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BRIEF**ING** 02

FIRE SAFETY STRUCTURAL FIRE DESIGN

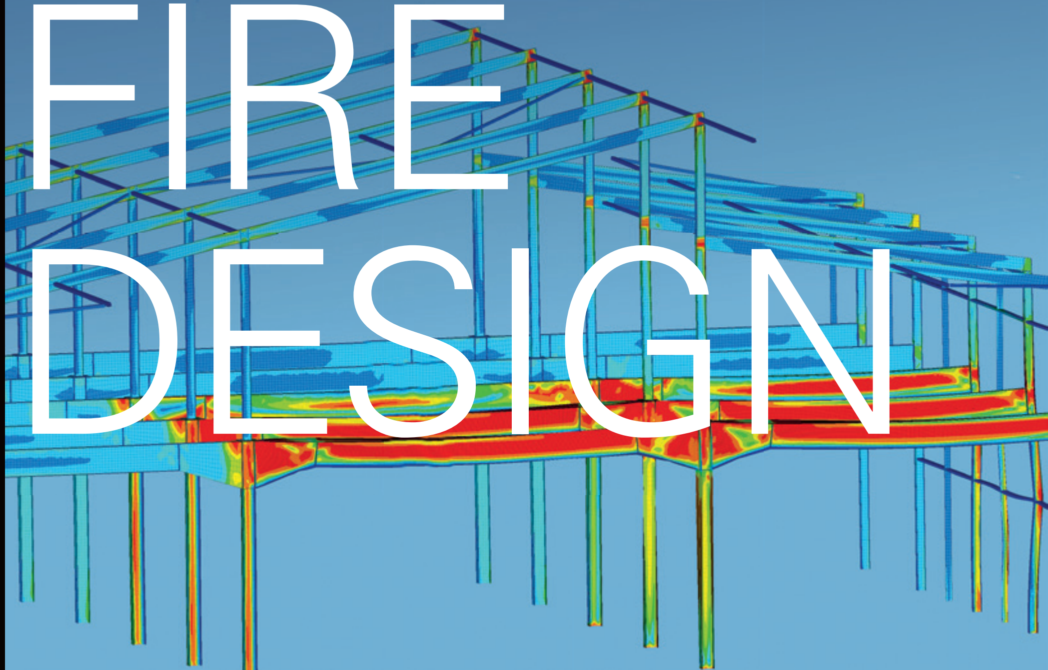
FIRE SAFETY FOR STEELWORK – OF THE HIGHEST STANDARD

STRUCTURAL FIRE DESIGN
SAFETY, COST SAVINGS, CREATIVE SCOPE

TAILOR-MADE SOLUTIONS
FOR ARCHITECTS, ENGINEERS, CLIENTS AND INVESTORS

EXAMPLE FROM PRACTICE
STRUCTURAL FIRE DESIGN

DETAILED SURVEYS CATERING FOR A FUTURE MARKET
INTUMESCENT COATINGS



The Gruner Group is a byword for construction services that set benchmarks in terms of quality. Founded over 150 years ago, Gruner now has more than 30 sites in Switzerland and all over the world. Expertise, knowledge and experience gained in many years of involvement in complex construction projects set us apart.

The Gruner Group has a broad set of competencies in the energy, building services, general planning, infrastructure, structural design, safety and environmental fields. When appropriate, we develop customized solutions for your construction project in interdisciplinary teams.

FIRE SAFETY

STRUCTURAL FIRE DESIGN

The use of structural fire design techniques to assess the fire performance of structures is a key part of state-of-the-art fire safety planning. By managing risk efficiently, these methods make it possible to design cost-effective, aesthetically pleasing buildings. This BRIEF**ING** presents the various cutting-edge simulation techniques used by Gruner to assess the performance of structures in fire conditions.

The aim of numeric investigations based on the finite-element method (FEM) is to provide a detailed analysis of the overall mechanical behavior of steel structures when exposed to high temperatures. Gruner adopts a hybrid approach combining coarse- and fine-scale modeling (GFEM/DFEM: global finite-element method/detailed finite-element method). This method is particularly effective for investigating large steel structures cost-effectively. Given the key role of connections in the mechanical performance of structural assemblies, the detailed model also factors in the fastening components.

In addition to modeling complete supporting structures, the method is also suitable for other detailed investigations, such as analyzing thermal bridges at connections with fire-protected members (e.g. beam clamps for pipes).

These state-of-the-art simulation techniques offer enormous potential for the fire design of steel structures, particularly in terms of maximizing cost-effectiveness. Our specialists will be happy to advise you.

We hope that what follows will make interesting reading.

Dr. Ralf Schnetgöke
Deputy Head of Fire Safety unit

MAXIMUM FIRE SAFETY FOR STEELWORK

Steel is an uncomplicated, easy to understand material: it is homogenous, isotropic and can be industrially produced with only minor quality variations – features that make it ideal for complex numeric methods. Consequently structural fire design techniques for steelwork have developed particularly rapidly.

"Structural fire design for steelwork is a job for highly specialized engineers with a strong sense of responsibility."


Prof. Mario Fontana, ETH Zurich

Both IT technology and the application of numerics to construction have advanced significantly in recent years. As far as structural fire design is concerned, this applies particularly to the realistic computation of temperature action with CFD models and the creation of models for complete supporting structures using the finite-element method.

In tandem with this, major progress has been made in the theory of statics for construction. These new numeric methods have paved the way for a geometrically nonlinear approach to the investigation of complete structures that can realistically factor in major deformation in the event of a fire.

The numeric modeling of oversize structures tends to be difficult. The sheer number of members and nodes pushes even powerful computer systems to their limits. The use of GFEM/DFEM, a technique borrowed from aircraft design, in which specific parts of the structure are analyzed in detail while the rest is only roughly modeled, provides a solution here by coupling different programs together or using them sequentially.

Advances have also been made in the statutory framework thanks to the periodic revision of fire regulations. Aside from various liberalizations, the use of engineering methods in fire safety design was promoted in Switzerland during 2015. For example, they can now also be used to plan escape routes. At the same time, the use of complex engineering methods increases clients' and owners' responsibility to society, particularly their duty to appoint suitable specialist designers. Unless they are able and willing, even years later, to accept responsibility for the calculations and decision-making documents they provide, owners and their insurers may well find themselves left in the lurch in the event of a fire. This is because personal responsibility and quality assurance are an inevitable part of any kind of liberalization.

Structural fire design for steelwork is generally a task for conscientious, highly specialized engineers, who apply scientific methodology and state-of-the-art techniques to work toward their goals. This method has already generated massive potential in the fields of steel and timber construction in recent years, and is set to shape the design of complex structures in the years ahead. Structural fire design that has a firm scientific basis can make a key contribution to optimizing the cost-effectiveness of fire safety measures without exposing the population to additional risks.

Prof. Mario Fontana, ETH Zurich,
Institute of Structural Engineering

SAFETY, COST SAVINGS, CREATIVE SCOPE

Background: traditional fire safety

Passive fire protection for steelwork involves the use of:
> Intumescent steel-coating systems
> Steel encasements with insulation board and spray plaster layers

The disadvantage of both is that the coating or encasement prevents any subsequent alterations to the structure or at least necessitates expensive remedial measures if any such alterations are made. Nor are many connection details or potential collisions with building services installations adequately resolved. Moreover, any poor workmanship on site may lead to damage that needs rectification.

The installation, protection and maintenance of passive fire safety systems are significant cost factors that alone may justify the use of structural fire design techniques.

Benefits of structural fire design

Structural fire design can be easily integrated into the regular structural design process. Fire is treated as a load case, like wind or snow, and becomes a subject of design calculations that are intended to optimize inbuilt fire resistance. Likewise during the construction phase, where structural members are to be protected by a coating or encasement, noncertified conditions (e.g. flaws in an intumescent coating or encasement) can be promptly and easily assessed using numeric structural fire design methods.

For existing building structures, numeric methods of structural fire design offer a reliable way of determining fire resistance under conservative assumptions or on the basis of data from tests. In many cases, simulation methods are the only option for obtaining sufficiently accurate information on existing fire resistance. They help to establish what additional measures are required and how to adapt these in terms of quality, quantity and cost to the particular situation.

Enhanced methods

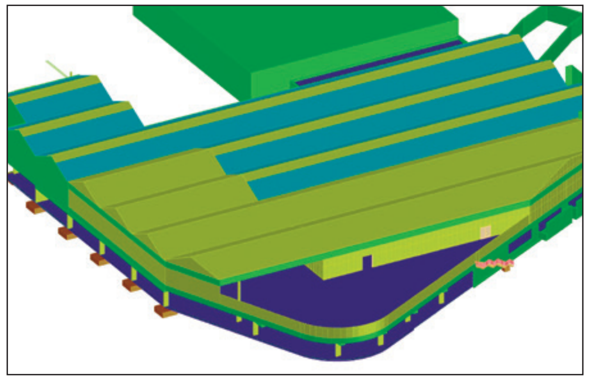
Continuing advances in fire safety and numeric simulation have yielded powerful tools that allow the efficient computation of complex physical processes. This has helped designers to verify cost-relevant parameters such as the fire resistance of supporting structures.

In the best-case scenario, steel assemblies can be erected without any passive fire protection, which reduces time and costs during the construction period. At the same time, existing structures can also be assessed, something that would be very difficult without simulation tools.

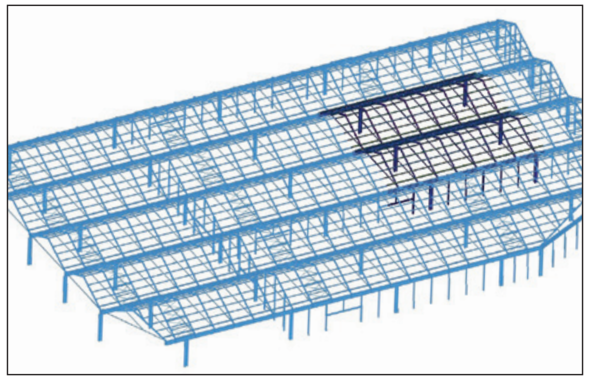
Simulation as a service

Simulating fires and their effect on building structures requires complex computational methods. Such investigations use a combination of structural analysis and flow simulation to model complete supporting structures and to analyze their behavior in fire conditions. The standard computational methods applied in construction statics are not suitable for complex structural-mechanical calculations that have to factor in the high-temperature behavior of building materials.

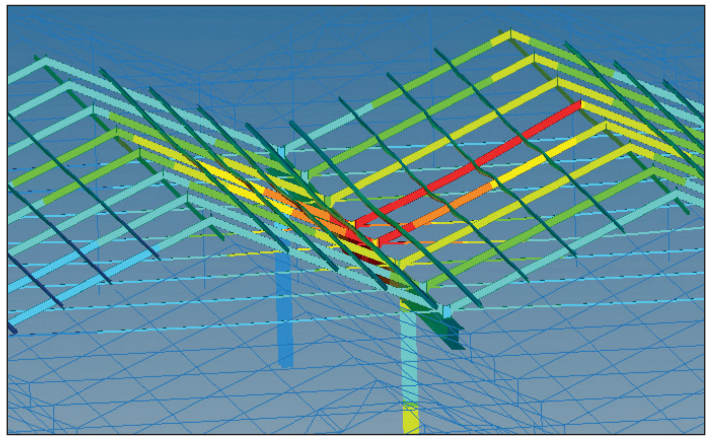
One key factor here is the use of nonlinear methods in all structural-mechanical applications (geometry, material and contact). The application to fire safety of simulation techniques from aircraft design has delivered a cost-effective means of performing high-accuracy calculations, particularly for large structures. Drawing on their extensive experience, our computational engineers can efficiently exploit these complex techniques for the new verification procedures.



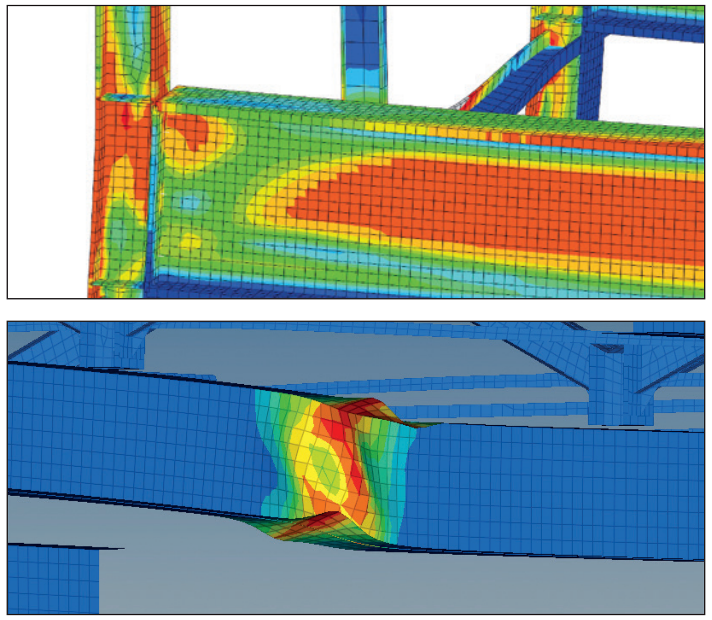
Building design model



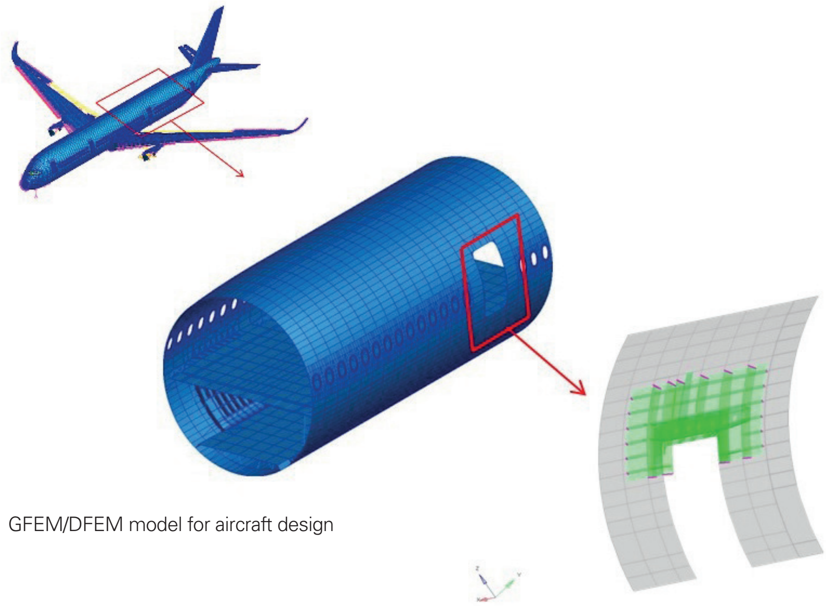
GFEM/DFEM model of building structure



Thermal analysis of near-fire area



Detail showing stresses and deformation caused by fire action



GFEM/DFEM model for aircraft design

TAILOR-MADE SOLUTIONS FOR

Architects

The coatings and encasements needed to meet passive fire protection requirements for steelwork may impose restrictions on design concepts, either by increasing their cost or reducing their esthetic impact. Moreover, the construction details for coating systems and encasements are not always properly regulated and often have to be approved on a case-by-case basis. Structural fire design techniques can be used to verify the fire resistance of unprotected supporting steel assemblies, thereby completely eliminating the need for passive fire safety measures.

Engineers

The latest developments in numeric analysis combined with powerful computer clusters mean that simulations can now deliver highly detailed predictions for many physical processes. Refinements in both hardware and software have led to the increasing use of these techniques – specifically those relating to structural fire design – in computational fire safety applications. Computational methods from engineering disciplines other than construction, e.g. aircraft design, can be intelligently integrated to facilitate the analysis of mechanical problems ranging from the plastic capacity of structures to their failure condition. Given its ease of application, the new technique can be used to analyze structures of virtually any size.

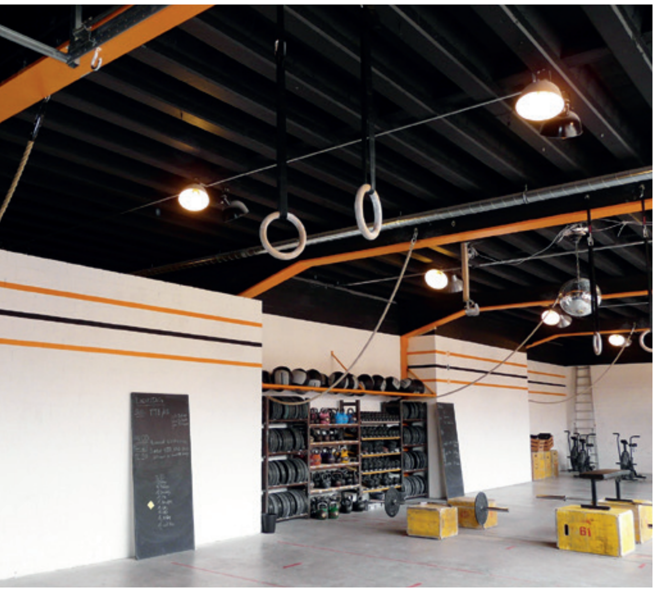
Clients and investors

Passive fire protection requires structural elements that offer adequate fire resistance. For structural steelwork, this resistance can be achieved by either coating or encasing the steel members. However, these protective systems are not only expensive to install, they also involve cost-intensive maintenance.

Our new structural fire design technique, based on computational principles from aircraft design, can be used both to efficiently analyze large assemblies and to investigate existing structures fitted with passive fire protection systems. In most cases, the results of our analyses can be used to cut costs and lower the quotations submitted for project design services. Early integration of this technique in the structural design process will yield optimizations to structural elements – either by eliminating the need for protective measures or reducing steel quantities. Moreover, the future facility operator will also be spared the problem of ensuring that the protective steel finish complies with the regulations in the long term.

EXAMPLE FROM PRACTICE STRUCTURAL FIRE DESIGN

The fire performance of unprotected structural steelwork had to be examined as part of a warehouse conversion project. Gruner used its structural fire design technique to verify fire resistance for a natural fire scenario.



Due to the conversion of a warehouse into an office and venue, the building needed an evaluation in accordance with the new fire safety requirements. The structure had to match the fire-resistance rating to withstand for at least 60 minutes. Given the thickness of the existing structural elements, which were oversized for the new facility, it was appropriate to investigate the fire performance of the unprotected steelwork. The primary structure comprises five haunched, two-span steel frames supporting a ribbed concrete slab. The building has one main story, with the upper level forming the attic space and thus imposing no requirements in terms of passive fire protection.

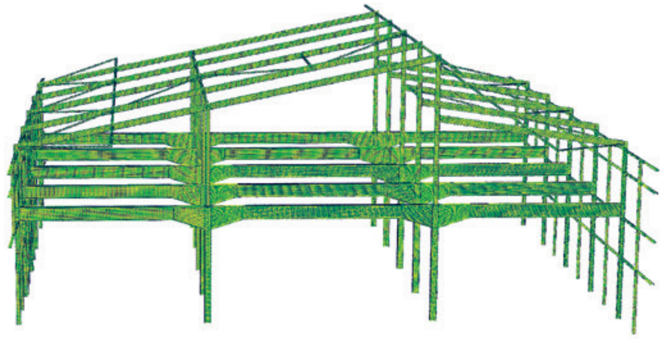
To assess the behavior of the complete unprotected supporting structure, the technique was applied for a natural fire scenario in the largest functional unit, the crossfit gym. The steel structure of the entire shed building was first translated into an FE model.

Since the functional units form separate fire compartments, it was possible to apply the GFEM/DFEM method. The part of the structure exposed to the fire was modeled in detail while the cold zone was modeled in simplified, idealized form in the FE program. The global and detailed parts of the model were coupled together.

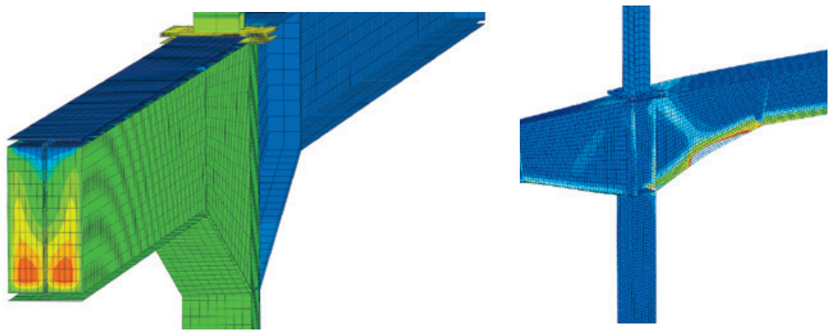
In some places, the beam webs are encased by concrete infill. Although the analysis excluded the mechanical effects of the concrete on the structure (conservative approach), it was factored into the thermal analysis for the determination of element temperature.

The temperature simulation for the crossfit gym was performed using a CFD model. The mechanical analysis, which was based on nonlinear FE computations, showed a sharp increase in plastic strain in the steel, particularly at the frame nodes (position of the greatest support moment).

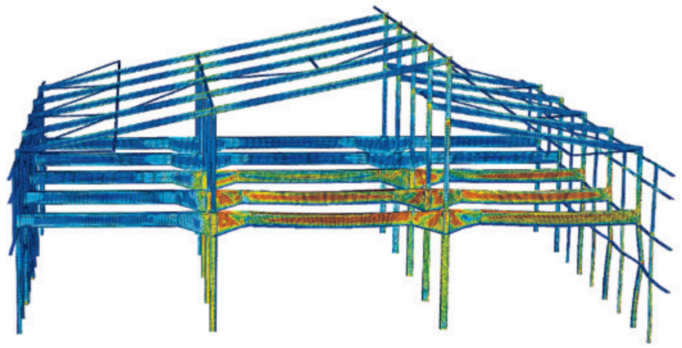
Given the large dimensions of the members, the protective effect of the concrete infill between the beam flanges and the partial enclosure of the columns by masonry, the structure was found to have sufficient plastic reserves for the fire temperature load case. Accordingly, when the unprotected assembly was analyzed for stress, strain and stability, no failure was observed.



FE model of steel shed structure



Thermal analysis of structural members (left) and plastic strain in structural member (right)



Mechanical analysis of steel structure under thermal loads

DETAILED SURVEYS CATERING FOR A FUTURE MARKET

Numeric modeling used to investigate intumescent coatings.

The certification-compliant application of protective coatings such as intumescent systems is not always possible under real-life conditions. Thermal bridging in protected structural members – due either to the design detailing (e.g. trapezoidal sheet-to-beam connections) or to later works (e.g. beam clamp systems for secondary assemblies) – occurs regularly.

Cases where unprotected service installations are subsequently clamped to protected primary structures raise key issues concerning the implications of thermal bridging for the steel member: How many clamps can be fixed to the beam given the main load of the primary beam? What is the maximum size of these clamps? Is one-sided loading by the clamps permissible?

The problems can be illustrated by the example of simple beam clamps fixed to a simple beam section: in the event of a fire, the intumescent coating would be unable to expand at the clamp positions, leaving unprotected fire-exposed surfaces. As a result, the clamp would be able to freely transmit heat into the structural member.

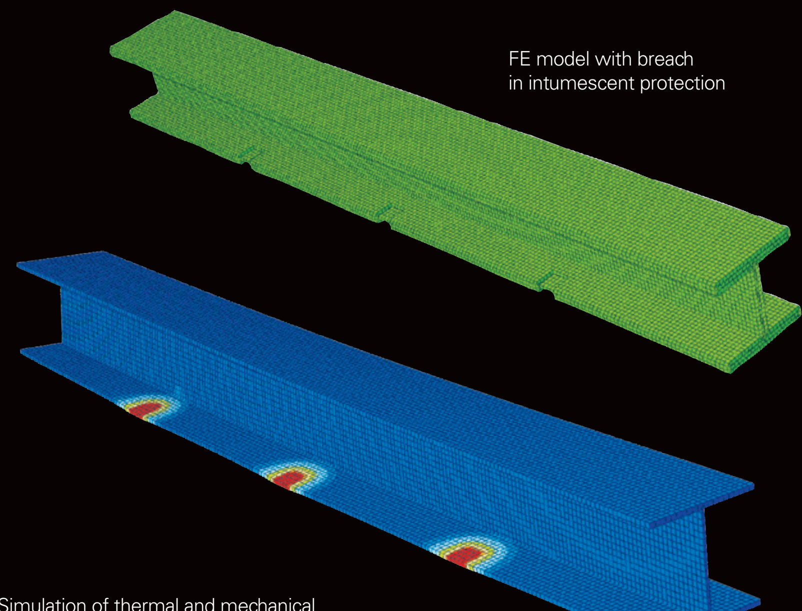
The precise thermal and mechanical impairment resulting from the noncertified condition of parts of the protective coating can be assessed by means of an FE-based simulation. This involves modeling the structural member with the intumescent coating in fully expanded state. The breaches in the coating are represented as defects or integrated in the model through inclusion of the unprotected clamps.

The thermal exposure is modeled by applying a standard ISO fire or natural fire temperature load to the entire structural member. The heat input distribution resulting from the breach in the intumescent coating can thus be assessed and established by means of a mechanical analysis that takes account of the background conditions and loads.

The numeric parameters for thermal analysis of the intumescent coating are derived from the specific heat capacity, emissivity, heat conduction and expanded thickness values for the intumescent material. The figures for specific heat capacity and emissivity are available from technical literature. Thermal conductivity, expanded thickness and expansion behavior at the breach, on the other hand, should be more closely investigated by means of full-scale fire tests. This validation can then be used in numeric models to arrive at more exact predictions, without the need to make overly conservative assumptions. The final results provide a reliable estimate of the temperatures prevailing in the structural member over a given exposure period due to the breach and a reliable verdict as to whether the structure's load-carrying capacity can be guaranteed for an adequate time under the existing conditions.

This demonstrates how powerful and efficient modeling tools, used in conjunction with the appropriate physical parameters, can deliver a prompt, reliable assessment of built structural assemblies.

The clamping of components to the structure may create weak points in terms of fire safety



Simulation of thermal and mechanical impairment

OVER-VIEW

SERVICES

> Fire safety consulting
> Fire strategies, fire safety plans
> Fire safety expert opinions
> Evacuation simulations
> Fire simulations (CFD)
> Structural fire design
> Quality assurance, fire safety supervision
> Fire emergency controls (planning, tests)
> Calibrated smoke tests
> Information and plans for firefighters
> Escape and evacuation plans
> Fire safety rules for buildings
> Fire protection officer
> Training, continuing professional development

Please feel free to contact us.
We will be glad to provide information and advice.

www.gruner.ch/en/competence/structural-fire-design

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