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Replacement fire protection solutions for a pick tower building - case study

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Abstract

Polish construction law and technical and building regulations allow for deviations from the requirements with appropriate alternative solutions. Modern buildings often require an individual approach due to the fact that the current regulations do not keep up with the constantly emerging modern technical solutions. This requires the development of engineering design documentation in the form of a technical opinion on the state of fire protection, prepared by building and fire protection experts. This documentation, previously agreed with the locally competent Regional Fire Chief of the State Fire Service, is submitted through the local building authority to the Minister responsible for construction issues. The subject of the article is the development of a justified set of alternative solutions for a warehouse building equipped with pick tower racks. Modern computer methods, simulations of evacuation, smoke extraction and construction were used to justify the solutions used. Determination of the mutual influence of the applied solutions on the expected level of fire safety allowed to confirm the validity of the adopted design concept. As a result, a complete fire protection concept was obtained, which, after its application to the documentation of the construction project, will allow safe use of the building. The analyzed building was implemented in Poland and, using the described fire safety concept, passed all stages of the investment process.

Keywords: fire safety, pick tower, building, fire risk, fire protection

1 Introduction

The subject of the analysis is a newly designed logistics and storage hall with social and office spaces and associated infrastructure. According to Article 6a item 1 of the Act [1], in the cases specified in the Fire Protection Regulations, the fire protection requirements for buildings or areas may be fulfilled in a different way than specified in these regulations, if the proposed alternative solutions to the fire protection requirements reduce the possibility of fire and in the event of its occurrence:

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1) ensure that the load bearing capacity of the structure is maintained for a specified period of time;
2) ensure limitation of the spread of fire and smoke within the building structure;
3) ensure limitation of fire spread to adjacent buildings or adjacent areas;
4) provide for the evacuation of persons or their rescue by appropriate means;
5) provide for the safety of rescue teams.

According to Article 9.1 of the Law [2], a deviation from the technical and construction regulations [3] is allowed in particularly justified cases. The deviation must not endanger human life or the safety of property. The subject of this article is to determine the necessary set of alternative solutions in connection with the presence of a storage mezzanine in a building intended for use by more than 10 people, the structure of which does not meet the requirements for fire resistance. Replacement solutions are also the subject of technical expertise on the state of fire safety [4].

Pick tower mezzanines consist of braced steel columns supporting the main beams of the platforms and reinforced beams of the shelves providing longitudinal stiffness of the racks. Transverse stiffness of the structure is provided by braced columns and floor crossbeams based on the main platform beams. There are 4 mezzanine levels:

- Level 0 (P0) - located on the floor of the room;
- Level +1 (P1) - located at a height of approximately 2.65 m;
- Level +2 (P2) - located at a height of approximately 5.27 m;
- Level +3 (P3) - located at a height of about 7.99 m.

Due to the mezzanine construction technology used, it is assumed that there are inconsistencies regarding the lack of the required fire resistance class R 30 for the supporting structure and REI 30 for the ceilings.

According to the adopted assumptions, the structure of the mezzanine should provide load-bearing capacity under fire conditions for longer than the time required for evacuation to the safe zone of all mezzanine users. In addition, based on the proposed alternative solutions and functional layout, it is assumed that there is an incompatibility concerning the absence of hydrants 52 in the area of two levels of the mezzanine (except for the first floor), which is incompatible with § 1 paragraph 2 of the Regulation [5].

The article presents proposals for alternative solutions, together with an assessment of their impact on the state of fire safety of the designed hall in relation to the indicated incompatibilities. The alternative solutions mentioned in this article should be understood as solutions that meet the fire safety requirements in a different way than specified in the technical and building regulations, ensuring an adequate level of safety for people, rescue teams and property. At the same time, due to social considerations [6], human safety will play a key role in the analysis.

One of the main reasons for the study is the lack of similar publications. The author's ambition is to stimulate a wider discussion on the subject under analysis.

2 Building characteristics

General information

The project in question is a single block divided into buildings (according to § 210 of the regulation [5]) by the construction of fire walls with fire resistance class REI 240 running vertically from the foundation to the roof overhang of the lower building. In view of the above, the fire protection requirements can be considered separately for each building.

Basic data of fire zone SP 1:

- Number of floors above ground: 1
- Number of underground floors: 0
- Interior area: approx. 35,000 m^2
- Volume: Approx. 450,000 m^3
- Height: 12.8 m (height group: mid-rise building "SW")

Fire zones

The subject building is a fire zone classified as production and warehouse Qd > 4000 MJ/m^2. For a one-story production and warehouse building equipped with fixed water extinguishing systems and automatic smoke removal systems, the allowable area of the fire zone is not determined. The fire zone in question has an area of approximately 35,000 m^2 (the area of the mezzanine is approximately 29,000 m^2 - it is not a storey within the meaning of the regulations).

Fire resistance class of the building

The basic fire resistance class of the building required for a one-storey production and storage building with a fire load density exceeding 4000 MJ/m^2 is class "A". Considering the chosen architectural and construction solutions and the designed fire-fighting equipment (single-storey building, equipped with fixed water extinguishing devices and automatic smoke removal devices), the building is designed in fire resistance class "E".

Evacuation conditions

The warehouse is designed with no corridors. Evacuation is carried out through no more than 3 rooms directly outside the building. The permissible length of the evacuation passage in the warehouse on the first floor is 175 m (100 m + 50 m due to the sprinkler system + 25 m due to the room height exceeding 5 m) and has not been exceeded. The fact that the building is equipped with an automatic smoke evacuation system is not taken into account in the extension of the length of the evacuation corridor due to the method of activation of this system, i.e. by the signal coming from the control and alarm valve of the sprinkler system on the basis of the adopted delay time.

The permissible length of the evacuation passage from the mezzanine floors is 150 m - assumed as for a one-storey building, without taking into account the height of the room (the height of the mezzanine floors +1, +2 is about 3 m), taking into account the equipment of the sprinkler system. The maximum designed length of the evacuation passage from the furthest point of the mezzanine to the adjacent fire zone does not exceed the permissible 150 m. The conditions for safe evacuation have been confirmed by simulations of the fire development and the effectiveness of the smoke removal system.

From one room of the warehouse (with an area of more than 300 m^2 and a fire load density > 500 MJ/m^2), at least two emergency exits have been provided, at least 5 m apart, with doors with a clear width of at least 0.9 m, opening outwards. In addition, due to the number of people likely to be in the warehouse exceeding 300 people (maximum 362 people), all evacuation doors (leading to stairwells, leading from stairwells to the outside, leading to adjacent fire zones, and leading from the warehouse directly to the outside of the building) should be equipped with panic devices.

Evacuation from the mezzanine floors is directly to one of two enclosed stairwells equipped with smoke removal devices activated by the stairwell smoke detection system. The staircases are located in separate buildings and are fire separated. The width of the escape routes in the mezzanine will be at least 0.9 m (applies to the main routes). In the stairwell, the width of the treads is at least 1.2 m and the width of the landings is at least 1.5 m. Doors leading from the stairwell to the outside are at least 1.2 m wide.

Marking for evacuation of escape routes and exits will be made in accordance with the requirements of Polish standards in such a way as to provide the necessary information for evacuation. Mezzanine floors will be additionally marked as shown in the section on alternative solutions.

3 Inconsistencies and alternative solutions

Incompatibilities

In the designed building it is assumed that there is the following non-compliance with current regulations:

1) Failure to equip levels P1, P2 and P3 of the mezzanine with hydrants 52 in connection with the use of hydrants 33.
2) Existence of mezzanine elements designed to accommodate more than 10 people without the required fire resistance class (applies to levels P1, P2 and P3), i.e:

a) maintaining the load bearing capacity of the structure for 225 s (for natural fire) in the absence of sprinkler actuation;

b) the presence of ceilings made of non-combustible panels (with a reaction to fire class of at least Bfl-s1 when exposed to fire from above and B-s1,d0 when exposed to fire from below) without a specified fire resistance class, based on a mezzanine structure that maintains its load-bearing functions for 225 s (for natural fire) in the absence of sprinkler systems,

with the required class R 30 for the structure and REI 30 for the ceiling.

The inconsistency regarding the lack of use of hydrants 52 at levels P1, P2 and P3 of the mezzanine is due to the proposal to use hydrants 33 at these levels. The use of hydrants 33 in these areas, taking into account the presence of a fire alarm system (rapid fire notification), will increase the likelihood of using this installation due to the lack of need to unroll a fire hose.

The ceilings forming a mezzanine in a room intended for use by more than 10 people, as well as its supporting structure, should meet the requirements resulting from the fire resistance class of the building, so the ceilings of the designed mezzanine, as well as its supporting structure, should meet the requirements as the fire resistance class of the building. For the building in question, due to the relaxation in terms of fire resistance class, the required fire resistance class of the mezzanine is R 30 for the structure and REI 30 for the ceilings. The design intention is to build a multi-storey mezzanine in lightweight steel construction, which will provide a large usable area with a small size of the structure. Since buildings and related facilities should be designed and constructed in such a way that, in the event of a fire, the load-bearing capacity of the structure is maintained for the time necessary to evacuate people to a safe place, the structural solutions for the mezzanine in question were analyzed in terms of evacuation conditions.

Replacement solutions

In order to achieve a proper state of fire protection of the building, it was considered necessary to implement the following solutions

1) Equipping the warehouse with a fire alarm system in the "total protection" variant, together with:
   a) connection to the fire monitoring system of the PSP;
   b) adoption of a fire scenario that ensures immediate alerting of the occupants of the mezzanine;
   c) density of manual call points so that the distance to each call point does not exceed 20 meters.
2) Provide evacuation from the mezzanine to two staircases located in separate fire zones and equipped with smoke removal devices activated by the smoke detection system.
3) Equipping evacuation stairs and doors leading to adjacent zones with panic devices (doors used to evacuate the number of people < 300).
4) Activation of smoke extraction in evacuation staircases in the event of a level I alarm in the detection zone covering the mezzanine floor.
5) Use of DN 33 hydrants with semi-rigid hose on each level of the mezzanine (except for the first level on the floor).
6) Provision of minimum width of escape routes on the mezzanine floors of 2 m with a required width of 0.9 m.
7) Provide a minimum height of 2.2 m on levels P0-P2 and 2.1 m on level P3 for escape routes within mezzanine floors.
8) Provide fire-resistant panels (with a fire reaction class of at least Bfl-s1 when exposed to fire from above and B-s1,d0 when exposed to fire from below) in the area of escape routes on the mezzanine floor.
9) Additional marking of the main mezzanine escape routes by:
   a) Use of evacuation luminaires with evacuation pictograms operating in the "bright" mode;
   b) Use of 1.05 m x 1.85 m horizontal escape signs (on the floor) on the primary means of egress;
   c) Use of graphic markings identical to the evacuation signs on all evacuation doors: depicting a moving person (white color) against a background of green door panels.

10) Use of additional solutions in the system of fixed water extinguishing device - sprinkler system increasing the protection of mezzanine levels:
    a) monitoring and control of the sprinkler system by control modules, including immediate transmission of technical alarms to the CSP with 24-hour monitoring by the facility security personnel;
    b) the use of separate sprinkler sections to protect the mezzanine - separate control and alarm stations with bypass systems to ensure that technical inspections and maintenance of the facility can be performed in a manner that ensures the efficiency of these devices during the above activities;
    c) use of quick response sprinklers.
11) Installation of emergency evacuation lighting with an intensity of 5 lx in the mezzanine area.
12) To equip mezzanine floors of the picking tower type with the number of fire extinguishers so that for every 100 m^2 of mezzanine floor there is one extinguisher with a 2 kg extinguishing agent weight.
13) Organization of a practical check of the conditions and organization of an evacuation of the entire facility on a semi-annual basis.

Confirmation of the maintenance of the load-bearing capacity of the structure and the provision of safe evacuation conditions for the time necessary to evacuate the occupants, through computer simulations of the static capacity of the structure under fire conditions without activation of the sprinkler system.

4 Engineering analysis of fire risk

Engineering risk analyses in fire protection have been performed for some time [7, 8, 9], but compiling them in a form that allows comparison of results in a single study may still be considered novel.

<u>Evacuation</u>

The method for checking the safety of evacuation has been adopted from the British Standard PD7974-6 [10]. The standard proposes to compare the required safe evacuation time (RSET) with the available safe evacuation time (ASET). RSET is defined as the time required for occupants to safely exit a building, plus a safety margin. ASET, on the other hand, is the time required for conditions in the facility to permit safe evacuation of occupants. The condition for safe evacuation is considered satisfied when ASET ≥ RSET.

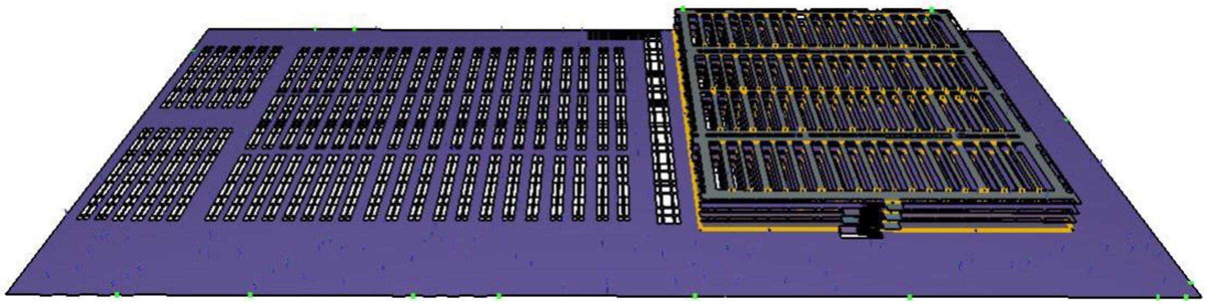


Figure 1. 3D model used in evacuation simulations

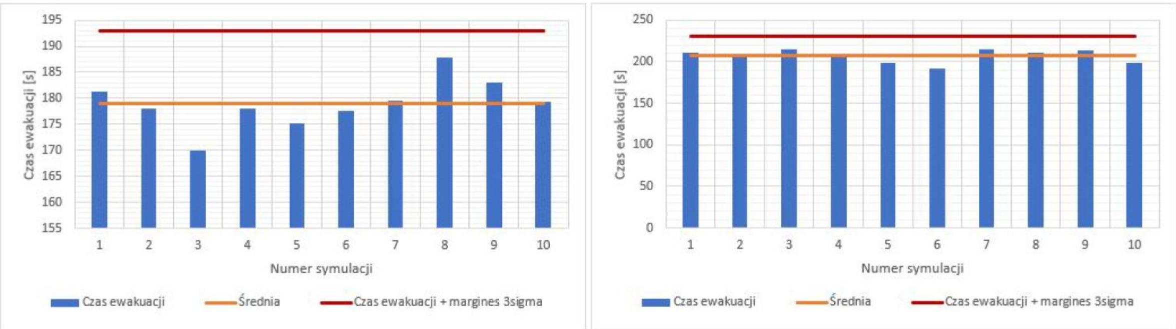
The Pathfinder 2021 program was used in this analysis. The scenario used in the simulations assumes that the evacuation covers the entire facility, regardless of where the fire is detected. Users are warned of the danger by sounders. The computer simulation takes into account the time of the first reactions. This is the time from the announcement of the fire alarm until individuals start the evacuation process. The value of the time of the first initial reactions is influenced by such behaviors as making sure that it is necessary to evacuate, finishing work that has been started, etc. The computer model used for the calculations is shown in Figure 1.

The analyzed event progression provides for:

- communication of information to the building occupants about the need to evacuate immediately after fire detection;
- the movement of the occupants to the evacuation exits;
- the end of the evacuation is considered to be the exit to the external, enclosed and smoke-filled stairwell and outside the hall.

The assumed evacuation scenario was recalculated 10 times, each time randomly changing the initial position and characteristics of the evacuees, resulting in 50 different evacuation scenarios. The purpose of this solution was to compensate for the error due to the stochastic nature of some of the parameters adopted for the simulation.

The results of the evacuation simulations are shown in Figure 2. The resulting evacuation time was assumed to have a normal distribution, and this hypothesis was confirmed by the statistical test performed [11]. The orange line indicates the average evacuation time calculated from all the iterations performed. The red line indicates the assumed safety margin at the "3σ" level. This value was determined by the average evacuation time of 207 seconds for the hall and 188 seconds for the mezzanine and three times the standard deviation of the performed calculations of 7.87 seconds and 4.68 seconds.



a) Antresola b) Hala

Figure 2. Evacuation time distribution from the mezzanine and hall space

In statistical science it is defined that if the obtained results are a normal distribution, then almost all values are within the sum of three standard deviations from the mean [12]. Using this approach, it was determined that the evacuation time in the event of a fire will not exceed 200 seconds from the area of all mezzanine floors and 240 seconds from the area of the entire hall with 99.85% probability.

Smoke removal

Three CFD simulations were developed for the analyzed warehouse and production hall facility. The FDS program was used for the calculations. The purpose of each scenario was to verify the possibility of evacuation under the assumptions presented in the previous step. In addition, it was verified that a fire in one area of the hall would not endanger people in other smoke zones of the analyzed building.

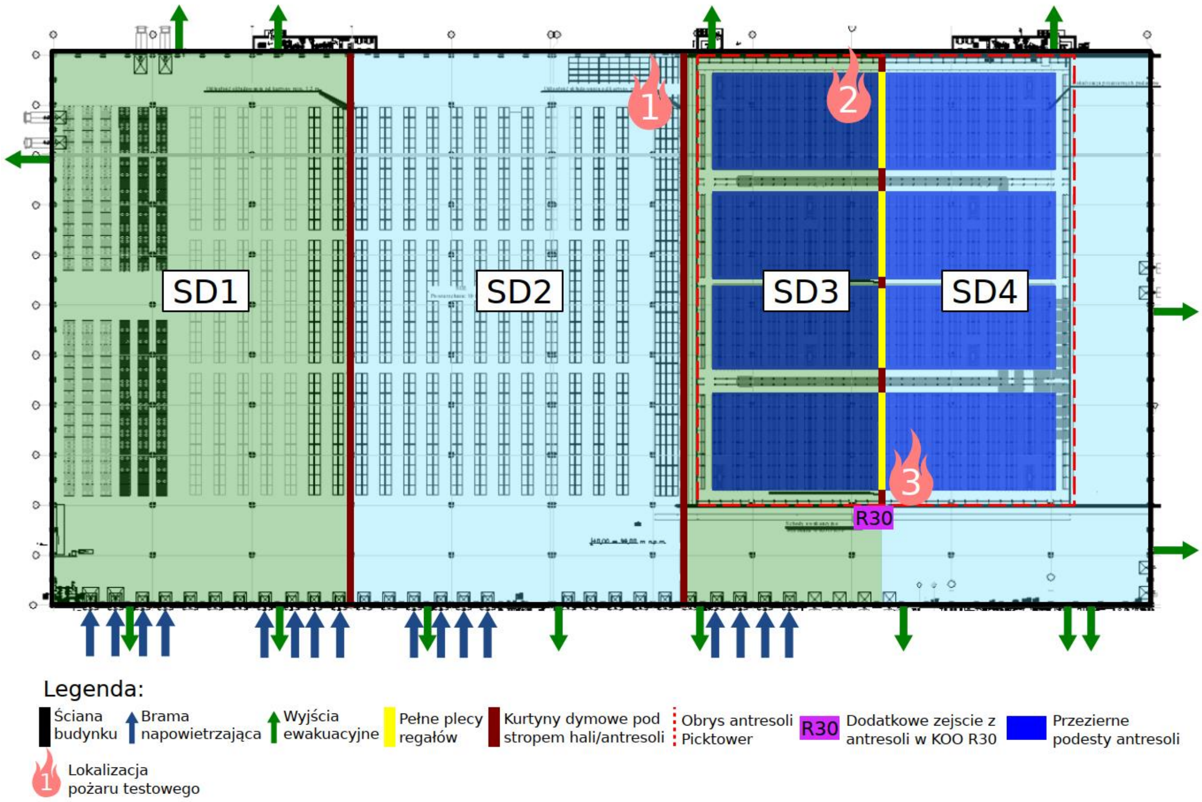


Figure 3. Evacuation time distribution from the mezzanine and hall space

Scenario 1: Fire in Smoke Zone SD2, in the high storage racking area on the hall floor (P0 level), near the boundary with Smoke Zone SD3 (mezzanine area) and one of the emergency exits. The location was chosen because of the potential impact of a fire in the racking area on people evacuating from the mezzanine level. The maximum fire power of approximately 4,700 kW is reached after a time of 96 s. The smoke extraction system is activated with a delay of 180 s after the sprinklers are triggered.

Scenario 2: Fire in Smoke Zone SD3, under the steel pick tower mezzanine on the hall floor (P0 level), between two staircases located in the northern part of the mezzanine. The location was chosen to verify the possibility of evacuation from the various levels of the mezzanine with the possibility of cutting off this escape route. The maximum fire power of approximately 1050 kW is reached after a time of 45 s. The smoke removal system is activated with a delay of 70 s after the sprinklers are triggered.

Scenario 3: Fire in smoke zone SD4, in the area of high storage racks on the top level of the mezzanine (level P3), near additional access stairs located in the southern part of the mezzanine on the border of two smoke zones (SD3 and SD4). The location of the fire was chosen based on a review of the possibility of evacuation in the event of a fire at this location with the possible flow of smoke into the adjacent smoke zone. The maximum fire power of approximately 1450 kW is reached after a time of 53 s. The smoke extraction system is activated with a delay of 70 s after the sprinklers are triggered.

In Scenario 1, the design fire was placed in Smoke Zone SD2 at the location shown in Figure 3. The purpose of this scenario was to test the effectiveness of the gravity smoke extraction system in removing smoke from the high bay racking space and to see if it would penetrate into the mezzanine space. For this purpose, the fire source was placed on the floor of the hall, at the boundary of the smoke zones. From the beginning of the simulation, the smoke rose to the top, where it dissipated into the space of the separate smoke container. The smoke curtains used limited the spread of fire gases into adjacent smoke zones and provided adequate evacuation conditions from adjacent mezzanines.

In Scenario 2, the design fire was placed in Smoke Zone SD3 at the location shown in Figure 3. The purpose of this scenario was to verify the effectiveness of the smoke control system in removing smoke from the steel mezzanine. For this purpose, the source of the fire was placed on the floor of the hall, between two staircases providing evacuation from all levels of the mezzanine. It was also verified that the smoke generated by the fire would be adequately transferred through all levels of the mezzanine to the smoke dampers installed in the roof of the hall. As shown in Figure 3, the fire source was placed at the boundary of the two smoke zones. From the beginning of the analysis, the smoke generated by the fire flowed upward between successive levels of the mezzanine. In addition to the transfer holes, the smoke also flowed through the free space between the mezzanine and the hall wall located at the northern edge of the mezzanine. The potential impact of the smoke on the evacuees was limited to the area immediately surrounding and above the fire. In the calculated evacuation time, the possibility of exit to both external staircases and an access staircase of R30 class was provided. The parameters of the conditions in the hall after the calculated arrival time of the fire brigade units do not exceed the accepted critical parameters.

In Scenario 3, the design fire was placed in Smoke Zone SD4 at the location shown in Figure 3. The purpose of this scenario was to verify the effectiveness of the smoke control system in removing smoke from the highest mezzanine level (P3). Due to the location of the fire source, it was not necessary to transport the smoke through the different levels of the platforms. Based on the results obtained, it can be concluded that, with the assumptions made regarding the time required for evacuation, the adopted evaluation criteria were not exceeded. The use of smoke curtains significantly reduced the flow of smoke between zones. Access to all emergency exits from the mezzanine was maintained throughout the evacuation. The conditions that may prevail in the hall after the calculated arrival time of the firefighting units do not exceed the critical parameters adopted for this area.

Construction

Three scenarios of fire development were assumed for each of three sections of the structure.

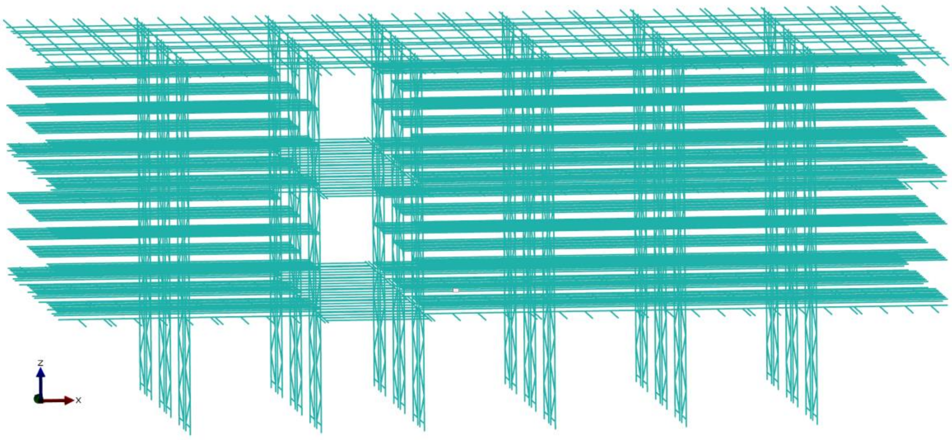
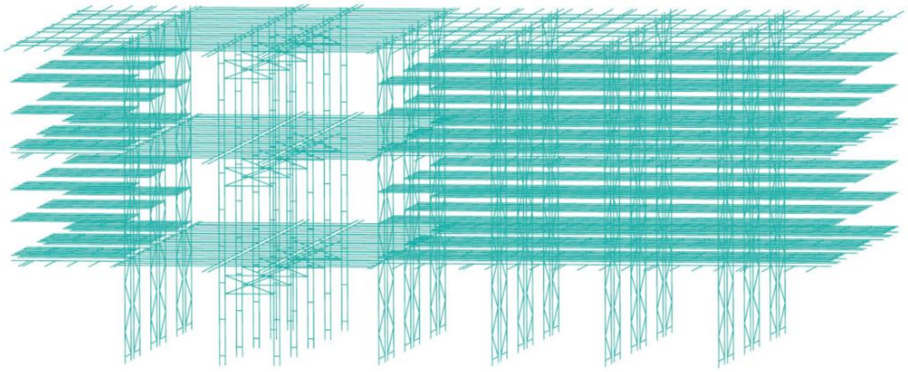

(a) regał przy alejce o szerokości 2,1 m

Figure 4. A rack in a 2.1 m wide alley

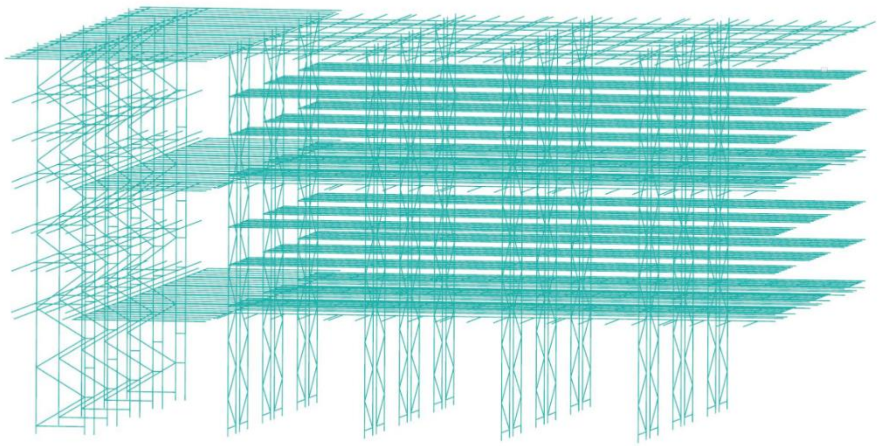
1. A section near a 2.1 m wide alley (Figure 4):
   a) fire developing steadily - representing complete sprinkler failure;
   b) fire considering ineffective sprinkler actuation - limited fire development;
   c) fire considering proper sprinkler activation - extinguishing the fire.

2. A section near a 6.2 m wide alley (Figure 5):
   a) fire developing steadily - representing complete sprinkler failure;
   b) fire considering ineffective sprinkler actuation - limited fire development;
   c) fire considering proper sprinkler activation - extinguishing the fire.



(b) regał przy alejce o szerokości 6,2 m

Figure 5. A rack in a 6,2 m wide alley



(c) regał przy alejce o szerokości 2,65 m (zewnętrzna alejka)

Figure 6. A rack in a 2,65 m wide alley (outer)

1. A section near a 2.65 m wide aisle (outer aisle) (Figure 6):
   a) steadily developing fire - representing complete sprinkler failure;
   b) fire considering ineffective sprinkler actuation - limiting fire development;
   c) fire considering correct sprinkler system operation - extinguishing the fire.

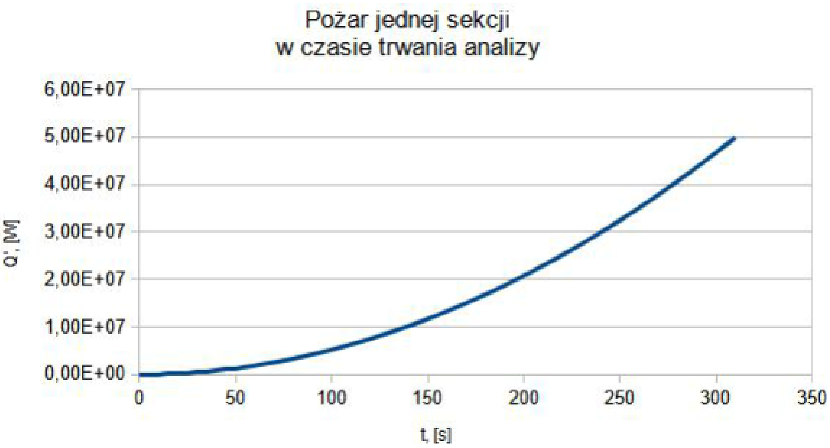


Figure 7. Fire power defined as the thermal effect on the structure, with complete sprinkler failure - Scenarios 1a, 2a, 3a

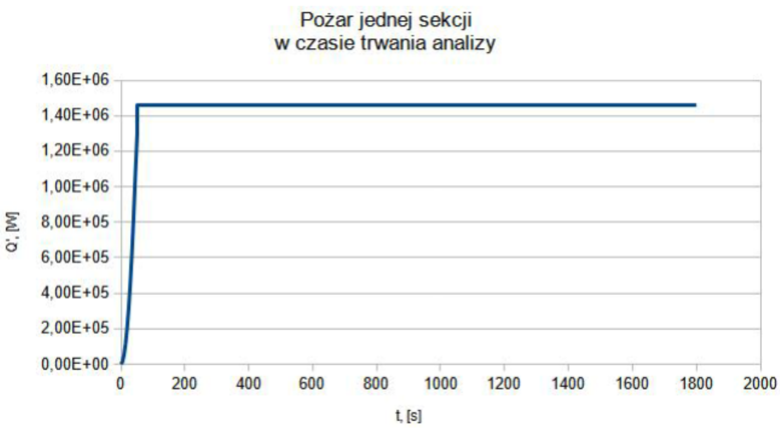


Figure 8. Fire power defined as thermal effect on the structure, with ineffective sprinkler system - Scenarios 1b, 2b, 3b

Since Scenarios 1a, 2a, and 3a (complete sprinkler failure) are the most adverse to the structure, these scenarios are considered for further analysis.

Scenarios 1a, 2a, and 3a (Figure 7) simulated sections of the steel mezzanine structure subjected to a free burning fire. The fire started at the level of the first floor, close to the means of egress. In all three scenarios, the initial and rapidly progressing changes in the structure can be seen from the beginning of the simulation. Due to the distribution of the columns in relation to the fire and the differences in the rate of progression of the thermal expansion, the magnitudes of the reactions in the supports of the outer columns, i.e., those supporting the main floor beams, decrease. However, the magnitudes of the reactions in the supports of the internal columns increase.

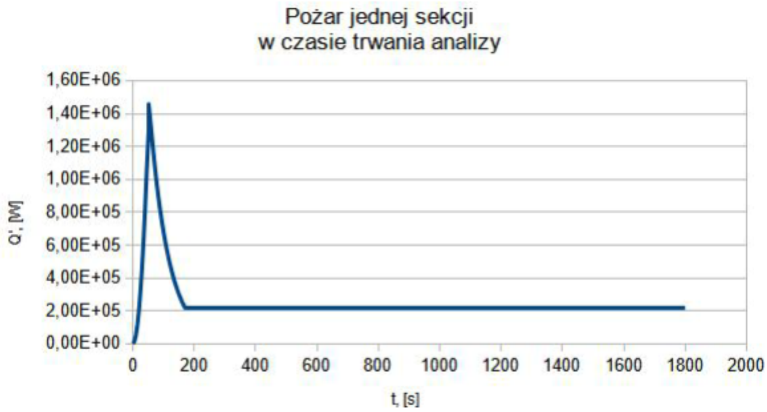


Figure 9. Moc pożaru zadana jako oddziaływanie termiczne na konstrukcję, przy prawidłowo działającej instalacji tryskaczowej - scenariusze 1c, 2c, 3c

In scenario 1a, buckling of the compressed beams of the lowest shelves directly above the fire occurs after approximately 85 seconds. In scenarios 2a and 3a, this occurs after approximately 100 seconds. The thermal expansions due to the length of the elements are significant, which only increases the deformations. Over time, more and more beams directly above the fire lose their load-bearing function. These are not key elements to ensure safe evacuation from the mezzanine. After about 145-150 s, buckling of the compression struts at the base of the columns is visible. These braces no longer contribute to the stabilization of the structure. The tension struts do not show any visual signs of deformation, while the thermal expansion of the columns increases the stresses in these elements. In the floor structure, deflections of the cross beams can be seen due to the applied loads. Axial forces also increase due to thermal expansion of the elements. These changes continue throughout the simulation period. Due to the short distances between the vertical structural elements of adjacent sections (adjacent shelf risers and adjacent racks), a relatively uniform thermal expansion of these elements occurs. As a result, the floor pan moves uniformly upward without any noticeable changes caused by thermal reduction of structural strength.

In scenario 1a, a floor beam in the main aisle buckles after about 157 s. This is due to a significant increase in axial force caused by thermal expansion of this beam and the racking beams. This beam does not affect the stability of the overall structure. Two beams in the aisles behave similarly after about 180 s in scenarios 2a and 3a.

In all three scenarios, after approximately 170 seconds, the outer columns of the racks immediately adjacent to the fire begin to take load from the inner columns. In scenario 1a, this condition continues until about 205 seconds into the simulation, when buckling of three additional floor beams (two in the main aisle, one between the racks) is observed. At this point, the ultimate limit state can be considered exceeded.

Structural stability in scenarios 1a and 3a is maintained until approximately 230 s, when buckling of the columns occurs directly in the fire. In scenario 2a, this occurs after 225 s. With them, the floor structure around them falls. For scenarios 2a and 3a, the ultimate limit state can be considered exceeded at this point.

5 Conclusions

An excerpt of a four-level shelving structure concept was analyzed. The stability results of the structure under fire conditions were based on FEM simulations. An analysis of the conditions on the evacuation routes was also carried out using CFD simulations. As a criterion for evaluating the correctness of the proposed solutions, it was assumed that the calculated evacuation time must be shorter than the time of occurrence of conditions preventing safe exit from the building (visibility range, critical temperature and structural load capacity).

Based on the analysis, taking into account the above recommendations, it is concluded that:

1) The conditions of the evacuation routes were examined in terms of visibility. It was determined that the installed fire protection equipment would allow safe evacuation of occupants from the facility.

2) Evacuation route conditions were evaluated for temperature. It was determined that the installed fire protection would allow for safe evacuation of occupants from the facility.
3) The conditions in the hall space for the work of rescue and firefighting units were examined in terms of temperature. It was determined that the installed fire protection systems would allow for safe firefighting operations.
4) The minimum time for the structure to maintain its load-bearing capacity for the scenarios of sprinkler failure and unrestricted fire development was 230 s, 225 s and 230 s, respectively (the most unfavorable location of the fire due to the impact on the columns). It was longer than the maximum evacuation time (200 s).
5) Despite the loss of stability of some elements, the structure of the evacuation routes of the multilevel shelf retains its load-bearing function for the time required for safe evacuation.

Summarizing the results of the analysis, it can be said that the design concept and the adopted assumptions provide an adequate level of fire safety in the analyzed building, despite the incompatibilities present in it.

Bibliography

1. Act of 24 August 1991 on fire protection (Polish Journal of Laws/ Dz.U. 1991 nr 81 item 351 as amended), https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU19910810351 [28.10.2023]
2. Act of 7 July 1994 construction law (Polish Journal of Laws/ Dz.U. 1994 nr 89 item 414 as amended), https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wdu19940890414 [28.10.2023]
3. Regulation of the Minister of Infrastructure of April 12, 2002 on the technical conditions to be met by buildings and their location (Polish Journal of Laws/ Dz.U. 2002 nr 75 item 690 as amended), https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20020750690 [28.10.2023]
4. KG PSP (2008). Procedury organizacyjno-techniczne w sprawie spełnienia wymagań w zakresie bezpieczeństwa pożarowego w inny sposób niż to określono w przepisach techniczno-budowlanych, w przypadkach wskazanych w tych przepisach, oraz stosowania rozwiązań zamiennych, zapewniających niepogorszenie warunków ochrony przeciwpożarowej, w przypadkach wskazanych w przepisach przeciwpożarowych.
5. Regulation of the Minister of Internal Affairs and Administration of June 7, 2010 on fire protection of buildings, other buildings and areas (Polish Journal of Laws/ Dz.U. 2010 nr 109 poz. 719 as amended), https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20101090719 [28.10.2023]
6. Pecio, M., (2014). Społeczno-ekonomiczne koszty pożarów, (Socio-economic cost of fires), BiTP Vol. 35 Issue 3, 2014, pp. 39-45, DOI:10.12845/bitp.35.3.2014.4.
7. Krasuski, A., Pecio, M., (2018), Application of an Integrated Risk Assessment Software to Quantify the Life Safety Risk in Building during a Fire, MATEC Web of Conferences 247, 00011 (2018), https://doi.org/10.1051/matecconf/201824700011.
8. Krasuski, A., Krauze, A., Kubica, P., Pecio, M. (2019). Wybór scenariuszy pożarowych do symulacji CFD instalacji wentylacji oddymiających bazujących na ilościowej analizie ryzyka (Smoke and Heat Exhaust Ventilation Design, Based on Probabilistic Risk Analysis). Ciepłownictwo, Ogrzewnictwo, Wentylacja, 50, DOI 10.15199/9.2019.2.5.
9. Krasuski, A., Kubica P., Pecio, M., (2017) Multisymulacje: analiza ryzyka pożarowego (Multisimulations: fire risk analysis). Ochrona przeciwpożarowa nr. 2, vol. 60.
10. PD 7974-6:2019 Application of fire safety engineering principles to the design of buildings Human factors. Life safety strategies. Occupant evacuation, behaviour and condition (Sub-system 6)
11. Samuel Shapiro and Martin Wilk (2016). An Analysis of Variance Test for Normality. Biometrika, 52(3):591–611.
12. Erik W Grafarend (2007). Linear and nonlinear models: fixed effects, random effects, and mixed models, volume 44.