Combining structural design and fire simulation of steel structures with product modeling

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ABSTRACT: New solution is developed combining both structural simulation and fire simulation tools as well as enabling automatic data exchange between the software tools. The tools provide a very fast route to safer building designs, and boosts efficiency at all project stages from design to production and installation of the steel foundation, frame, and envelope structures.

The software has been developed in co-operation with fire authorities and research institutes, and provides the means to automatically export product models designs into the Fire Dynamics Simulator (FDS) tool from NIST (National Institute of Standards and Technology, USA). The fire engineering includes the fire simulation using well established fire sources to typical buildings. The fire sources, so called fuel packages, have been developed based on both the experimental and the theoretical basis. The results from FDS are used in steel structure dimensioning. The procedure and the results will be described in detail in the paper.

1 PROJECT DESCRIPTION

1.1 *General*

As it is known, the performance based fire design has been invented long ago. In this project the aim was to develop further the practical tools and instructions to get the method more useful in normal structural design using the idea of product modeling.

Product modeling is also widely used in the production chain of metal structures, especially for steel structures. Lot of information for the entire life cycle of the building is included in the models. This includes load-bearing structures and cladding as well. Both the research activities and the practical use of product models are at the high level for steel structures. So far, not much information is available in product models dealing with fire safety of buildings.

The product models mean rather well established and potential basis to store, use and transfer the fire safety information e.g. to end users of the buildings, to rescue units, to evacuation planning etc. On the other hand, the natural safety concept enables realized fire scenarios for buildings.

The Natural Fire design (NFD) -project started in the beginning of 2007 and was completed by the end of 2008. The project was financed by steel industry and the Finnish Funding Agency for Technology and Innovation (TEKES).

The co-operation partners were VTT Technical Research Centre of Finland (VTT), Tampere university of Technology (TUT) and the Finnish Constructional Steelwork Association (FCSA). The building and fire authorities were also informed about the project and valuable feedback was got from them.

1.2 *Objectives*

Main aim of the project is to adopt the natural fire safety design of steel structures into the daily construction business. The concept itself exists already and some further implementation projects have also been carried out (NFSC and DIFISEK –projects). Several publications concerning the subject have also been published, but a larger implementation to practice is still needed.

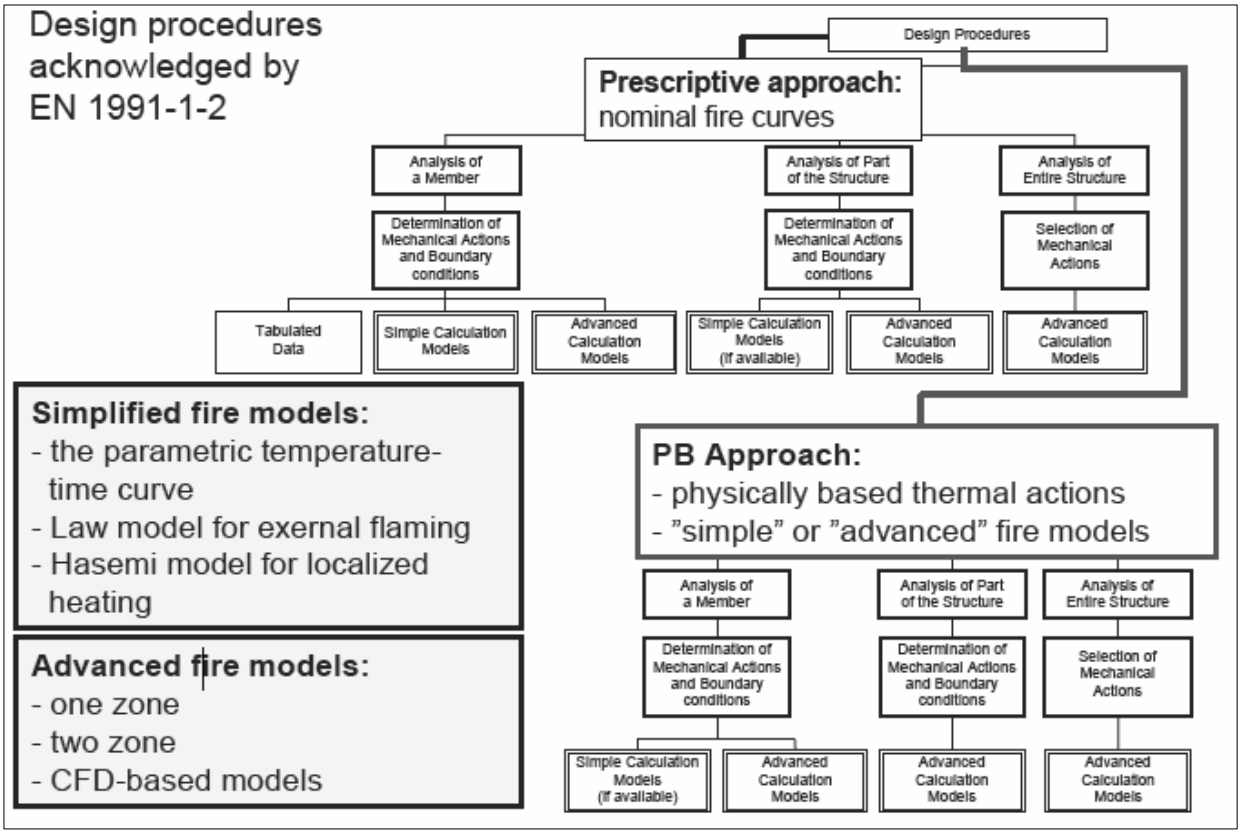

Figure 1. Design procedures acknowledged by EN 1991-1-2.

The objective was to gather together a chain of design tools (methods, software) to get a useful package to support the performance based fire design. The method supports strongly the change from design by testing to numerical modeling in a safe way. The tools and the whole chain will be tested and evaluated within the project group.
Basic knowledge of the acceptance criteria in different countries was also studied in order to find out the main problems in the use of performance based fire design. Basically in all the countries using Eurocode design, the performance based structural fire design should be possible to use. The practice is still something else. There's a huge difference in the acceptance of it in different countries.

The basis of fire engineering is the fire scenarios in each building case. A set of so called "fire packages " was gathered based on tests, actual fire statistics and simulations. This was done by VTT and the work is still going on.

2 WORK STAGES

2.1 *Study of the available software, other research and regulations*

The objective was to define the state of art of current software, research and regulations related to the project. The idea was to obtain the most important information about the applicability of the software for the purposes of the project. The choice of most suitable programs was carried out on the basis of this survey.

The state of the art of the research concerning the project's objectives was also carried out. Results of the former research projects were studied and the international contact network was used to find out the ongoing projects related to Natural Fire Design project.
The regulations in different European countries were studied and a separate report of this was accomplished. A large variation in regulations was found out. The outcome from this will be used in the international co-operation to try to inform the authorities of the differences and to create a basis to somehow harmonize the regulations. By harmonizing the regulations the industry has a way better basis to do business in different countries. In Figure 2 a table about the differences in different countries is presented.

Fire Resistance required for elements of structure

type	s	B	D	F	I	L	NL	FIN	SP	UK
HALL	YES	0	0	0/30	0/60	0	0	0	-	0
	NO	0		0/30	30/90	0-60	0	0	-	0
COMMERCIAL CENTER AND SHOP	YES	0	0	0 H 30 V	60/90	30	0	0	90	0
	NO			30	90/120	30	0	30	90	0
SCHOOL	YES	60		60		90	60	60	60	60
	NO	60	90	60	60	90	60	60	60	60
SMALL RISE OFFICE BUILDING	YES	60		60		90	60	60	60	30
	NO	60	90	60	60	90	60	60	60	60
HOTEL	YES	60		60		90	60	60	90	60
	NO	60	90	60	60	90	60	60	90	60
HOSPITAL	YES	120		60		90/120	120	60	120	90
	NO	120	90	60	120	120	120	60	120	90
MEDIUM RISE OFFICE BUILDING	YES	120		120		90	60	120	120	120
	NO	120	90	120	90	120	90	120	120	
HIGH RISE OFFICE BUILDING	YES	120	90	120		120	90	120	120	120
	NO	120		120	120	120	90	120	120	

Figure 2. Fire resistance requirements in different countries.

2.2 *Instructions to authorities and designers*

A simple guide to performance based structural fire design (FCSA, Ruukki, 2008) was published in Finnish, Swedish and in English. This has been delivered mainly for Finnish fire and building authorities. The guide gives basic information about the performance based fire design, procedure and documentation. Also the legislation of the method is emphasized in the guide.

Figure 3. Performance-based structural fire design guide in three languages.

2.3 *Development of software combination*

The aim was to find a decent software combination and to develop the interfaces so that the data could be transferred fluently from software to another. The problem of course comes from the fact that these software were al commercial and the programming and data transfer differed from each other. After the evaluation of a variety of different software the project group decided to start developing the combination of Fire Dynamics Simulator (www.nist.gov), Tekla Structures (www.tekla.com) and SCIA Engineering (www.scia.com).

The data transfer was solved by developing modules reading the different software input and output data. These are owned by Ruukki Construction, which was the starter and financer of the project.

The product model software used in this study is Tekla Structures. The fire simulation program is FDS, Version 5. FDS includes both the fire fluid dynamics and the evacuation module. Only the fire dynamics module is applied in this study. Virtual thermometers are modeled in the fire simulation input file. The locations of these are determined on the basis of the structural analysis model. In this study, the thermometers are located at the centre points of each steel member.

It is worth noting that typically the steel skeleton is so slender that its inclusion in the fire simulation model is not necessary. If desired, however, the steel skeleton can be included in the fire simulation. Difficulties when modeling the steel skeleton to the fire simulations have been considered in (Heinisuo & Laasonen, 2007). If there are important changes in steel skeleton layout during the design, the fire simulation should be done again, if it is modeled to the fire simulations, which can cause extra work.

After fire simulations the temperatures of the virtual thermometers are transferred into the structural analysis program and the resistance of the steel skeleton is checked using these temperatures. In this study the linear analysis resistance checks of the steel members were done using the program SCIA Engineering and its fire engineering module [15]. Some cases have been checked using the program ABAQUS Standard program in order to verify the analyses and obtain information on the geometrically and materially non-linear 3D behavior of the building.

The target was reached and the system is working. The procedure consists of different stages:

1. Modeling the frame of the building by structural engineer
2. Putting the frame model to structural analysis software also by structural engineer
3. Defining the fire scenario with fire consultant and authorities
4. Putting the temperature points to structures
5. Fire simulation with FDS
6. Getting the temperatures to structures
7. Dimensioning the structures in fire temperatures (fire protection if needed).

In Figure 4 the principle of this is presented as a simple chart.

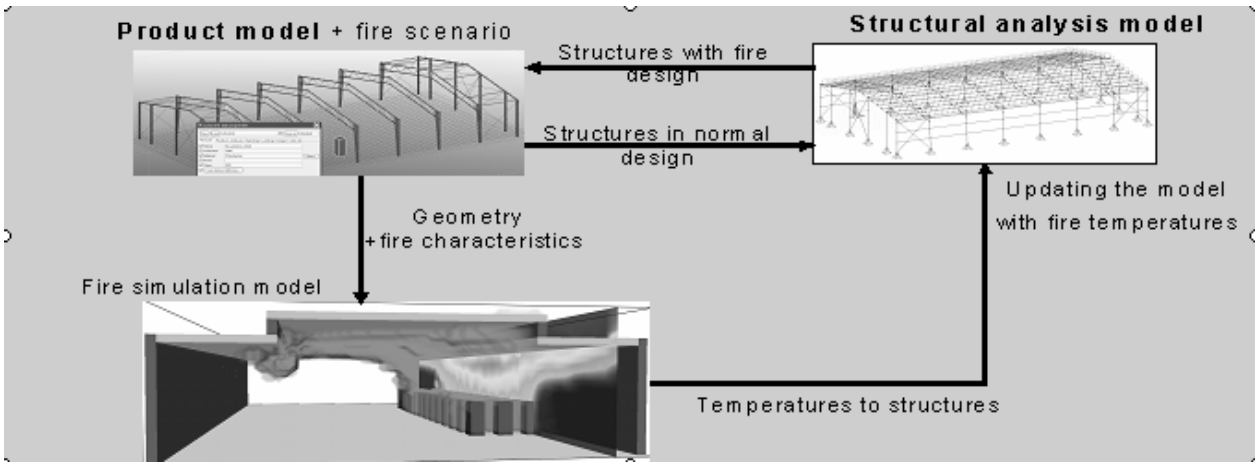

Figure 4. Natural Fire Design software combination.

2.4 *Fire packages*

The essential features when running the fire simulations are the applied fire sources. In this study, well established fire sources, called fuel packages (Hietaniemi, 2009), based on experimental and theoretical bases are proposed for the cases under consideration, and fulfilling the safety level of the Eurocodes. The fuel packages were gathered for a variety of different cases, e.g. storage, office, sports halls, big vehicles, etc.

2.5 *Implementation*

The system is now in use in the first pilot case, and the system is working well. One basic problem is that the fire simulations especially in big buildings need a lot of computer capacity and time. Therefore in very fast building processes, where the fire design is not totally done in advance, this might be a problem. On the other hand the computer speed and capacity is developing so fast that this problem will be a lot smaller very soon.
All in all the aim is to get this system into a wider use and with this kind of safe an still optimized calculation procedure to get steel structures more competitive.

3 CONCLUSIONS AND ACKNOWLEDGEMENTS

A project aiming to further development of design tools, guidance and basic data concerning performance based fire design was carried out in Finland and the results were promising.
A software combination was utilized in th research project to use the fire simulation software, structural analysis and detailing software together. This was to get an efficient chain of design tools to be used in performance based structural fire design. The work was accomplished during 2007-2008 and is in use now.
Further development will be done in the next years.The system that has been developed is already in use, but more research and development is needed. The software development itself is going on so fast, that this kind of combination tools have to follow this development. Also more information to authorities and designer is still needed to get the system as part of normal design.

Simple guide to the design and also to documentation of the method was published in several languages. Also some basic data was gathered about typical fire loads and scenarios in typical building types. These will be published by VTT.

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4 REFERENCES

Natural fire safety concept – Valorisation project, Dissemination of Structural Fire Safety Engineering Knowledge – DIFISEK, RFS-C2-03048, 2005.

Heinisuo M., Laasonen M., Product modeling, part of the fire safety concept in the future for metal structures?, Advanced Research Workshop, Fire Computer Modeling, Santander 18-20 October, Universidad de Cantabria, 2007, pp. 261-272.

Hietaniemi, J., Fuel Packages for structural fire safety design, VTT, to be published in 2009.

Performance based structural fire safety design, www.ruukki.com, Ruukki Construction, 2008.

Rakenteiden toiminnallinen palomitoitus, www.terasrakenneyhdistys.fi, FCSA, 2008.

Funktionell branddimensionering av konstruktioner, www.terasrakenneyhdistys.fi, FCSA, 2008

Tekla Structures, Tekla Corporation, www.tekla.com

Fire Dynamics Simulator, National Institute of Standards and Technology, USA, www.nist.gov

SCIA Engineer, Nemetschek Scia, www.scia-online.com