NATURAL FIRE DESIGN AT THE UNDERGROUND CAR PARKING OF „TIROL THERME LAENGENFELD“ - AUSTRIA

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ABSTRACT

In an alpine valley in Austria a generous thermal spring project with water scenery, a luxurious hotel and parking area for 500 cars was built using a natural healing water. The demand for a car-free countryside in combination with the unfavourable ground water situation led to a single floor underground car park with a roof of 12.000 m². The high loads due to the massive soil coverage and the severe snow loads together with the wish for generous parking spaces without disturbing columns were a challenge for the engineers. Focussing on the architectural appearance, construction costs and erection time a steel-concrete composite structure proved to be optimal. To fulfil the economical demands avoiding expensive measures for fire protection a comprehensive theoretical investigation on the object-related natural fire conditions was carried out. In that regard especially the discussions with the local authorities and the achievement of their conviction for this up-to-date design method instead of the uneconomical standard fire design played an important role.

1 INTRODUCTION

1.1 Project overview

In the Tyrol a modern wellness project (Fig. 1) with a luxurious hotel, health clubs, pools in a “crystal” hall, outside basins as shell constructions and a generous underground car parking was built at a cost of 70 million Euro. Construction work started mid 2002 and end of 2004 it was inaugurated.

Fig. 1: Tyrolean Thermal Project “Aqua Dome”

1.2 Roof of the car parking

Taking into account the high ground water level this garage for 500 cars was designed with one single floor of 12.000 m^2 at a level of –1,3 or –1,6 m below terrain (Fig. 2). For conservation reasons the roof had to be covered with massive soil for plantation.

The following objectives were aimed at:

- minimisation of disturbing columns in spite of the high loads (parking comfort: bright, open, user-friendly)
- fast progress of construction work
- cost optimisation
- modern aesthetics

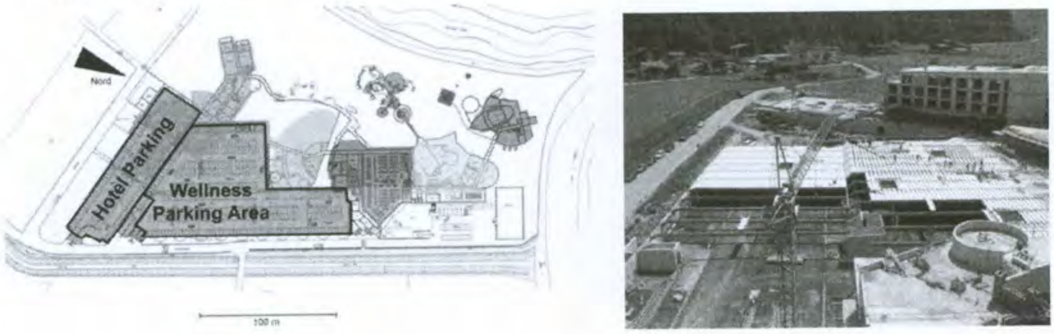


Fig. 2: Area of the underground car park with soil cover or hotel floor

These demands led to continuous steel-composite beams spanning 16 m (5 m parking, 6 m traffic lane, 5 m parking) (Fig. 3). By tension and compression column couples at the beam ends nearly full restraints could be achieved. Thus end and internal spans behave quite in the same way.

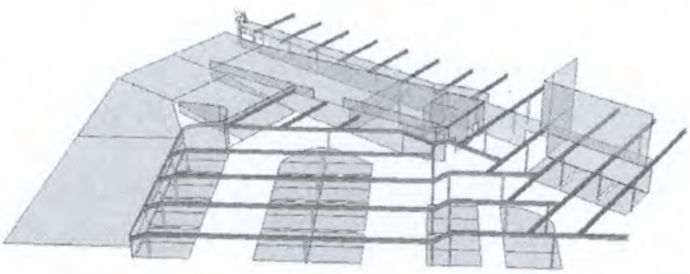


Fig. 3: Structural system: Continuous beams with end restraints

The following beam cross sections were applied (Fig. 4): steel beam type HEB 400 (S355) with an upper concrete slab (3,5 + 10 cm, f_{ck}=26,5 N/mm² ≈ C25/30) and reinforcement in the hogging areas (f_{sk}=550 N/mm²). Shear connection was realised with headed studs. For sagging the effective width was taken as 0,25*0,7*L; for hogging only the reinforcement within 3*B_{flange} was considered. To achieve 90 min fire resistance below the hotel the beam chambers were concrete encased (longitudinal reinforcement + stirrups). Overall 2.300 m of steel beams (360 tons) were used.

The regular secondary span of 5 m transverse to the composite beams resulted from the choice for "Hoesch additive slabs" (Fig. 5). There a deep steel sheeting is combined with a concrete ribbed slab (20+10 cm) without the need for conventional stirrups. The resistance of the steel deck enables concreting without temporary supports.

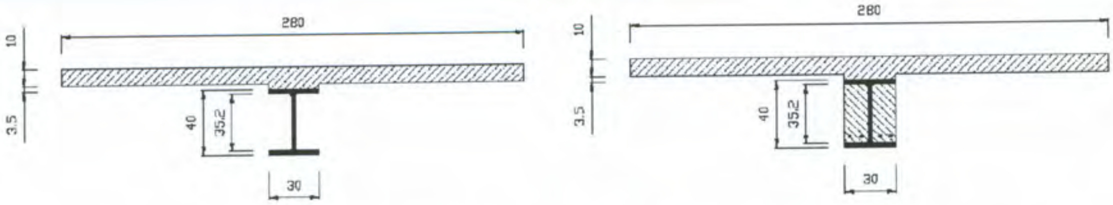


Fig. 4: Beam cross section with and without web encasement

Fig. 5: Ribbed concrete floor in addition to the steel sheeting – system of Hoesch

The advantages of the chosen composite construction system met the client's requirements. In comparison any construction type with prefabricated concrete slabs would have looked heavy and industrial. In case of fire the following benefits can even be added in view of safety of the fire brigades: the steel sheeting prevents from local blasting of the concrete coverage and the composite beams provide an enormous ductility with remarkable deflections instead of brittle failure.

1.3 Fire design

Comprehensive knowledge is applied for cold stage design. Innovative design methodology is also available for the fire case – though it is not yet applied very often in daily design practise. By means of modern calculation tools the temperature development and its distribution in the compartment as well as within the cross sections itself can be determined very realistically basing on object-related fire loads. In that sense this report covers a realistic fire scenario – not a terrorist attack.

In EN1994-1-2 [12] three different verification levels are provided:

- recognised design solutions called tabulated data for specific types of structural members
- simple calculation models for specific types of structural members based on the ISO standard fire curves
- advanced calculation models (sophisticated, object-related): "Advanced calculation models shall provide a realistic analysis of structures exposed to fire. They shall be based on fundamental physical behaviour in such a way as to lead to a reliable approximation of the expected behaviour of the relevant structural component under fire conditions.... Advanced calculation models may be used for individual members, for subassemblies or for entire structures."

In comparison with the simplified models the design efforts for an advanced verification are much more demanding in view of time and necessary simulation programs. Though this extra cost is more than compensated by a more efficient construction.

By comprehensive information the local authorities could be convinced of this modern approach. As "bonus" it was offered not only to prove the demanded ISO fire resistance of 60 minutes in the wellness parking area but even a time-unlimited resistance related to the actual fire conditions.

An advanced, object-related calculation can be subdivided into the following steps:

- thermal response (see section 2 and 3): determination of a most-realistic temperature development within the exposed fire compartment (based on the actual fire loads and compartment parameters) and – from that – derivation of the temperature distribution within the cross sections
- mechanical response (see section 4): heat dependant resistance and stiffness of the individual construction elements or the entire structure based on the mechanical temperature-related properties

2 GAS TEMPERATURES

The determination of the sophisticated time-temperature curves was performed by the Institute for Technical Fire Protection and Safety Research in Austria regarding the fresh-air / bad-air conditions as well as the expectable extreme fire loads.

2.1 Basis

Generally one can distinguished between nominal and parametric time-temperature curves. Parametric ones are taking into account the object-related fire loads and the physical parameters of the fire compartment such as the room size, ventilation conditions, time-dependant heat release rate, construction materials within the compartment and climatic parameters (humidity and temperature) [8],[9] (Fig. 6). Here the simulation software FastLite of NIST (US Department of Commerce) was used to investigate the fire and smoke expansion and the hot gas levels. The software had been calibrated against fire tests.

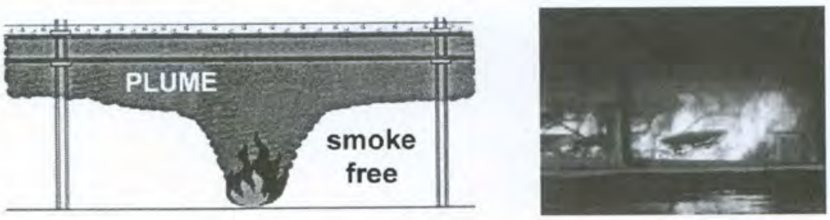


Fig. 6: Physical parameters: plume, hot smoke zone and smoke free zone

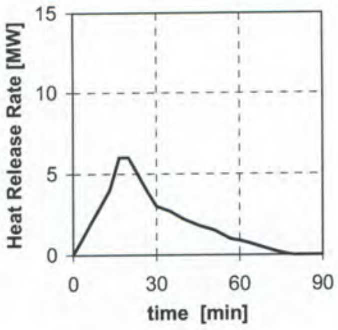
2.2 Fire scenarios

The following fire scenarios should be a basis for a realistic structural assessment. They are not covering exceptional situations like explosions or terrorist attacks.

Fire scenario in the wellness parking area: According to [15] three burning cars were considered with an ignition interval of 10 minutes. One can distinguish between three fire zones: direct fire area (5 x 12 m), indirect fire area (10 x 24 m) and distant fire area (20 x 48 m). For these zones the time-temperature curves of the gas were determined for both the minimum and maximum room height (2,6 or 3,8 m). Fire scenario below the hotel: Simulating the unfavourable case of a "burning wave" there even four cars in fire were considered.

2.3 Fire load

From parametric studies of fires in car parkings [15] the heat release rate of a single vehicle shown in (Fig. 7) could be derived. With an overall heat release of 11.200 MJ from ignition till complete destruction that corresponds to a car of category 4 and 5 according to Fig.8 [6].



TYPE	category 1	category 2	category 3	category 4	category 5
Peugeot	106	306	406	605	806
Renault	Twingo-Clio	Megane	Laguna	Safrane	Espace
Citroen	Saxo	ZX	Xantia	XM	Evasion
Ford	Fiesta	Escort	Mondeo	Scorpio	Galaxy
Opel	Corsa	Astra	Vectra	Omega	Frontera
Fiat	Punto	Bravo	Tempra	Croma	Ulysse
VW	Polo	Golf	Passat		Sharan
energy	**6000 MJ**	**7500 MJ**	**9500 MJ**	**12000 MJ**	

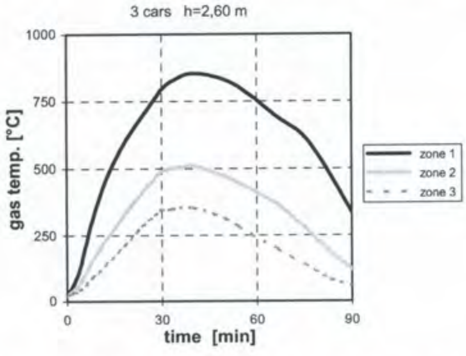
Fig. 7: Heat release rate of a single car of category 4 or 5

Fig. 8: Energy release of different vehicle types

Wellness parking area: In principle the total heat release rate of all three cars with an ignition interval of 10 minutes can be derived by summing up the curves of the single vehicles. But due to the changing thermal-dynamic conditions and the reduction of oxygen close to the fire the realistic total curve lies below this theoretical sum of single curves. Basing on that the total heat release rate was derived - with a maximum value of 12 MW after 30-40 minutes [2]. The positive effect of fire-fighting measures was even neglected.

2.4 Results

Wellness parking area – 2,6 m height: After 30 minutes the gas temperature in the fire-close zone 1 amounts 794°C and after 40 minutes a maximum temperature of 854°C is reached. In zone 2 the gas reaches 491°C after 30 minutes and 513°C as a maximum. In zone 3 the corresponding values are 345°C and 354°C (Fig. 9).



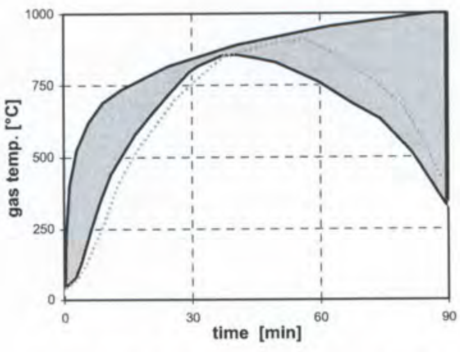


Fig. 9: Air temperature at the ceiling of the Thermal Parking Area

Fig. 10: Comparison between the actual and the standardised temperature curve

Curves and comparisons: Fig. 10 gives the difference in the gas temperature development caused by the different fire loads (three or four burning cars / thermal or hotel parking). Of course in addition to the different fire loads also the different room heights and ventilation conditions were influencing the results. Comparing the object-related natural fire curves with the international standard temperature curve one can see that the maximum realistic temperature agrees with the standard temperature at that time, but the gradient of the natural temperature curve is clearly delayed and furthermore the significant cooling down after the maximum peak is missing in the standard curve. As not only the maximum gas temperature is decisive for the heating of the structure - but the whole energy integral (area below the curves) – the sophisticated and object-related temperature curves provide a significant saving in view of the further fire design calculations.

3 CROSS SECTION TEMPERATURES

3.1 Basis

By means of the finite element program CEFICOSS [1],[14] the team of Arcelor determined the temperature development in the different cross section layers with the time-dependent gas temperature curves as input data. The calorie exchange is based on the material characteristics according to EC4-1-2 [12] and EC1-2-2 [10].

According to the three fire zones three different fire scenarios (different locations of the burning cars related to the beams and columns) were investigated (Fig. 11) – scenario no.1 proved to be decisive. The temperature calculations of course were performed for the different cross section types (sagging and hogging).

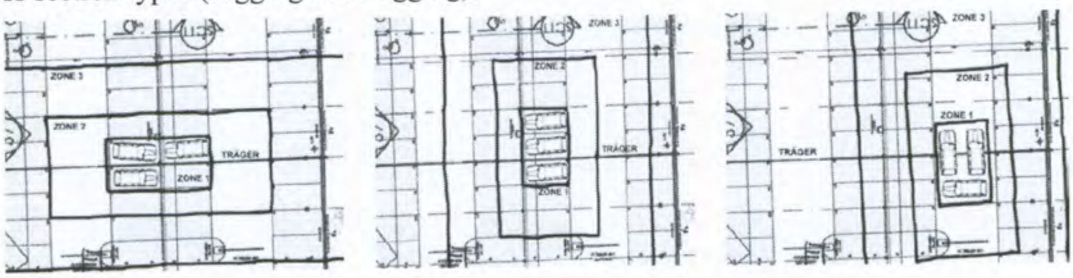


Fig. 11: Different fire location scenarios

3.2 Cross section temperatures in the wellness parking area

Fig. 12 shows the temperatures at different cross section layers depending on the time. Due to the heat transfer into the massive concrete slab the upper flange reaches much less heat than the bottom flange. Also the severe warming of the slender beam web can be seen. After 45 minutes the steel reaches a maximum temperature of 840°C. As the temperature of the reinforcement embedded in the concrete slab does not exceed 100°C it remains fully resistant over the whole time.

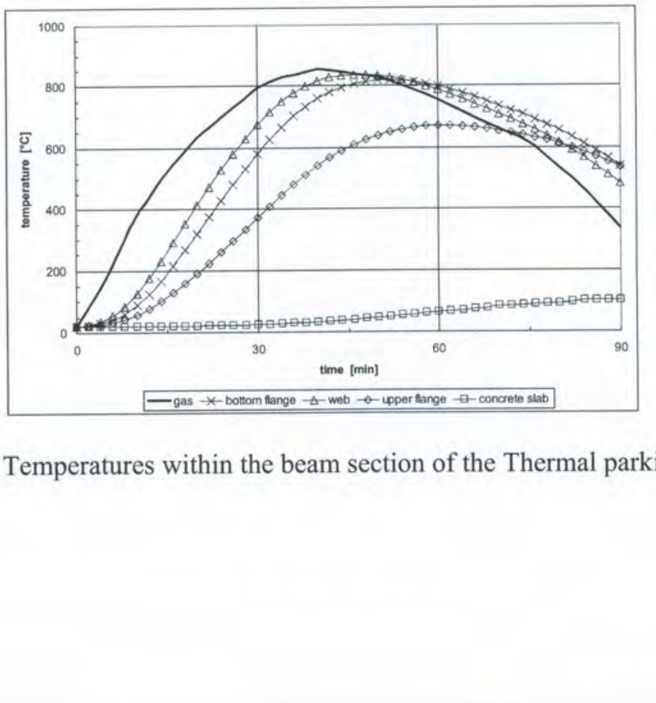


Fig. 12: Temperatures within the beam section of the Thermal parking area

4 MECHANICAL RESPONSE IN CASE OF FIRE

4.1 Basis

Knowing the full temperature development in all cross section layers over the full beam length the structural response now could be investigated with CEFICOSS on the basis of the reduced loads in case of fire (exceptional action) for the different beam systems.

In the wellness parking area the following loads were considered: dead load (beams, Hoesch slab, soil coverage) and imposed load (3 kN/m²) from snow or utilisation alternatively. In the hotel area a floor load of 3 kN/m² and a live load of 5 kN/m² were assumed.

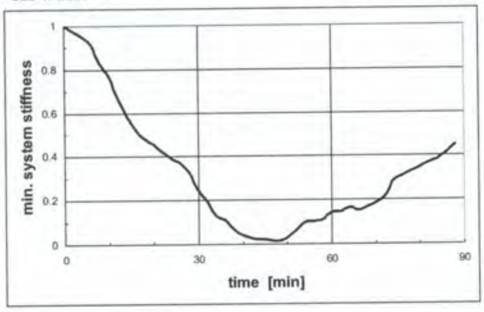
According to Eurocode 1 all dead loads were multiplied with the partial safety factor γ_F =1,0. For the snow load γ_F =0,2 and for the live load γ_F =0,5 were used:

wellness parking area: $q_{d(RF)}$ = 1,0*dead load + 0,2 * snow = 32,4 kN/m
hotel parking area: $q_{d(RF)}$ = 1,0*dead load + 0,5 * live load = 42,2 kN/m

Falling back on the previously determined temperatures, cross sections, beam spans and loads CEFICOSS evaluated the resistance decrease and deformation development of the structure with progressing fire duration basing on the temperature dependant material characteristics (yield strength, ultimate strength, E-modulus).

4.2 Results wellness parking area

The time-dependant system stiffness (eigenvalue of the stiffness matrix) and the deflection at mid span are represented in Fig. 13. As long as this eigenvalue is greater than zero the system remains in a stable equilibrium. Thus the actual structure proves to resist the loads in case of fire not only for the demanded 30 or 60 minutes but even for unlimited time with a maximum deflection of about 49 cm after 60 minutes. In a further iterative calculation the maximum possible soil coverage for the given structure without fire protection measures was determined to be 39 kN/m.



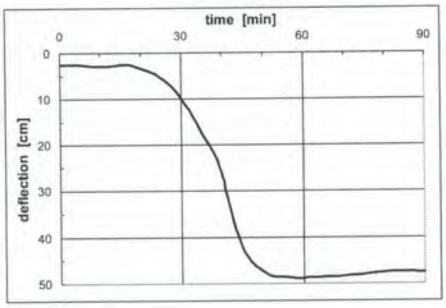


Fig. 13: Stiffness minimum and maximum beam deflection at midspan (Thermal parking area)

5 COMPARISON BETWEEN NATURAL FIRE DESIGN AND STANDARD CALCULATION

To prove the economic importance of this sophisticated approach a comparative study between the standard calculation and the natural fire design was carried out. In the case of the wellness parking area the standard calculation would have led to the need of strengthening measures of the beams (bigger profiles or beam encasement) because the actual cross section would only resist the ISO fire for 21 minutes. In the hotel parking area a system collapse would occur after 45 minutes ISO fire. To prevent from that the reinforcement of the concrete encasement would have to be doubled.

6 CONCLUSION

For the first time the natural fire design concept was accepted by the authorities of the Tyrol/Austria at the underground parking of "Tirol Therme Laengenfeld". The following calculation steps were performed as a teamwork of the authors.

- object-related fire loads of the parking areas
- resulting time-dependant gas temperatures (in comparison with the standard curves)
- temperature development in the cross section
- stiffness and resistance decrease by increasing temperature until collapse
- optimisation of loads (soil depth for planting)

For the actual underground parking roof with an optimised structural system the robustness in case of fire was proven to be non-limited in time by a natural fire design. The chosen system of a ribbed concrete slab on a steel sheeting offers the advantage to behave very ductile and to prevent from sudden blasting of the concrete coverage.

The object-related, natural fire design concept enabled considerable savings in view of fire protection measures. For the actual system finally even the cold stage design (factored loads in ultimate state and deflection limits in serviceability state) became decisive.

REFERENCES

[1] ARBED-Research Centre, Luxembourg, University of Liège, Belgium; REFAO-CAFIR, Computer Assisted Analyses of the Fire Resistance of Steel- and Composite *Concrete-Steel Structures. C.E.C. Research 7210-SA/502, Final Report*, Luxembourg, 1986

[2] CTICM References INC-99/1d-DJ/NB-IM: Statistiques fur le feux de parking en France, Daniel Joyeux, 1999

[3] ECCS: Fire resistance of steel structures – Euro-Nomogram, *ECCS Publication No. 89*, 1996

[4] ECCS: Fire Safety in open car parks, *ECCS Publication No. 75*, 1993

[5] ECCS: Model Code on Fire Engineering, *ECCS Publication No. 111*, ISBN 92-9147-000-65, 2001

[6] Joyeux D.: Statistiques sur les feux de parkings en France. *CTICM*, 12/1999

[7] Austrian Standards Institute: ONORMEN für den Verbundbau – *ON-Einfuehrungsseminare* Wien, Graz, Innsbruck, 2001

[8] ONORM B 3800, Part 2: Brandverhalten von Baustoffen und Bauteilen, Bauteile: Begriffsbestimmungen, Anforderungen, Prüfungen, 1997

[9] ONORM B 3800, Part 4: Brandverhalten von Baustoffen und Bauteilen, Bauteile: Einreihung in die Brandwiderstandsklasse, 2000

[10] ENV1991-2-2: Basis of design and actions on structures: Actions on structures exposed to fire, 1995

[11] ENV1994-1-1: Design of composite steel and concrete structures: General rules and rules for buildings, 1992

[12] ENV1994-1-2: Design of composite steel and concrete structures: Structural fire design, 1994

[13] ProfilARBED: Development of Design Rules for Steel Structures Subjected to Natural Fire in Closed Car Parks, *ECSC Agreement N°.7210.SA/211/318/518/620/933*, 1997

[14] Schleich J.B.: Numerische Simulation – zukunftsorientierte Vorgehensweise zur Feuersicherheitsbeurteilung von Stahlbauten, *Der Maschinenschaden 60*, 1987

[15] Steinert C.: Parameterstudie ueber Garagenbraende, *Bautechnik 74*, 1997

[16] VDS Schadenverhütung Bemessungsbraende, VDS 2827-2000/05/01

[17] Zhao B.: Numerical Modelling of Structural Behaviour of Open Car Parks under Natural Fire. *CTICM*, 2001

KEYWORDS

Natural fire design, car parking, steel-concrete composite beams, exceptional actions - interaction