TECHNICAL REPORT

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Fire safety engineering — Performance of structure in fire —

Part 3: Example of an open car park

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

Partie 3: Exemple d'un parking aérien largement ventilé

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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

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Foreword

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: Foreword — Supplementary information.

The committee responsible for this document is ISO/TC 92, *Fire safety*, SC 4, *Fire safety engineering*.

Introduction

This Technical Report is an example of the application of ISO/TS 24679, prepared in the format of ISO/TS 24679. It includes only those sections of ISO/TS 24679 that describe steps of the methodology for assessing the performance of structures. It preserves the numbering of sections in ISO/TS 24679 and so omits numbered sections for which there is no text or information for this example.

This example is intended to illustrate the implementation of the steps of fire resistance assessment, as defined in ISO/TS 24679. Only steps that are considered as relevant in this example are well detailed in this Technical Report.

Fire safety engineering — Performance of structure in fire —

Part 3: Example of an open car park

1 Scope

This Technical Report provides a fire safety engineering application relative to fire resistance assessment of an open car park according to the methodology given in ISO/TS 24679. This report describes the adopted process which followed the same step by step procedure as that given within ISO/TS 24679. The Annexes of this Technical Report presents the detailed numerical analysis results obtained for most severe fire scenarios on the basis of this specific fire safety engineering procedure for open car parks.

The fire safety engineering applied here to open car parks, with respect to their fire resistance, considers specific design fire scenarios as well as corresponding fire development. It takes account of localized heating, global structural behaviour rather than single structural member resistance, etc.

In fact, in case of fire in open car parks, only a small part of structure will be exposed directly to fire because of the limited fire spread due to open environment as well as rapid fire brigade intervention. In consequence, the load redistribution to cold parts might become possible and can be taken into account through global structural analysis.

This kind of approach based on 3D modelling of the mechanical response of composite floor was already used in various fire safety engineering projects in France to check the stability of unprotected composite steel framed open car parks subject to most severe real fire scenarios.

Finally, it should be mentioned that these severe fire scenarios have been selected for fire resistance purposes only. They should not be used, for example, for smoke control purposes.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/TS 24679:2011, *Fire safety engineering — Performance of structures in fire*

EN 1990:2002, *Eurocode 0: Basis of structural design*

EN 1991-1-2:2002, *Eurocode 1: Actions on structures — Part 1-2: General actions — Actions on structures exposed to fire*

EN 1992-1-2:2004, *Eurocode 2: Design of concrete structures — Part 1-2: General — Structural fire design*

EN 1994-1-1:2004, *Eurocode 4: Design of composite steel and concrete structures — Part 1-1: General — Common rules and rules for buildings*

EN 1994-1-2:2005, *Eurocode 4: Design of composite steel and concrete structures — Part 1-2: General — Structural fire design*

3 Terms and definitions

For the needs of this example, following terms and definitions are used in addition to those described in ISO/TS 24679:2011, Clause 3.

3.1
edge secondary beam
secondary beam located at the façade part of the floor and parallel to façade

3.2
edge primary beam
primary beam located at the façade part of the floor and parallel to façade

3.3
internal secondary beam
secondary beam located in internal part of the floor (other secondary beams than edge secondary beams)

3.4
internal primary beam
primary beam located in internal part of the floor (other primary beams than edge primary beams)

3.5
PRS
profil reconstitué soudé
welded steel section

4 Design strategy for fire safety of structures

The built environment is an open car park. With its well-ventilated configuration and easy intervention condition of firefighters, a fully developed fire covering the whole area of the floor is not possible. In consequence, the fire spread will be limited and remains always localized according to a statistic survey of real fires in open car parks. As a result, burning of several cars is considered as relevant to predict the impact on structural stability. A global structural analysis is carried out to evaluate the behaviour of non-insulated steel frame and profiled steel deck slab. This approach is based on 3D modelling of the mechanical response of composite floor which takes account of localized heating and global structural behaviour rather than single structural member resistance.

5 Quantification of the performance of structures in fire

5.1 Fire performance of structures — Design process

The various steps of the design process considered in the conducted fire safety engineering study are detailed in the following sections.

5.2 Step 1: Scope of the project for fire safety of structures

5.2.1 Built environment characteristics

The car park is a 3-storey building, of which all façades are open. According to the French regulation, it is considered as an “open car park”, meaning that it meets simultaneously the following conditions:

— At each level, the openings shall be put at least on two opposite façades;

— These openings shall have a total area equal to at least 50 % of the total area of these façades, of which the height has to be taken as the free height of the floor and shall not be less than 5 % of the corresponding single floor total area;

— The maximum distance between two opposite and opened façades shall be less than 75 m.

There are about 520 car park spaces (130 spaces per level). Each car park place occupies an area of 2,5 m by 5,0 m. Moreover, two access ramps allowing vehicle access to various levels are predicted at longitudinal edge part of the building (see Figure 1). Each gross floor area is 31,30 m× 112,65 m. The total building height is 10,274 m (height for ground storey: 4,658 m and for other stories: 2,808 m).

The structure of this building is designed with the following sizes:

— Span of secondary beams: 15,5 m;

— Span of primary beam: 10,0 m;

— Spacing of columns: 10,0 m in direction of primary beams and 15,5 m in direction of secondary beams.

As the building is located in a region subject to strong seismic action, the owner of the building decided to use steel and concrete composite structures for this building. However, the ramps remain in concrete and separated structurally from parking area. In consequence, the spacing of secondary beams is about 3,33 m which is also the span of the 120 mm thick floor composite slab (with a trapezoidal 0,88 mm thick steel decking).

The applied load of design on the floors is taken as follows:

— Live load: 2,5 kN/m^2;

— Permanent load on the floor due to screed and services: 0,2 kN/m^2 for intermediary floor level and 1,10 kN/m^2 for roof level;

— Self weight of floor (slab and steel members): 2,53 kN/m^2;

— Self weight of façade: 0,8 kN/m on longitudinal edges and 2,0 kN/m on transverse edges.

More details of structure are given in Annex B.

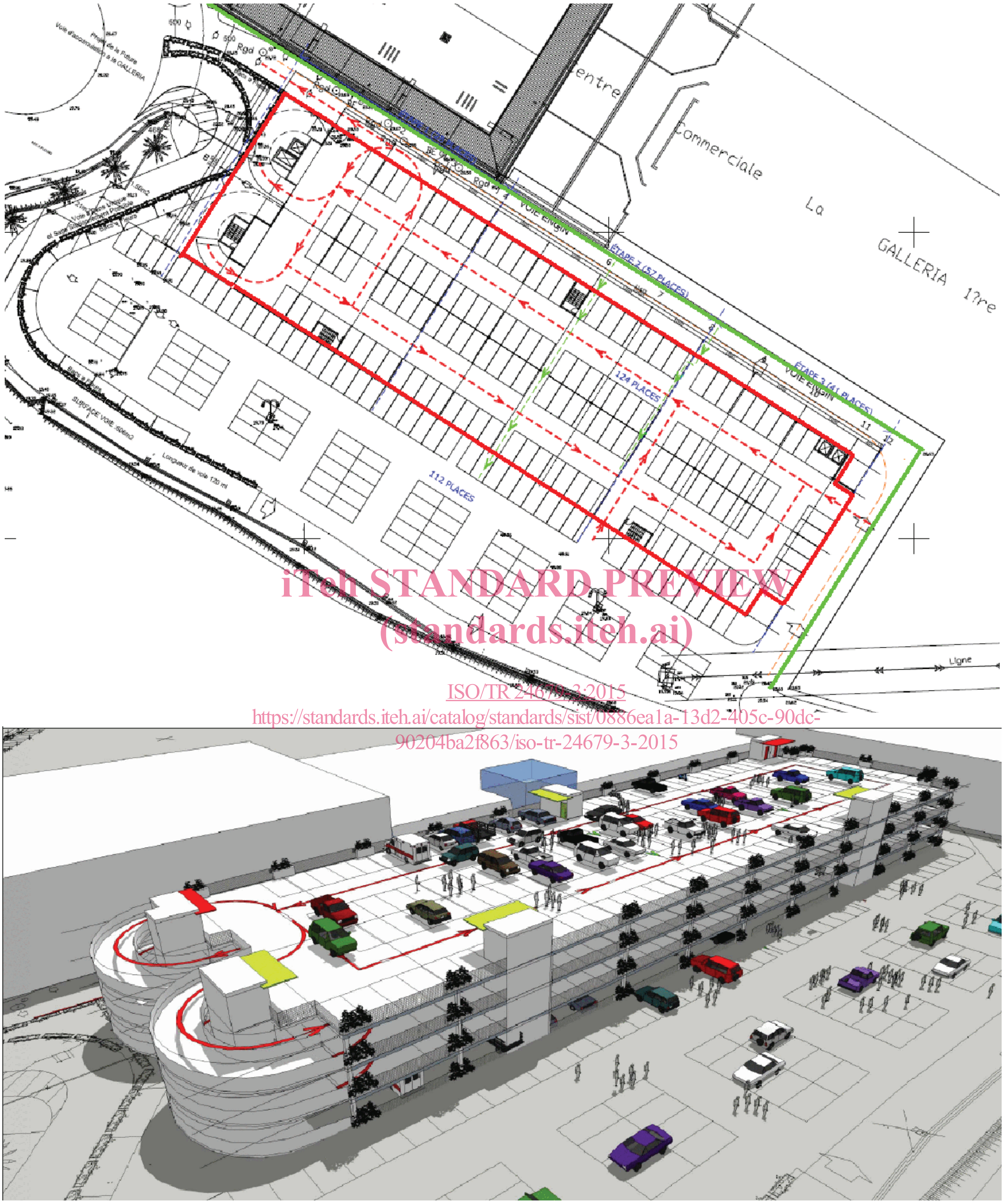


Figure 1 — View of the built environment of investigated open car park: plan view (top) and perspective view (bottom)

5.2.2 Fuel loads

In order to reach both realistic and efficient means of fire resistance safety of the structure, fuel loads are characterized on an available scientific data basis in terms of the heat release rate of car fires and fire propagation behaviour between cars according to real car fire tests performed at CTICM in the scope of a European research project.[1] The average mass, the mass of combustible materials, and the heat released of 5 categories of European cars are reported in Table 1.

Table 1 — Average car mass, mass of combustible materials, and heat release for different category of cars (of the 90s)

Category	Car mass (kg)	Mass of combustible materials (kg)	Heat release (MJ)
1	850	200	6 000
2	1 000	250	7 500
3	1 250	320	9 500
4	1 400	400	12 000
5	1 400	400	12 000

Fire from cars using liquefied petroleum gas is considered to be less severe on the basis of French fire tests with this type of cars.

5.2.3 Mechanical actions

The mechanical actions in fire situation are determined in accordance with EN 1990. In consequence, the following load combination is used:

$$1{,}0\ G + 0{,}7\ Q$$

with: G for sum of all the permanent loads and Q for live load.

The snow actions are considered as negligible because the construction zone is in a tropical region.

As far as design wind loads are concerned, they are much lower than the lateral seismic loads and the resisting systems (bracing system shown in Annex B of this report) to seismic actions are therefore strong enough to resist wind effects which, under fire situation, have a combination factor equal to 0,2 (instead of 1,5 at ultimate state design at room temperature). In this case, the wind effects under localized fire become also negligible with respect to the resistance capacity of the whole bracing system of the structure. It has to be noted that according to the French national regulations, no other accidental actions need to be combined with fire action as it is already an accidental action on the structures.

Moreover, as the considered floor area in the design is important, according to EN 1990, the live load can be reduced by a factor of 0,8 which leads to a reduced live load of 2,0 kN/m^2. Therefore, the final design loads in fire situation over the floor are thus 1,60 kN/m^2 and 2,50 kN/m^2 for intermediary floor level and roof level, respectively. In addition to these uniformly distributed loads, a linear load of 2,0 kN/m from façade self-weight is applied safely on the perimeter beams.

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

According to current French national regulations relative to fire safety, the statutory requirement is no increase of risk to life safety of occupants, fire fighters, and others in the vicinity of the building, due to the structural behaviour of the building once subjected to fire.

To fulfil this objective, the functional requirement is to not have any failure of the building during the whole duration of fire, including their cooling phases.

Consequently, the following performance criterion in terms of stability of the structure is:

— No overall failure of the building, e.g. due to the loss of stability of columns.

More precisely, the overall failure is considered to be avoided if following performance criteria are met:

— Maximum deflection of all beams does not exceed 1/20 of their spans;

— Maximum mechanical strain of reinforcing steel mesh remains lower than 5 %, because such limitation is not taken into account directly in the stress-strain relationship of reinforcing steel.

The deflection limit is introduced for the following two reasons:

— to avoid the risk to have concrete crushing which cannot be taken into account rigorously in the material model of the computer code ANSYS and

— to avoid any risk of loading.

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

Preliminary designs, at room temperature, were carried out in accordance with EN 1994-1-1, to determine the sizes of various structural members of composite floors on the basis of structural grid system described in 5.2.1.

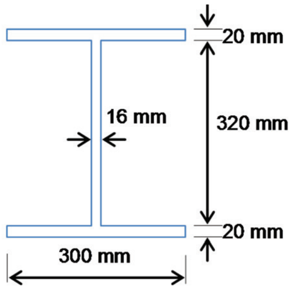
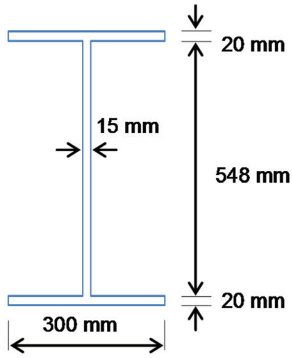
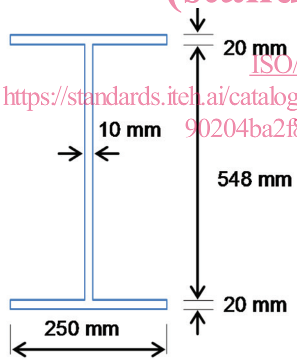
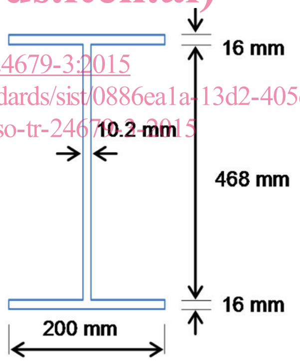
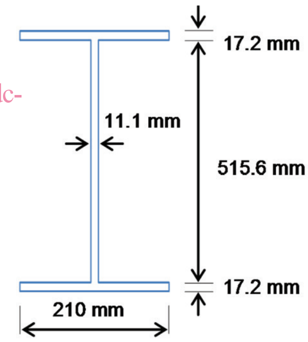
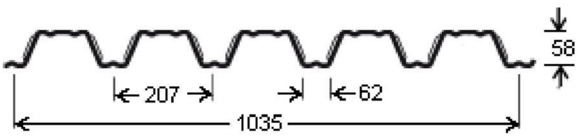
As far as the material properties used in these designs are concerned, the grade of structural steel is S355 with a yield strength of 355 MPa. The quality of concrete was assumed to be C30/37 with a compressive strength of 30 MPa. With respect to shear connectors, they all are in headed studs with a diameter of 19 mm and a height of 100 mm. The partial shear connection was designed for all composite beams. Thus, its distribution over steel beams is one stud every 207 mm for secondary beams and one stud every 200 mm and 150 mm for edge primary beams and internal primary beams, respectively. The complementary structural details of structure are reported in Table 2.

As the heating of unprotected steel members will be very important (more than 700 °C), the fire resistance of the floor can no longer be ensured with classical structural resistance approach without any fire protection. The only way to get an unprotected floor structure is to have the floor system behaving under membrane action through which the load redistribution becomes possible. In order to achieve this structural behaviour, a reinforcing steel mesh composed of steel bars of 7 mm in diameter along two perpendicular directions (parallel and perpendicular to span of composite slab) with the same grid size of 150 mm along the two directions is placed at 35 mm from the unexposed face of composite slab. The grade of the reinforcing bars is S500 with the yield strength of 500 MPa.

Another strategy adopted in this fire design is to use steel grade of S355 which will provide higher fire resistance than other steel grades below.

The steel columns need also to be dealt with in a particular way. It is decided to combine two solutions; on the one hand, the steel section of columns has to be partially concrete encased and on the other hand, their applied load in fire situation is limited to 0,35 of their room temperature ultimate load bearing capacity.

Table 2 — Summary of structural members

Floor levels	Ground floor	Intermediary floor	Roof
Column (four sides exposed)	PRS 320 × 16/300 × 20 (A/V = 110 m^{-1})		
Primary beam (three sides exposed)	PRS 548 × 15/300 × 20 (A/V = 116 m^{-1})		
Secondary beam (three sides exposed)	PRS 548 × 10/250 × 20 (A/V = 93 m^{-1}) 	IPE 500 (A/V = 134 m^{-1}) 	IPE 550 (A/V = 124 m^{-1}) 
Steel decking	thickness: 0,88 mm 		
Total depth of composite slab	120 mm		

