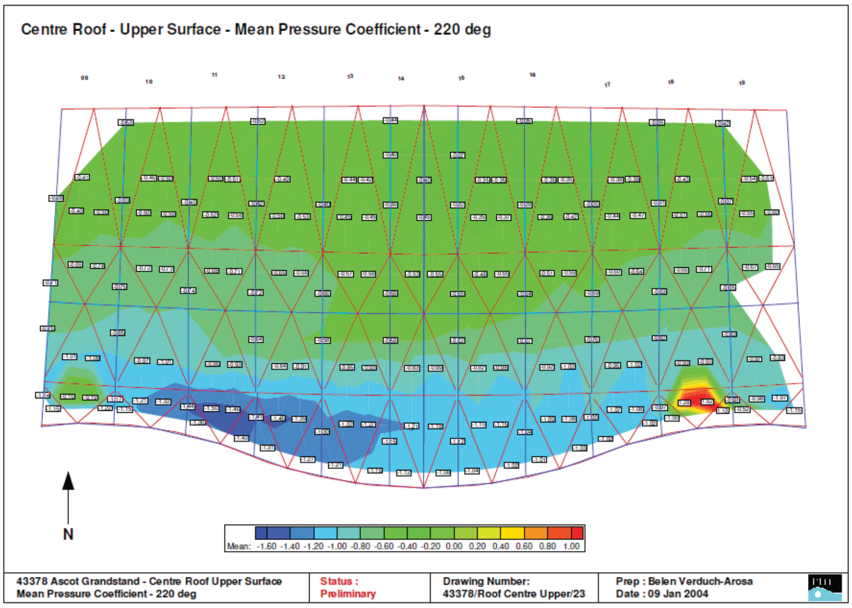


Fig. 8.6 Wind pressure contours – wind tunnel test output supporting location of vents and roof structure profile

For fires on low level floors with sprinklers (Case 1 and 2) the smoke was so dispersed that the visibility was well above the limit normally associated with a dilution system (an approach that allows low density, low risk smoke in occupied areas). The calculations were steady state so there was no time limit built into the calculations, which was conservative. The extent of significant smoke was relatively small with the limits of the smoke plume defined by a 10m visibility iso-surface (see Fig. 8.7). The majority of the Galleria had a visibility well in excess of the 25m, which compared favourably with the normal 10m limit. Christmas trees give very intense fast growing fires but were not a critical case because of the short duration of the fire and the relatively small impact they had on a large space like the Galleria.

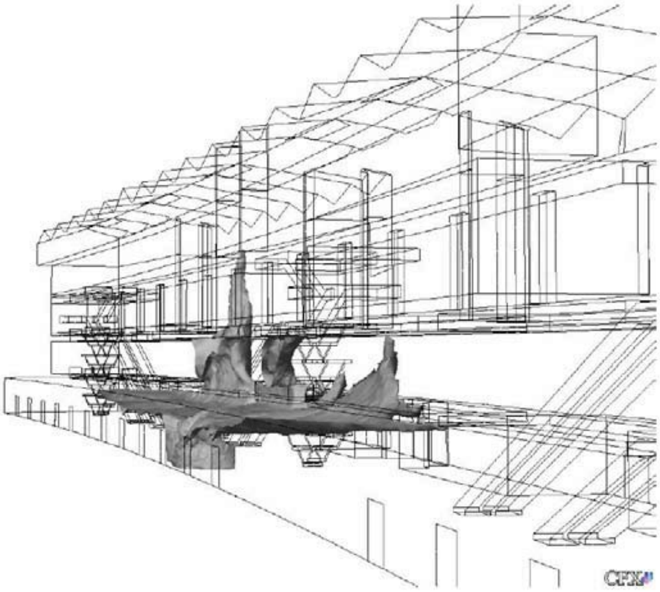


Fig. 8.7 CFD output at 10 minutes – shows 10m visibility iso-surface demonstrating limited extent of thicker smoke and thus which stairs are likely to be affected

8.5 STRUCTURAL RESPONSE AND FIRE SPREAD

The elements of structure supporting the proposed Ascot Grandstand were required to achieve 90 minutes fire resistance according to prescriptive guidance. However a fire engineering assessment was adopted to rationalise the applied passive fire protection to the steelwork to test that: -

- Structural elements do not fail prematurely when exposed to fire
- Disproportionate collapse does not occur, and
- A local fire does not adversely affect the structural stability of the overall frame.

A qualitative risk assessment was conducted to determine the appropriate level of applied fire protection considering the following parameters:

- The **probability** or likelihood of an element of structure being exposed to a fire that is sufficiently hot to cause significant structural damage. Consideration was given to the use (fire load density) and size of the space, the openness of the galleria and the effects of automatic sprinkler protection etc.
- The **consequence** of the failure of a particular element of structure to the entire stability of the structure. The consequence of life safety for both building occupants and fire fighters were taken into account. Consideration was also given to property protection / business continuity.

Fig. 8.8 Main structural steel components

The following table was the basis of the fire resistance requirement

Tab. 8.1 Fire resistance matrix

Fire Resistance	Low Probability	Medium Probability	High Probability
Low Consequence	0 minutes	0 minutes	30 minutes
Medium Consequence	30 minutes	60 minutes	90 minutes
High Consequence	60 minutes	90 minutes	90 minutes

Definitions used: -

Low Consequence – local distortion of a single element which may lead to higher deflection. However, collapse of any part of the structure is not anticipated and life safety of any occupants and fire fighters are not affected.

Medium Consequence – local failure to an element or part of a structure may occur. There may be excessive deflection and/or local collapse at a later stage of the fire. However, major collapse caused by the local failure is not anticipated and life safety of any occupants and fire fighters are not affected.

High Consequence – Major collapse or structural instability may occur as a result of the fire.

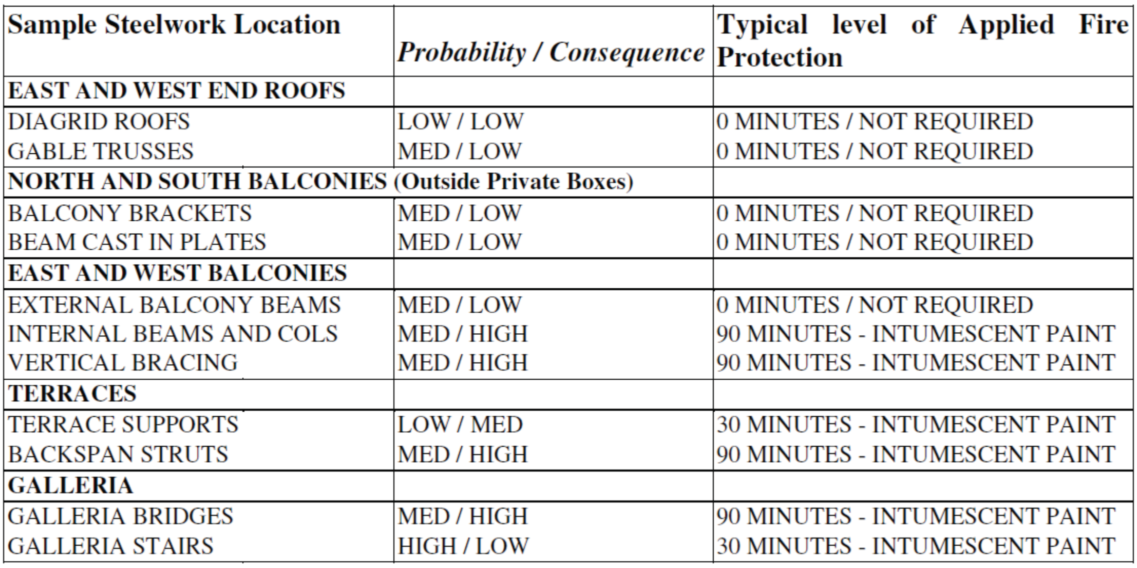
Low Probability – Steelwork exposed to fire sterile area or remote from/external to any significant fire load (e.g. roof steelwork supporting the PTFE)

Medium Probability – Steelwork in the proximity of fire load that is protected by sprinklers or other automatic suppression system.

High Probability – Steelwork in the proximity of fire load that is not covered by any automatic suppression system.

This approach resulted in the fire resistance ratings given below.

Tab. 8.2 Resulting fire resistance requirements to structural members



Sample Steelwork Location	*Probability / Consequence*	**Typical level of Applied Fire Protection**
EAST AND WEST END ROOFS		
DIAGRID ROOFS GABLE TRUSSES	LOW / LOW MED / LOW	0 MINUTES / NOT REQUIRED 0 MINUTES / NOT REQUIRED
NORTH AND SOUTH BALCONIES (Outside Private Boxes)		
BALCONY BRACKETS BEAM CAST IN PLATES	MED / LOW MED / LOW	0 MINUTES / NOT REQUIRED 0 MINUTES / NOT REQUIRED
EAST AND WEST BALCONIES		
EXTERNAL BALCONY BEAMS INTERNAL BEAMS AND COLS VERTICAL BRACING	MED / LOW MED / HIGH MED / HIGH	0 MINUTES / NOT REQUIRED 90 MINUTES - INTUMESCENT PAINT 90 MINUTES - INTUMESCENT PAINT
TERRACES		
TERRACE SUPPORTS BACKSPAN STRUTS	LOW / MED MED / HIGH	30 MINUTES - INTUMESCENT PAINT 90 MINUTES - INTUMESCENT PAINT
GALLERIA		
GALLERIA BRIDGES GALLERIA STAIRS	MED / HIGH HIGH / LOW	90 MINUTES - INTUMESCENT PAINT 30 MINUTES - INTUMESCENT PAINT

8.6 MEANS OF ESCAPE AND RISK ASSESSMENT

For each of the fire cases there was the potential for a stair or a walkway to be blocked and so a series of evacuation studies were carried out accounting for these potential blockages, which were estimated from the extent of the smoke plumes (see Fig. 8.7). The analysis demonstrates there was no real upper limit on the evacuation time so means of escape was not critical. Therefore an in depth assessment of time to detection, pre-movement time (the time taken for people to start moving) was not required. Therefore a figure of 8 minutes taken from the Guide to Safety at Sports Grounds was used to ultimately determine the acceptability, even though there is currently some debate on the relevance of this particular figure. Means of escape for disabled people was planned to be via a combination of refuges at the stairs and also more effectively via horizontal evacuation to the outside areas at the ends of the stand.

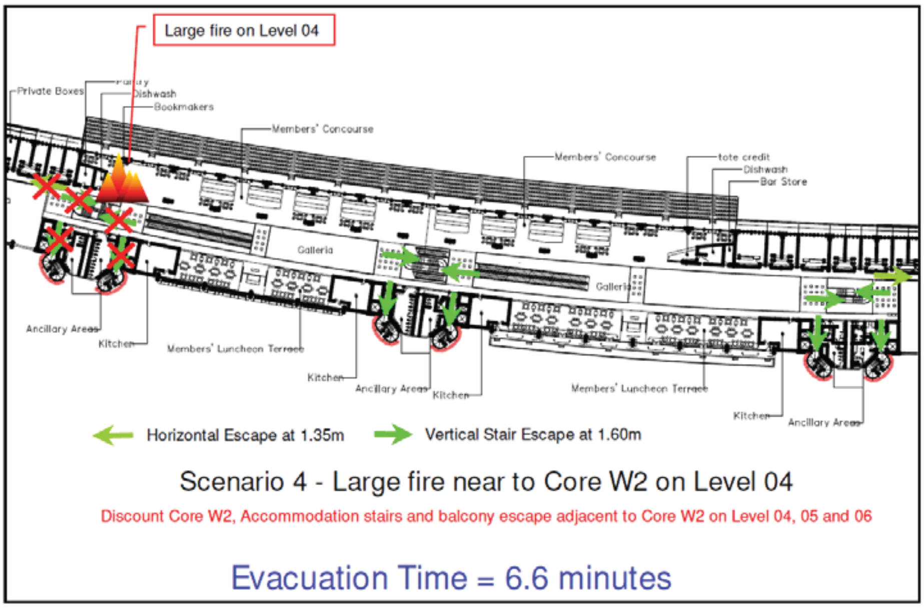


Fig. 8.9 Evacuation scenario - showing blocked stairs and primary exits available for escape

8.7 CONCLUSION

This paper summarises the fire engineering assessments undertaken for the redevelopment of the Ascot Racecourse. The creation of a stadium and an adjacent multilevel space to accommodate larger numbers of people are at the heart of the redevelopment. The varied activities associated with a modern major horse racing facility requires an holistic approach to fire safety including structural performance, smoke management and means of escape. To support this requirement a fire engineering approach was fundamental to deliver the essential safety and viability of densely populated spaces of this nature. The strategy to deliver an adequate standard of safety, background to the risk assessments and supporting analyses are explained to demonstrate what an engineered approach can deliver.

Acknowledgment

The authors would like to thank the Ascot Racecourse Ltd for their permission to publish this case study.

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9 FAULTY DESIGN OF A SPORT HALL

Summary

Considered building covers a sport hall with social and recreational facilities, and a hotel part. The primary function of the building is to organize mass sport events. The building was designed in 2009 as foreseen for about 2,300 users (including the auditorium for 2,000 people). This two-storey building rises 15.3 m above ground level and its floor area is 6116 m2. Due to the usage and the number of persons who may reside in the facility, it is equipped with a variety of fire protection solutions within both the structural design and technology. The building was designed in breach of the requirements posed by technical regulations, governing the construction and fire safety in Poland. At the project stage there were committed several errors which have a significant impact on the safe evacuation. The design errors were duplicated during the construction phase and led to difficulties with gaining the official acceptance for usage.

9.1 GENERAL DESCRIPTION OF THE BUILDING

The subject of the study is a localized in a small town (51 000 inhabitants) a sport - cultural center consisting of the sports hall and the hotel part. The facility is intended to be used for mass events, sporting or cultural (eg, concerts). In the Hall's ground there is a court with the audience for two thousand people and hygienic sanitation facilities (changing rooms and showers) as well as auxiliary storage rooms. In addition, functionally related parts of the sports hall located on the entresol, provide recreational functions implemented in the rooms designed for gym, exercise, fitness, wellness centre, and a restaurant. The facility also includes a two-storey hotel, office space, and a conference room, see Fig. 9.1.

There is also a two-story hotel part in the building. It contains 26 beds and offices and a conference room, which may be occupied by about 27 people.

The building's structure is designed as consisting of a concrete part cast in situ and a steel part. The roof structure is made of prefabricated glued timber elements. The facade walls consist of glass curtains on a steel structure, and masonry walls. Building height is 15.3 m above ground level. The area is 6116 m^2 and building area about 4300 m^2. The plan of the object is an irregular shape with dimensions of approximately 78m x 65m.

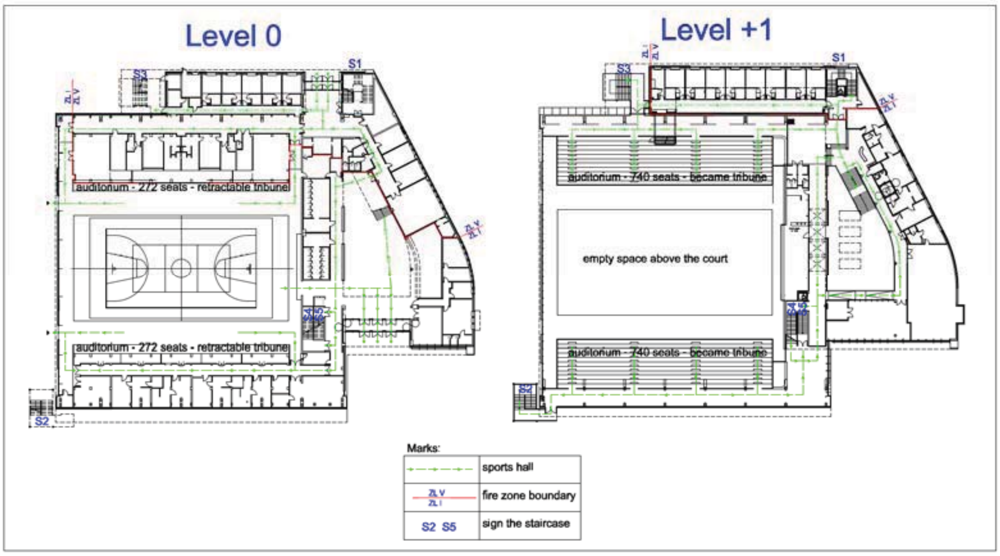

Fig. 9.1 Plan of the building

9.2 FIRE SAFETY ENGINEERING SOLUTIONS USED IN THE FACILITY

In terms of passive protection the considered facility was designed as reinforced concrete structure with required fire resistance applied and steel structure protected by fire protection paint. The object was divided into two fire zones (Tab. 9.1 and Fig. 9.1). The need for two zones was due the surface limitations for fire zones, specified in the regulations (Dz.U. 2002 vol.75) (5000 m^2).

Tab. 9.1. Fire zone distribution

Zone No	Name	Description
Zone I	Sport hall	The main entrance to the building, sports hall with the audience, changing rooms and toilets facilities are under one of the stands some of the rooms, and service loft.
Zone II	Hotel part	Hotel rooms on the ground floor and first floor of the building, communication and ancillary facilities within the zone as well as changing rooms and storage areas functionally connected to the sport located below the one from the stands.

It is difficult to justify why the locker room and sports magazines located under one of the stands were functionally associated with the hotel part (zone II). This division according to the authors was not the optimal solution, and also forced the need for additional passive solutions (additional and unwarranted costs). According to the authors a better solution would be to treat the building with different functions (hotels and sport) as a separate fire zones.

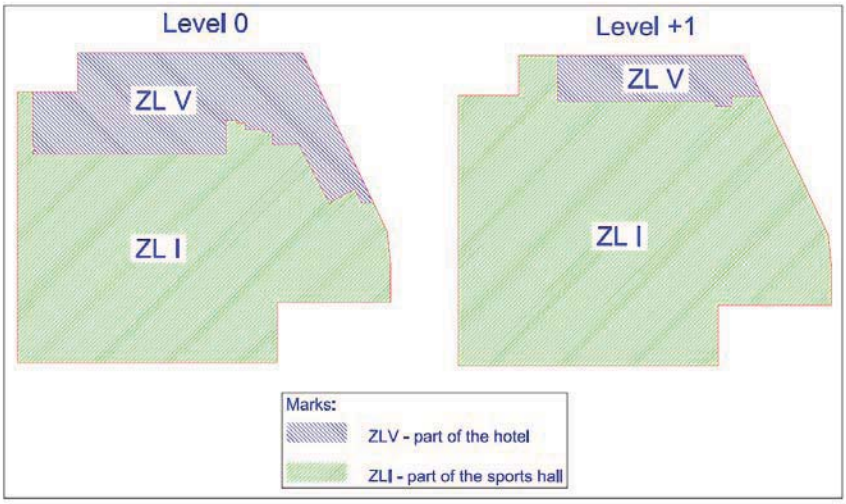

Fig. 9.2. Fire zone distribution

The facility is equipped with the following active fire protection:

- fire alarm system (initially the total facility protection was assumed while in the implementation phase some storage facilities were omitted),
- audible warning system covering the whole object,
- 10 fire hydrants (6 on the ground floor and 4 on the floor), located in recessed cabinets,
- equipment to remove smoke, only installed in the stairwell at the hotel, smoke extraction is carried out by the smoke vents mounted in the ceiling, no air supply holes are made on the ground floor,
- fire electricity breaker covering the entire building.

From the viewpoint of evacuation the facility is functionally divided into three parts (see Fig. 9.1):

- sports hall - part of the audience, on the ground floor main entrance (east) and the hall with cloakroom and staircase to the floor level (entrance to the stands), on the floor of the stands on both sides of the court, located inside the main lobby bar and recreational area (gym, fitness and wellness room), along with ancillary rooms and a mezzanine on which the entrance is located on the eastern grandstand,
- sports hall - part for the players on the ground floor of the room stands the two changing rooms, showers, storage ancillary sports hall and associated ancillary facilities,
- part of the hotel, in the western part of the building, separated from the sports hall includes space on the ground floor entrance (west) with a reception desk, hotel rooms and part of the club with a conference hall and hotel rooms located on the floor.

In the initial phase of the project the evacuation of was organized as follows:

Sports hall – the part for the audience (see Fig. 9.1):

- stairs in the hall (leading to the eastern exit),
- enclosed staircase and smoke extraction in the parts of the hotel leading to the western exit (K1),

- staircases K4 and K5 leading of the floors in the eastern part of the main hall and on to the eastern exit,
- communication from the mezzanine stairs being "extension" of the cage K4,
- if additional grandstands are placed on the floor, the evacuation of a sports hall provides an additional two outputs of the hall immediately outside the northern half, in the southern part of the main door to the hall and outside on the east and exit doors to the reception hall and hotel further out west exit.

Sports hall - part of the players (see Fig. 9.1):

- the exits leading to the sports hall and further out the through the door in the northern part,
- the exit leading to the main hall and outside through the east exit (the eastern portion under the stands),
- the exit leading to the reception hall and hotel further out through the west exit (the western portion under the stands),
- for the people in the main hall there are two outputs directly to the outside in the northern and southern parts of the door to the main hall and additionally a door leading into the reception hall and hotel further out through the west exit.

Hotel part:

- the enclosed staircase K1 with smoke extraction leads from the floor to floor and then through the reception hall outside the west exit (from the floor in the north),
- the exit directly to the reception hall and further out west exit (from the ground floor in the southern part),
- the exit directly outside the cage K3 (from the ground floor in the north).

The space of the sports hall was taken as a room where there is no evacuation enters. This solution was supposed to ensure the evacuation consistent with effective requirements, but as it turned out, after verification, it required substantial changes.

9.3 FORMAL AND LEGAL REQUIREMENTS

In practice the requirements for a building are placed in advance based on classifying its usage and based on its height. Because of the way buildings are used they are divided into (Dz.U. 2002 vol.75): risks to humans, and production - livestock handling. In terms of human risk there are distinguished five categories known as bad, ZLII, ZLIII, ZLIV and ZLV. The considered building is a subject of two these categories:

- in the entertainment - sports part - bad (the building containing a room for more than 50 people who are not regular users of the building),
- in the hotel part - ZLV (collective residence building).

In terms of the building’s height there are distinguished five groups of buildings (Dz.U. 2002 vol.75): low (no higher than 12 m), medium-high (more than 12 m to 25 m) high (more than 25 m to 55 m) and very high. The building under consideration belongs to a group of medium-high buildings.

This assignment is the starting point to determine the fire resistance class of the building denoted by the letters A, B, C, D, E, based on Tab. 9.2

Tab. 9.2 Fire resistance of buildings

Building height	**Hazard category for people (ZL)**				
	ZL I	ZL II	ZL III	ZL IV	**ZL V**
1	*2*	*3*	*4*	*5*	*6*
low (N)	„B”	„B”	„C”	„D”	„C”
medium-high (SW)	**„B”**	„B”	„B”	„C”	**„B”**
high (W)	„B”	„B”	„B”	„B”	„B”
very high (WW)	„A”	„A”	„A”	„B”	„A”

Tab. 9.3 Requirements for the major elements of structure based on the fire resistance class

Fire resistance class of the building	**Fire protection classes for elements of the building**					
	main supporting structure	roof structure	ceiling slab	external wall	internal wall	roof decking
"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 4)	R E 30
"C"	R 60	R 15	REI 60	EI 30 (o-i)	EI 15 4)	R E 15
"D"	R 30	(-)	REI 30	EI 30 (o-i)	(-)	(-)
"E"	(-)	(-)	(-)	(-)	(-)	(-)

In accordance with above requirements, the bad and the medium-high buildings ZLV shall meet the requirements for Class B of fire resistance. This gives a basis for determining the detailed requirements for fire resistance of individual elements of the building, according to Tab. 9.3. It should also be added that here that the above requirements are not strictly imposed. By applying appropriate solutions for the fire protection some of the requirements set can be released. Additionally, if the building element is also a part of the fire zone borderline, it must meet the requirements for fire resistance specified in Tab. 9.4.

Tab. 9.4 The requirements for building elements forming the fire protection separations

Fire resistance class of the building	**Fire resistance class**				
	fire separating elements		fire doors and other closures of fire	fire door from the fire protection vestibule	
	walls and ceilings, with the exception of ceilings in ZL	ceiling in ZL		the corridor and into the room	the staircase
„A”	REI 240	REI 120	EI 120	EI 60	E 60
„B” i „C”	REI 120	REI 60	EI 60	EI 30	E 30
„D” i „E”	REI 60	REI 30	EI 30	EI 15	E 15

Another requirement, which determines the subsequent functional layout of the building is acceptable surface fire zone. It is determined based on Tab. 9.5.

Tab. 9.5 Permissible surface of fire zones

Hazard category for people	Permissible surface of fire zone [m^2]			
	In a building with one floor above ground (no height restrictions)	in multi-story building		
		low (N)	**medium-high (SW)**	high and very-high (W) i (WW)
1	*2*	*3*	*4*	*5*
ZL I, ZL III, **ZL IV**, ZL V	10 000	8 000	**5 000**	2 500
ZL II	8 000	5 000	3 500	2 000

It is worth noting that the rules (Dz.U. 2002 vol.75) allow the treatment of one building as consisting of many independent if they are properly separated. All elements of separating (from foundation to roof covering the roof, walls, and in particular the closing holes) must then satisfy the imposed requirements (Tab. 9.4).

From the viewpoint of evacuation important parameter is the number of persons who may reside in the building. The parameters of the escape routes are described below. The rooms designed to accommodate people should be prepared for evacuation. This should be achieved by allowing the exit to the outside of the building or to an adjacent fire zone - directly or through overall channels of communication. According to the regulations (Dz.U. 2002 vol.75), there are two parameters of the length of an escape route: crossing routes and access routes.

Additionally, in terms of fire protection equipment in the facility there are required (Dz.U. 2010 vol.109) the following devices:

- fire alarm system,
- audible warning system

- fire hydrants,
- equipment to remove smoke in the stairwells for evacuation,
- electricity fire breaker.

Building under consideration also needs to ensure water supply for fire (Dz.U. 2010 vol.124) - in the amount of 20 dm^3 /s and must be equipped with fire roads (Dz.U. 2010 vol.124), providing convenient vehicle access for the fire fighting and rescue units. Furthermore, based on the standards (PN-92/N-01256.01, PN-92/N-01256.02) the building should be equipped with building evacuation and safety signs.

9.4 ACCEPTED WAY OF ASSESSING

In this case, the assessment of the solutions covering primarily the verification of safety-related parameters was focused on the evaluation of:

- the length of evacuation pass,
- the length of evacuation access,
- width of escape routes (corridors, stairs and landings),
- total and a minimum width of exit from the premises,
- total and a minimum width of exit outside the building.

Based on the above it was determined how an object is split into fire zones and the distribution of fire stairwells, which can be used for evacuation.

9.5 DESCRIPTION OF THE PROJECT APPROVAL PROCESS

The project is being developed by a team of designers of various sectors based on established principles and utility regulations and standards (Dz.U. 2010 vol.243). Then, fire safety in most of the projects is subject to verification by an expert of fire protection. The necessity of this verification shall be governed by (Dz.U. 2010 vol.121) and it is dependent on the usage of the object, its height and area.

An investor verifies the project in terms of functional requirements previously established. The designer is responsible for the project and that it complies with the requirements of the law. Later in the investment process the designer is required to fulfill the author's supervision (Dz.U. 2010 vol.243).

At the stage of building construction the construction manager is responsible for its proper implementation. On completion, he shall make a declaration of conformity of the draft rules of technical knowledge and the law (Dz.U. 2010 vol.243). It is understood by the principle that the contractor should catch any errors in the design and in consultation with the designer, make the necessary changes. With good preparation of construction managers in the design and architectural issues there are observed simultaneously inadequate consideration for fire issues. Sometimes this results in a duplication of errors during the implementation of the design.

The last stage, before the building is open to use, there are various departments involved in the control aimed to ascertain compliance with the construction project (Dz.U. 2010 vol.243). At the same time there is carried out an assessment of compliance with the law. All too often this leads to a detection of serious deficiencies in fire safety at this stage only, and this was the case here.

Before the end of construction, in preparation for the reception of the building for fire protection, the investor asked the independent expert to prepare a document required by the rules "fire safety instruction." Such a document is required in all facilities with a capacity exceeding 1000 m^3. This document contains requirements for the fire protection. In the analysis of the object in question, the most important issue raised was concerning exceeded length of the pass and reach exits.

In extreme cases, the length of the transition evacuation (evacuation of the stands), was more than 80 m at the limit of 40 m. In addition, there is an isolated room on the mezzanine floor recreation and wellness center, which meant that these areas should guide the access routes, which was permissible length of 10 m, and in one case 40 m. A similar problem was noted on the evacuation of the floors of the hotel, where the length of evacuation was reaching over 27 m. As these distances are exceeded, it allows to describe the building as a life-threatening for humans. In addition, separation of the room on the mezzanine causes it to be considered as a regular floor.

Another problem concerned here are the staircases. They were not made in accordance with the requirements for smoke (K4 and K5), or even the stairs were open without casing and closing fire door and smoke.

Also the requirement for housing fire escape route and closing holes on the section between the staircase and leaving the building was not satisfied. Moreover, it was noted that according to the requirements, the door of the premises on evacuation routes in the hotel (except the door to hygienic sanitation) should have a fire resistance of not less than T30. This resulted in the need to replace the doors to rooms and spaces under the grandstand and offices located within the same fire zone.

9.6 ADOPTION OF SOLUTIONS RESULTING FROM THE THEORETICAL ANALYSIS

According to the project the facility is equipped with additional external stairs (one for each of the stands), located in the northern part of the building (staircase K2 and K3) for the evacuation of a sports hall and the floor of the hotel. This solution eliminated the problem of escape from the stands and the floor in the hotel part. In connection with the requirement of closing the exit from the premises for general communication path in the medium-high ZLV (hotel) building the fire doors needed to be exchanged under the grandstand in the fire zone areas (total 18 units) by the doors with a fire resistance EI 30th. It should be noted that it would be possible to avoid part of this exchange if the hotel would be separated from other parts of the building by fire separation walls, which would be treated as a separate hotel building with a height of 9.8 m (low building in which there is no such requirement). The division that has not been foreseen in the draft and at a stage when this requirement was identified as necessary to complete the building was at the finish stage.

It should also be noted that the system used does not guarantee the required area of fire zones in accordance with the requirements, which is less than 5000 m^2. However, adequate separation from the sports hall of the hotel building would treat sports as part of the one-story building which would allow the fire zone area to be 10000 m^2. Such fire zoning would be compliant with the regulations.

Another problem is related to the wellness facilities and dedicated sports hall on the mezzanine, which in accordance to (Dz.U. 2010 vol.243), is considered as the next story. This problem was solved by dismantling the walls that emit up to the room ceiling, along with separate spaces previously formed as one whole. This work was carried out on a stage adaptation of premises by the user.

The major problem was improper construction of the fire zoning. On the floor at the exit of the sports hall on the escape stairs at the hotel (frame K3) there were installed doors without fire protection. At this point, the designer clearly marked fire zone boundary, but also did not provide fire doors. This error has been discovered after finishing work. There was therefore necessary to replace the exit door of the hotel by fire doors.

As previously mentioned the escape route leading from the closed fire door and the staircase with smoke removal outside the building should have a cover and closing openings meeting the requirements for fire resistance - the same as the staircase (Dz.U. 2002 vol.75). This requirement was not included in any of the staircases provided as the escape way (frames K1, K4 and K5). In the case of the staircase K1 there was possible to make an appropriate enclosure. This required, however, the exchange of 10 pieces of ordinary fire doors. The exchange was carried out at the stage of completion.

In the case of the staircases K4 and K5 the above requirements were not satisfied because the exit of those staircases on the ground floor leads to the space combined with a sports hall. At the same time in these staircases there are no channels connecting staircases with smoke flaps. Finally smoke removal was abandoned for these staircases. These staircases were treated as regular mezzanine staircases connecting the ground floor in the same room. However, the investor has incurred costs associated with the installation of useless control devices, smoke control and smoke flaps.

One year after the completion of the fire protection systems, the inspection revealed irregularities in their operation and performance. Below are some examples that have occurred in the present building:

- no connection control signal from the fire detection system to the system startup smoke dampers,
- no revision allowing access to the detectors located above the suspended ceiling (about 10% of all detectors,
- lack of proper control of ventilation and air conditioning,
- lack of protection (not installed detectors) in several storage rooms,

- some of the evacuation light lamps were not constantly powered to enable charging of the batteries (power supply is connected with the lighting circuit).

Removing these errors and the introduction of the aforementioned changes, will allow bringing the object into line with the requirements of the fire.

9.7 CONCLUSION

Any solution for fire safety is costly due to the need to ensure an adequate level of reliability of equipment and due to the process of certification. Moreover, a better effect is to use an expensive material for the interior use of fire equipment, which usually are in such case less visible or they may "spoil" the aesthetics of the object. This means that security is an area that is not popular among investors. It is often not accompanied by an appropriate level of security awareness.

As shown by the considered case, an improper design of the object leads to additional expenditures for fire safety. In this case, the introduced solutions beyond those incurred before putting the building to use will not have a significant impact on the cost of continued operation of the building. No less, it appears advisable to ensure that the proper handling of the planning and implementation of fire safety solutions alongside with the professional architectural design and construction.

Moreover, it is questionable to let conduct reception operations by the contractor. This can lead to concealment of serious shortcomings as described above, lack of access to the detectors mounted above the suspended ceilings, etc..

The significant impact on the correct operation of the investment process has the knowledge and experience of designers and contractors. Remains an open question how an investor should proceed to choose a team to guarantee a comfortable course of investment.

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Dz.U. 2002 vol. 121: Rozporządzenie Ministra Spraw Wewnętrznych i Administracji z dnia 16 czerwca 2003 r. w sprawie uzgadniania projektu budowlanego pod względem ochrony przeciwpożarowej [Regulation of the Minister of Internal Affairs and Administration agreeing on a construction project in terms of fire protection] (Dz.U. 2003, vol. 121, item 1137, with amendments).

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