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# Fire safety engineering — Performance of structure in fire —

## Part 2: Example of an airport terminal

*Ingénierie de la sécurité incendie — Performance des structures en situation d'incendie —*

*Partie 2: Exemple d'un terminal d'aéroport*



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# Foreword

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This document was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

A list of all parts in the ISO 24679 series can be found on the ISO website.

# Introduction

This document is an example of the application of ISO 24679-1. It preserves the numbering of subclauses in ISO 24679-1 and so omits numbered subclauses for which there is no text or information for this example. Therefore, the following two points should be kept in mind.

a) This document is not intended to provide uniform technical provisions for the user, but rather demonstrate how ISO 24679-1 is applied in compliance with the related standards of China.

b) Fire service intervention has been considered when defining the maximum heat release rate of the design fire in this case because the fire brigade is dedicated and is approximately 1 km away from the airport terminal. It is completely legal in China to consider the fire service intervention, which may not be the case in other countries. Therefore, when taking any reference from this document, attention should be paid to the requirements of the related national standards.

It should be noted that this example does not follow every step described in ISO 24679-1, but rather follows its principles as applicable to the building regulatory in China.

# Fire safety engineering — Performance of structure in fire —

# Part 2: Example of an airport terminal

## 1 Scope

This document provides a fire engineering application relative to fire resistance assessment of an airport terminal structure according to the methodology given in ISO 24679-1. It follows step by step the procedure given by ISO 24679-1. Some requirements relative to Chinese building regulation are taken into account concerning the fire scenarios.

The fire safety engineering applied to an airport terminal takes into account the real fire data based in fire tests. It is important to note that the intervention of fire service brigade dedicated to this airport, located approximately 1 km away, has been taken into account in definition of fire scenarios. For the fire modelling, both fire extinguishing system and the smoke extraction are not considered but the fire fighter intervention has been taken into account 10 min after the starting of fire.



## 2 Normative references

There are no normative references in this document.

## 3 Terms, definitions and symbols



### 3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 24679-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

### 3.2 Symbols

$S_m$ design value of combination of action effect

$S_{Gk}$ nominal value of permanent load effect

$S_{Tk}$ temperature effect of fire on structure

$S_{Qk}$ nominal value of floor or roof live load effect

$S_{Wk}$ nominal value of wind load effect

$\Psi_f$ frequency coefficient of floor or roof live load

$\Psi_q$ quasi-permanent coefficient of floor or roof live load

| | |
|---|---|
| $\gamma_0$ | partial safety factor associated with the uncertainty of the action and/or action effect model, 1.15 for Class A building and 1.05 for other buildings |
| $\dot{Q}$ | heat release rate of the fire source (kW) |
| $\alpha$ | fire growth rate (kW/s$^2$) |
| $t$ | time |
| $t_0$ | smouldering time (s) |
| $t_j$ | alarm time (min) |
| $t_c$ | time for fire brigade to respond and start leaving the fire station, (min) |
| $t_l$ | travel time (min) |
| $t_z$ | prepare for firefighting (min) |
| $\Delta t$ | time step (s) usually not larger than 5 s |
| $T_s$, $T_g$ | internal temperature of the steel under fire condition and air temperature (K) |
| $\rho_s$ | density of the steel (kg/m$^3$) |
| $c_s$ | specific heat of the steel [J/(kg·K)] |
| $F$ | exposed surface area per unit length (m$^2$/m) |
| $V$ | volume per unit length (m$^3$/m) |
| $\alpha_{c+r}$ | combined heat transfer coefficient [W/(m$^3$·K)] |
| $\alpha_c$ | convective heat transfer coefficient between air and the surface of the element, $\alpha_c$ = 25 [W/(m$^2$·K)] |
| $\alpha_r$ | radiant heat transfer coefficient between air and the surface of the element [W/(m$^2$·K)] |
| $\varepsilon_r$ | combined radiant emissivity, $\varepsilon_r$ = 0,5 |
| $\sigma$ | Stefan-Boltzmann constant, σ = 5,67 × 10$^{-8}$ (W/(m$^2$·K$^4$) |
| $T_s$ | temperature of the steel (°C) |
| $\alpha_s$ | coefficient of thermal expansion (K$^{-1}$) |
| $\lambda_s$ | heat conductivity [W/(m·K)] |
| $c_s$ | specific heat [J/(kg·K)] |
| $\rho_s$ | density (kg/m$^3$) |
| $f_{\mathrm{yT}}$ | yield strength of the steel at elevated temperature (N/mm$^2$) |
| $f_{\mathrm{y}}$ | yield strength of the steel at room temperature (N/mm$^2$) |
| $\eta_{\mathrm{T}}$ | reduction factor of the yield strength of steel at elevated temperature |
| $E_{\mathrm{T}}$ | modulus of elasticity of steel at elevated temperature (N/mm$^2$) |
| $E$ | modulus of elasticity of steel at room temperature (N/mm$^2$), taken from GB 50017 |

| | |
|---|---|
| $\chi_T$ | reduction factor of the modulus of elasticity of steel at elevated temperature |
| $f_{yT}$ | effective yield strength under temperature |
| $f_{pT}$ | proportional limit under temperature |
| $E_T$ | lope of the linear elastic range under temperature |
| $\varepsilon_{pT}$ | strain at the proportional limit under temperature |
| $\varepsilon_{yT}$ | yield strain under temperature |
| $\varepsilon_{tT}$ | limiting strain for yield strength under temperature |

## 4 Design strategy for fire safety of structures

The built environment is an airport terminal that has been provided with automatic fire alarm system, sprinkler system, fire hydrant and smoke control system, etc. Furthermore, the fire service brigade dedicated is located approximately 1 km away from the airport terminal. Consequently, their intervention has been taken into account in definition of fire scenarios. The heat release rates (HRR) of combustible products, which could be found at the different locations of the terminal, have been defined by fire tests. An advanced model has been used to define the thermal action in different volumes of the studied terminal. The thermomechanical behaviour of the principal structure of the terminal, based on advanced and simplified methods, is carried out in function of the real thermal actions defined previously.



This case study is intended to illustrate the steps given in ISO 24679-1. Therefore, the following design process has been adopted.

## 5 Quantification of the performance of structures in fire



### 5.1 Step 1: Scope of the project for fire safety of structures

This is the initial step in a fire safety design process for a new or an existing built environment. Below are the main items included in this step.

#### 5.1.1 Built environment characteristics

This airport terminal (see Figure 1) is 80 m deep, 252 m long and 22,13 m high. It has two stories above the ground and one underground, with a total floor area as about 7,1 × $10^4$ $m^2$. More details are given in Annex A. The airport terminal has been provided with automatic fire alarm system, sprinkler system, fire hydrant and smoke control system, etc.

**Figure 1 — View of the terminal building**

See Table 1 for the main functions on different floors.

**Table 1 — Main functions at different floors of the terminal**

| Floor | Floor level | Main function |
|---|---|---|
| First floor | −1,45 m~0,00 m | Domestic departure hall, domestic baggage sorting hall, international baggage sorting hall, international baggage claim hall, baggage claim hall for transfer, international arrival, entry formalities hall, shopping area and so on. |
| Second floor | 7,25 m | Hall for sending off, international check in, international departure, shopping area and offices. |



The column, beam, floor structures on first floor are reinforced concrete. The column and roof structures on the second floor are steel. In case of fire, the flame and hot smoke may endanger the integrity and stability of steel structures on the second floor. Therefore, the purpose of this case study is to calculate the mechanical performances of the steel elements in the event of fire so as to determine if the trial plan is feasible.

### 5.1.2 Fuel loads

**Fuel load analysis**

Fuel load is the essential factor to analyse the full developed fire. Therefore, combustibles inside the terminal, including their amount, properties and location should be understood thoroughly before analysing the fire scenario.

In this case study, fuel loads is classified as

a) dead load,

b) live load, and

c) temporary load.

The fuel loads of this airport terminal have been defined based on the survey and investigation done by University of Science and Technology of China (see Reference [7]). See Table 2 for the detail.

**Table 2 — Fuel load density**

| No. | Location | | Fuel load density<br>MJ/m$^2$ |
|---|---|---|---|
| 1 | Shopping area | | 470,0 |
| 2 | Offices | | 439,0 |
| 3 | Departure hall | | 93,0 |
| 4 | Baggage sorting area | National | 104,0 |
| | | International | 93,0 |
| | | Baggage warehouse | 670,0 |
| 5 | Security check area | | 81,0 |
| 6 | Frontier inspection and the customs | | 31,0 |
| 7 | Check-in hall | | 64,0 |

### 5.1.3 Mechanical actions

Fire action on structures is an accidental action. The probability of the occurrence of fire is quite low. Therefore, when considering the combined load, only the combination of one accidental (fire load in this case study) load with other loads, such as permanent load, floor or roof live load or wind load, is considered.

CECS 200 requires that the combination of action effects in case of fire shall be calculated according to Formula (1) and Formula (2):



$$S_m = \gamma_0 \left( S_{Gk} + S_{Tk} + \psi_f S_{Qk} \right) \quad (1)$$

$$S_m = \gamma_0 \left( S_{Gk} + S_{Tk} + \psi_q S_{Qk} + 0{,}4 S_{Wk} \right) \quad (2)$$

where



$S_m$ is the design value of combination of action effect;

$S_{Gk}$ is the nominal value of permanent load effect;

$S_{Tk}$ is the temperature effect of fire on structure;

$S_{Qk}$ is the nominal value of floor or roof live load effect;

$S_{Wk}$ is the nominal value of wind load effect;

$\Psi_f$ is the frequent coefficient of floor or roof live load (given in GB 50009);

$\Psi_q$ is the quasi-permanent coefficient of floor or roof live load (given in GB 50009);

$\gamma_0$ is the partial factor associated with the uncertainty of the action and/or action effect model, 1.15 for Class A building and 1.05 for other buildings.

Temperature effect of fire on structure $S_{Tk}$ is the inner force and deformation caused by elevated temperature, which is equivalent to rod end effect.

The roof of the terminal is arch-shaped. The rise-to-span ratios of the roof arches are quite small ($f/l$ < 0,1) as shown in Figure 2. Therefore, the shape coefficient of the wind load is negative according to GB 50009. The action effect of the wind load is in the form of suction, which is just the opposite force of other action effects. As a result, Formula (1) is used to calculate the worst combined load.

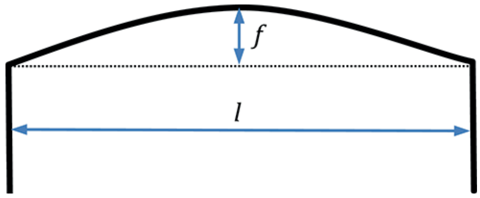


**Figure 2 — Schematic of rise-to-span ratio ($f/l$) of a roof arch**

The structure consists of a series of parallel portal steel frames. For simplification, each of the frames is generally considered as an independent structural assembly with no out-of-plane deformation when doing the engineering calculation. Therefore, only a single steel frame has been calculated. When doing the structural analysis under fire condition, only the above-mentioned loads were considered. For example, the effects of change of the pressure inside the terminal caused by fire or the impact of water used for firefighting have not been considered.

## 5.2 Step 2: Identify objectives, functional requirements and performance criteria for fire safety of structures

The objectives, functional requirements and performance criteria are defined according to the statements in related codes and standards of China.

This document assesses the fire safety of the main and secondary portal frame of an airport terminal. Therefore, the performance criteria are defined according to the requirements of CECS 200, which is a technical code of China Association for Engineering Construction Standardization.



According to the related national codes and standards of China, the fire safety objectives of this airport terminal should address

— the life safety (occupants inside the airport terminal and fire fighters), and

— conservation of property and continuity of operations.



In order to fulfil the fire safety objectives, the functional requirements of the steel structure should be:

— no serious damage to the structure or successive collapse in case of fire.

Therefore, efforts should be put on how to prevent or limit the partial structural failure in case of fire so as to protect the life safety of the occupants and fire fighters, and how to prevent or limit the structural deformation or collapse so as to reduce reconstruction cost and ensure the continuity of operation and not to increase the cost or difficulties of the after-fire restoration.

According to the statements in CECS 200, one of the following performance criteria shall be met.

a) The load-bearing capacity of the structure ($R_\mathrm{d}$) shall not be less than the combined effect ($S_m$) within the required time, that is $R_\mathrm{d} \geq S_m$:

  — the maximum permitted deflection for the steel beam shall not be larger than L/400;

  — the maximum stress of the structure under fire condition shall not be larger than $f_{yT}$.

b) The fire resistance rating of the steel structure ($t_d$) shall not be less than the required fire resistance rating ($t_m$), that is, $t_d \geq t_m$.

c) The critical temperature of steel structure ($T_d$) shall not be less than the maximum temperature of the structure ($T_m$) during the fire resistance time duration, that is $T_\mathrm{d} \geq T_m$.

The critical temperature ($T_d$) represents the structural failure temperature. For this example, $T_d$ taken into account is 300 °C. According to CECS 200, at this temperature, the yield strength of steel is not

 