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Fire safety engineering — Performance of structures in fire —

Part 6: Example of an eight-storey office concrete building

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

Partie 6: Exemple d'un immeuble de bureaux de huit étages en béton renforcé

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Foreword

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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).

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

Introduction

The work described in this document is an example of the application of ISO 24679-1. The procedure in this document is intended to follow the principles outlined in ISO 24679-1. The sections of ISO 24679-1 which are considered relevant to this example are identified and thus, the section titles are the same and appear in the same order.

The purpose of this study is to demonstrate the application of the steps outlined in ISO 24679-1 for fire safety engineering and performance of structures in fire in compliance with the related standards of France. As such, the relevant sections to this example are applied and discussed.

Fire safety engineering — Performance of structures in fire —

Part 6: Example of an eight-storey office concrete building

1 Scope

This document provides an example of fire safety engineering design in the application of ISO 24679-1 to an office building.

In this document, an overall structural analysis of a building is undertaken. It consists in a numerical assessment of the structural performance of an eight-storey concrete building when subjected to a fire. This analysis is performed in order to demonstrate that the fire safety objectives, for the relevant design fire scenarios, due to structural behaviour of building in the event of fire, are met with the trial plan for the safety of structure. With regards to this, a fully developed fire was studied.

The purpose of this document is to assess the performance of an office building which is fully accessible to public in case of fire, using ISO 24679-1. In this respect, a critical design fire was identified and analysed using detailed fire modelling. A more detailed analysis was then performed for critical design fire using the finite element model. The advanced model provided all the comprehensive information necessary for analysing the given built environment with respect to fire safety.

It is to be noted that this document only addresses the fire safety objectives related to the structural performance during fire. The analysis within this document is therefore only part of the overall building fire safety strategy.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 24679-1:—[1)], *Fire safety engineering — Performance of structures in fire — Part 1: General*

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

1) Under preparation. Stage at the time of publication: ISO/DIS 24679-1:2017.

3.2 Symbols

A_f	floor surface area
A_t	total area of enclosure (walls, ceiling and floor, including openings) (m^2)
A_v	total area of vertical openings on all walls (m^2)
D	diameter of fire source (m)
EC	Eurocode
O	opening factor of the fire compartment (m$^{1/2}$)
O_{lim}	reduced opening factor in case of fuel controlled fire (m$^{1/2}$)
RMT	maximum rebar temperature (°C)
T_g	gas temperature (°C)
T_0	ambient temperature (°C)
$V_{Ed,fi}$	the design value of the fire induced shear load
$V_{Rd,fi}$	the design value of shear resistance in case of fire
b	thermal inertia for the total enclosure (J/m^2·s$^{1/2}$·K)
c	specific heat (J/kg·K)
dx	grid size (m)
h_c	convective coefficient of exposed side (W/m^2·K)
h_b	convective coefficient of unexposed side (W/m^2·K)
h_{eq}	weighted average of window heights on all walls
k	thermal conductivity (W/m·K)
m	combustion factor
$q_{f,d}$	design fire load density related to the floor area A_f (MJ/m^2)
$q_{f,k}$	characteristic fire load density related to the surface area A_f (MJ/m^2)
$q_{t,d}$	design fire load density related to the surface area A_t (MJ/m^2)
t_{lim}	time to reach maximum gas temperature in case of fuel controlled fire (h)
t_{max}	time to reach maximum gas temperature (h)
t_{RMT}	time to reach the rebar maximum temperature (min)
Γ	time factor function of the opening factor O and the thermal absorptivity b
Γ_{lim}	time factor function of the opening factor O_{lim} and the thermal absorptivity b
ε	surface emissivity of the member
ρ	density (kg/m^3)

δ_{q1} activation risk due to the size of the compartment equal to 1 in this example

δ_{q2} fire activation risk due to the type of occupancy equal to 1 in this example

δ_{n} factor taking into account different active fire-fighting measures equal to 1 in this example

4 Design strategy for fire safety of structure

4.1 General design process for fire safety of structures

This example studies the fire resistance assessment of an office building using ISO 24679-1. According to the history of the real fires in an open plan office, a generalized fire is possible.

Potential design fire scenarios in the build environment were studies. Temperature time curves were produced and analyses were carried out so as to identify the plausible worst case scenarios[1], [2].

In order to provide a more detailed and broader resolution of the fire scenario for the use of detailed structural analysis, the critical design fire scenario was investigated using advanced fire modelling and design fire was established.

The comprehensive structural behaviour was studied via advanced structural modelling of the worst case scenario.

Additionally, factors and influences in quantification process and uncertainty of material properties where studied. As such, a more detailed analysis was carried out by means of sensitivity analyses in which the OAT (i.e. one-factor-at-a-time) was used where only one input variable in the base case fire scenario was changed[3]. In this respect, a range of input variables in generating the fully developed fire and heat transfer models were investigated by means of a literature study.

4.2 Guidance of practical design process for fire safety of structure

ISO 24679-1:—, Table 1, illustrates various steps and parameters to be considered when assessing the behaviour of structures subjected to fire exposure. The details of the relevant steps to this example are presented in the following clauses.

5 Qualification of the performance of structures in fire

5.1 STEP 1: Scope of the project for fire safety of structure

5.1.1 Built-environment characteristics

The building studied is an open-plan office building without any interior vertical compartmentations, with a glazed façade all around the perimeter. It has a floor area of approximately 420 m^2 and total gross area of 3 360 m^2. The building is divided into two basement levels, a ground floor, and five floors above ground, which are open to the public. The building is 30,25 m long by 14,25 m wide and 25 m high. The ground floor has a height of 4 m whereas the upper storeys have a height of 3 m. Elevators and staircases are placed in the central core.

The length is divided into five structural bays, and the width into two bays. Each bay is 6 m by 7,125 m as shown in Figure 1. The building frame is composed of reinforced continuous concrete beams and columns, supporting concrete floor slabs which are 180 mm thick; the exterior walls are 200 mm thick; the columns are 500 mm by 500 mm wide, and the beams are 400 mm deep by 250 mm wide.

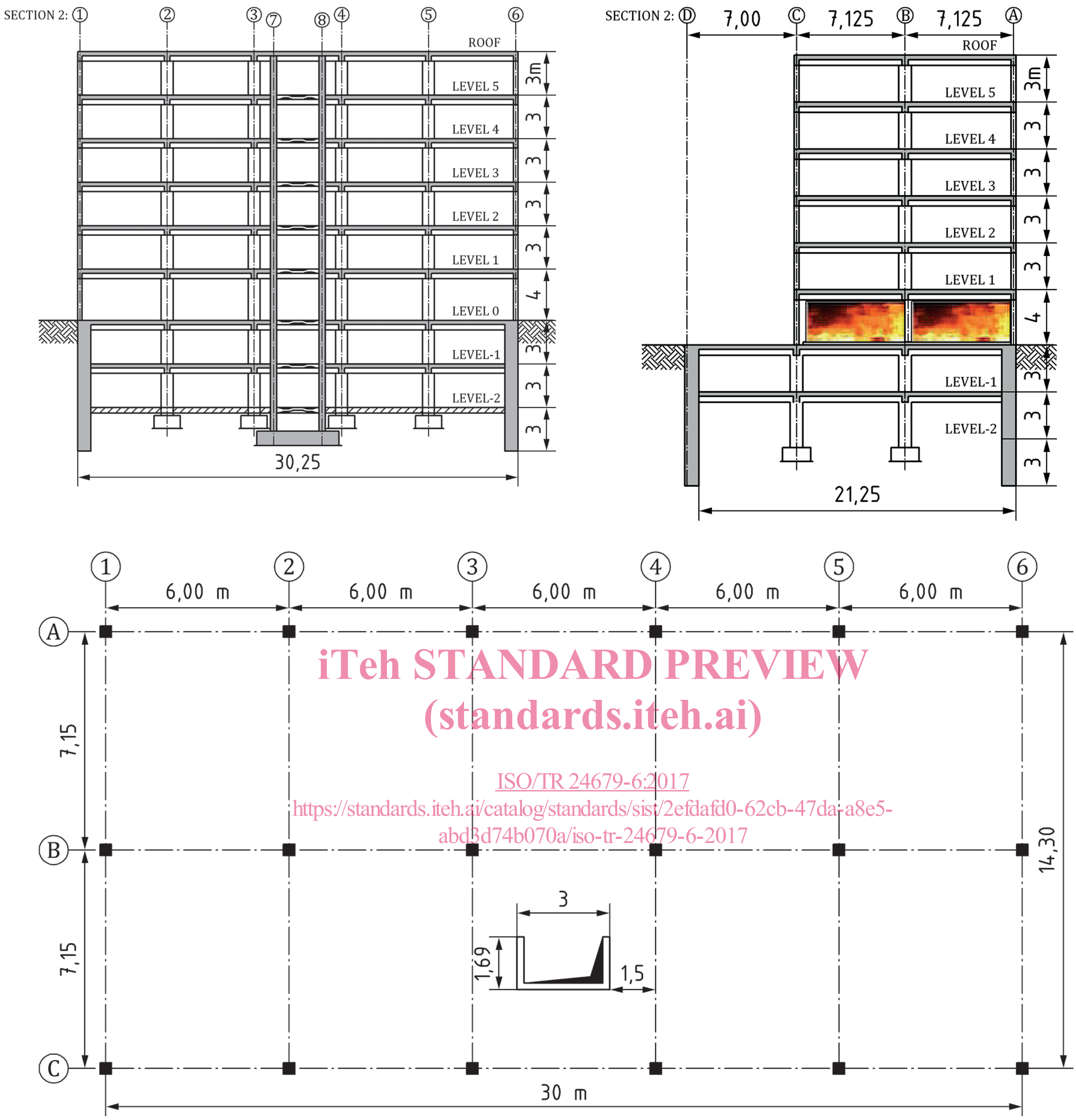


Figure 1 — Plan and elevation of the structure, dimensions in metres

The structure includes three kinds of structural members: reinforced concrete columns, beams and slabs. The cross section of the column is equal to 0,25 m^2 and is presented in Figure 2. For the first floor, the height of the column is equal to 4 m whereas the upper storeys have a column height of 3 m. The materials are:

— concrete: C30/37;

NOTE 30 and 37 are the characteristic cylinder and cube compressive strengths, respectively, in Mpa.

— steel: hot rolled, grade 500 class B.

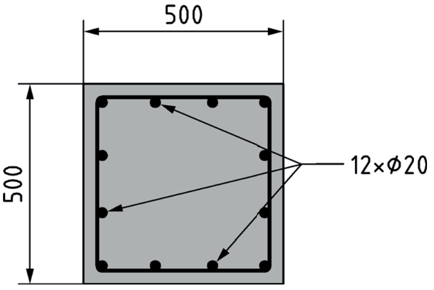


Figure 2 — Column cross section

The reinforcement in the column and the axis distance are presented in Table 1.

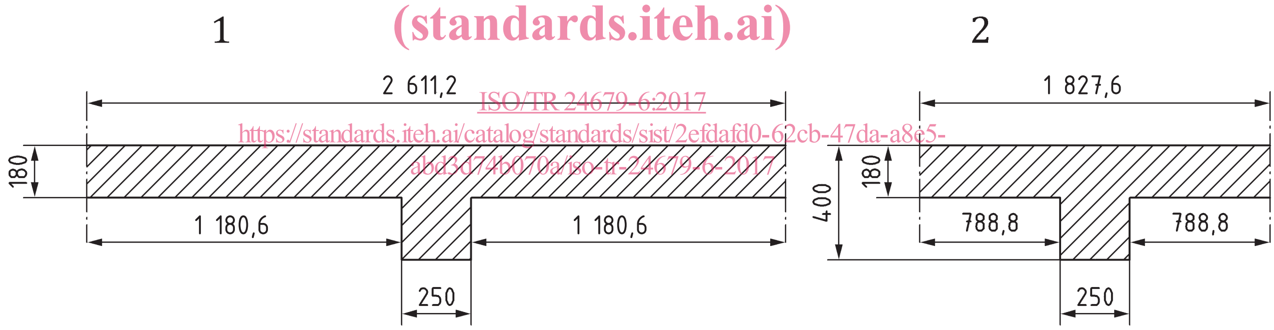
Table 1 — Column reinforcements and the axis distance of reinforcements

Column	Ø	Axis distance
Longitudinal reinforcement	12 Ø 20	52 mm
Stirrups	Ø12/200 mm	36 mm

In Figure 3, the cross sections of the beams are illustrated. The materials are as follows:

— concrete: C25/30;

— steel: hot rolled, grade 500 class B.



Key

1 cross-section at mid-span

2 cross section at intermediate support

Figure 3 — Continuous beam cross section

The reinforcement and the axis distances in the beams are presented in Table 2.

Table 2 — Reinforcement and axis distance in the beams

Beam	Perimeter support	Mid-span	Intermediate support	Axis distance
Upper	7 Ø12	2 Ø10	9 Ø12	42 mm
Lower	3 Ø16	3 Ø16	3 Ø16	44 mm
Stirrups	Ø8/175 mm	Ø8/175 mm	Ø8/175 mm	34 mm

The slab is 180 mm thick and the reinforcement is presented in Figure 4 and Table 3. The materials are as follows:

— concrete: C25/30 concrete;

— steel: hot rolled, grade 500 class B.

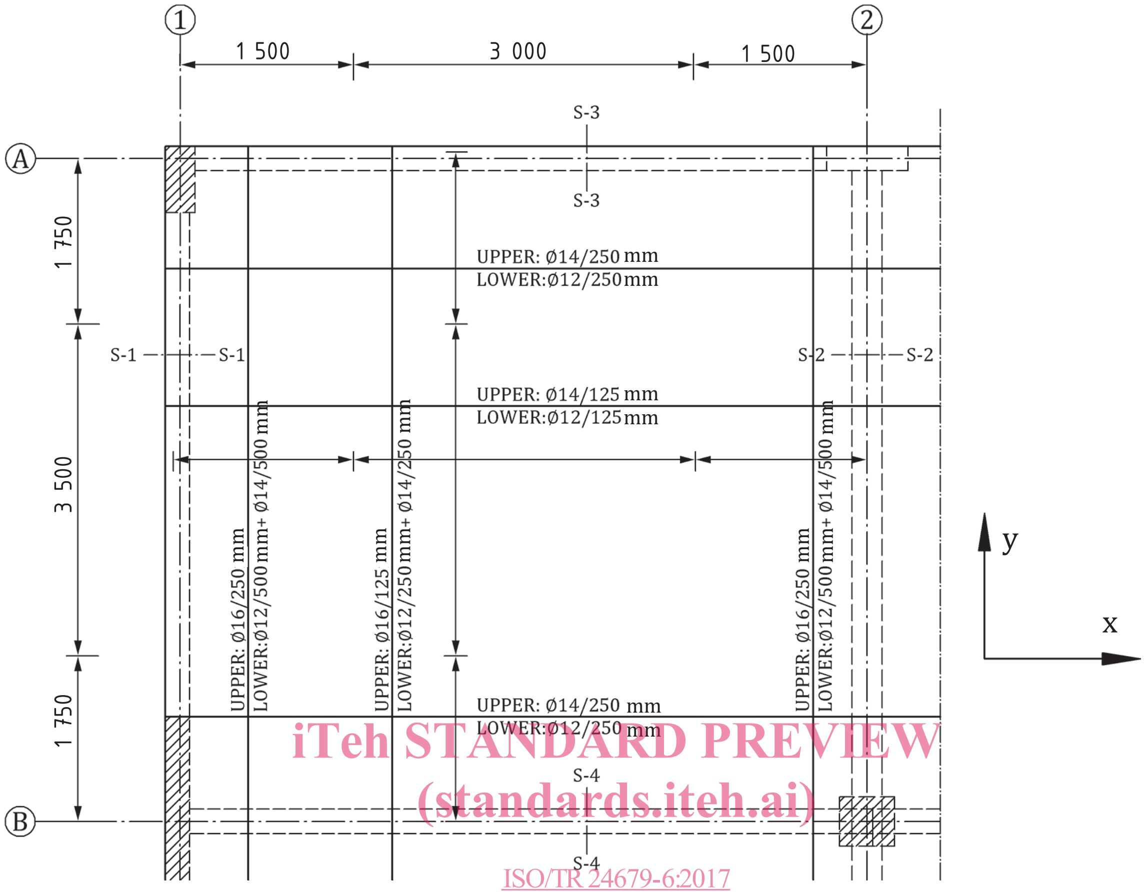


Figure 4 — Reinforcement distribution in the slab

Table 3 — Slab reinforcement and axis distance

X direction slab	**Middle strip (3 m)**	**Axis distance**
Upper	Ø14/125 mm	37 mm
Lower	Ø12/125 mm	36 mm
Y direction slab	**Middle strip (3 m)**	**Axis distance**
Upper	Ø16/125 mm	52 mm
Lower	Ø12/250 mm Ø14/250 mm	49 mm

NOTE Stress-strain relationships of concrete and steel are given in Reference [4] As such, an explicit model for transient strain was applied. Tensile strength of concrete has been considered in the advanced modelling.

5.1.2 Fuel loads

The building is an office space with cellulosic (i.e. majority of fuel load), plastic, and miscellaneous type fuel, which is assumed to be uniformly distributed throughout the compartment. The fuel load varies greatly depending on the building types and available guidance provides typical ranges. Moreover, the fire load density from construction elements, linings and finishing should be calculated and added to the tabulated fire load densities[5][6].

There is no clear information on the use of this building. As such, potential fire scenarios with possible fire load densities for sparsely furnished (i.e. office machine sales) to densely loaded (i.e. business office, library) ranging from 350 MJ/m^2 to 1 350 MJ/m^2[6] were examined to define the acceptable fuel load density in this building.

5.1.3 Mechanical actions

Dead and live loads are presented in Table 4.

Table 4 — Loads

	Load name	Value of load
Dead load	Self-weight	25 kN/m^3
	Finishing, pavement, embedded services, partition	1,5 kN/m^2
Live/variable load	Office	4 kN/m^2

The mechanical action in fire situation was determined in accordance with Reference [7]. Consequently, the load combination given in Formula (1) was used:

$$G+\Psi_{2,i}Q_i \tag{1}$$

where

G is the sum of all the permanents loads;

Q is the dominant live load;

Ψ_2 = 0,6.

The loads which were used for calculation with an advanced structural model (finite element model in 3D that takes account of the nonlinearities of materials and geometric) are summarized in Table 5.

NOTE No wind action was considered because Ψ_2 = 0 for wind. The charge from upper storeys will be added in detailed structural modelling.

Table 5 — Used loads in detailed structural analysis

				Unit
Slab	Dead load (G)	0,18 × 25 +1,5	6	$\frac{kN}{m^2}$
	Live load (Q)	4	4	
	Total load	**G + 0,6Q**	**8,4**	
Exterior beams	Dead load (G)	0,25 × 0,40 × 25	2,5	$\frac{kN}{m}$
	Dead load façade (G_F)	8	8	
	Total load	**$G+G_F$**	**10,5**	
Interior beams	Dead load (G)	0,25 × 0,40 × 25	2,5	$\frac{kN}{m}$
	Total load	**G**	**2,5**	

For the detailed structural analysis, only the first floor was modelled in a structural modelling software. This assumption was discussed in 5.6.2. The action of the floors above was considered in the detailed structural analysis, by applying vertical forces acting at the top of the first floor columns.

The vertical forces representing the floors above are presented in the Figure 5.

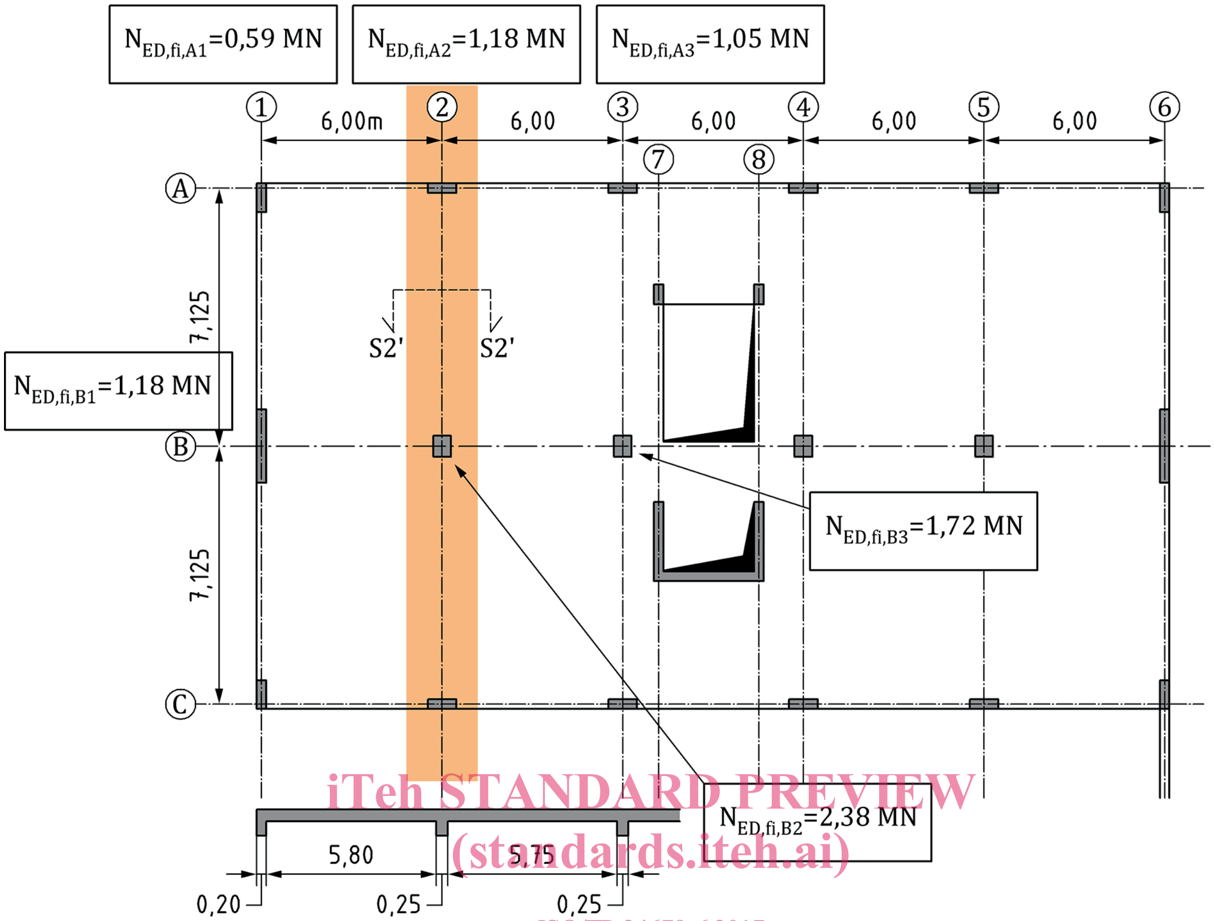


Figure 5 — Vertical forces representing the floors above

5.2 STEP 2: Identifying objectives, functional requirements, and performance criteria for fire safety of structure

The objectives of structural fire safety in this study are:

— life safety of occupants, fire-fighters and others in the vicinity of building in terms of structural behaviour of building in the event of fire;

— conservation of property and continuity of operation.

The functional requirement consists of structural stability to prevent failure of any structural element during the entire duration of fire, including the cooling phase. It results to prevent the fire from spreading to other storeys due to failure of floor and ceiling within the compartment.

A set of performance criteria were selected to fulfil the above objectives and functional requirements:

— the maximum temperature in the tension reinforcement of the concrete structure: It allowed to rapidly compare the relative impact of large numbers of potential design fire scenarios and to identify the critical fire scenario for detailed structural analysis[8].

The following performance criteria in terms of structural stability were assumed for the detailed structural analysis:

— no overall failure of the building, e.g. due to the loss of stability of columns, shear failure, rotational capacity;

— maximum deflection of all slabs does not exceed 1/20 of their spans;

— rotational capacity does not exceed 250 mrad[9].

The critical temperature of tension reinforcement at elevated temperature was calculated assuming a reduction of 0,6 for the design load level in the relevant the fire situation[4] and a partial safety factor of 1,15 for reinforcing steel according with Reference [10]. As such, failure in selected structural member occurred when the characteristic strength of reinforcement steel reached 0,52 of its original capacity. In accordance with 4.2[4], for reinforcing steel (hot rolled) in concrete and for strain larger than 2 % (which is the case for slabs and beams with no high reinforcement ratio), the critical temperature is 583 °C. For the purpose of this document, the value was conservatively taken as 560 °C.

Figure 6 shows a summary of applied methodology in this document.

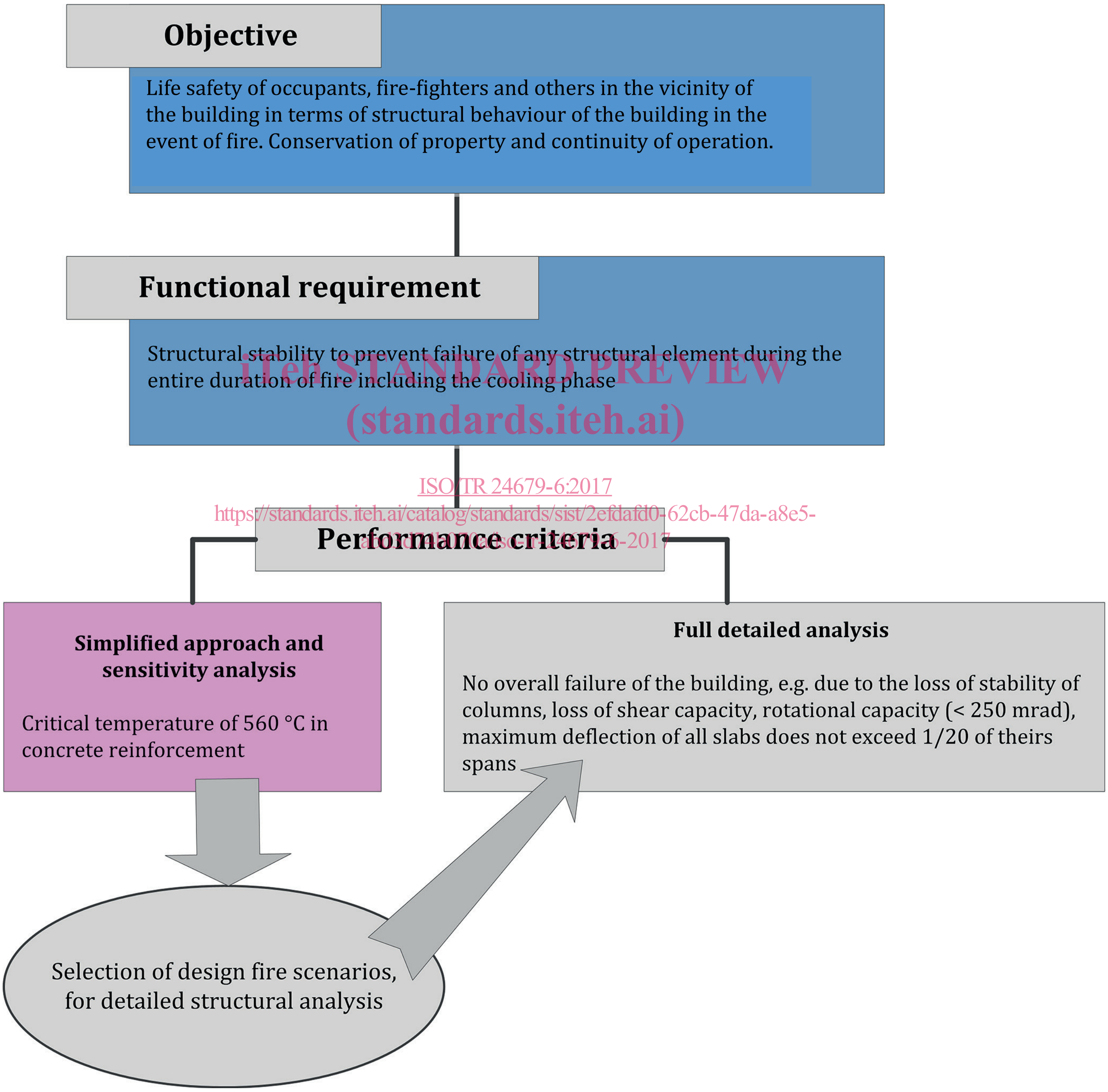


Figure 6 — Schematic overview of the applied methodology

