TECHNICAL REPORT

ISO/TR 24679-2

First edition
2017-07

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

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

Reference number
ISO/TR 24679-2:2017(E)

© ISO 2017

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

COPYRIGHT PROTECTED DOCUMENT

© ISO 2017, Published in Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

 © ISO 2017 – All rights reserved

Contents

Page

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

© ISO 2017 – All rights reserved

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

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.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

 © ISO 2017 – All rights reserved

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.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

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

Ψ_f frequency coefficient of floor or roof live load

Ψ_q quasi-permanent coefficient of floor or roof live load

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

© ISO 2017 – All rights reserved

γ_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)

α 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)

Δt 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)

ρ_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)

α_{c+r} combined heat transfer coefficient [W/(m^3·K)]

α_c convective heat transfer coefficient between air and the surface of the element, α_c = 25 [W/(m^2·K)]

α_r radiant heat transfer coefficient between air and the surface of the element [W/(m^2·K)]

ε_r combined radiant emissivity, ε_r = 0,5

σ Stefan-Boltzmann constant, $\sigma = 5{,}67 \times 10^{-8}$ (W/(m^2·K^4)

T_s temperature of the steel (°C)

α_s coefficient of thermal expansion (K^{-1})

λ_s heat conductivity [W/(m·K)]

c_s specific heat [J/(kg·K)]

ρ_s density (kg/m^3)

f_{yT} yield strength of the steel at elevated temperature (N/mm^2)

f_y yield strength of the steel at room temperature (N/mm^2)

η_T reduction factor of the yield strength of steel at elevated temperature

E_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

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

© ISO 2017 – All rights reserved

χ_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

ε_{pT} strain at the proportional limit under temperature

ε_{yT} yield strain under temperature

ε_{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.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

© ISO 2017 – All rights reserved

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.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

© ISO 2017 – All rights reserved

Table 2 — Fuel load density

No.	Location		Fuel load density 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

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

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;

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

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

γ_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.

© ISO 2017 – All rights reserved

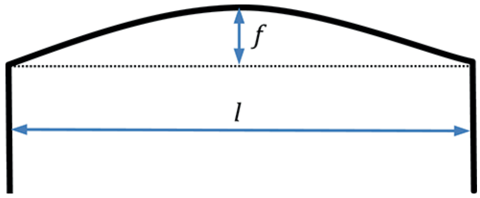


Figure 2 — Schematic of rise-to-span ratio (f/l) of a roof arch

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_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

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

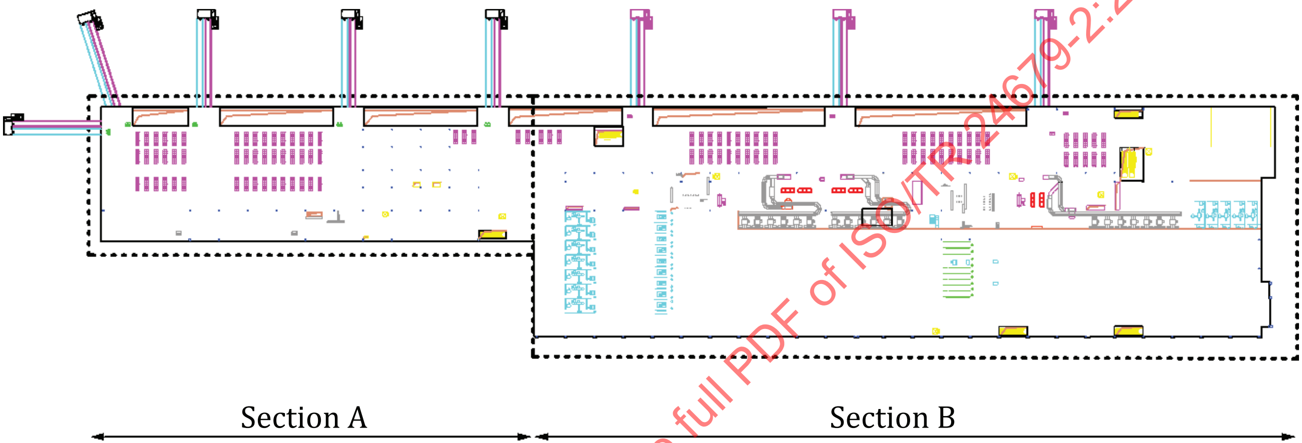
 © ISO 2017 – All rights reserved

affected by the temperature because its value remains the same as the value at ambient temperature. Furthermore, the local buckling of thin sections of steel elements is avoided.

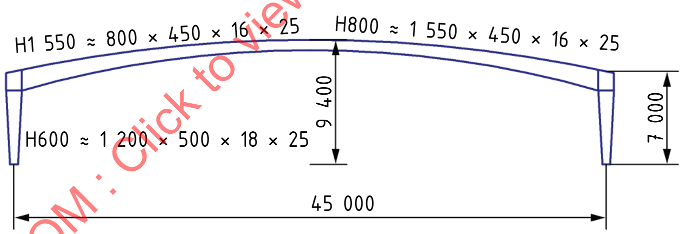
5.3 Step 3: Trial design plan for fire safety of structures

As far as steel frames used in these designs are concerned, there are two types of portal steel frames located on the second floor in the terminal; see Figure 3. One type is a 45 m long single-span frame, used in Section A and spaced at 10 m. The other type is a two-span frame, used in Section B and also spaced at 10 m. The primary frame has a span of 53,5 m and the secondary frame has a span of 25 m.

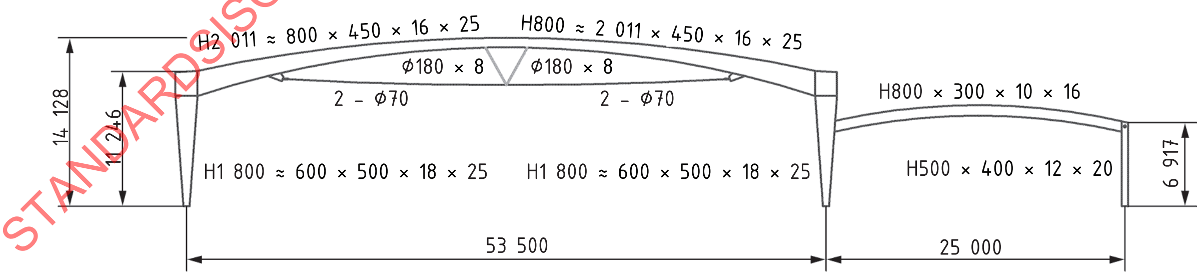
Preliminary designs of the steel structure, at room temperature, were carried out in accordance with GB 50017-2003[12] to determine the sizes of various structural members of steel frames.



a) Second floor of the terminal



b) Single-span frame in Section A



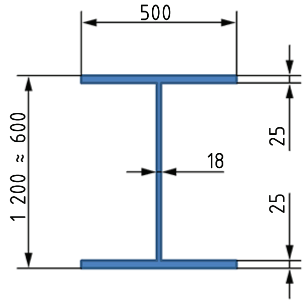
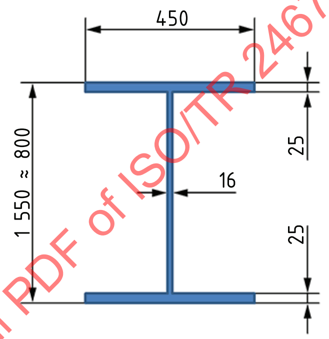
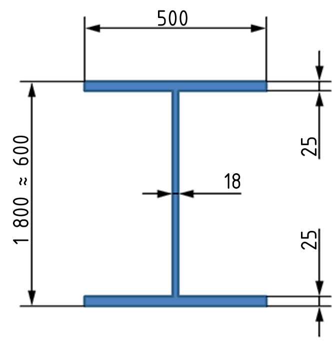
c) Two-span frame in Section B

Figure 3 — Two types of steel frames in the terminal

The complementary structural details of steel frames are reported in Table 3. The grade of structural steel is Q345 as classified in GB 50017-2003.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

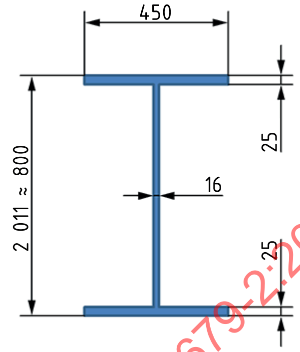
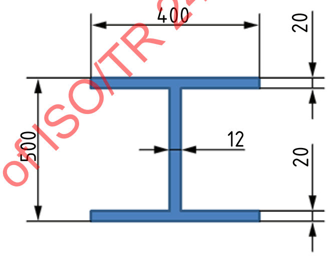
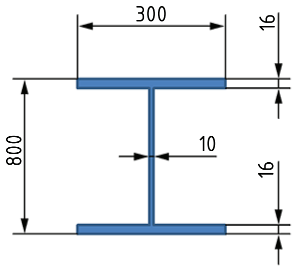
Table 3 — Summary of structural members

Element	Cross-section size mm	Cross-section illustration mm
Column of the single-span frame in Section A	H1 200~600 × 500 × 18 ×25	
Primary beam of the single-span frame in Section A	H1 550~800 × 450 × 16 × 25	
Column of the main frame in Section B	H1 800~600 × 500 × 18 × 25	

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

 © ISO 2017 – All rights reserved

Table 3 *(continued)*

Element	**Cross-section size** mm	**Cross-section illustration** mm
Primary beam of the main frame in Section B	H2 011~800 × 450 × 16 × 25	
Column of the secondary frame in Section B	H500 × 400 × 12 × 20	
Primary beam of the secondary frame in Section B	H800 × 300 × 10 × 16	

According to GB 50016-2014[11], this airport terminal belongs to Class B building. In this case study, the steel columns are the main load bearing elements on the second floor and are more easily subjected to the effect of fire. Therefore, in the trial design plan, it is suggested that the columns shall be protected by thick fire coating and its fire resistance rating shall not be less than 2,50 h as required by GB 50016-2014. The testing of the coating in China should follow the requirements of GB/T 9978, which is equivalent to ISO 834.

For the steel roof, it is suggested that the steel be designed without any protection. The reason is that the roof is quite high and the fire origin is located in one of the shops. It is required by the fire code that the fire resistance rating of the walls and ceiling of the shops in the airport terminal shall not be less than 2 h and 1,5 h, respectively. If a fire occurs in one of the shops, the fire would initially develop inside the shop, then spreads out of the shop through the openings.

However, necessary calculations and simulations shall be done to verify if the trial design plan is feasible.

5.4 Step 4: Design fire scenarios and design fires

Design fire scenarios and design fires are an important step in the assessment of the performance of structures in fires. However, on one hand, a design fire scenario is a specific qualitative description of the course of a fire, and on the other hand, a design fire is a quantitative description of assumed fire characteristics within a design fire scenario.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

When defining the design fire scenarios of the airport terminal, fire scenarios in the mid-span of the beam, the effectiveness of sprinkler, fire alarm and smoke extraction system, as well as fire brigade intervention have been considered.

See ISO 16733-1 and the planned ISO/TS 16733-2 for more information about the selection of design fire scenarios and design fires.

5.4.1 Design fire scenarios

In this case study, according to the locations of the structural elements to be analysed, two types of fires were considered.

1) Luggage fire: There are lots of combustibles and flammables inside the unaccompanied baggage. If they are over heated or impacted during the handling, fires may break out.

2) Shop fire: There are different types of shops in the terminal for clothes, books, magazines, foods, cosmetics and so on, which may cause fires by electricity-related causes, cigarette buds and so on.

In order to select reasonable design fire scenarios, the distribution of combustibles in the terminal has been studied according to the main functions of the terminal mentioned in 5.1.1. See Table 4 for the detail.

Table 4 — Main combustibles at different floor levels

Floor	Floor level	Main combustibles
First floor	1,45 m ~ 0,00 m	Registered baggage, office furniture, benches, books, paper, computers, electric equipment and commodities in the shops
Second floor	7,25 m	Personal luggage, benches, computers and commodities in the shops

After considering the geometry of the terminal, the result of fire risk analysis and the distribution and type of the combustibles in the terminal, three fire origins have been selected for structural analysis according to the following principles.

a) They can represent typical locations inside the terminal.

b) Typical combustibles have been selected.

c) They are the worst case for the stability of the steel structure.

Table 5 gives the locations and combustibles of the different fire origins.

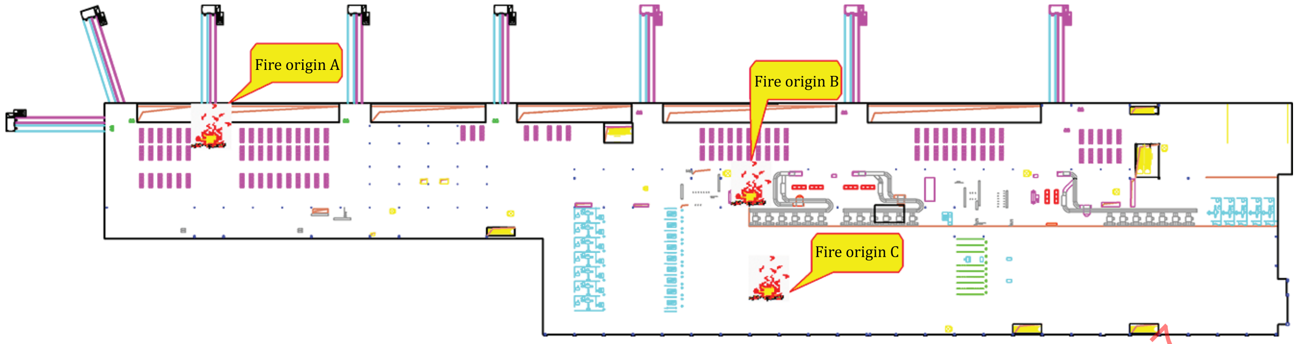
Table 5 — Locations and combustibles of the fire origin

Fire origin	Location	Floor	Fuel	Figure
A	One of the departure halls	Second floor	Benches, baggage	Figure 4
B	One of the shops	Second floor	Clothes, shoes and hats, etc.	Figure 4
C	One of the shops	Second floor	Clothes, shoes and hats, etc.	Figure 4

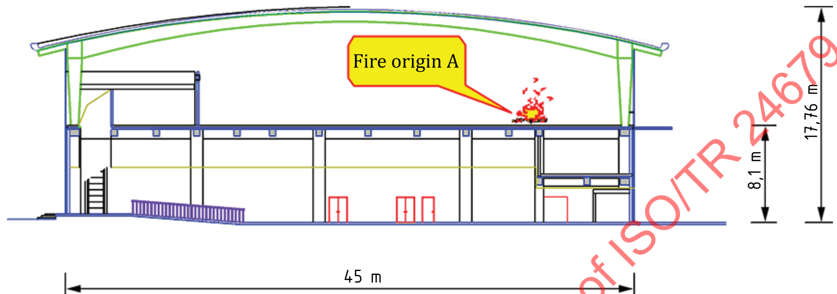
Fire origin A, B and C have been considered for analysing their effects on the steel structure. The reason is that fire origin A has direct effect on the temperature rise of the column and B and C are located directly under the main and secondary portal frame, which have been considered as the worst cases. And from Table 2, it can be seen that the fire load density in the shopping area is 470 MJ/m^2, which is highest compared with those of the departure hall and check-in hall on the second floor. Table 2 also shows that the fire load density in the baggage sorting area (670 MJ/m^2) is quite high, but it is on the first floor, which has no effect on the steel structure on the second floor.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

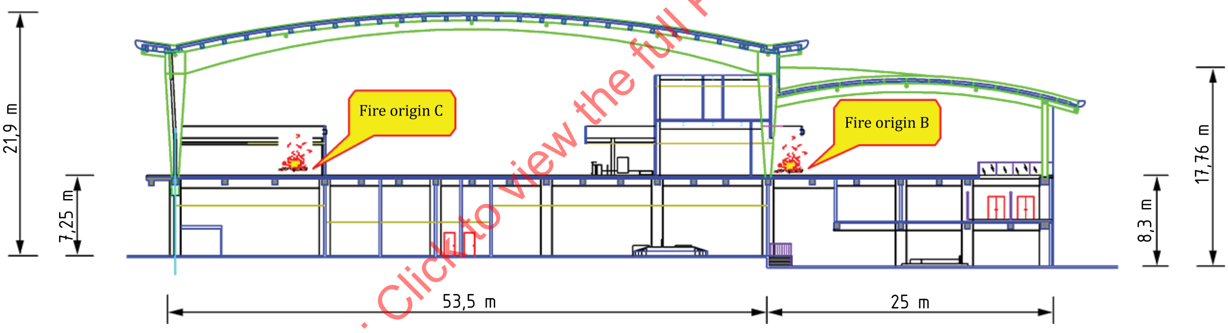
 © ISO 2017 – All rights reserved



a) Fire origins on the second floor



b) Sectional view of fire origin A



c) Sectional view of fire origin B and C

Figure 4 — Fire origins of A, B and C

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

5.4.2 Design fires (thermal actions)

5.4.2.1 Fire growth rate

The fire growth rate can be obtained from experiment, model calculation, empirical estimation or from the requirements of the related codes or standards. For example, if there are no combustible liquids or flammable gases contributing to the fire, most civil building fires grow quite slowly at the initial stage. Therefore, the HRR-time relationship of the fire can be expressed as shown in Formula (3):

© ISO 2017 – All rights reserved

$$\dot{Q}=\alpha(t-t_0)^2 \quad (3)$$

where

$\dot{Q}$ is the heat release rate of the fire source (kW);

α is the fire growth rate (kW/s^2);

t is the burning time (s);

t_0 is the smouldering time (s).

Smouldering time has little effect on the fire spread. Therefore, in this case study, it is expressed as $t_0 = 0$. Then the time-heat release rate relationship can be simplified as shown in Formula (4):

$$\dot{Q}=\alpha t^2 \quad (4)$$

For the categories of t^2 fire, ISO 16733-1 lists four categories of fire growth rate. See Table 6 for the detail. Figure 5 gives their characteristic curves.

Table 6 — Fire growth factor

Categories of fire	Typical combustibles	Fire growth factor kW/s^2	Time for HRR to reach 1 MW s
Slow	Hardwood furniture	0,002 93	600
Medium	Cotton or polyester cushion	0,011 72	300
Fast	Mail bags full of letters, wood pallet racks, plastic foam	0,046 89	150
Ultra-fast	Pool fire, fast burning decorations, sheer curtain	0,187 5	75

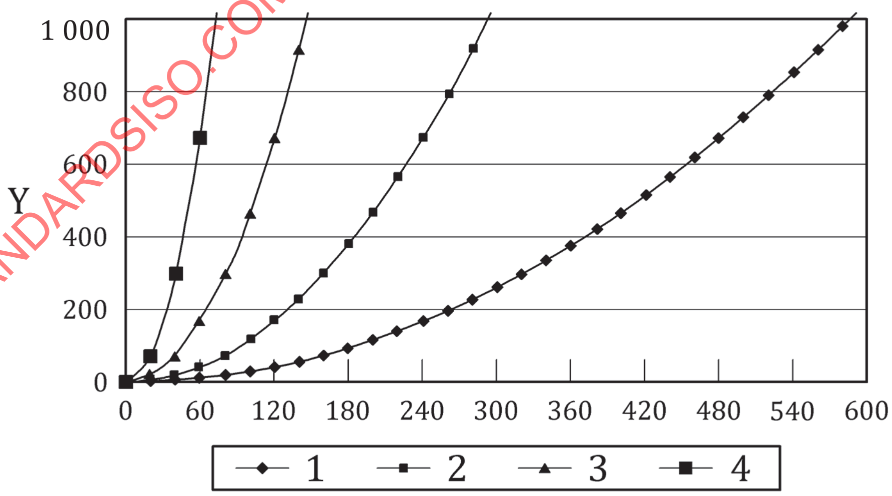


Figure 5 — Characteristic curve of t^2 fire

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

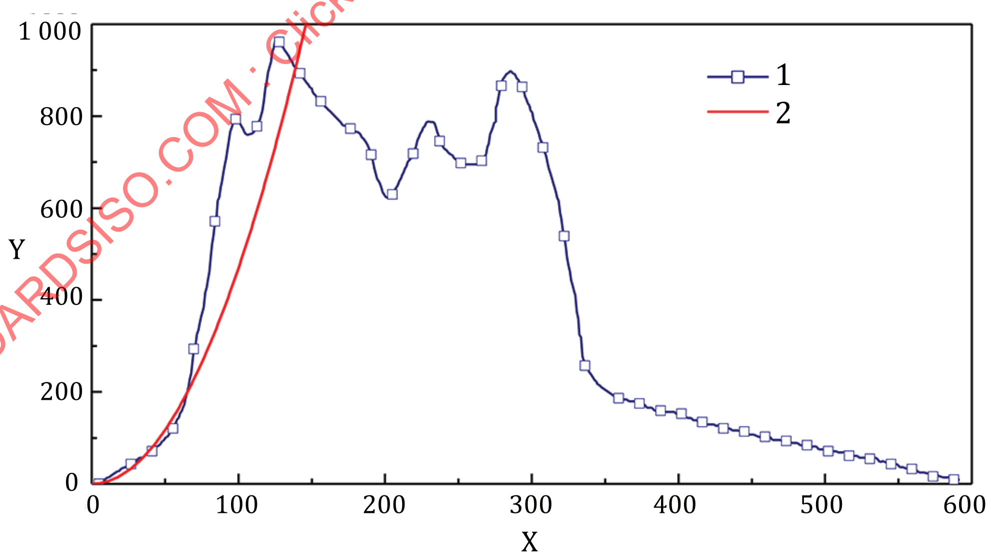
 © ISO 2017 – All rights reserved

5.4.2.2 Shop fire

The airport terminal often has shops and stores. Combustible contents in the shops and stores are complex and have big variations, e.g. souvenirs, clothing, food, books, newspapers and suitcases, etc. The layout and the arrangement of combustible contents in the shops and stores can be located in any order. To consider a worst case, a shop was assumed to contain a large amount of clothes with a heavy fire load.

Tianjin Fire Research Institute (TFRI) did a series of clothing shop fires tests in "Ninth-five-year" plan of China, based on the test method described in ISO 9705-1. Two tests have been described here as examples of simulating clothing shop fires. One of the tests is shown in Figure 6. The fuel, a rack of jeans weighting 20 kg, was ignited in the middle by a burner at 150 mm below the pants. Figure 7 shows the measured HRR curve and the curve of a fire with fast growth rate. In the first 50 s, the measured growth rate matched with the curve of the fast-growth fire, but after 50 s, the fire grew faster than the fast-growth fire.

Figure 6 — Jeans fire test (20 kg)



Key

X t/s

Y temperature (°C)

1 test curve

2 α = 0,047

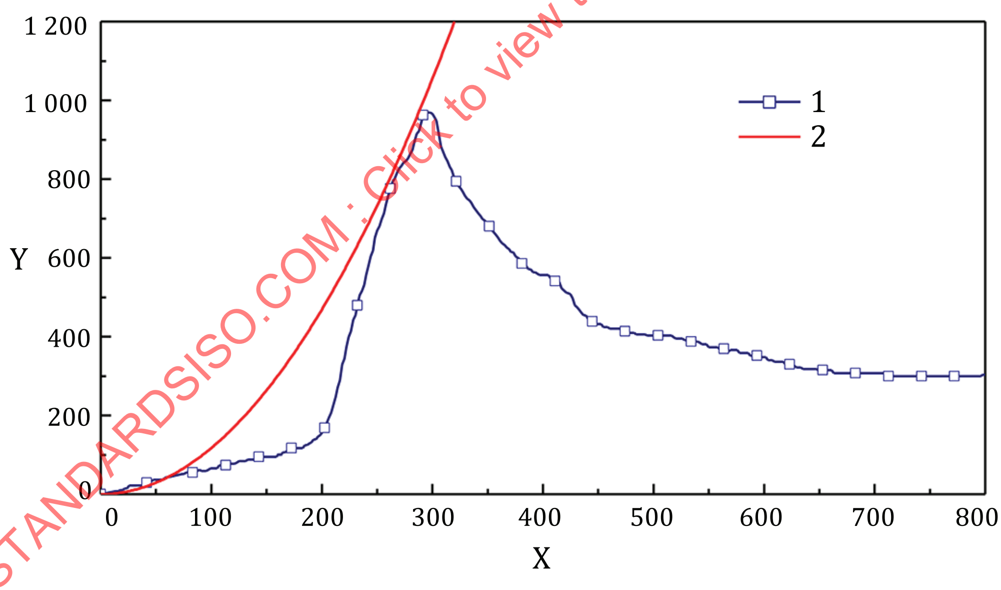
Figure 7 — HRR curve as a function of time

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

© ISO 2017 – All rights reserved

In the other test, the fuel was a pile of mixed textile clothes, setting on a steel counter, as shown in Figure 8. The clothes were ignited by a burner at 150 mm below. Figure 9 shows the measured HRR rate curve and the curve of a fire with medium growth rate. The fire grew a little slower than the medium-growth fire.

Figure 8 — Mixing textile clothes (70 kg)



Key

X t/s

Y temperature (°C)

1 test curve

2 α = 0,02

Figure 9 — HRR curve as a function of time

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

© ISO 2017 – All rights reserved

From the two tests, it can be indicated that the piled-up clothing fire had a fire growth rate slightly less than a medium-growth fire (α = 0,011 72), while the clothing fire with hanging clothes had a growth rate slightly larger than a fast-growth fire (α = 0,046 89).

Considering that other type of shops or stores in the airport have lower fire risk than that of the clothes shop, the fire growth rate in the airport shops has been assumed to be fast growth rate.

5.4.2.3 Definition of heat release rate

The HRR defined for design fires (thermal actions) in order to analyse the thermomechanical structural behaviour represents the worst cases of design fire scenarios.

It has been considered that both fire extinguishing system and the smoke extraction system fail to activate in case of fire. Therefore, the response of the dedicated fire brigade of the airport has been considered, since the automatic fire alarm system, monitoring system and fire control room have been provided in the airport and consequently the fire brigade can receive the fire alarm timely.

For conservative consideration, it has been assumed that the dedicated fire brigade of the airport could receive the fire alarm 3 min (t_j = 1 min for recognition and 2 min for verification of the fire by the local staff and then send fire alarm signal to the on-site fire station) after the occurrence of the fire. The fire brigade responds to the alarm and starts to go to the fire site (t_c = 1 min required by the "*Ordinance of fire brigades*" from receiving the alarm to the departure of the fire engine from the garage), then 2 min for travelling and 2 min (t_z) for preparing and starting the fire fighting and controlling. By far, the effective burning time of the fire would be as shown in Formula (5):

$$t = t_j + t_c + t_l + t_z = 3 + 1 + 2 + 2 = 8 \text{ (min)} \quad (5)$$

where

t is the effective burning time (min);

t_j is the alarm time (min);

t_c is the time for fire brigade to respond and start leaving the fire station (min);

t_l is the travel time (min);

t_z is the prepare for fire fighting (min).

According to the calculation, the effective burning time of the fire is 8 min for all selected design fire scenarios. For conservative consideration, it has been assumed that the effective burning time of the fire is 10 min.

After considering the response time of the fire brigade, it has been assumed that the maximum heat release rate of the selected shop fire scenario is:

Shop fire: $Q = \alpha t^2 = 0{,}04689\, t^2 = 0{,}04689 \times 600^2 = 16880$ (kW), take 16,9 (MW).

Table 7 gives the summary of all the fire scenarios selected for fire safety analysis of the whole project, including the analysis of safe evacuation system and fire compartmentation. But for steel structural analysis, only two scenarios (B00 and C00, where the fire extinguishing system and ventilation system failed to activate in the event of fire) have been considered.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

© ISO 2017 – All rights reserved

Table 7 — Summary of fire scenarios

Fire scenario	Fire origin	Location	Fire growth factor kW/s^2	Automatic fire extinguishing system	Smoke extraction system	Maximum HRR MW
A10	Second floor	A	0,011 72	Failure	Valid	4,3
A00				Failure	Failure	4,3
B10		B	0,046 89	Failure	Valid	16,9
B00			0,046 89	Failure	Failure	16,9
C10		C	0,046 89	Failure	Valid	16,9
C00			0,046 89	Failure	Failure	16,9

5.4.2.4 Numerical fire simulations

Fire Dynamics Simulator (FDS) 5[1)] was used to simulate the fire and smoke spread inside the terminal. The following assumptions were adopted when doing the simulation:

a) fire origin (see 5.4.1);

b) clear height of the terminal, actual height of the building;

c) temperature conditions: room temperature is 24 °C, outdoor temperature is 30 °C, wind effect is neglected, that is, wind velocity is 0 m/s;

d) assumed fire source: the initial development of the fire is defined according to the above fire growth analysis;

e) smoke extraction system: if valid, will activate after 90 s of the occurrence of fire;

f) type of the fuel: wood and composite material;

g) time for simulation: 1 200 s;

h) surface type of the material: inert.

The dividing of the computational domain will directly affect the precision of the simulation. Considering the balance between economy and precision, non-uniform mesh division method has been used: the mesh size has been defined as 0,25 m × 0,25 m × 0,25 m near the fire source and 0,5 m × 0,5 m × 0,5 m for other areas. Sensitive study has been carried out when defining the mesh size.

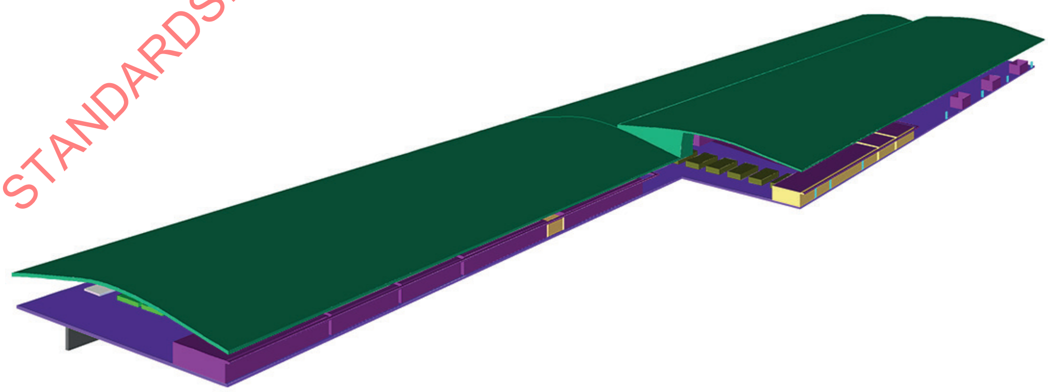


Figure 10 — Design sketch of FDS model-1

1) Fire Dynamics Simulator (FDS) 5 is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

© ISO 2017 – All rights reserved

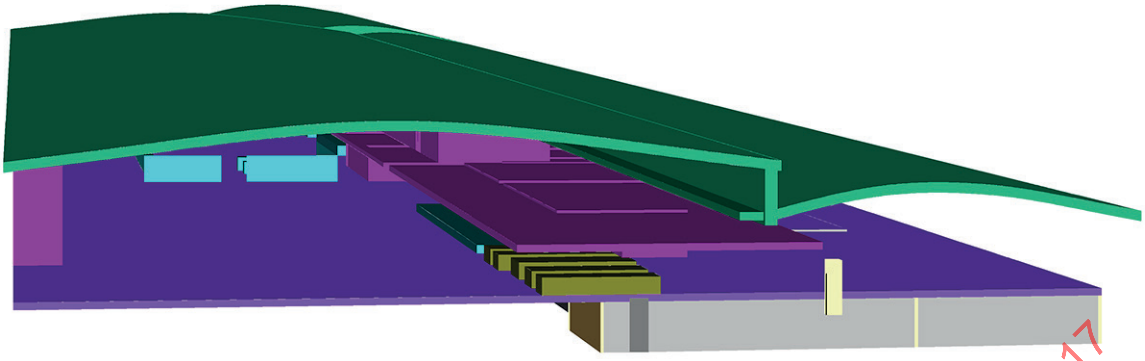


Figure 11 — Design sketch of FDS model-2

5.5 Step 5: Thermal response of the structure

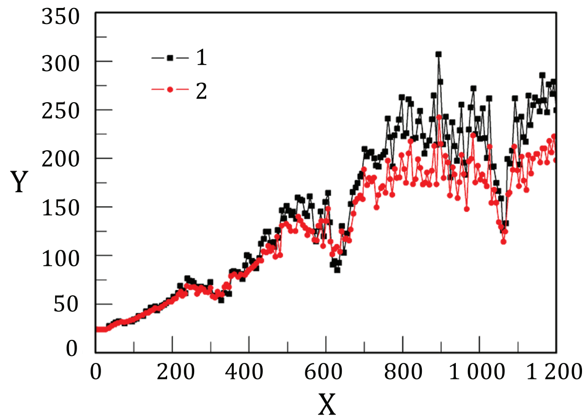
5.5.1 Smoke temperature from FDS simulation

It can be seen from Table 7 that the design fire scenarios of A00, B00 and C00 are the worst cases. In these three cases, both sprinkler system and smoke extraction system fail to activate in case of fire. After FDS simulation of the design fire scenarios, time-temperature curves of smoke near steel roof elements are obtained for A00, B00 and C00 as shown in Figure 12.

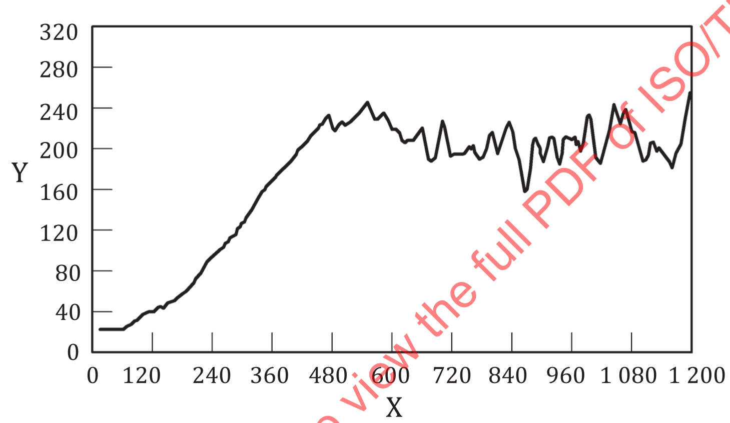
A00 refers to the fire origin located at the waiting area of the second floor (fire origin A), B00 refers to the fire origin located at the shops in the middle of the second floor (fire origin B) and C00 refers to the fire origin located at the shops at south part of the second floor (fire origin C). Figure 12 shows the gas temperature curves obtained from FDS calculation, which have some variations, and will be used to analyse the temperature profile of steel structures.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

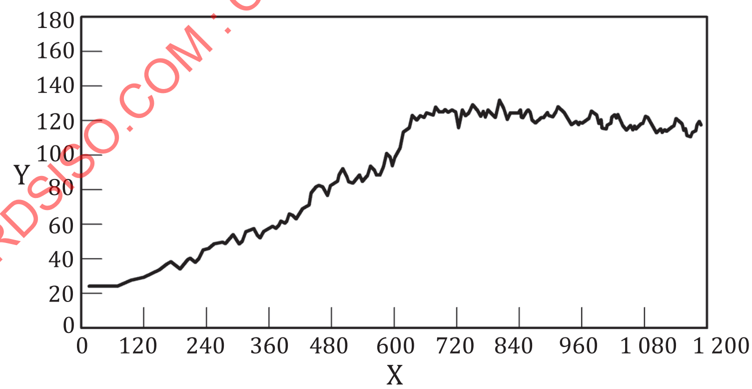
© ISO 2017 – All rights reserved



a) Scenario A00



b) Scenario B00



c) Scenario C00

Key

X t/s

Y temperature (°C)

1 h = 5 m

2 h = 6 m

Figure 12 — Temperature curve of fire

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

© ISO 2017 – All rights reserved

The calculation showed that when the fire occurred in the seating area on the second floor, the part of the steel column that was next to the fire origin could be affected directly. From Figure 12, it could be seen that the temperature at the height of 5 m is 310 °C and 250 °C at the height of 6 m. For conservative consideration, it has been suggested that the part of the column below 8 m shall be protected with fire coating and the fire resistance rating of the protected part shall not be less than 2,50 h.

5.5.2 Calculating steel temperature exposed to smoke

The internal temperature rise of the unprotected steel exposed to a hot smoke environment can be calculated according to Formula (6) to Formula (8) as recommended in CECS 200:

$$T_s(t+\Delta t)-T_s(t)=\frac{\alpha_{c+r}}{\rho_s c_s}\cdot\frac{F}{V}\cdot\left[T_g(t+\Delta t)-T_s(t)\right]\Delta t \quad (6)$$

$$\alpha_{c+r}=\alpha_c+\alpha_r \quad (7)$$

$$\alpha_r=\varepsilon_r\sigma\frac{(T_g+273)^4-(T_s+273)^4}{T_g-T_s} \quad (8)$$

where

t is the temperature rising time (s);

Δt is the time step (s) usually not larger than 5 s;

T_s, T_g is the internal temperature of the steel under fire condition and air temperature (°C);

ρ_s is the density of the steel (kg/m^3);

c_s is the specific heat of the steel [J/(kg·K)];

F is the exposed surface area per unit length (m^2/m);

V is the volume per unit length (m^3/m);

α_{c+r} is the combined heat transfer coefficient [W/(m^3·K)];

α_r is the convective heat transfer coefficient between air and the surface of the element, α_c = 25 W/(m^2·K);

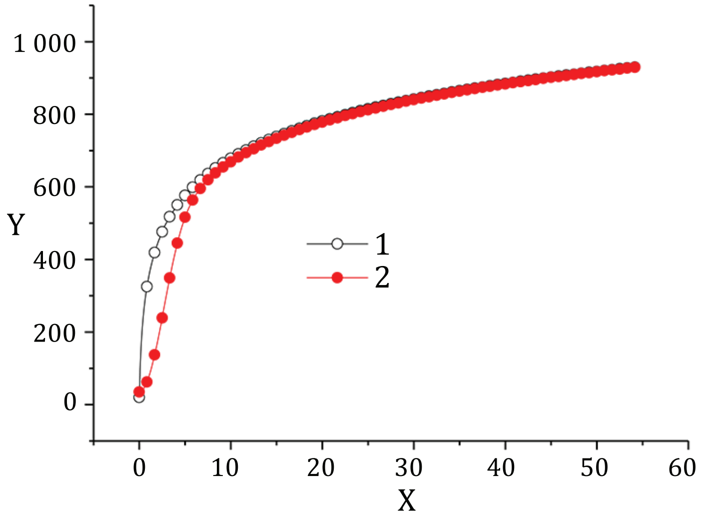
α_r is the radiant heat transfer coefficient between air and the surface of the element [W/(m^2·K)];

ε_r is the combined radiant emissivity, ε_r = 0,5;

σ is the Stefan-Boltzmann constant, σ = 5,67 × 10^{-8} W/(m^2·K^4).

Thermal conductivity of steel is high and consequently the steel temperature increases quickly. For example, when the ambient temperature is the same as that of the ISO 834 curve, the temperature of an exposed steel frame can be calculated based on Formula (6) to Formula (8), shown in Figure 13.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017



Key

X time (min)

Y temperature (°C)

1 ISO 834

2 steel member temperature

Figure 13 — ISO 834 curve versus temperature curve of the steel frame

Figure 13 shows that the steel temperature is very close to the ambient temperature. Therefore, conservatively it is reasonable to take ambient temperature as steel temperature for simplification.

In this case study, steel temperatures are assumed to be equivalent to temperatures of smoke close to the steel element as shown in Figure 12. The maximum temperature of smoke is used to be the calculating temperature for the steel element. Moreover, because the maximum thickness of the steel is 25 mm in this case, which is not very thick, it can be assumed that the temperature profile in the steel elements is evenly distributed.

5.6 Step 6: Mechanical response of the structure

As foreseen, the results of FDS simulation showed that the temperature of the steel frame directly above the fire source was rather high, while the temperature of the steel frame outside the fire room was comparatively low. Therefore, only the mechanical response of one steel frame directly above the fire source has been analysed.

The steel frame used in this case study is H-shaped Q345 steel. Its strength under normal temperature is 295 MPa and elasticity modulus is 206 GPa. The spacing of the steel frames is 10 m. The coefficient of the thermal expansion of the steel was taken from CECS 200, which is $1,4 \times 10^{-5}$ (m/m °C).

The calculated load was provided by the designer with the dead load as 0,8 kN/m^2 and roof live load as 0,5 N/m^2. The frequent coefficient of the roof live load is taken from GB 50009, which is 0,5. This airport terminal belongs to Class B according to the classification of buildings in China. Therefore, γ_0 is 1,05.

3D element BEAM189[2)] of ANSYS10.0 was used to simulate the behaviour of the portal frame under elevated temperature. BEAM189 is an element suitable for analysing slender to moderately stubby/thick beam structures. It is based on Timoshenko beam theory. Shear deformation effects are included. At the same time, it also considers nonlinear behaviour. Section stress considered in this case

2) BEAM189 is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

© ISO 2017 – All rights reserved

study can be obtained from the output. See Figure 14 for the computational model of the typical single steel portal frame.

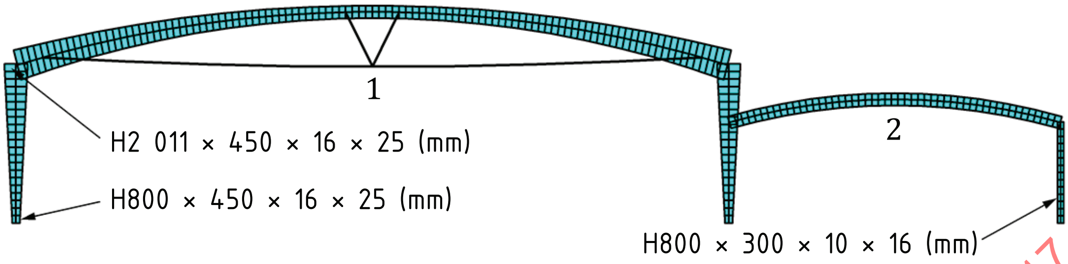


Figure 14 — Computational model of a single steel frame

As shown in Figure 14, the span and the height of the main frame are 53,5 m and 13,9 m, while the span and the height of the secondary frame are 25 m and 8,3 m, respectively. The columns of the main frame are with non-uniform cross sections. The cross-section size is H800 × 450 × 16 × 25 (mm) at the bottom and H2 011 × 450 × 16 × 25 at the top. The column of the secondary frame is with a uniform cross section, of which the size is H800 × 300 × 10 × 16 (mm). The frame columns are hinge-connected to the base. See 5.9.1 for more details about the other parameters of the steel frame and 5.1.3 for the combined load calculation.

In this subclause, fire scenarios B00 and C00 are taken as examples to analyse effects of fire temperatures on the steel structure. The mechanical response of the steel structure is calculated when the fire occurred under the main frame and the secondary frame. See Figure 4 for the location of the fire origins. The analysed steel frame is located right above the fire origins.

5.6.1 Deformation analysis of the structure

When fire occurred under the main frame, in design fire scenario C00, the maximum temperature of the roof structure was 140 °C as shown in Figure 12 c). Therefore, the steel roof trusses were assumed to be heated to 140 °C for simplification. See Figure 15 for the calculation result.

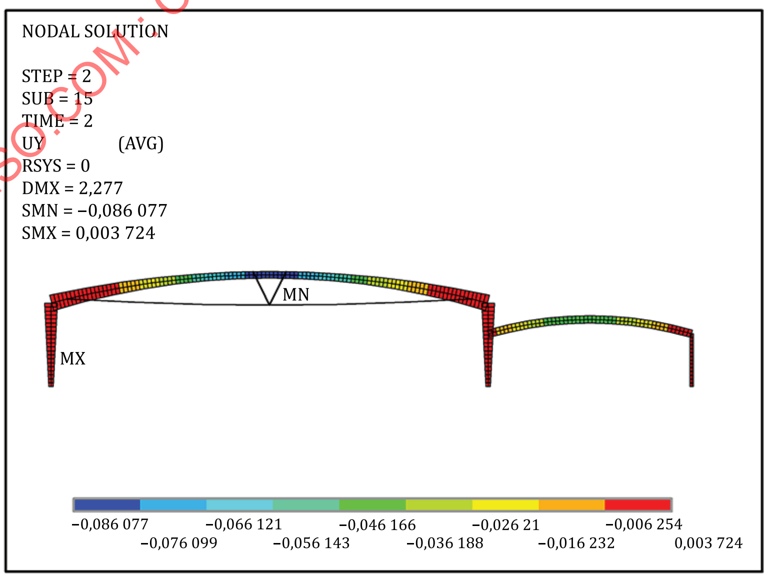


Figure 15 — Vertical calculated displacements of the steel frame (m)

From the calculation, it can be seen that the maximum mid-span deformation of the main frame under the design temperature was 0,086 m and the deflection of the structure was L/662. Compared with

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

© ISO 2017 – All rights reserved

the value (L/400) given in GB 50017-2003, the deflection of the steel portal frame under the design temperature did not exceed the required value.

When fire occurred under the secondary frame, based on the calculated temperature in fire scenario B00, the maximum temperature of the roof elements was 240 °C. Therefore, the calculation in Figure 16 was obtained.

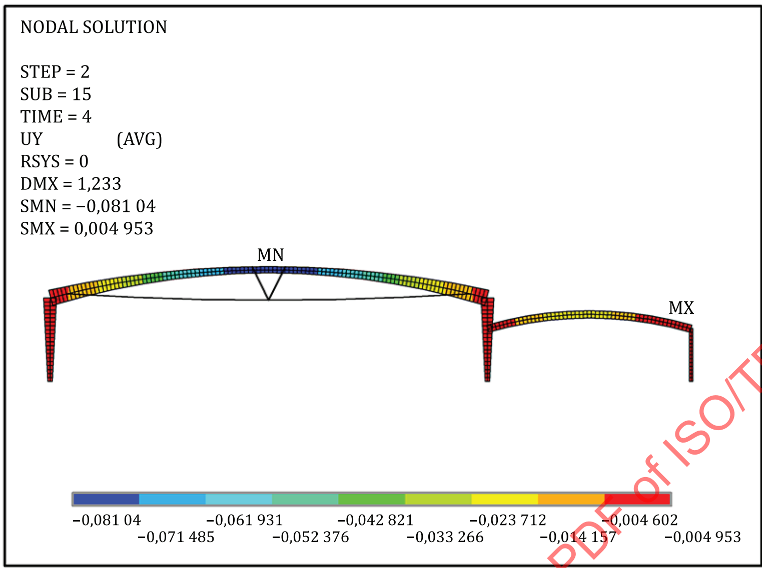


Figure 16 — Vertical deformation calculation (m)

From the calculation, it can be seen that the maximum mid-span deformation of the main frame under the design temperature was 0,081 m and the deflection of the mid-span of the secondary beam was 0,023 m. Compared with the value (L/400) given in GB 50017-2003, the deflection of the steel portal frame under the design temperature did not exceed the required value.

5.6.2 Strength analysis of the main span under fire exposure

The evolution of strength in function of time, in the point of the structure where the strength is maximum, is presented here above, and some comments concerning the fire behaviour of the structure are given.

a) When fire occurred under the main span (fire scenario C00), the results of the stress and the internal force of the steel frame were as follows.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

 © ISO 2017 – All rights reserved

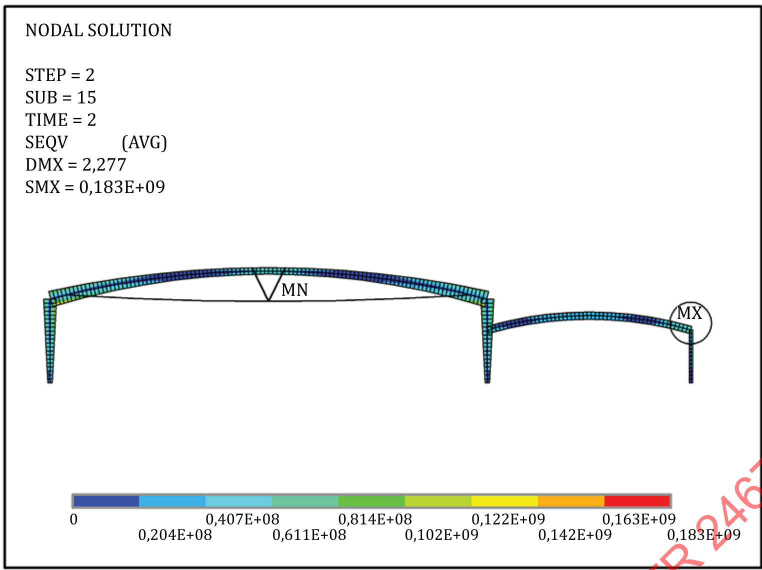


Figure 17 — Maximum von Mises stress (Pa)

Figure 17 showed that the maximum equivalent stress of the structure occurred at the joint of the arc beam and the column. The maximum value is 183 MPa. Since the maximum temperature of the roof structure was 140 °C, the strength reduction factor is 1,0 at this temperature (see 5.9.1.2 for the reduction factor as a function of time). Therefore, the strength of arc joint is not affected at all.

Figure 18 showed that the maximum tensile and compressive stress of the structure occurred at the joint of the beam and the column, which were 166 MPa and 183 MPa, respectively. Both of them are less than the strength at the maximum elevated temperature of 140 °C.

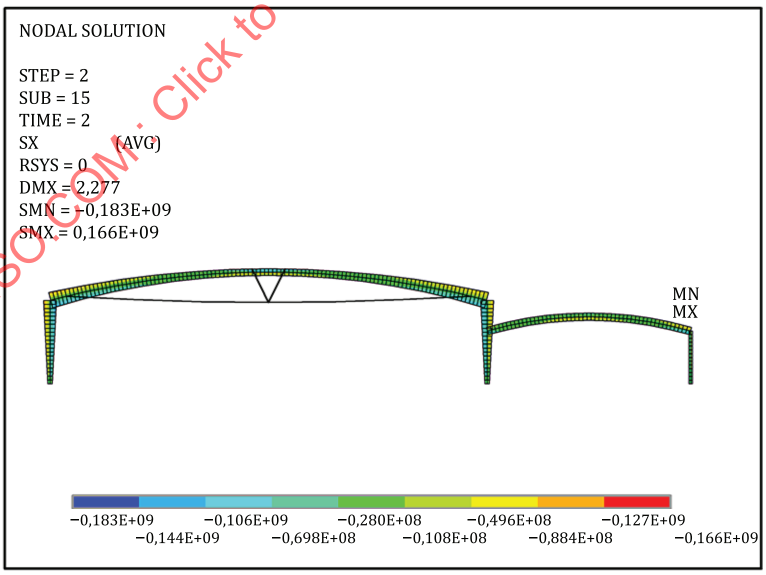


Figure 18 — Stress of the frame in the direction of X (Pa)

Figure 19 and Figure 20 showed the internal force of the main frame. Calculation was then done and the result showed that the stability of the main frame could meet the related requirement.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

© ISO 2017 – All rights reserved

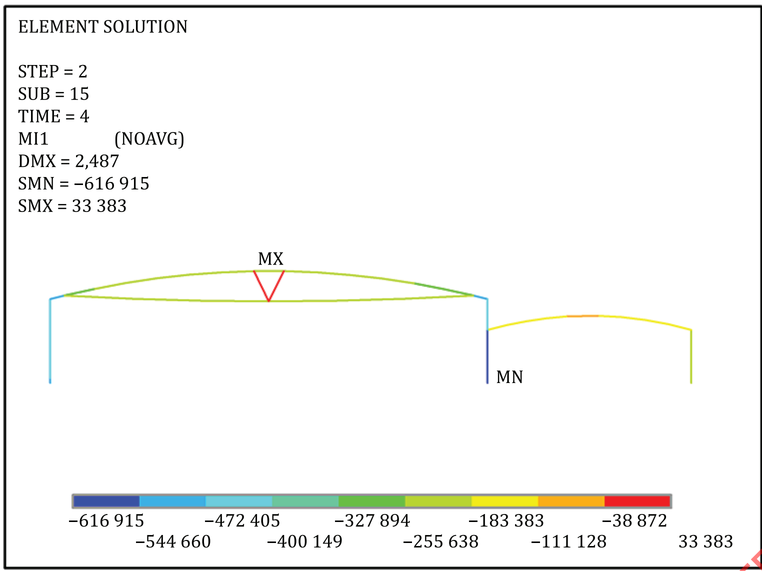


Figure 19 — Axial force of the frame (N)

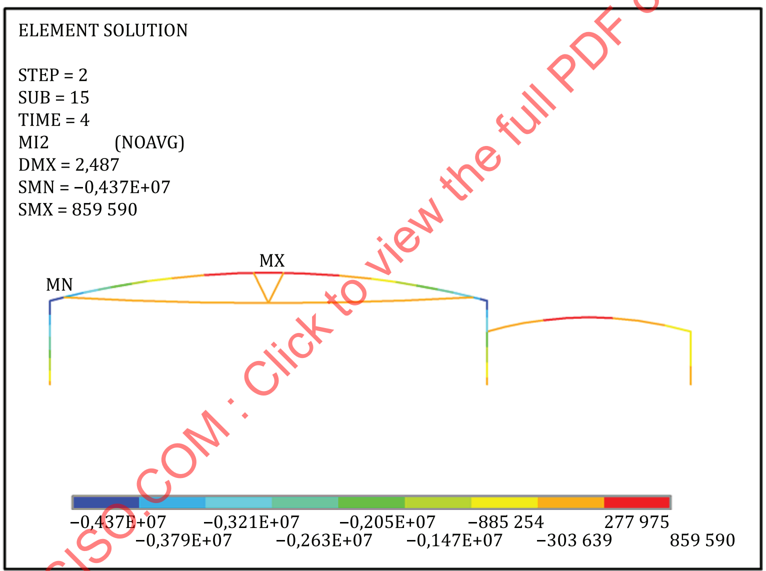


Figure 20 — In-plane bending of the truss

b) When fire occurred under the secondary span (fire scenario B00), the results of the stress and the internal force of the steel frame were as follows.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

© ISO 2017 – All rights reserved

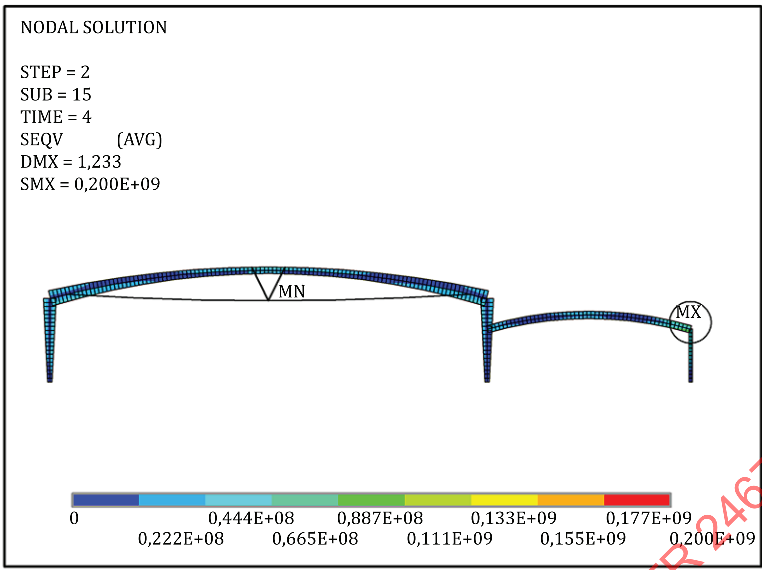


Figure 21 — Maximum von Mises stress (Pa)

Figure 21 showed that the maximum equivalent stress of the structure occurred at the joint of the arc beam and the column. The maximum value was 200 MPa, which is less than the required design strength (295 MPa) of the steel at the maximum elevated temperature in this fire scenario.

Figure 22 showed that the maximum tensile and compressive stress of the structure occurred at the joint of the beam and the column, which were 183 MPa and 200 MPa, respectively. Both of them are less than the required design strength (295 MPa) of the steel at the maximum elevated temperature in this fire scenario.

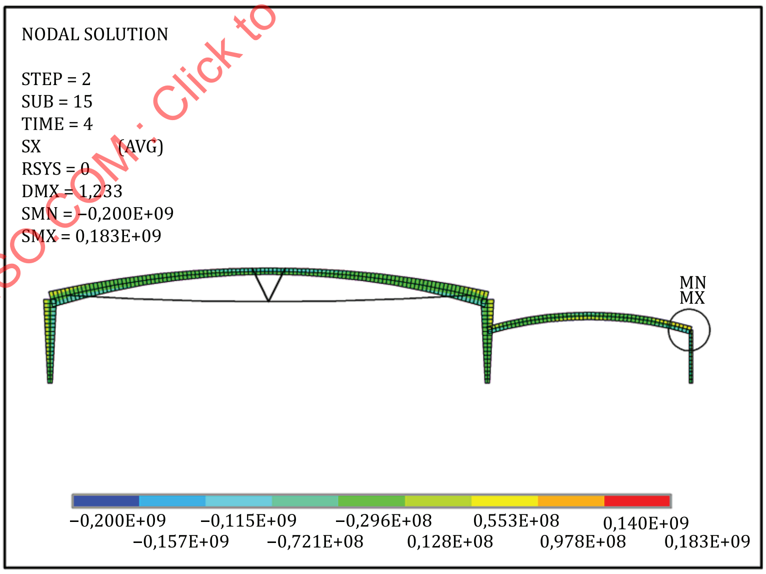


Figure 22 — Stress of the frame in the direction of X (Pa)

Figure 23 and Figure 24 show the diagrams of the internal force distribution of the secondary span. Calculation was then done and the result showed that the stability of the main frame could meet the related requirement.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

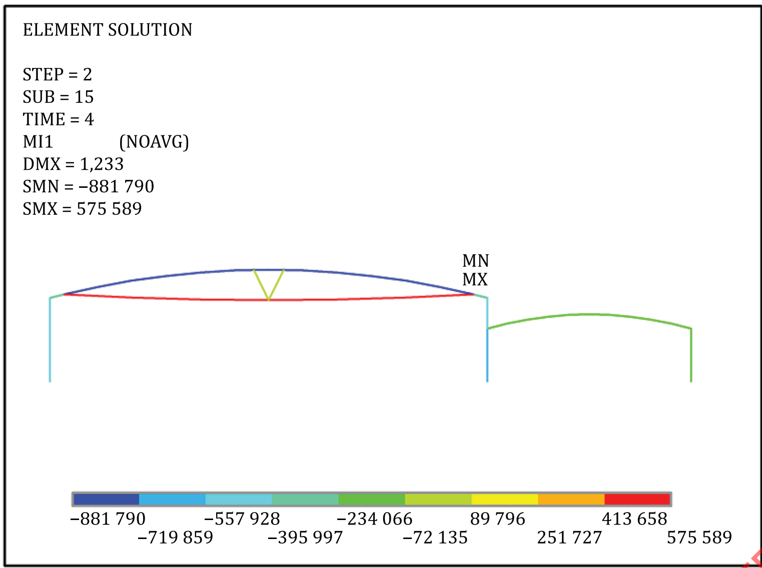


Figure 23 — Axial force of the frame (N)

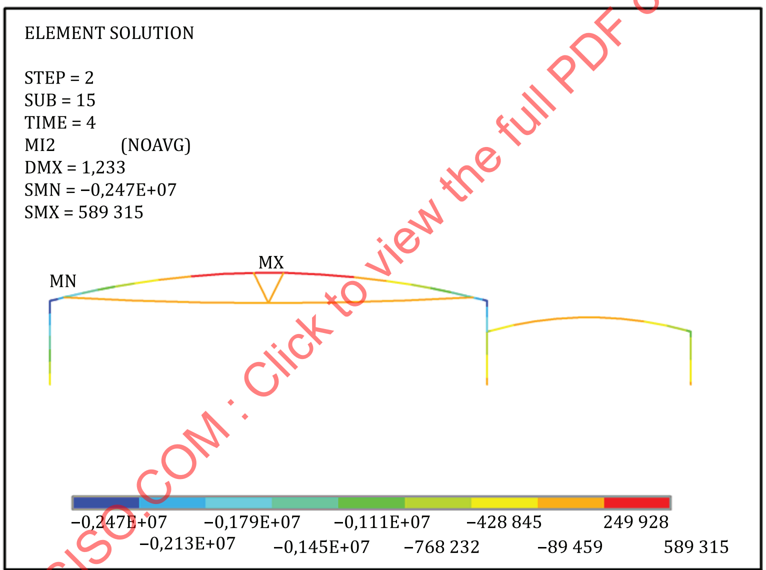


Figure 24 — In-plane bending of the truss (N·m)

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

5.7 Step 7: Assessment against the fire safety objectives

In the design fire scenarios B00 and C00, the calculation showed that the maximum deformation in the middle of the portal frame, whether it was the main frame or the secondary frame, was less than the permitted deflection (L/400) required in GB 50017-2003. Therefore, the deflection of the portal frame under given temperature was less than the required value. Furthermore, the maximum tensile and compressive stress was less than the required design strength of the steel at the maximum elevated temperatures calculated. Therefore, the strength of the structure satisfies the requirement $R_d \geq S_m$. Indeed, the load-bearing capacity of the structure (R_d) is higher than the combined actions (S_m) that structure could be submitted in fire conditions, not only during the required time by Chinese regulation, but during entire time history of fire, because after the fire fighter intervention the fire will be extinguished.

© ISO 2017 – All rights reserved

FDS5 was used to simulate the ambient temperature of the steel structure. According to the analysis in 5.5, the temperature of the steel under fire condition is close to that of the ambient temperature; see Table 8.

Table 8 — Temperature of the steel roof under the design fire scenario

Design fire scenario (FDS simulation)	B00 (secondary frame)	C00 (main frame)
Maximum fire size(MW)	16,9	16,9
Distance from the lowest point of the steel roof structure to the floor (m)	6,2	9,2
Temperature at the lowest point of the steel roof structure (°C)	240	140

When FDS5 was used to do the calculation, it was assumed that the fire broke out in a shop directly under the steel roof structure. The temperature of the steel roof structure was calculated when the hot smoke spread out of the shop and reached the steel roof.

The result of the calculation showed that in case of fire in a shop (the fuel was the commodities in the shop) on the second floor, the maximum temperatures of the main steel frame and the secondary frame were 140 °C and 240 °C, respectively, which were smaller than the design value (300 °C). Therefore, the steel roof structure could be unprotected. It met the related requirement $T_d \geq T_m$. Indeed, the critical internal temperature of the steel structure at its ultimate state (T_d) is higher than the maximum temperature of the heated structure (T_m) not only during the required time by Chinese regulation, but during entire time history of fire, because after the fire fighter intervention the fire will be extinguished.

According to the calculation result, the design and protection method of the steel structure in this case study is feasible.

5.8 Step 8: Documentation of the design for fire safety of structures

This case study is prepared for the implementation of ISO 24679-1. Therefore, the procedure of the document has been followed.

a) Interested and affected parties include the owner of the airport terminal, the designer — China Airport Construction Group Cooperation of CAAC as well as Tianjin Fire Research Institute (TFRI).

b) Scope of the project.

   See 5.1 for the detail.

c) Objectives, functional requirements and performance criteria for fire safety of structures were defined according to the occupancy of the assessed object, the properties of the structure, as well as the existing requirements of some related codes and standards.

d) Trial design plan for fire safety of structures: based on the fire risk analysis, the design fire scenarios have been defined. Then FDS5 was used to simulate the room temperature under fire condition and ANSYS was used to analyse the thermomechanical behaviour of steel frames so as to see if the trial design plan was feasible or not.

e) Design fire scenarios and design fires: in this case study, three fire scenarios have been simulated. But for the fire safety of the steel roof, fire scenario B00 and C00 are considered. The reasons are as follows.

   1) The fire scenarios B00 and C00 are on the second floor and the fire origins are in the shops directly under the steel column and steel roof.

   2) Both the smoke exhaust system and the automatic sprinkler system fail to activate when the fire breaks out.

   Therefore, it is considered that B00 and C00 are quite representative.

STANDARDSISO.COM : Click to view the full PDF of ISO/TR 24679-2:2017

© ISO 2017 – All rights reserved