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## Performance Based Fire Design of a Large Indoor Theme Park

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### Abstract

Based on the space layout, project operation and configuration of recreation facility of a real case of a large indoor theme park, this paper demonstrated the performance based fire design of fire zone, safety of occupant evacuation, fire suppression system, selection of fire detectors, as well as settings of mechanical smoke extraction for the park. At last, some fire safety measures were proposed by the author.

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*Keywords:* indoor theme park; recreation facility; performance based fire design; fire safety measures

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### 1. Introduction

As the diversification of market demand and business mode, traditional commercial building is gradually changed from the single shopping functionality into the comprehensive commercial building with full functions and various forms, which combines the consumption functions such as shopping, dining, entertainment, culture, art, etc. As a new entertainment venue, indoor theme park can meet the growing demand of the majority of shoppers for recreation and leisure. However, due to the unique structure of indoor theme park building, complex usage functionality, the density of visitors and other factors, the related fire safety issues are prominent. This paper uses an engineering example of a large indoor theme park to explore and study the fire safety design on indoor theme park, and proposes a number of fire safety measures, hoping to provide reference for fire designs for places of similar characteristics.

### 2. Theme Park Overview

The large indoor theme park is located on the top floor of the shopping mall; the single-storey architectural area is about 30000m<sup>2</sup>. The overall floor height is 15m, the roofing is flat roofing of reinforced concrete, interlayer is locally set and the floor height is from 5m to 10m. The indoor theme park gives priority to large and medium-sized amusement facilities, such as roller, coaster, high-altitude bounce tower and pirate ship, etc., outdoor amusement

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Large indoor theme park is a kind of novelty, there is no explicit stipulation in the fire control technical standard in force on its availability of being set on the top floor of building, and it needs to analyze the feasibility of its setting from the angle of theory and practice. Large amusement facilities cover large area of land, the amusement activity has large site and the space flowability is strong, etc., high and large space that adapts to it is required for matching, fire compartment is required to be performed to it, and that will certainly cause extra large area of fire zone. In addition, in-depth research needs to be performed on ascertaining the evacuation person number of large indoor theme park, personnel evacuation strategy and the security of evacuation, the suitability of setting fire fighting device including extinguishment and fire detection, etc., the effectiveness of smoke removal, etc.

### **3. Feasibility analysis of setting architectural top floor**

This engineering is based on consideration in multiple aspects, such as reasonable layout of functional space, engineering technical limitation, etc., large indoor theme park is set on the top floor of building, and the objective need for its setting is as follows:

- Single-stop type large comprehensive commercial business that integrates shopping, diet and amusement is the certain choice of urban commercial development, and indoor leisure amusement has become an indispensable component of it;
- Indoor theme park generally covers relatively large area, and it needs relatively independent and complete space, but through consideration from the angle of architectural space, if it is set on the top floor of building, its architectural internal space is less affected by the restriction effect of structure, so that high and large space suitable for large indoor amusement facilities can be provided;
- Some domestic and foreign examples have proved the feasibility of setting leisure amusement facilities at high floor of commercial center, such as Qingdao Baolong Indoor Amusement Park and Hebei Langfang GMOC Indoor Theme Park, etc.

Through analysis from the angle of theory and practice, it is feasible to set large indoor theme park on the top floor of this engineering building, but the difficult problem in fire control design brought about by that needs analysis and demonstration.

#### 4. Setting of fire compartment

Indoor theme park covers relatively large area, the size of large amusement facilities is big, the activity site is large and the space flowability is strong, etc., those features determines from objective service function that indoor theme park could not use firewall for performing fire compartment. Because of the need to visual permeability for space of indoor theme park, the interlayer connection and cantilever position are different and the shape is irregular, the difficulty of wholly setting fire-proof roll screen for performing fire compartment is increased. In addition, setting fire-proof roll screen for large area is prone to separating the originally smooth public path of travel and open space into certain areas, people could not find the evacuation exit, people might have panic feeling, and using fire-proof roll screen for large area could not guarantee the reliability of its action in case of fire.

Because of the above reason, so long as fire spread can be effectively controlled and safe evacuation of personnel can be guaranteed, the public activity area of indoor theme park can be taken as an independent fire zone for design. For the other equipment house, ventilation and air conditioning machine house (etc.) of indoor theme park, the separating wall whose fire endurance is not less than 2.0h and the floor slab whose fire endurance is not less than 1.5h shall be adopted, and class A fireproof door and public activity area shall be separated.

Similarly noticeable, since there is a round shaped atrium which is vertically through in the indoor theme park, in order to prevent any influence on the safety of personnel in the indoor theme park caused by the smoke produced in case of fire at the bazaar region at the lower part, effective fire compartment needs to be performed to it. Fire-proof roll screen is adopted for segregation in the original fire control design scheme, but it is considered that the action reliability of such large area of profiled fire-proof roll screen is very low, therefore, it shall be changed into adopting one-chip cesium-potassium flame-proof glass with high strength for fire compartment. For the structural pattern of flame-proof glass, the structure of steel frame glazed with flame-proof glass can be adopted, and the seam between flame-proof glasses shall be filled with fire-proof glue whose fire-barrier performance reaches 4h.

#### 5. Analysis of personnel evacuation safety

##### 5.1. Design of fire sight

According to the actual circumstance of indoor theme park, combined with the recognition and analysis of fire danger source, it is considered that fire at electrical appliance of amusement facilities and fire at shop are the most possible to occur. In the selection of fire source position, the worst principle is taken into consideration, the position of fire source is set near the safe egress, thus the smoke produced during fire will directly block that safe egress, making personnel incapable of using that egress for evacuation. The clear height of smoke layer shall be respectively selected as 3m height (3m) from ground surface, 2m height (7m) from the accessible roofing of interlayer and maximum operation track height of amusement facilities (10m). The smoke movement simulation condition is set as the extreme adverse condition of automatic fire extinguishing system and mechanical smoke extraction system being both failed. FDS fire simulation software is adopted for simulating the movement process of smoke. The design of fire sight and the simulation result are shown in Table 1.

Table 1 Design of fire sight and the simulation result

Fire category	Position of fire source	Fire growth rate (kw/s <sup>2</sup> )	Fire power (MW)	Automatic fire extinguishing system	Mechanical smoke extraction system	Available safe egress time ASET (s)	
Electrical fire of amusement facilities	Amusement facilities near safe egress	Quick square fire (0.047)	12.0	Failure	Failure	Ground surface 3m height	1077
						Interlayer 2m height	825
						Facilities track height	458
Shop fire	Shop near safe egress		8.0			Ground surface 3m height	>1200

Interlayer 2m height	947
Facilities track height	597

### 5.2. Selection of personnel load

At present, there is no explicit stipulation in domestic relevant code about the personnel load for special buildings, such as indoor theme park. Therefore, on the basis of referencing internationally universal principle for design of amusement center and stipulations in domestic and foreign code about other similar places, this paper will comprehensively ascertain its evacuation personnel number according to the use character and function of indoor theme park.

- Principle for design of amusement center and the calculation method

According to internationally universal principle for design of amusement center, the instant maximum visitor volume of indoor amusement center shall be calculated according to base  $0.2 \text{ person/m}^2$ , and the calculated instant maximum visitor volume is 7399 persons.

- Statistical method for the actual service function

Indoor theme park can be divided into amusement facilities zone, waiting zone and other function zone according to its service function, statistics shall be respectively performed on the number of persons according to each service function, and the eventual evacuation person number shall be obtained through addition.

Among them, the instant visitor loading capacity of all amusement facilities in the amusement facilities zone is totally about 611 persons; the total area of waiting zone is 538  $\text{m}^2$ , in reference to literature of New Zealand Fire Engineering Design Guide which includes ‘the personnel density index of waiting zone is  $2.6 \text{ persons/m}^2$ ’, it is obtained through calculation that the person number at the waiting zone is 1399; in reference to Code of design on building fire protection and prevention for other zone, the evacuation person number of other song and dance amusement playing and amusement place shall be ascertained through calculation according to the architectural area of the place  $0.5 \text{ person/m}^2$ , and the person number of other zone is calculated as 12467. In general, the total number of person in each functional zone through addition is 14477.

Compared with the evacuation person number obtained through calculation according to the principle for design of amusement center, the evacuation person number calculated according to the actual service function of indoor theme park is in conformity with actual circumstance and relatively conservative. In addition, since entrance ticket needs to be bought for entering indoor theme park, one shall enter through ticket examination at gate, so the total number of person into the park can be technically guaranteed. Therefore, the eventually ascertained 14477 as the evacuation person number of indoor theme park is reasonable.

### 5.3. Simulation result and analysis of personnel evacuation

This paper uses evacuation simulation software Building EXODUS for performing simulation calculation of personnel evacuation of indoor theme park. In the simulation process of personnel evacuation, simulation is performed under the condition of safe egress being sealed at the time of worst fire sight. The special aspect of personnel evacuation in the indoor theme park is that the personnel are stranded on the amusement facilities track at the time of fire occurrence, they could not be immediately evacuated, and evacuation needs to be performed after automatic resetting of the amusement facilities. Since automatic resetting device is set for each amusement facilities in the indoor theme park, it can be guaranteed to return to the initial position within a short time in case of emergency, so as to ensure timely evacuation of personnel. According to the statistics, the maximum automatic resetting time of amusement facilities in indoor theme park is 7min, and that is taken as the time needed for safe evacuation at the highest operation track height of amusement facilities (REST). The analysis result of personnel evacuation safety is shown in Table 2. The simulation results show that safe evacuation of personnel can be guaranteed in each fire.

Table 2 Analysis of personnel evacuation safety

Position of fire source	Safety judgment	Available safe egress	Time needed for	Safety margin
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	height	time ASET(s)	personnel evacuation REST (s)	
Amusement facilities near the safe egress	Ground surface 3m height	1077	774	303
	Interlayer 2m height	825	536	289
	Facilities track height	458	420	38
Shop near the safe egress	Ground surface 3m height	>1200	774	>426
	Interlayer 2m height	947	536	411
	Facilities track height	597	420	177

Since the outdoor platform with an area of about 1400m<sup>2</sup> is set for indoor theme park, it can be taken as the buffer zone for personnel refuge and evacuation, the personnel evacuated to outdoor platform can perform evacuation through the smokeproof stairway connected with it, so that the safety of personnel evacuation is strengthened. In addition, it is proposed to evacuate personnel to the roof of adjacent building furniture center through additionally setting three outdoor galleries, thus the pressure of personnel evacuation in the theme park can be alleviated, that requires relevant zone on roof of the furniture center shall be designed according to the standard of refuge layer, and it is required that part of evacuation stair of the furniture center shall be directly linked with the roof for evacuation of personnel evacuated there from the indoor theme park.

## 6. Type selections for fire control extinguishing system and fire detector

The fire control extinguishing system of the indoor theme park shall be set by zone according to the feature of automatic fire extinguishing system and the appropriateness, preaction sealed automatic sprinkler system shall be set for the 5m height zone, preaction sealed quick response automatic sprinkler system shall be set for the 10m height zone, and fixed fire nozzle extinguishing system shall be set for the zone whose space height exceeds 15m.

It is proposed to select and use aspirating smoke fire detector for the fire detection mode. Since air conditioning system has disturbing and diluting effect on fire smoke, it is critically important to select the detector with high sensitivity capable of real-time indication of obscuration rate, the detection sensitivity of aspirating smoke fire detector is high, and early detection of fire can be realized by means of active aspirating and multipoint sampling. Aspirating smoke fire detector can be conveniently installed and maintained, the detection principal machine can be installed onto the wall face to facilitate repair, and high-pressure air can be used for rinsing the sampling pipeline. In addition, aspirating smoke fire detector is not prone to influence by the shield, such as amusement facilities. At the time of setting aspirating smoke fire detector, the tubing mode of combining horizontal tubing along ceiling and vertical tubing along the vertical prop shall be adopted.

## 7. Mechanical smoke removal setting

Mechanical smoke removal mode shall be adopted for the indoor theme park, axial-flow smoke exhaust fan shall be set on the roof and roofing, the radius of zone for which each smoke exhaust fan is responsible shall not exceed 30m, and the quantity of smoke removal shall be selected by the following principle: for the zone where floor height is less than 6m, it shall be designed according to the requirements of relevant code; for the zone where floor height is greater than 6m, smoke zone shall not be divided, and the air quantity of smoke exhaust fan shall be calculated according to being not less than 60m<sup>3</sup>/h per square meter of area; the mode of natural make-up air shall be adopted for the make-up air at the time of smoke removal, and make-up air shall be performed through the external window that can be automatically opened at the external lateral surface of building.

## 8. Other measures for fire safety

- Adopting class A material for the material of indoor scenery, scene and amusement facilities, etc.

Glass fiber reinforced cement (GRC) can be used for wall surface decoration and modeling of landscape modeling, GRC has the features of good fire resistance, thin wall and light body, free modeling, vivid quality sense and excellent dynamic performance, etc., it can not only meet the demand of decoration and modeling, but also guarantee incombustibility of material.

- Setting electroluminescent type indication symbol with visual continuity for evacuation on the ground surface of evacuation exit

Special-purpose evacuation exit connected with indoor staircase and outdoor platform shall be divided in the indoor theme park, it shall be guaranteed to be smooth, and no combustible and obstacle shall be put. Lamp light type symbol belt for evacuation indication shall be set on the ground surface, so as to form visual continuity. At the time of setting the evacuation indication symbol on ground surface, it is appropriate to continuously set along the path of travel, at the time of intermittent setting, the interval of symbol shall not be greater than 3m; at the time of setting on the wall surface, distance of the upper rim of symbol from indoor ground level shall not be greater than 1m, and the interval of symbol shall not be greater than 10m; when it is set by hanging, the interval of symbol shall not be greater than 15m; the indoor advertisement board and ornament (etc.) shall not shield the evacuation indication symbol.

- Restricting the resetting time of amusement facilities under exigency

The resetting time of part of amusement facilities in the indoor theme park is too long in case of exigency, it can reach 7min at most, thus quick evacuation of personnel is affected to some extent, therefore, it is proposed that the project operator shall perform consultation with the manufacturer of amusement facilities, so as to shorten the resetting time of amusement facilities as far as possible.

- Improving the acoustic pressure level of acoustooptic alarm and fire control broadcast

Since various background music needs to be played at the time of operation of each amusement facilities in the indoor theme park, and the personnel might be noisy, personnel might be prone to not hearing the voice of acoustooptic alarm and fire control broadcast in case of fire, therefore, the acoustic pressure level of acoustooptic alarm and fire control broadcast shall be improved.

## 9. Conclusions

Indoor theme park is a kind of emerging amusement place, and the technical standard of fire control in force could not fully cover its fire control design. The performance-based fire design of a large indoor theme park is taken as an example by the authors of this paper, through analysis of engineering example, it is hoped to provide experience and reference for relevant engineering technicians.

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