TECHNICAL REPORT

ISO/TR 24679-3

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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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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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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.

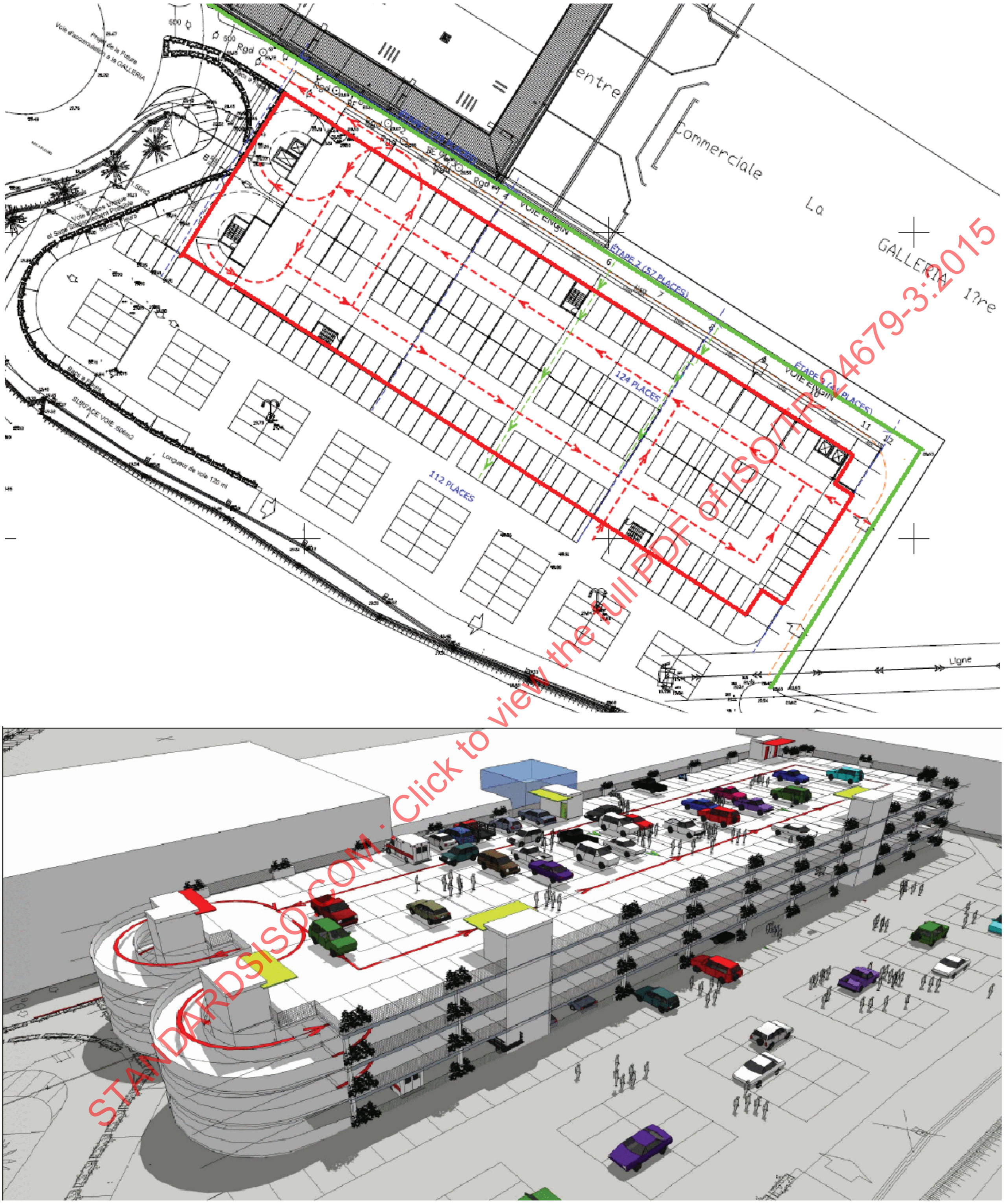


Figure 1 — View of the built environment of investigated open car park: plan view (top) and perspective view (bottom)

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.

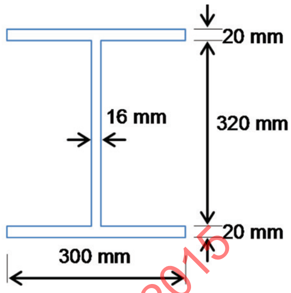
As the heating of unprotected steel members will be very important (more than 700 °C), the fire resistance of the floor can no longer be ensured with classical structural resistance approach without any fire protection. The only way to get an unprotected floor structure is to have the floor system behaving 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.

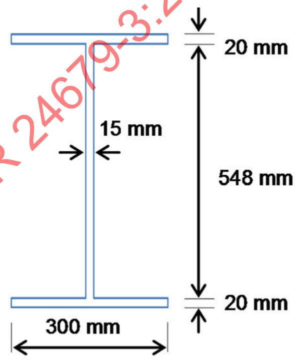
Another strategy adopted in this fire design is to use steel grade of S355 which will provide higher fire resistance than other steel grades below.

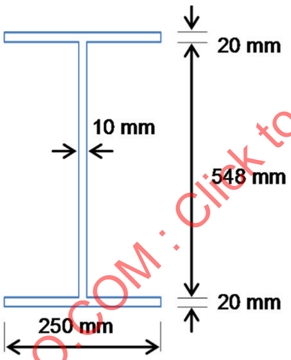
The steel columns need also to be dealt with in a particular way. It is decided to combine two solutions; on the one hand, the steel section of columns has to be partially concrete encased and on the other hand, their applied load in fire situation is limited to 0,35 of their room temperature ultimate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

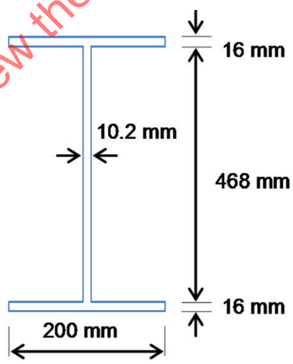
Table 2 — Summary of structural members

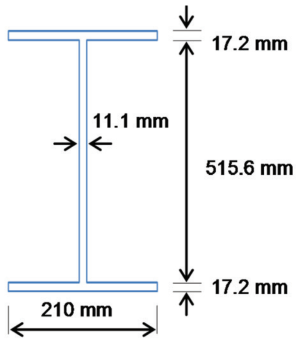
Floor levels	Ground floor	Intermediary floor	Roof
Column **(four sides exposed)**	PRS 320 × 16/300 × 20 (A/V = 110 m^{-1})		(see section drawing below)
Primary beam **(three sides exposed)**	PRS 548 × 15/300 × 20 (A/V = 116 m^{-1})		(see section drawing below)
Secondary beam **(three sides exposed)**	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		

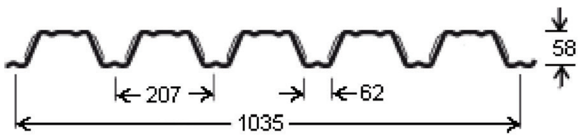












5.5 Step 4: Design fire scenarios and design fires

5.5.1 Design fire scenarios

In fire resistance assessment, three basic families of fire scenarios are considered,[2] derived from a statistic survey of real fires in open car parks with respect to the number of cars that get involved within a fire.[3] As shown in Figure 2, these families of fire scenarios are as follows:

— Burning of seven cars including a utility vehicle in the same parking line, with the fire spreading after ignition progressively from the central vehicle to three vehicles at each side according to a propagation time of 12 min from one vehicle to another.

— Burning of four cars including a utility vehicle situated in two different parking lines, with the fire spreading after ignition progressively from the first vehicle to other three vehicles according to a propagation time of 12 min from one vehicle to another.

— Burning of one utility vehicle located at any position of the floor.

The above fire scenarios are more or less the standard fire scenarios imposed by French authorities though according to above mentioned statistics of real fires in open car parks, the highest number of cars involved in a fire does not exceed three. It has to be noted also that the cars except the utility vehicle to be considered should be all in class 3.

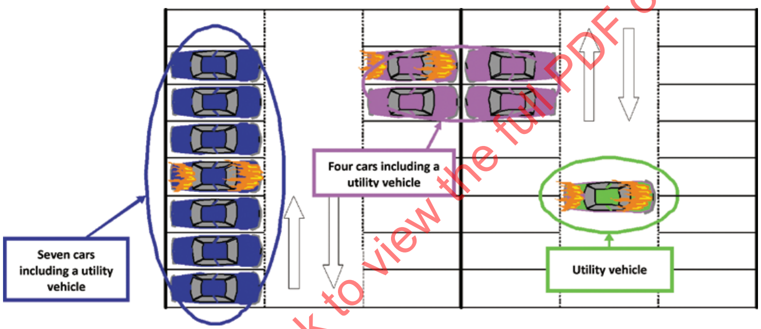


Figure 2 — Basic scenarios of car fire

The above three basic families of fire scenarios have to be applied in combination with structure arrangement in order to derive the most severe scenarios in terms of fire resistance objective of considered open car park. Therefore, for floor structure at first level of the open car park (columns and floor structure above), the following fire scenarios are taken into account (see Figure 3):

— Fire scenario S1.1: seven cars including a utility vehicle involved in fire, which are located at the corner part of the floor where the structural continuity is present only at two sides.

— Fire scenario S1.2: four cars including a utility vehicle involved in fire, which are located under mid-span of a primary beam leading to most severe heating of primary beams.

— Fire scenario S1.3: four cars including a utility vehicle involved in fire, which are located around a column of ground level leading to most severe heating of the column (surrounded by fire flames).

— Fire scenario S1.4: one utility vehicle located at the edge part of the composite floor and under mid-span of a secondary beam.

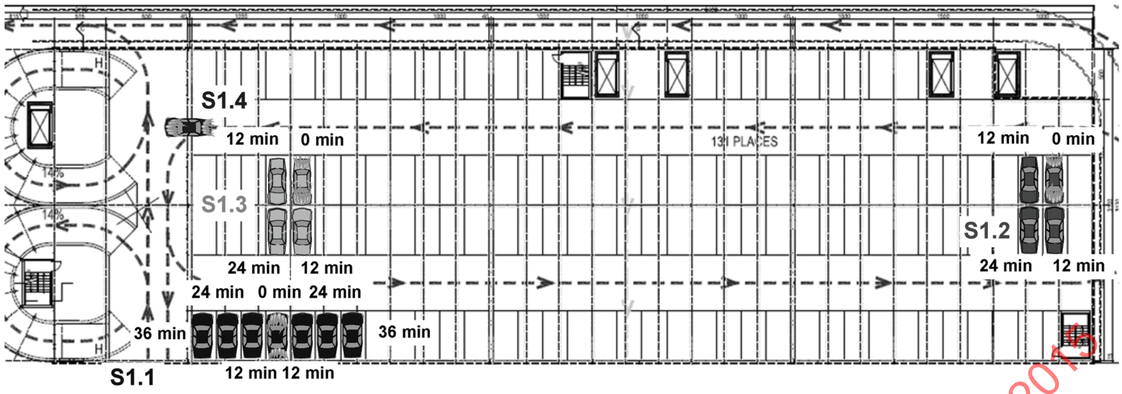


Figure 3 — Possible fire scenarios applied to ground floor level

The possible fire scenarios on intermediary floor levels of the modelled structure are as follows (see Figure 4):

— Fire scenario S2.1: seven cars including a utility vehicle involved in fire, which are located at the corner part of the floor where the structural continuity is present only at two sides.

— Fire scenario S2.2: seven cars including a utility vehicle involved in fire, which are located at the edge part of the floor and under a secondary beam.

— Fire scenario S2.3: four cars including a utility vehicle involved in fire, which are located under mid-span of a primary beam leading to most severe heating of primary beams.

— Fire scenario S2.4: four cars including a utility vehicle involved in fire, which are located around a column of concerned floor leading to most severe heating of the column (surrounded by fire flames).

— Fire scenario S2.5: one utility vehicle located at the edge part of the composite floor and under mid-span of a secondary beam.

It can be observed that most fire scenarios at intermediary levels are identical to those at ground level. The reason to consider them independently is that the storey height is different between ground level and the levels above.

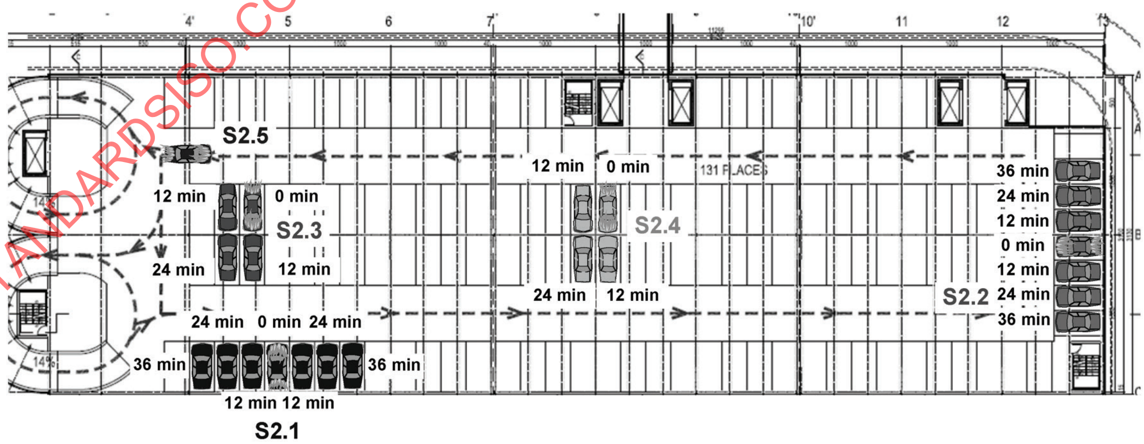


Figure 4 — Possible fire scenarios applied to intermediary floor levels

In the present report, the calculation results for ground floor and intermediary floor levels are given for two representative fire scenarios, respectively:

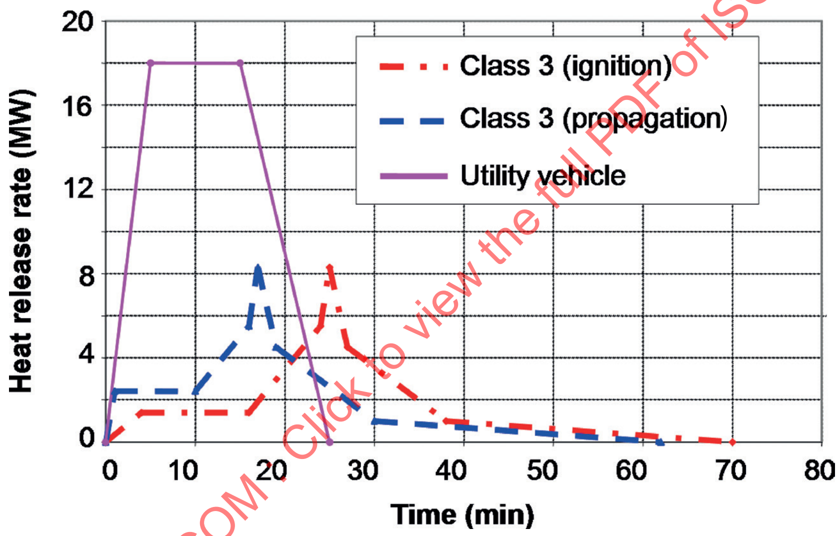
— taking into account the buckling length of steel columns for ground level which is higher than intermediary floor levels, resulting therefore in most critical cases under fire scenario S1.3 with four vehicles around a column at ground floor;

— under fire scenario S2.2 involving seven vehicles perpendicular to secondary beams at edge part of open car park leading to the most critical situation to structural behaviour of composite floor because the steel beams are much more heated in this case.

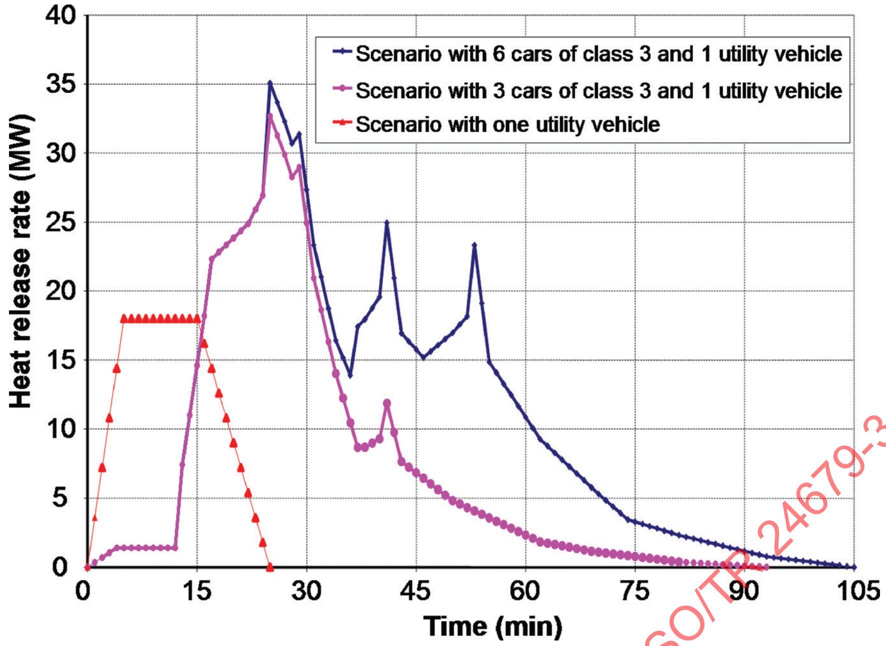
5.5.2 Design fires (thermal actions)

As mentioned in the previous paragraph, the vehicles to be considered for design fire scenarios should be systematically in class 3 in combination with one utility vehicle filled of combustible materials. The heat release rates of class 3 cars initiating the fire and subject to fire spread are compared with that of utility vehicle, as shown in Figure 5.

In addition, the total heat release rate obtained from different fire scenarios are also given in Figure 5 for information.



a) Comparison of heat release rate of different vehicles



b) Total heat release rate under different fire scenarios

Figure 5 — Heat release rates

It has to be noted that the heat release rate of a utility vehicle is significantly more important (see Figure 5) than class 3 car.

Thermal actions resulted from fire flames to the structural members near burning cars in fire safety design of the structure are calculated according to simple analytical formulae given in EN 1991-1-2 (Hasemi's method). In addition, as for thermal effect of the hot smoke layer on structural members far from fire, a two-zone model is used.[4] The combination of both above models allows the determination of the temperature field near and far away from the fire. In consequence, the thermal actions for all the structural members are obtained by taking the most important value predicted by above two models, as shown in Figure 6.

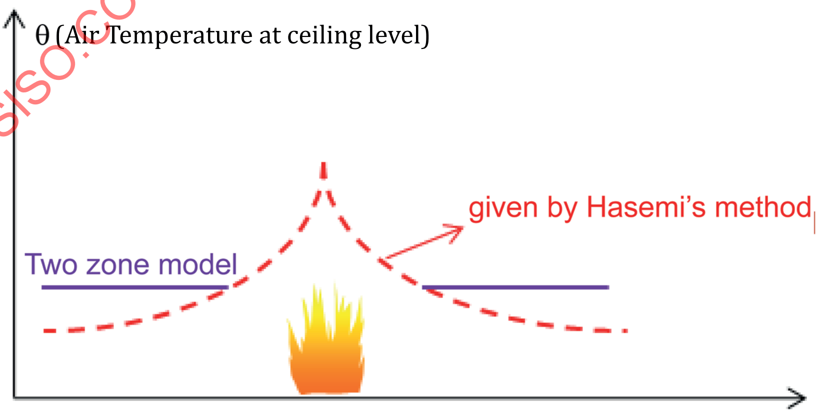


Figure 6 — Combination of two-zone model with localized fire model

This procedure has been applied to predict the heating of structural members. For example, the incident heat fluxes received by primary and secondary beams above the utility vehicle and the hot gas layer temperature versus time under fire scenario S2.2, is plotted on Figure 7. The evolution of the heat fluxes received by internal secondary beam above vehicles in fire as a function of both time and space is plotted on Figure 8. As for column, the evolution of the heat fluxes received by column surrounded by four vehicles in fire at ground floor, as a function of time and for different heights of column, is also plotted on Figure 9.

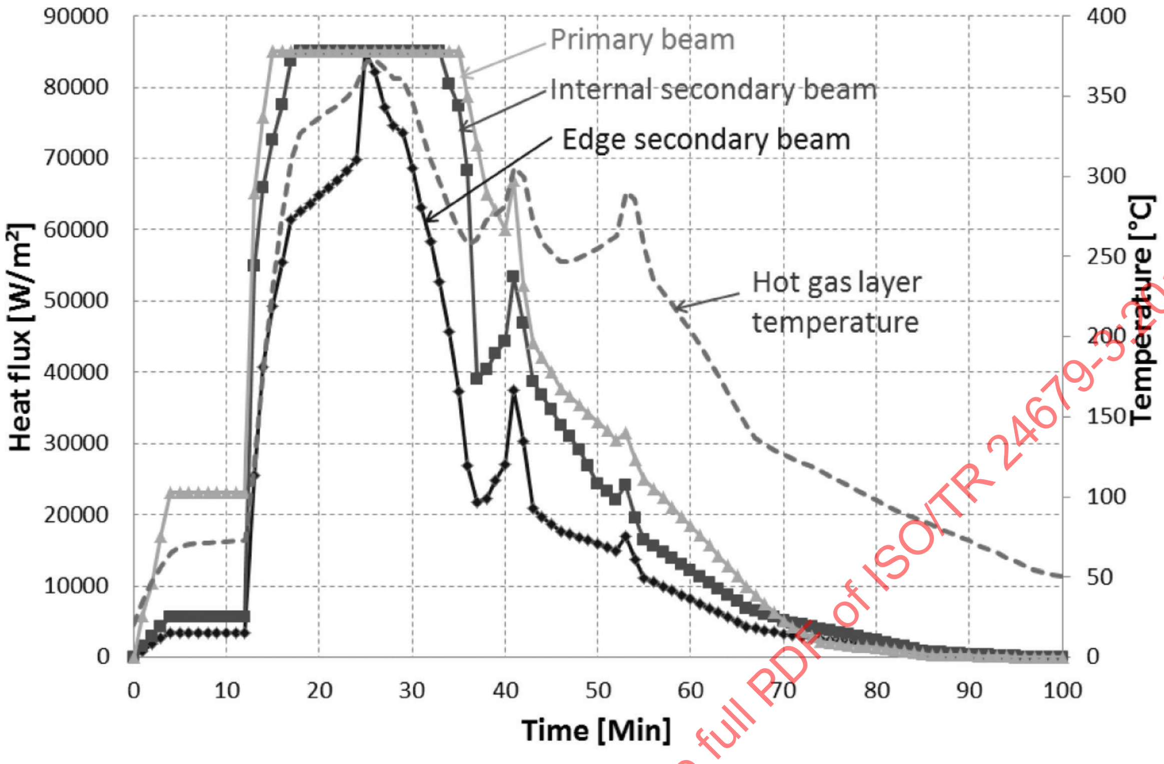


Figure 7 — Time evolution of the heat flux received by primary and secondary beams above vehicles in fire and of the hot gas layer temperature under fire scenario S2.2

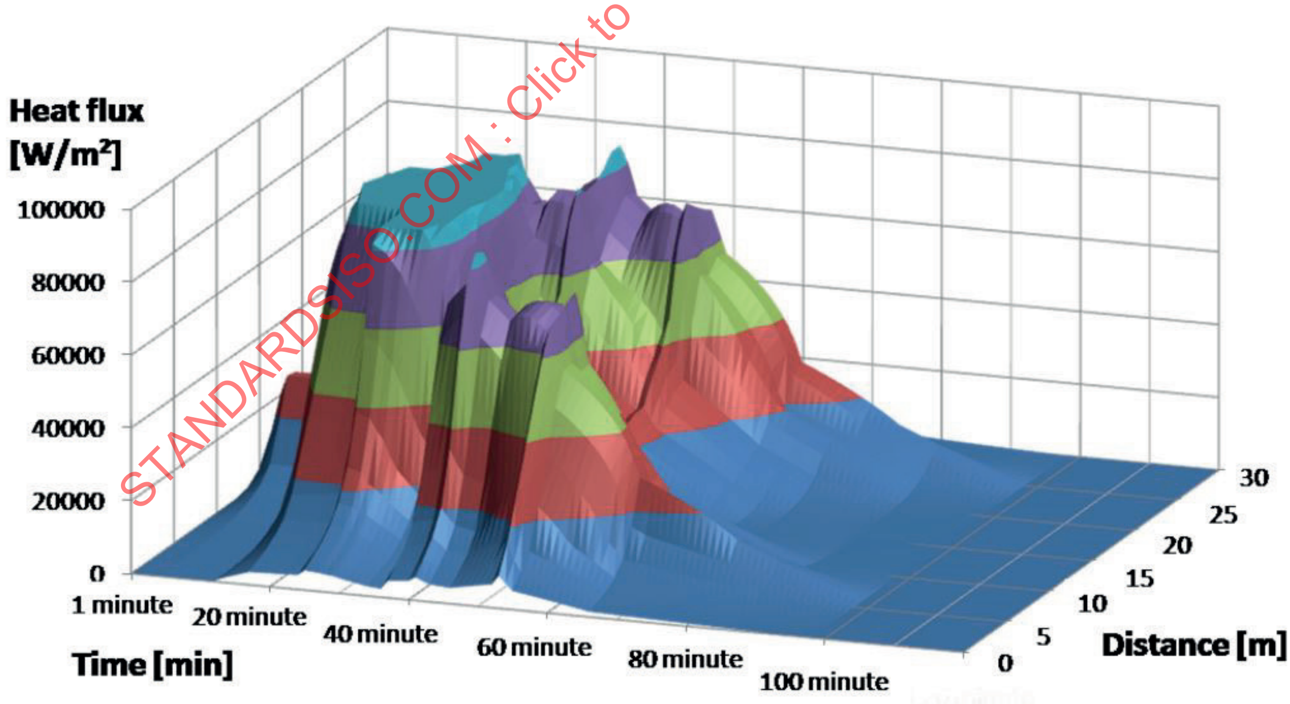


Figure 8 — Time evolution of the heat flux received by internal secondary beam above vehicles in fire, under fire scenario S2.2

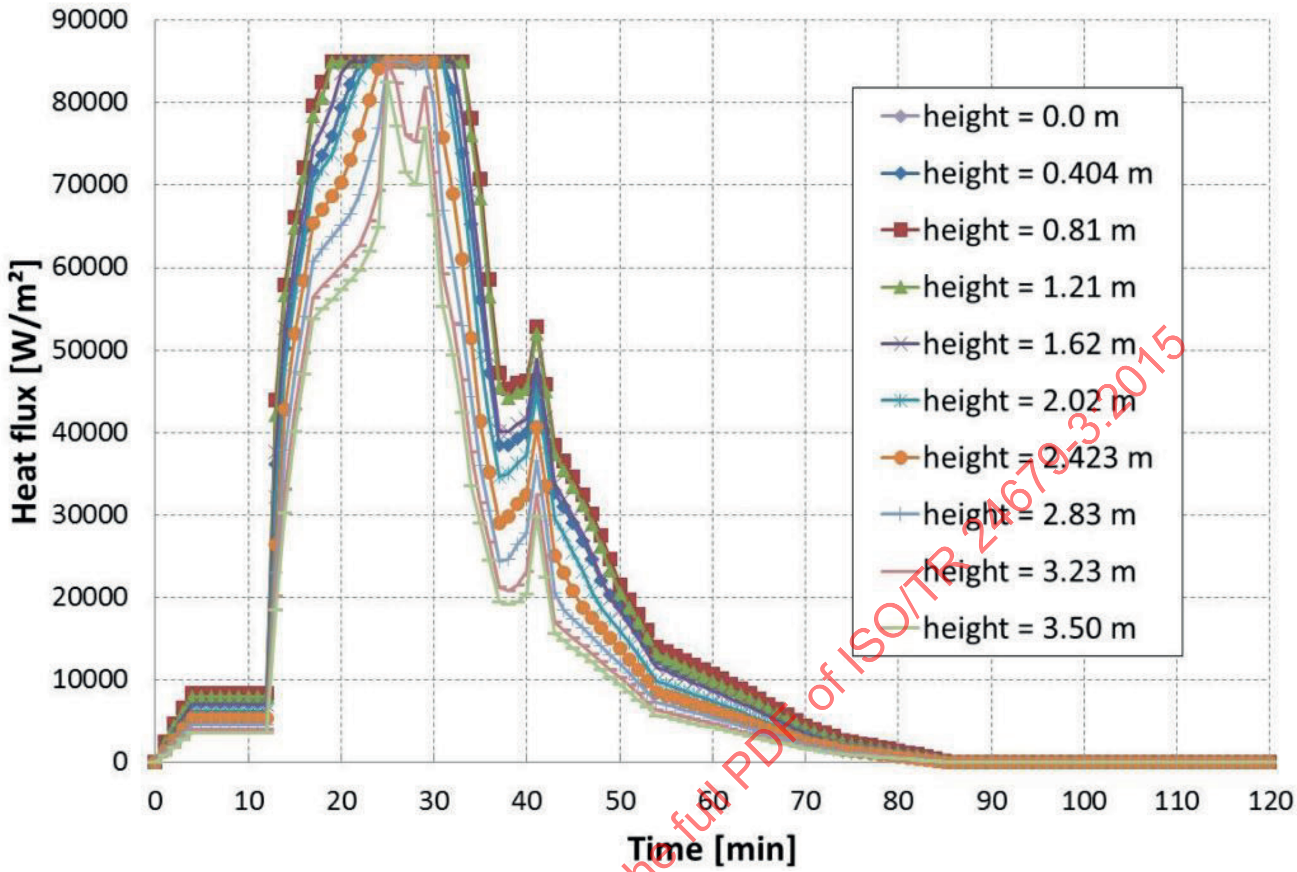
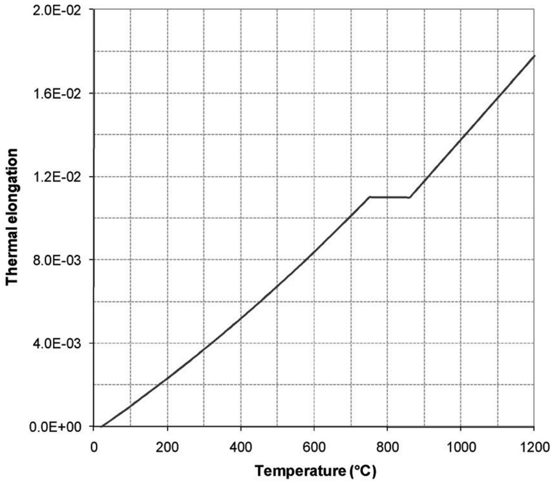


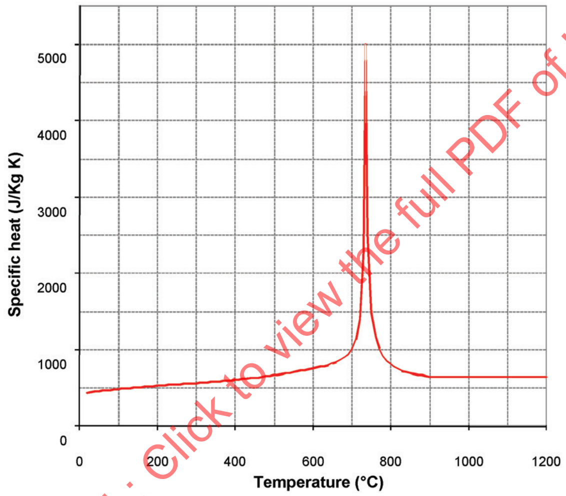
Figure 9 — Time evolution of the heat flux received by column surrounded by 4 vehicles, under fire scenario S1.3

5.6 Step 5: Thermal response of the structure

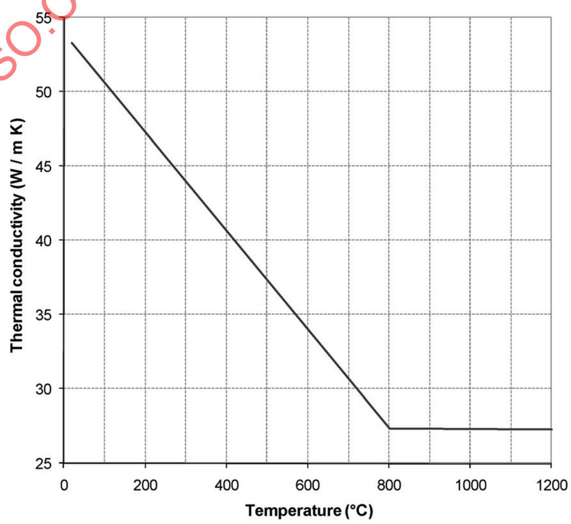
The above thermal actions are applied to different structural members to calculate their heating as a function of time. The heat transfer analysis of all structural members subjected to thermal actions is conducted with help of 2D models using the typical cross section of each structural member, under the computer package ANSYS. The thermal properties of the steel are those given in EN 1994-1-2 and represented in Figure 10. Moreover, the densities of steel and of concrete are respectively 7 850 kg/m^3 and 2 300 kg/m^3, and remain constant with temperature. As far as thermal properties of the concrete are concerned, the thermal elongation, specific heat and thermal conductivity are taken for a normal concrete with 3 % moisture content, as shown in Figure 11.



a) Thermal expansion

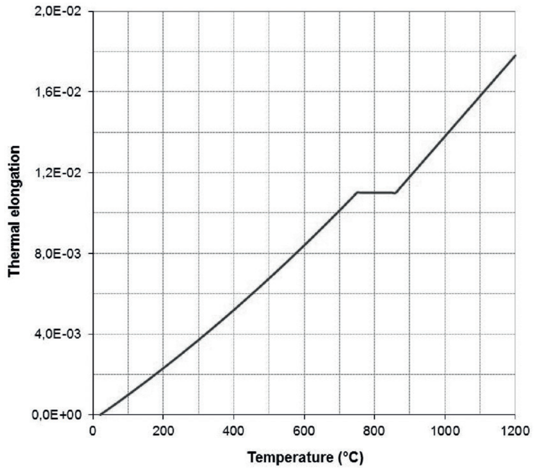


b) Specific heat: peak value at 735°C because of phase change of steel

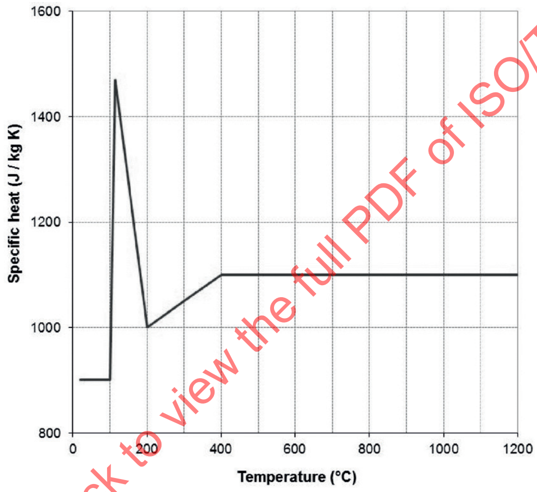


c) Thermal conductivity

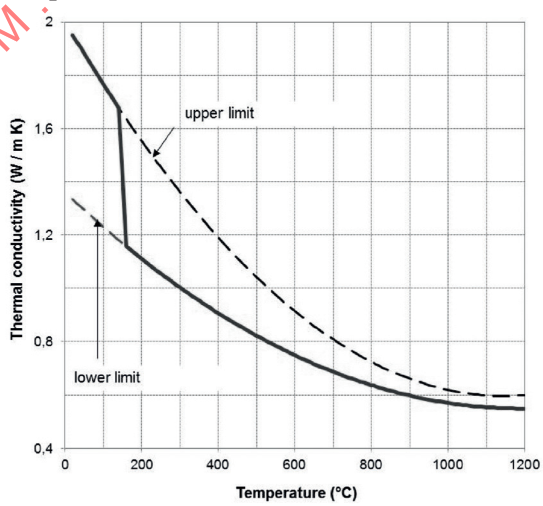
Figure 10 — Thermal properties of steel



a) Thermal expansion



b) Specific heat: peak value at 125°C because of water evaporation



c) Thermal conductivity

Figure 11 — Thermal properties of concrete

In thermal analysis, for the exposed face to the car fire, the coefficient of heat transfer by convection is taken as 25 W/m^{2}K, while on the unexposed side of the slab, this value is reduced to 4 W/m^{2}K. The emissivity factor of elements is taken as 0,5 in accordance with the recommended value in the fire safety engineering procedure adopted in France for open car parks.

The maximum heating of four principal structural members of the modelled structure for fire scenario S2.2 on an intermediary floor level is given hereafter in Figure 12. Only one half of the composite slab was modelled to reduce the size of the model. Each structural member was considered to be thermally independent and its connection with other members was neglected.

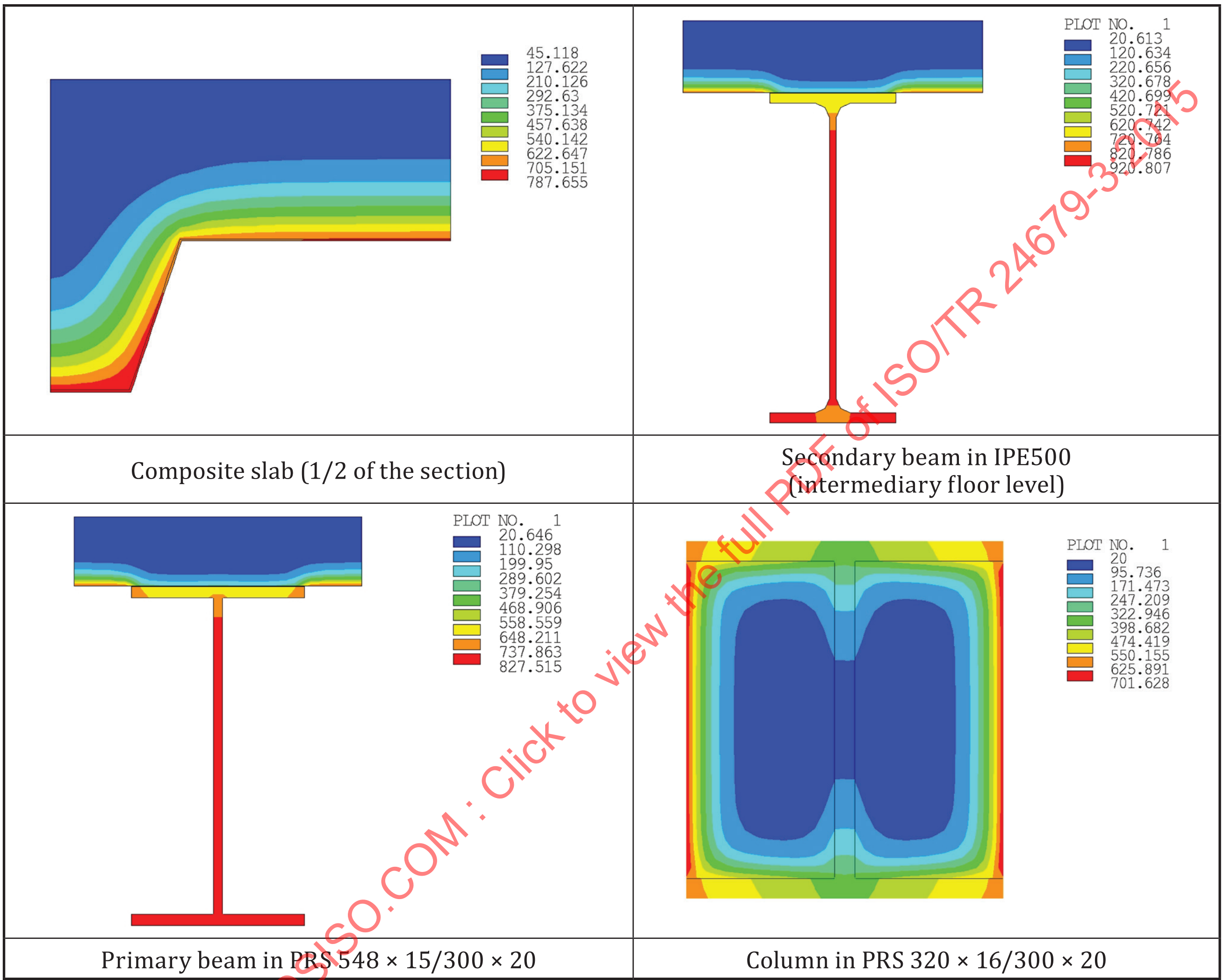


Figure 12 — Maximum heating of structural members

The secondary steel beam above utility vehicle in fire under fire scenario S2.2 can be locally heated up to more than 900 °C. However, the edge column which is not engulfed in fire near the central vehicle is much less heated due to the protection from filled concrete. Moreover, the primary steel beam connected to this column can be heated up to about 800 °C. The maximum temperatures versus time of above structural members are shown on Figure 13.

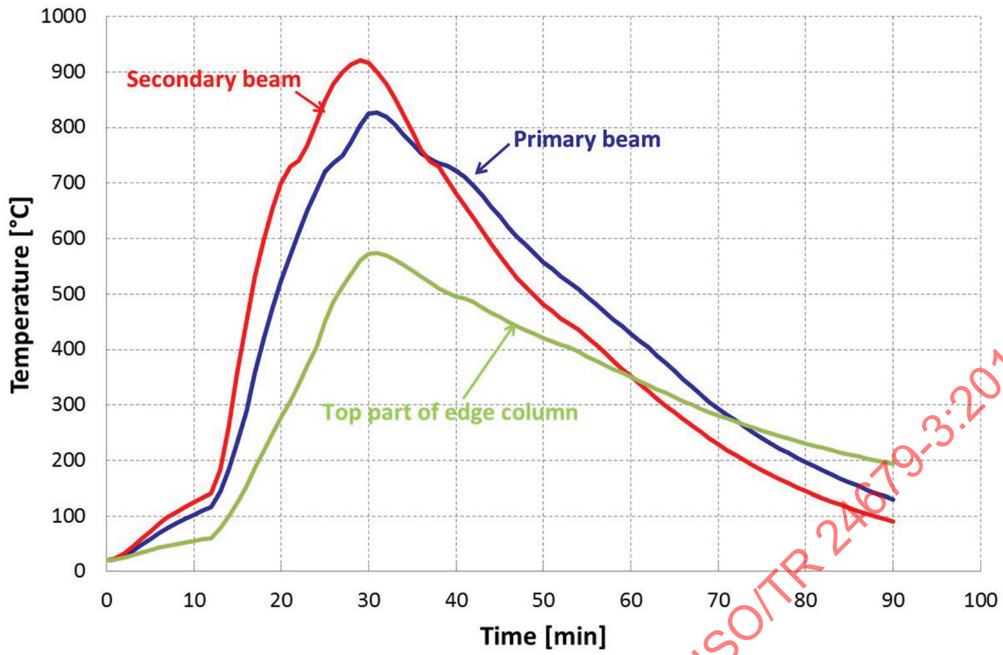


Figure 13 — Time evolution of the maximum temperature of steel members over vehicles in fire

5.7 Step 6: Mechanical response of the structure

As mentioned earlier in Clause 1, the global structural analysis approach with help of advanced calculation models is adopted in order to investigate the load redistribution of the floor system. A 3D Finite Element model is developed under a specific computer code[5], and was already validated against the fire tests. As shown in Figure 14, the following three types of finite elements are used in this modelling as follows:

— 3D nonlinear line element – BEAM24;

— 3D nonlinear multi-layer shell element – SHELL91;

— 3D linear line element – PIPE16.

The mechanical material properties of both steel and concrete at elevated temperatures used in this modelling are fully in accordance with those recommended by Reference [5].

One floor level is taken into account in this modelling for floor and one or two levels of columns are considered according to investigated floor level. Because of the computation cost with such type of models, only a reduced part of the floor area is dealt with in the model considering that the car park structure is subjected to the localized heating from car fire. The influence of the remained part of the structure is represented by continuity conditions of the composite slab on its edge. Moreover, other floors below or above the modelled floor have been also neglected and replaced by appropriate boundary conditions. For instance, the modelled structures for fire scenarios S1.3 at ground floor and S2.2 at an intermediary floor level are given in Figure 15.

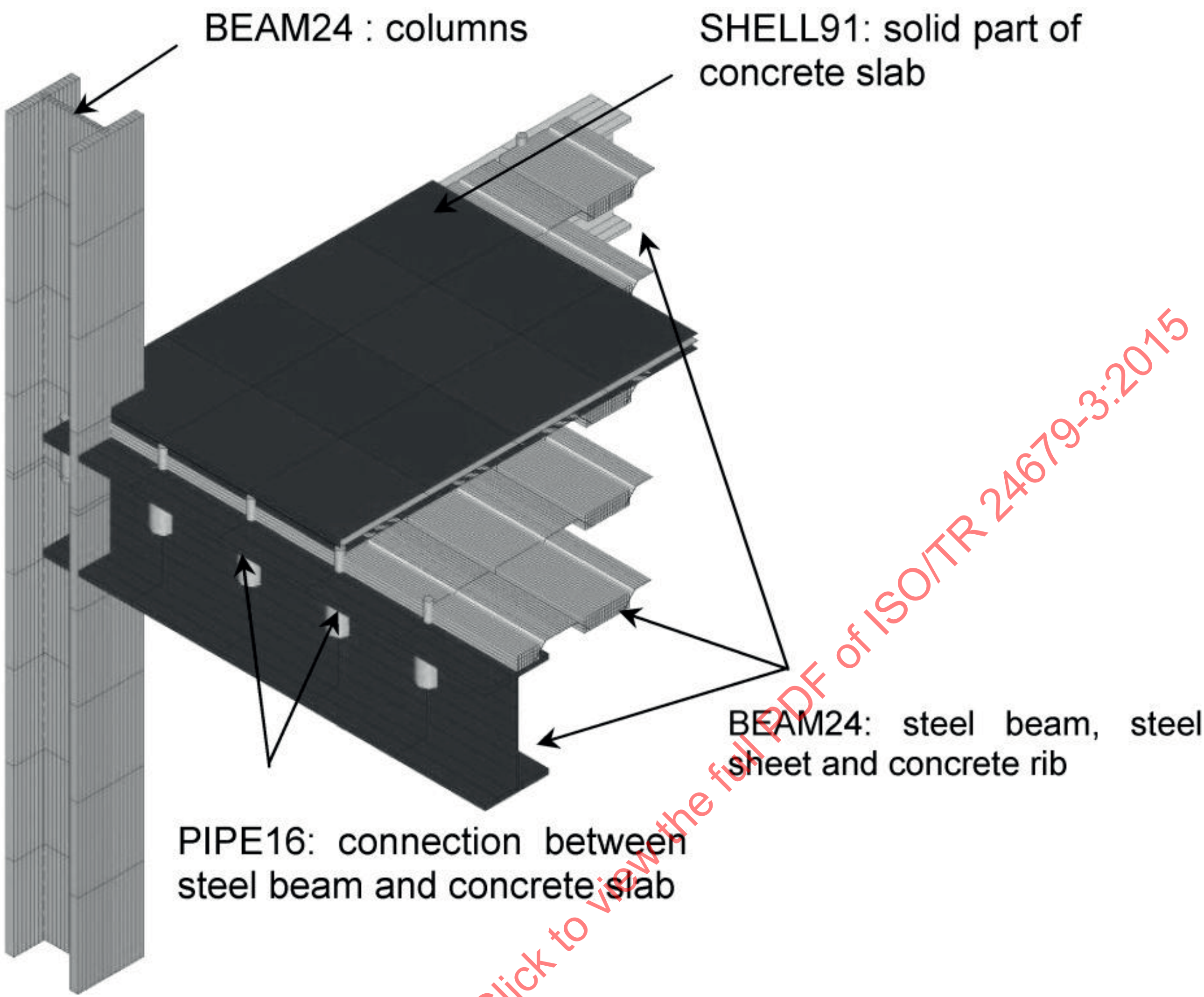


Figure 14 — Detail of numerical modelling for structural analysis of open car parks

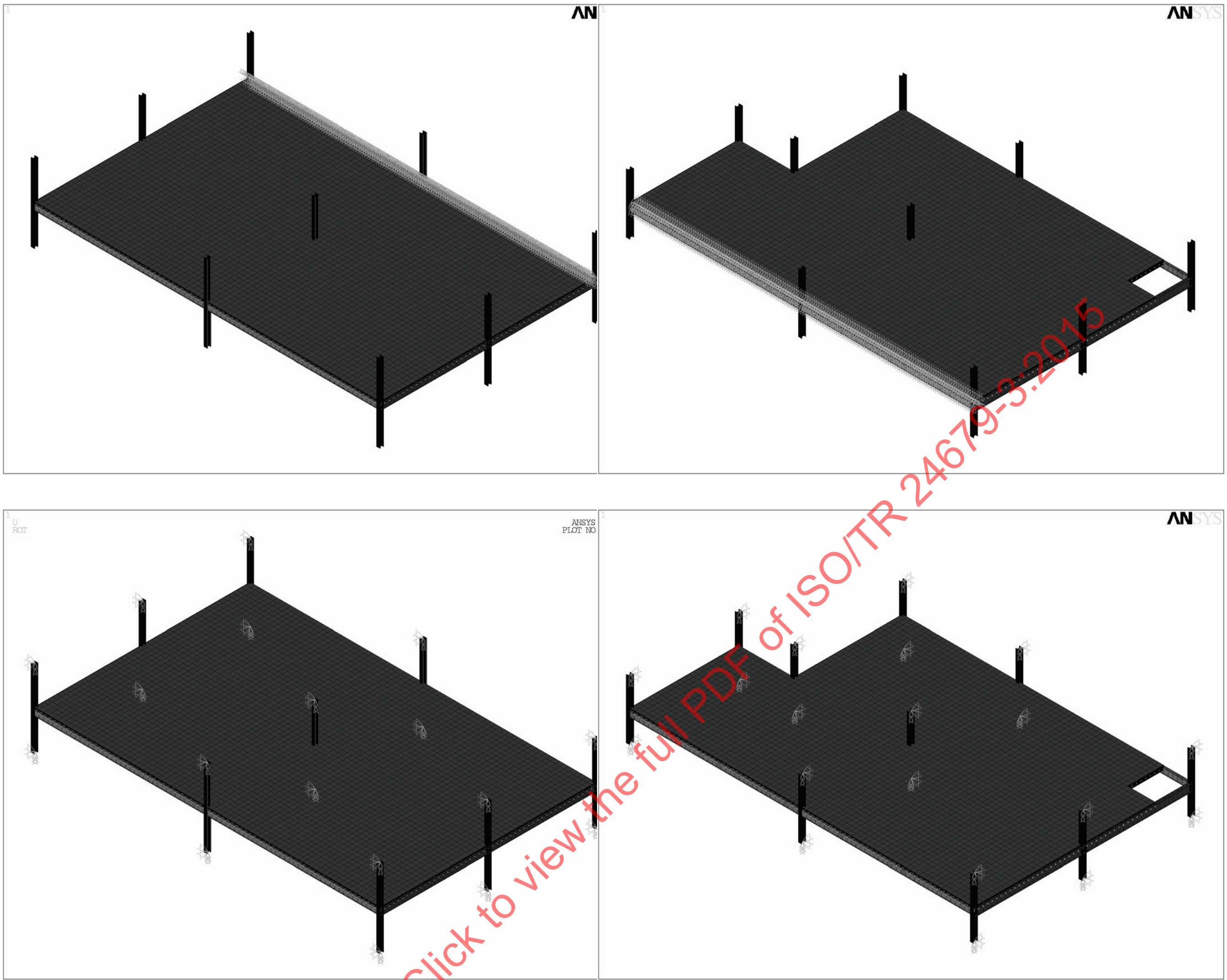


Figure 15 — Modelled structure for fire scenarios (left) S1.3 on ground floor and (right) S2.2 on an intermediary floor level

Some representative results are given hereafter. The numerical results of intermediary floor are given in Figure 16 in terms of maximum deflection of the floor and mechanical strain in reinforcing steel mesh obtained at 55 minutes of fire, respectively.

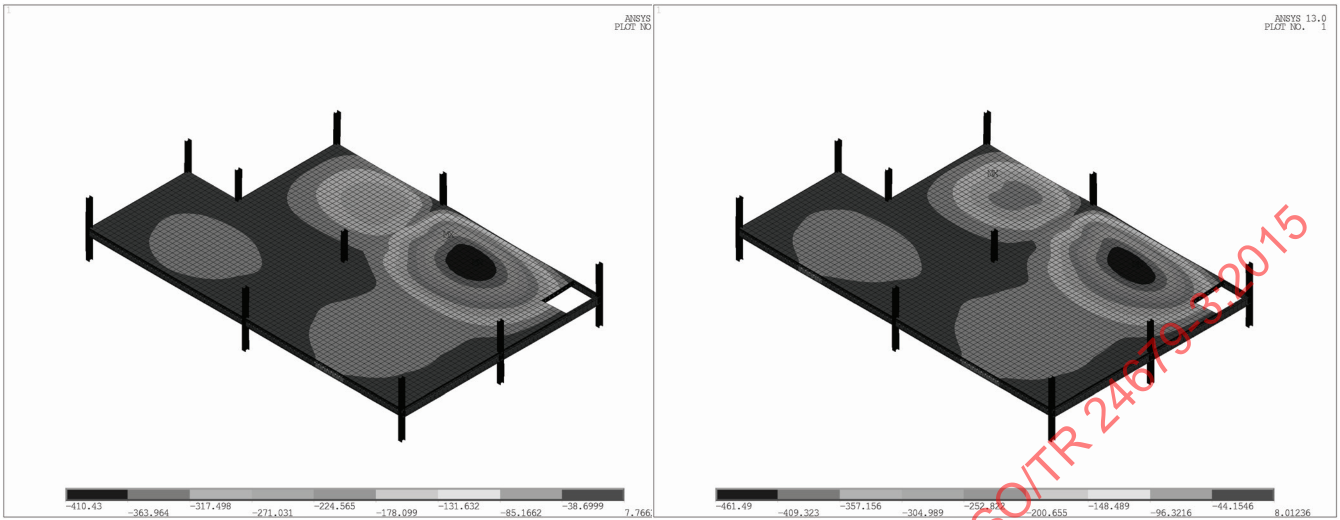


Figure 16 — Simulated deformed floor for intermediary floor under the fire scenario involving seven cars (S2.2) at 30 minutes (left) and 55 minutes (right) of fire

As explained already, since all beams are left unprotected, the floor undergoes large deflection. The membrane action develops in the composite slab of the floor that leads to important tension in reinforcing steel mesh. The maximum elongation of reinforcing steel grid is 2,2 % under fire scenario S2.2 (see Figure 17).

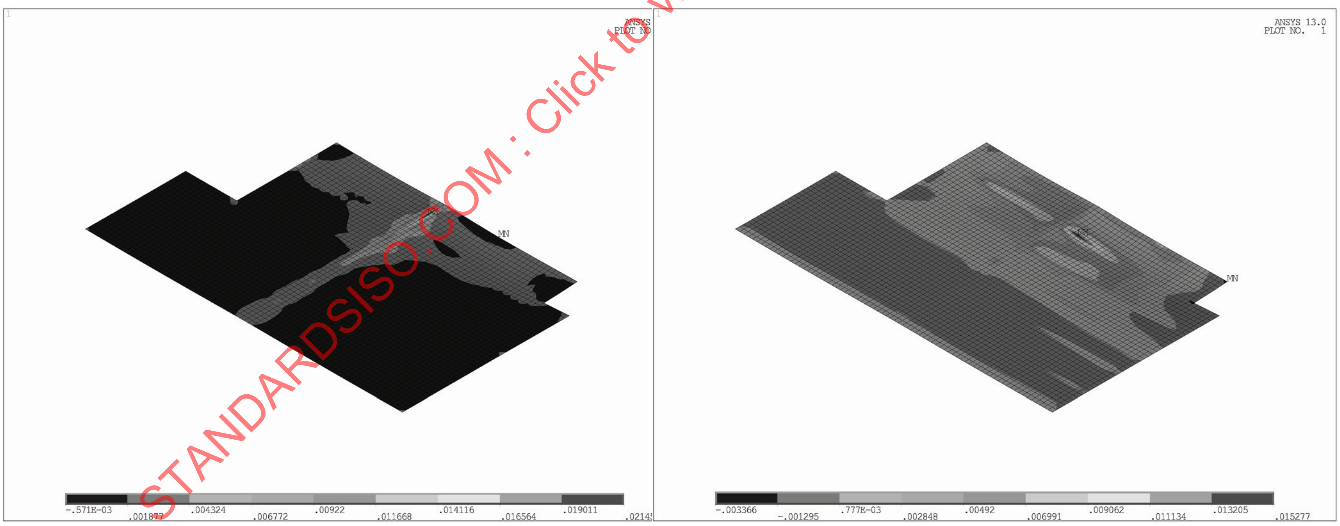


Figure 17 — Mechanical strain of reinforcing steel at 55 minutes of fire; ⊥ slab span (left) // slab span (right)

Figure 18 shows the time evolution of the maximum vertical displacement of most heated steel beams as a consequence of the localized fire development. With respect to the secondary beams, the maximum vertical deflection increases from 40 mm at 12 minutes of fire exposure to 457 mm after 55 minutes of fire in the internal secondary beam above utility vehicle, and decreases then to 343 mm at 90 minutes of fire due to the fact that the fire intensity has passed its maximum level and entered the cooling phase.

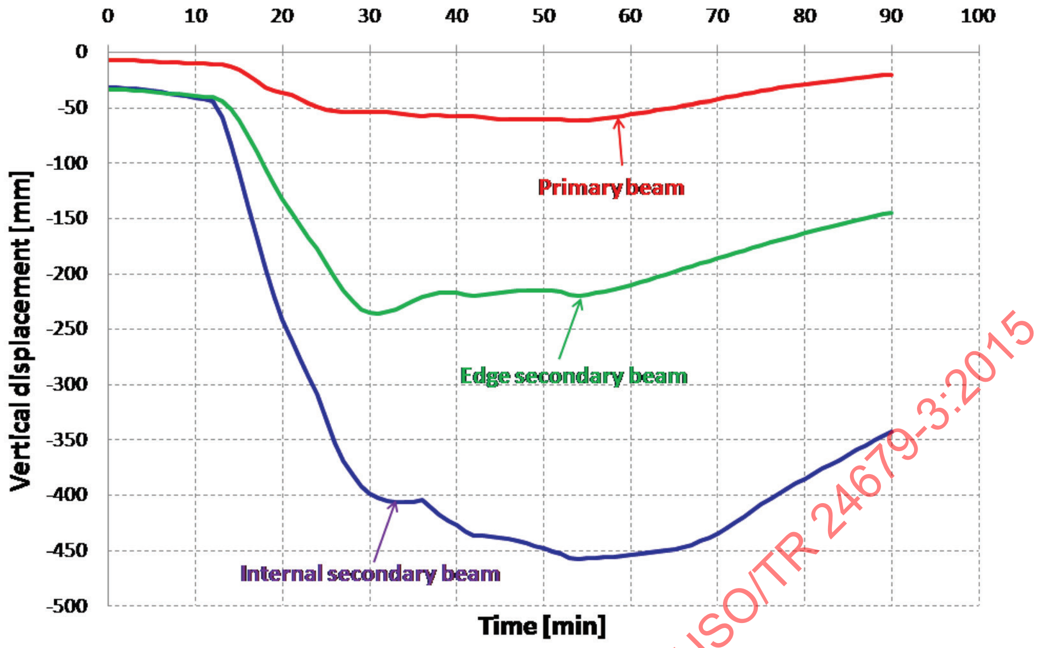


Figure 18 — Deflection of steel beams versus time

Other typical results are presented in Figure 19 for fire scenario S1.3 involving four vehicles around an internal column at ground floor. It can be found in this case that the membrane effects of the floor under localized heating from car fires cause also important tension in reinforcing steel mesh of concrete slab near its supporting steel beams with the maximum value of 2,0 %.

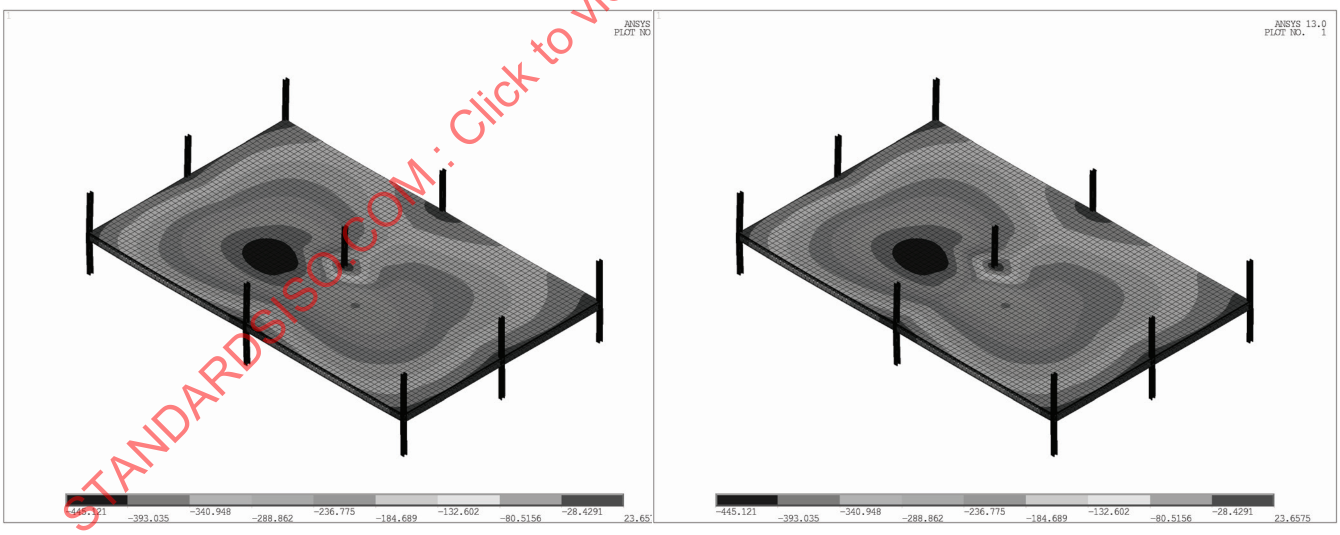


Figure 19 — Simulated deformed structure for ground floor under the fire scenario involving four cars around an internal column at 31 minutes of fire (left) and mechanical strain in the reinforcing steel mesh of concrete slab (right)

The numerical results of the structure related to maximum deflection of the floors obtained during all fire durations and the maximum mechanical tensile strain in reinforcing steel mesh are summarized in Table 3 given below.

Table 3 — Deflection of the floor and elongation of reinforcing steel

Levels	Fire scenario	Max. displacement in fire (mm)						Max. strain in the reinforcement	
		Time (s)	Total		Primary beam		Secondary beam	⊥ slab span	// slab span
Ground floor	S1.3	1 860	378	262	L/38	211	L/74	2,2 %	2,97 %
Intermediary floor	S2.2	3 240	461	47	L/212	430	L/36	2,5 %	1,7 %
Roof		3 240	457	84	L/119	407	L/38	2,5 %	2,0 %

A detailed presentation of the above results is shown in Annex A.

5.8 Step 7: Assessment against the fire safety objectives

As mentioned in paragraph 5.3, two criteria need to be checked.

With respect to the criterion relative to maximum deflection, it can be found that the maximum relative deflection of all beams is less than L/20 even if the absolute deflection is quite important.

Regarding the maximum mechanical tensile strain of reinforcing steel mesh, it can be found that the maximum value does not exceed 3 % so far away from considered limit elongation value of 5 %, the minimum elongation capacity of all types of reinforcing steel in fire situation according to EN 1992-1-2.

However, in order to ensure enough structural resistance in fire situation, the following modifications are introduced in comparison with room temperature design:

— use of strong reinforcing steel mesh in composite slab;

— use of steel grade of S355 (yield strength: 355 MPa) for all steel members;

— partially concrete encased H shape steel columns;

— limited load level of steel columns under fire situation.

5.9 Documentation of the design for fire safety of structures

This section is not relevant in this example.

5.10 Factors and influences to be considered in the quantification process

This section is not relevant in this example.

6 Guidance on use of engineering methods

This section is not relevant in this example.

Annex A
(informative)

Analysis of structural behaviour of open car parks

The full analyses have been performed according to the fire safety engineering methodology explained in the previous paragraphs. As the most unfavourable situation from structural point of view, the seven vehicles involved in fire are considered to be situated at the corner. The simulated results from numerical modelling are given hereafter for roof and an intermediary floor level.

A.1 Intermediary floor level — Fire scenario S2.2

To investigate the fire performance of unprotected steel structure under this fire scenario, the adopted structural model occupies the relevant edge part of the global floor as shown in Figure A.1 and the location of seven vehicles involved in fire is indicated in Figure A.2.

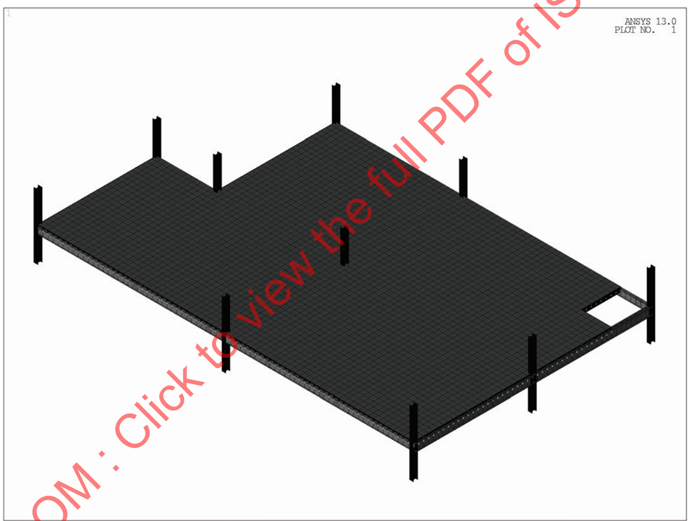


Figure A.1 — Modelled structure of an intermediary floor level for fire scenario considering seven vehicles situated perpendicular to secondary beams

As only a part of the structure is modelled, the boundary conditions for slabs and columns are respectively given in Figures A.3 and A.4.

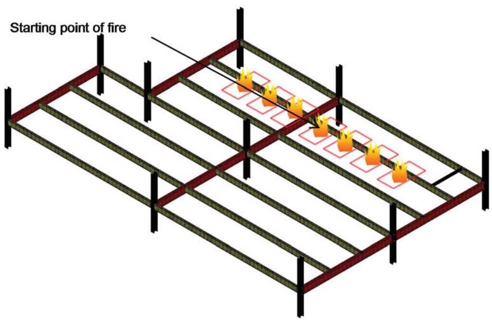


Figure A.2 — Steel frame of the modelled structure

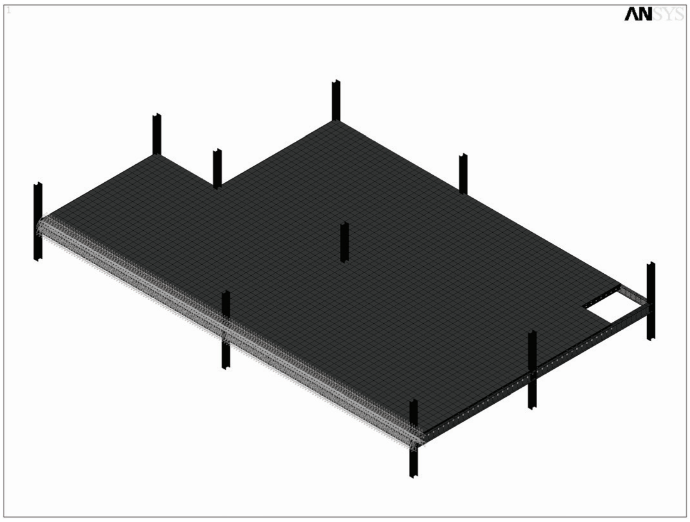


Figure A.3 — Restrained rotation and translation to simulate continuous slab

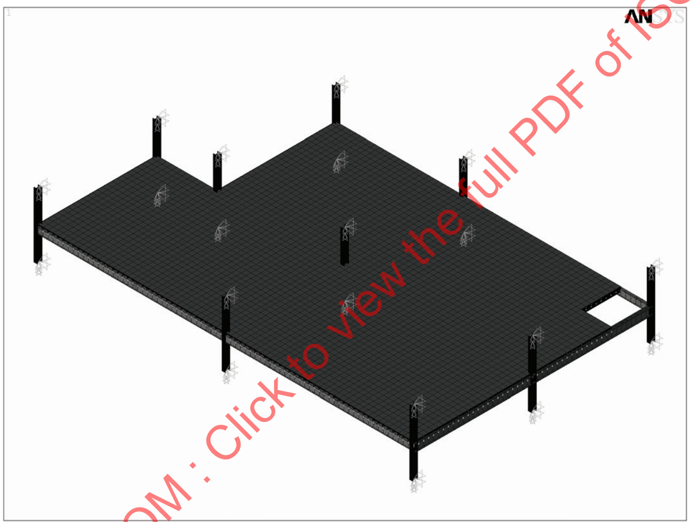


Figure A.4 — Boundary conditions applied to the columns

The numerical results for an intermediary floor level are given in terms of vertical displacement field, respectively before the fire and at 30 minutes, 55 minutes, and 80 minutes of fire (Figures A.5 to A.9). It can be found that the maximum deflection obtained at 55 minutes of fire is about 461 mm (see Figure A.7). From the maximum elongation of reinforcing steel, one can observe that it is only slightly more than 2 %, so much smaller than 5 %, considered as critical elongation value of reinforcing steel (see Figures A.10 and A.11).

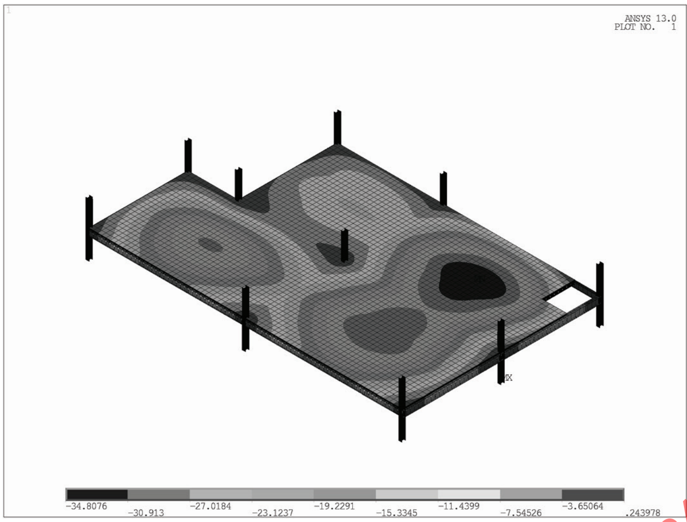


Figure A.5 — Deformed state of floor before the fire (unity in mm)

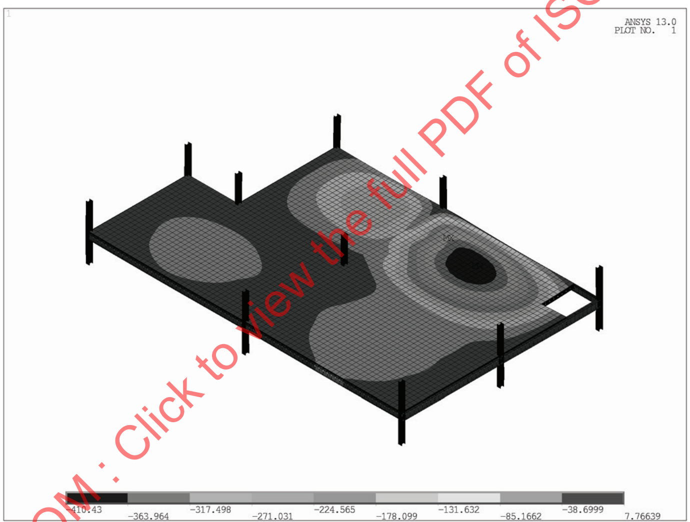


Figure A.6 — Deformed state of floor at 30 minutes of fire (unity in mm)

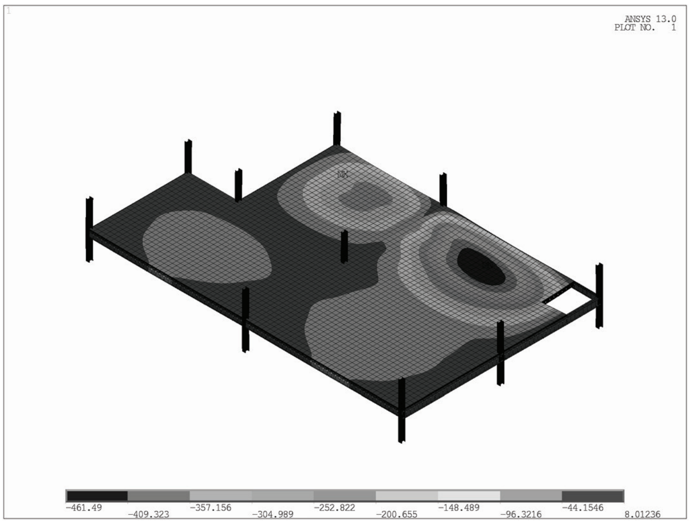


Figure A.7 — Deformed state of floor in its maximum value at 55 minutes of fire (unity in mm)

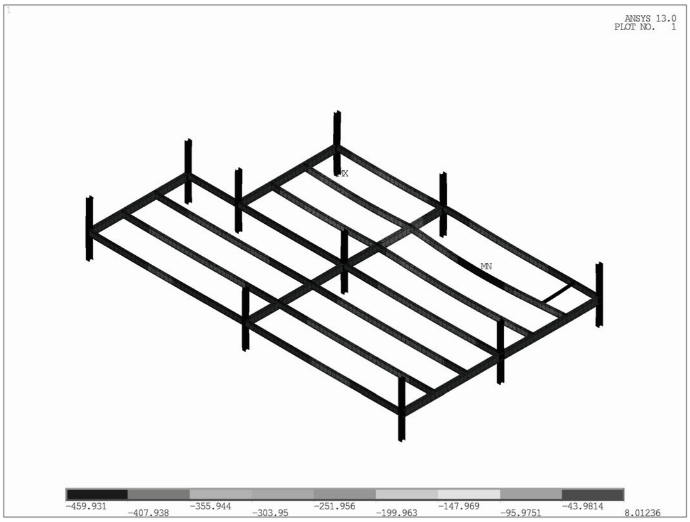


Figure A.8 — Deformed state of steel frame in its maximum value at 55 minutes of fire (unity in mm)

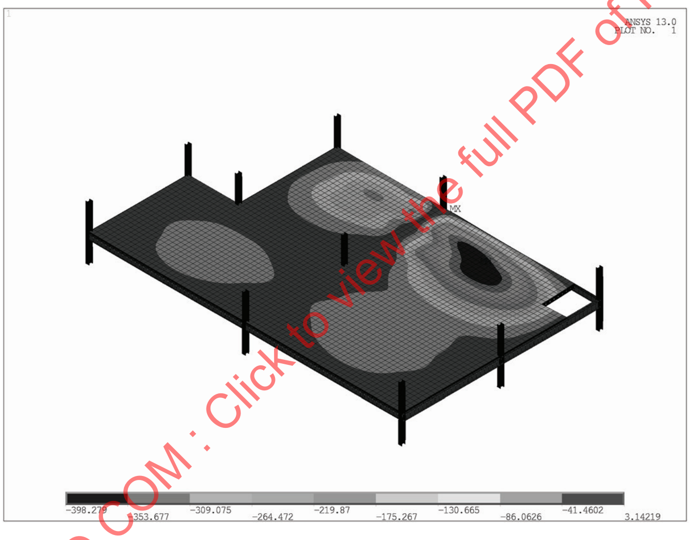


Figure A.9 — Deformed state of floor at 80 minutes of fire (unity in mm)

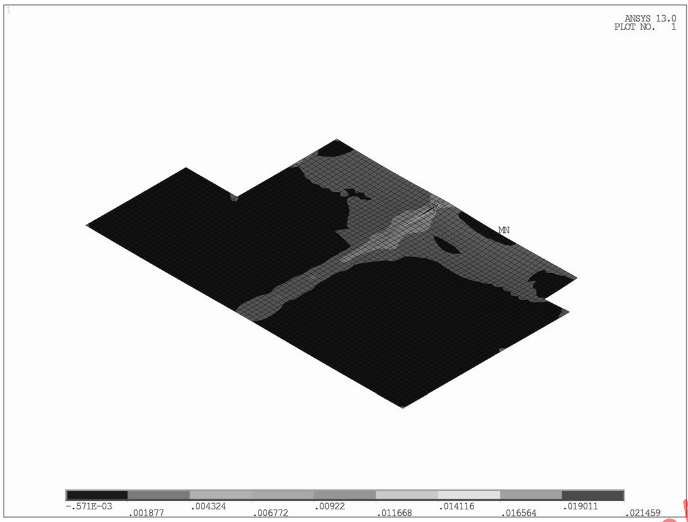


Figure A.10 — Mechanical strain of reinforcing steel ⊥ slab span at 55 minutes of fire

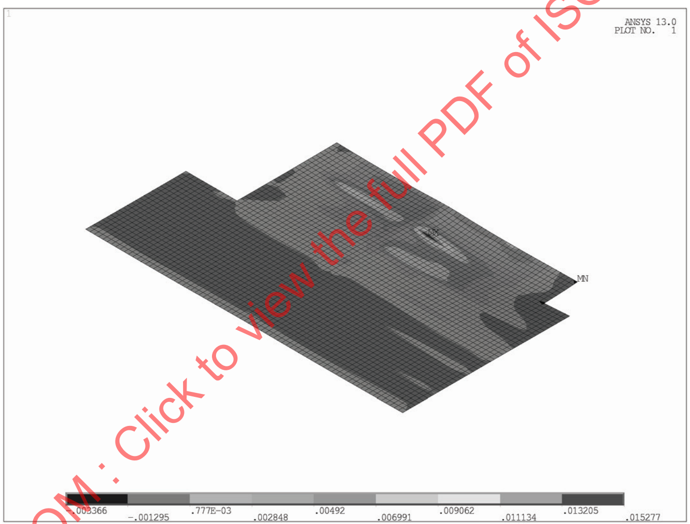


Figure A.11 — Mechanical strain of reinforcing steel // slab span at 55 minutes of fire

A.2 Roof floor level — Fire scenario S2.2

The typical results are presented in the following figures for roof floor level subjected below to fire scenarios involving seven vehicles at the edge part of car parks, perpendicular to secondary beams. Similar to previous case, the modelled structure as well as the corresponding boundary conditions are illustrated in Figures A.12 to A.15.

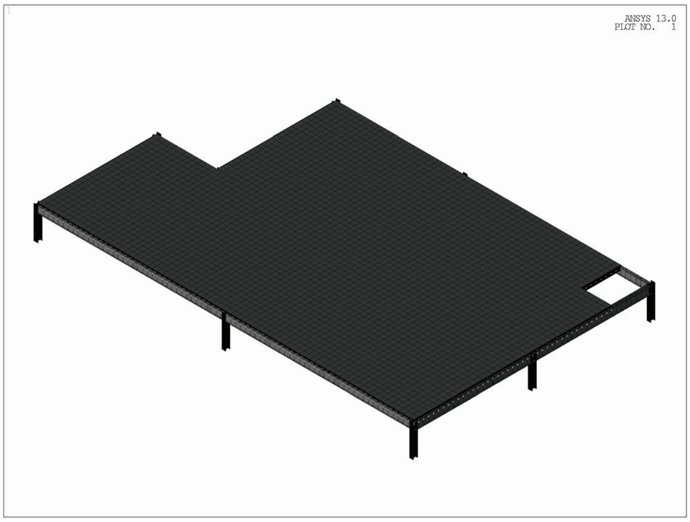


Figure A.12 — Modelled structure for roof floor level according to the applied scenario considering seven vehicles situated perpendicular to secondary beams

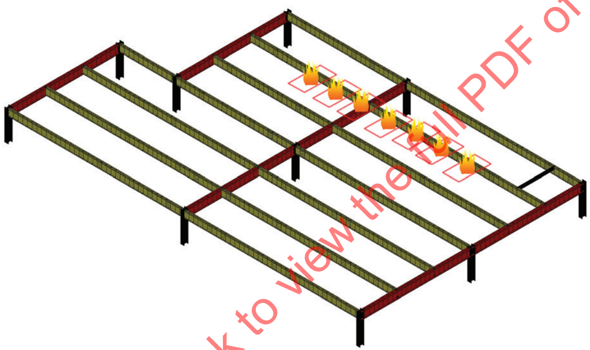


Figure A.13 — Steel frame of the modelled structure

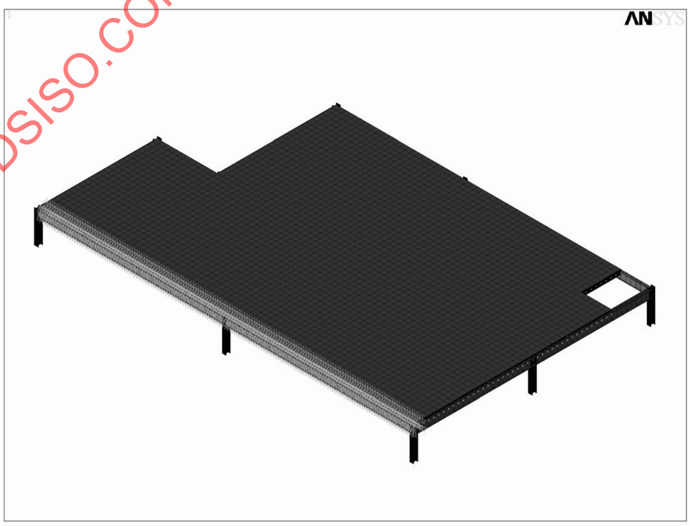


Figure A.14 — Restrained rotation and translation to simulate continuous slab

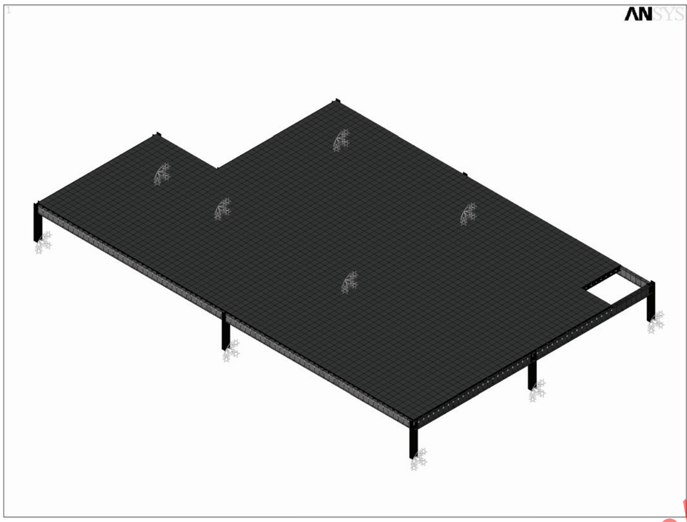


Figure A.15 — Boundary conditions applied to the columns

The deformed structure obtained prior to the fire and at 30 minutes, 55 minutes, and 80 minutes of fire is shown in Figures A.16 to A.20, respectively. It can be found in this case that the maximum deflection of floor for this fire scenario is about 458 mm, so also far away from 20th of secondary beam span (775 mm), at 55 minutes of fire (see Figure A.18). Concerning the maximum elongation of reinforcing steel, it is only about 2,2 %, so smaller than 5 % considered as critical elongation value of reinforcing steel (see Figures A.21 and A.22).

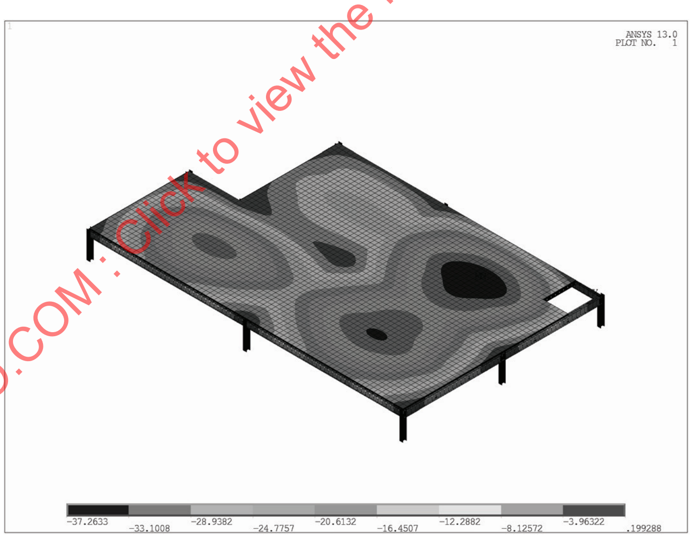


Figure A.16 — Deformed state of floor before the fire (unity in mm)

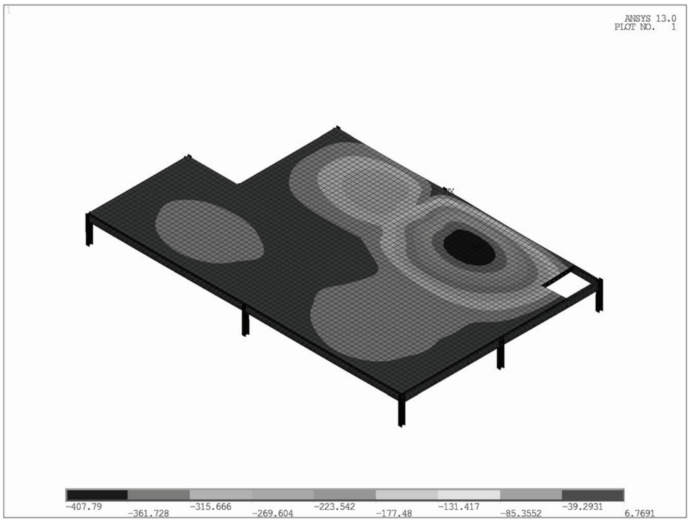


Figure A.17 — Deformed state of floor at 30 minutes of fire (unity in mm)

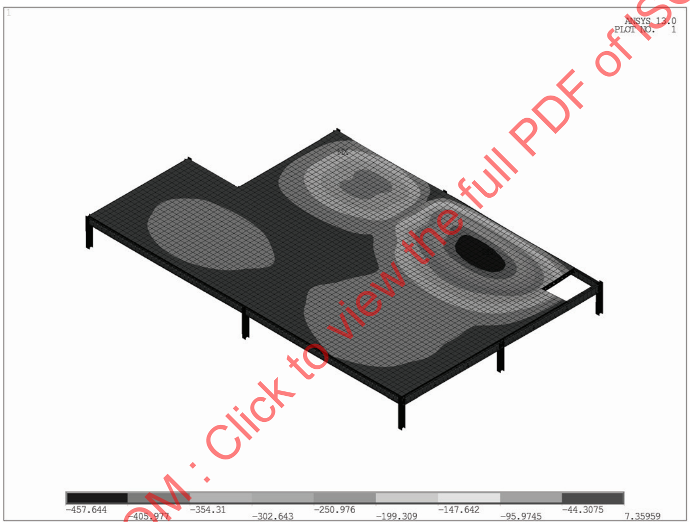


Figure A.18 — Deformed state of floor in its maximum value at 55 minutes of fire (unity in mm)

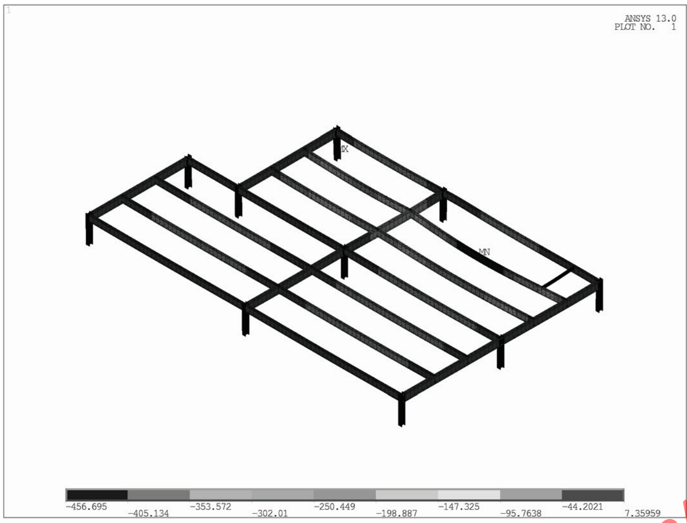


Figure A.19 — Deformed state of steel frame in its maximum value at 55 minutes of fire (unity in mm)

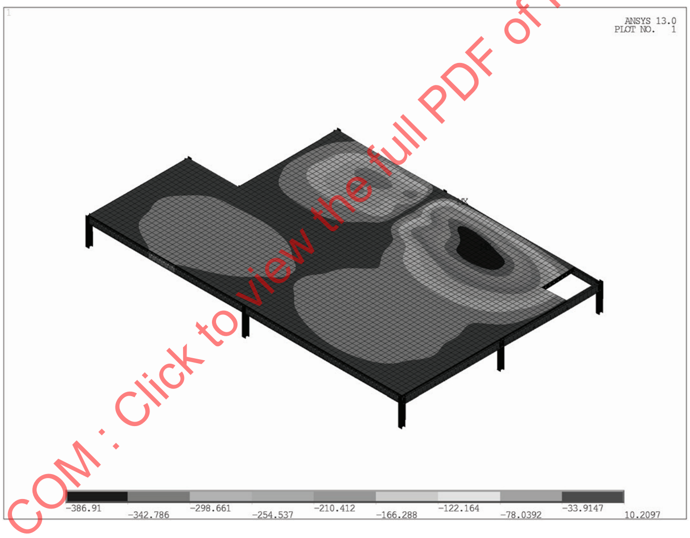


Figure A.20 — Deformed state of floor at 80 minutes of fire (unity in mm)

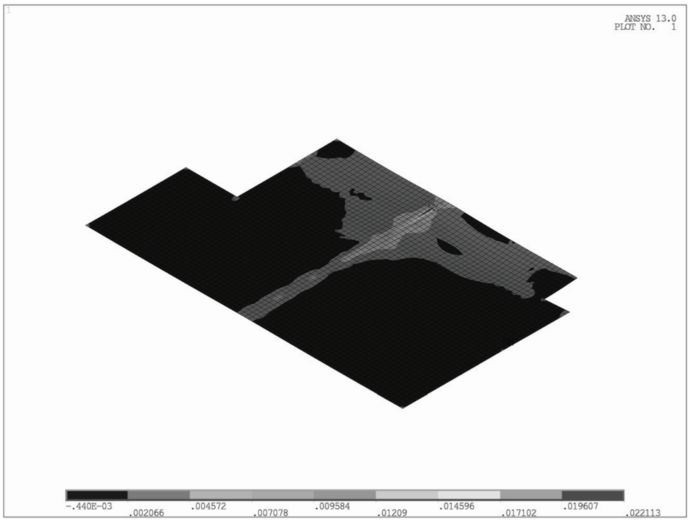


Figure A.21 — Mechanical strain of reinforcing steel ⊥ slab span at 55 minutes of fire

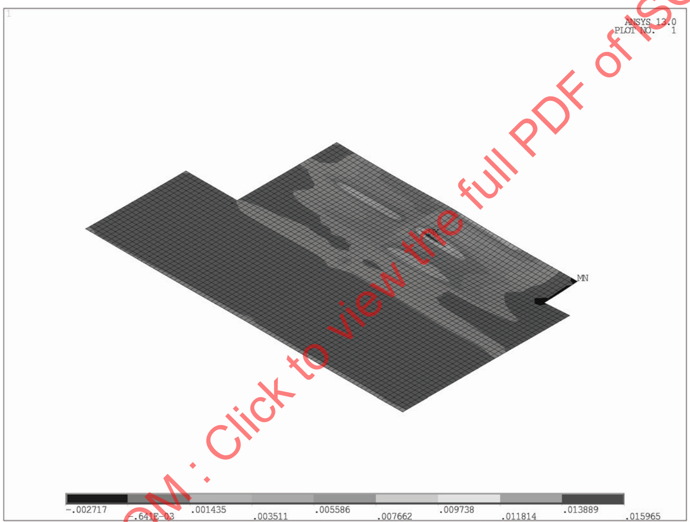


Figure A.22 — Mechanical strain of reinforcing steel // slab span at 55 minutes of fire

A.3 Ground level — Fire scenario S1.3

Structural behaviour under fire scenario S1.3 at ground level has been investigated considering four vehicles involved in fire around an internal column. Modelled structure, as well as fire location for this fire scenario, is given in Figures A.23 and A.24. Only four floor grid panels have been taken into account in the modelled structure, in which the influence of the remained part of the structure is represented by continuity conditions of the composite slab at its internal edge parts (Figure A.25). Moreover, floors of the upper level have been neglected in the modelling and replaced by appropriate boundary conditions (Figure A.26).

