Designers now have access to a range of tools and guidance to help them take an engineered approach to the fire protection of structural steel.

Structural Steel

ALTERNATIVE SOLUTIONS FOR FIRE PROTECTION

Exposed steel deck and beams at Nova Scotia Community College Pictou Campus. Design by Fowler Bauld & Mitchell Architects.

BY GEORGE FRATER, P.ENG., CANADIAN STEEL CONSTRUCTION COUNCIL

Almost all Canadian provinces and territories have adopted the 2005 edition of the National Building Code of Canada (NBCC). Written in objective-based format, the code now creates more favourable conditions to pursue "alternative solutions" for structural steel fire protection. The method to arrive at an alternative solution is commonly referred to as "Performance-based Design," or PBD.

Designers — especially fire protection engineers — use performance based design to demonstrate that buildings meet the fire safety levels required by the code without adopting all of the prescriptive code provisions. Most build-

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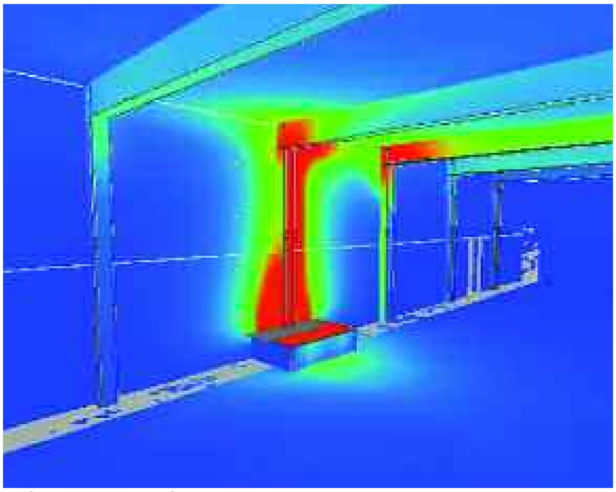
ing designs still follow the prescriptive-based design requirements in Division B, Part 3, Fire Protection, Occupant Safety and Accessibility, NBCC (2005).

However, there is a strong demand from design groups and developers to design some areas of buildings, such as main entrances and atriums, using fire protection engineered analysis as an alternative solution. There are many examples where a performance-based design approach has led to steel components in the building structure being designed to be unprotected or with a significant reduction in fire protection materials.

Performance-based design with Fire Dynamics Simulator

The engineered approach to fire safety known as performance based design is manifesting itself in more and more buildings as fire researchers develop a wider understanding of the response of structures in fires.

In Canada, for example, fire protection engineering with the aid of advanced calculation techniques and computer fire modelling produced a performance-based design where "unprotected" structural steel was used in a Nova Scotia Community College expansion project, and at Halifax's



NIST Fire Dynamic Simulator used to model a design fire at the base of an exposed steel column. Modelling by R.J. Bartlett Engineering.

new Citadel High School project (CISC, *Advantage Steel*, No. 23 summer 2005, No. 27 fall 2006).

Traditionally, structural steel would require some form of passive fire protection such as spray-applied fire-resistive materials or gypsum wallboard encasement. However, the classrooms in these school buildings feature an innovative use of exposed structural steel in the floor assembly fire separations throughout classroom areas (see photo p. 17).

The Authority Having Jurisdiction (AHJ) reviewing these projects required that the fire protection engineering analysis should follow an established process, i.e. all the steps outlined in the Society of Fire Protection Engineers (SFPE) Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings. This guide basically describes "How To" conduct a performance-based design.

The SFPE guide overviews the development of design fire scenarios that in turn require an examination of expected fire hazards and fuel loads within building compartments. The design fire for the Nova Scotia school buildings was modeled with a software package called Fire Dynamics Simulator, which was developed by the National Institute of Standards and Technology in the U.S. and is categorized as a computational fluid dynamics field model (see image below left). The model also represents the compartment's associated physical properties such as geometry, ventilation, finish, etc. Output from the model simulations provide relevant information such as ceiling jet temperatures, fuel burning rates, heat flux on enclosure boundaries, and sprinkler activation times. The data was used in traditional heat calculation methods to determine the structural response of the exposed steel beams.

Today, engineers who are involved in performance-based design for fire protection of buildings can use a range of computer models. A useful website with a survey conducted on a range of computer models in fire and smoke is www.firemodelsurvey.com. The site lists 168 fire and smoke models in six categories: fire endurance, egress, detector response, zone, field and miscellaneous. The website also provides background information on the development of fire and smoke modelling in the form of two downloadable *SFPE Fire Protection Engineering* journal papers (Friedman, R., 1992 & Olenick, S.M. and Carpenter, D.J. 2003).

SAFIR and the Natural Fire Safety Concept

Cited in the above website survey, is SAFIR, a finite element software tool for modelling the behaviour of structures subjected to fire (Franssen, 2003)[1].

SAFIR determines the temperatures in the structure due to fire and with associated analysis allows a prediction of the structure's equilibrium until it collapses. SAFIR has been used by fire protection engineers to predict the heat transfer to a structural element and to see its behaviour under applied lateral and gravity load conditions. One such example was documented by fire protection engineers in SFPE's *Fire Protection Engineering* magazine (Chen and Gemeny, 2004)[2] where 21-metre high columns, constructed as concrete-filled, steel hollow structural sections (HSS, 750 mm diameter and 25 mm wall thickness) in the main lobby of a performing arts centre outside Los Angeles were assessed to see if they would resist fire for three hours. The columns were too long to do a full-scale fire resistance test in a column furnace. They were also beyond the 4.5 metre validity limit for fire resistance formulae developed specifically for concrete-filled HSS now published in codes (NBCC's Appendix D) and standards (ASCE/SFPE 29-99). Hence

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SAFIR provided the performance-based design for steel columns under fire conditions.

The use of the fire modelling methodology cited above basically replaces the nominal fires, referred to as standard time temperature curves, defined by fire test standards such as ULC-S101, ASTM E119 and ISO 834. These fire test standards are referenced in prescriptive building codes for meeting fire resistance ratings for structural elements and assemblies.

Another engineering tool and alternative to complex computer modelling is the "natural fire safety concept" where one uses natural fire "design" curves that have been established from realistic fire loads. The European steel industry, in collaboration with research centres and universities, developed the natural fire safety concept during the last 20 years (Profilarbed S.A. Groupe Arcelor, Luxembourg, August 2001). The concept has been validated with real tests, and the results are now accepted and implemented in Eurocode 3 (design of steel structures) and Eurocode 4 (design of composite steel and concrete structures). One example where the temperature response of partially exposed steel members was calculated under natural fire design curves is a 72-metre high office building in Espoo, Finland. In that building the fire protection thickness for the floor structure was reduced by 80% (IISI, 2004)[3].

Structural design for fire conditions in national steel design standards

Another advance is given in the American Institute of Steel Construction's 2005 Specification for Structural Steel Buildings, Appendix 4 entitled, Structural Design for Fire Conditions. The technical committee responsible for the Canadian structural steel design standard (CSA-S16) has incorporated a similar appendix, namely Appendix K, for the next edition of the standard in 2009. These documents are relatively short (10 pages) and are an aid for engineers to develop performance-based fire safety for buildings with structural steel.

CSA-S16's Appendix K also references a new gravity load combination stipulated in the User's Guide - NBCC 2005, Structural Commentaries (Part 4 of Division B). Commentary A, Limit States Design, Paragraph 25, "Load Combination for Determination of Fire Resistance," reads as follows:

$$D + T_S + (\alpha L \text{ or } 0.25S)$$

where

α = 1.0 for storage areas, equipment areas and service rooms, and 0.5 for other occupancies

D = specified dead load

L = specified occupancy live load

S = specified variable load due to snow

T_S = effects due to expansion, contraction, or deflection caused by temperature changes due to the design-basis fire

With the above equation, structural engineers are now in a position to treat structural design for fire as an engineered process, as is done for other load cases such as gravity, wind and earthquake, using codified procedures and sophisticated numerical tools.

The CSA-S16 Appendix K also tabulates Reduction Factors for Stress-Strain Relationship of Steel at Elevated Temperatures as given by Eurocodes 3 and 4. The particular part of Eurcode 3 (Part 1-2) deals solely with structural fire design and is an 80-page document — significantly more comprehensive in technical direction than the aforementioned AISC and CSA-S16 appendices.

WE ARE NOW IN A POSITION TO TREAT STRUCTURAL DESIGN FOR FIRE AS AN ENGINEERED PROCESS, AS IS DONE FOR OTHER LOAD CASES.

International fire engineering guidelines

The provisions in AISC and CSA-S16 appendices are general introductory guidelines to orient a structural engineer in performance-based fire engineering, a skill that, for the most part, is unfamiliar territory for the profession.

Many organizations such as the Society of Fire Protection Engineers have enhanced the dissemination of information related to fire protection engineering. Recently, collaboration among building code organizations has resulted in a 500-page document entitled International Fire Engineering Guidelines. Published by the Australian Building Codes Board in 2005, these guidelines set the stage for more fire safety design of buildings by aiding both the authorities who approve building designs and the practitioners who are plying the relatively new approaches to fire protection engineering. CCE

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[1] Franssen, J.M. 2003. "SAFIR, A Thermal/Structural Program Modeling Structures," Proceedings North American Steel Construction Conference, Baltimore, MD, April 2-5, 2003.

[2] Chen, F.F. and Gemeny, D.F. 2004. "Case Study Using SAFIR to Predict Fire Resistance of a Column in a Performance-Based Environment," *Fire Protection Engineering*, No. 23, summer 2004, pp. 30-35, SFPE.

[3] IISI. 2004. "Fire Safe Multi-storey Buildings, Economic Solutions in Steel." International Iron and Steel Institute, Brussels, Belgium.

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