Value Engineering of Passive Fire Protection for Structural Steel

By Arthur Nestor R. Iwankiw, P.E., PhD, J. Parker, P.E. and Jesse J. Beitel

Customary practice in the US is for the project architect to specify the necessary steel fire protection, as required by the prescriptive criteria of the building code. The structural engineer of record typically has no involvement in this process. Sometimes value engineering by a designated fire protection consultant or material supplier can result in substantial project cost savings and benefits. In some cases, it may not be project economy, but rather the nature of the innovative expressive design itself may motivate an engineered design. In such instances, the published fire resistance ratings and criteria may be too restrictive and more advanced or alternative, means and methods to comply with the code intent are often necessary. The latter is often referred to as “performance-based design”. Other background information on these topics was excerpted from the AISC publication Facts for Steel Buildings-Fire (2003) written by Iwankiw.

Building Code Requirements for Structural Fire Resistance

Fire resistance requirements are intended to provide for life safety and property protection by preventing fire spread and the collapse of the structure until all the building occupants have had an opportunity to evacuate the premises. Passive structural protection contributes only one part to the building’s overall fire safety. Several complementary fire and life safety features are necessary to enable adequate fire response, and the safe exiting of the occupants of a building in the event of a fire emergency. These include:

• Structural fire protection.
• Compartmentation, with both horizontal and vertical fire barriers.
• Fire alarm and detection devices.
• Automatic sprinklers.
• Smoke control.
• Egress provisions, including exits, stairs, elevators, and their locations and distances.
• Standpipes for fire department operations.

The balance of this article will deal exclusively with structural fire protection.

The newer IBC 2003 and NFPA 5000 model building codes are the most prominent model codes for present and future design and construction, though some vestiges of the prior 1997-2000 model codes from ICBO, BOCA and SBCCI remain in effect. These two codes are generally similar in terms of both structural design and fire resistance requirements. The reader should verify the actual fire protection requirements in the governing local building code, the referenced national code and standards for all the actual code requirements in a particular jurisdiction.

The method long used by the building codes is to separate buildings into various occupancy categories and use group sub-
categories. The IBC lists 10 occupancy categories, while NFPA 5000 has 11, such as assembly, business, educational, and factory/industrial. These categories are further segmented into use groups that are specifically described. For example, the assembly “A” occupancy in the IBC has 5 possible groups: A-1 through A-5.

Types of construction distinguish between combustible or non-combustible construction and the degree of fire resistance of the primary structural framing material. The principal structural elements of the building in Types I and II construction are required to be noncombustible, with some minor exceptions. Steel, concrete and masonry construction are noncombustible, and classified as either Type I or II construction. This IBC code classification system thereby specifies the highest inherent structural fire resistance to Types I and II, and the least to Type V. Accordingly, the more critical building occupancies and uses are prescribed to have the preferred Type I and II construction designations, with accompanying more liberal heights and area limitations. Types III, IV and V are progressively more restrictive in terms of allowable heights and areas. The building size, footprint, and its fire protection are typically determined in conjunction with the occupancy and type of construction allowed by the code.

The allowable heights and areas (see Table 503 in the IBC; Table 7.4.1 in NFPA 5000) contain the detailed information that delineates the various occupancy groups, heights and area limitations, and types of construction. These allowable heights and areas are the baseline reference, from which further increases are possible when provided with such considerations as sprinklers and frontage separation.

The high-rise building is defined by the IBC as one having an occupied floor more than 75 feet above the lowest level of fire department vehicle access. Automatic sprinklers are required for all high-rise buildings, with just a few exceptions in the IBC and no exceptions in NFPA 5000. Where supervised sprinkler control valves for each floor are present, either a reduction of the Type IA Construction to Type IB requirements, or a reduction of Type IB Construction to Type IIA requirements is permitted in the IBC. Similar reductions are allowed in NFPA 5000. These Construction Type reductions are important in determining the minimum required fire resistance ratings for the building elements. The fire resistance ratings for building elements have historically been defined

<table>
<thead>
<tr>
<th>Building Element</th>
<th>Type I</th>
<th>Type II</th>
<th>Type III</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>Structural frame</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Bearing Walls</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Exterior</td>
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<tr>
<td>Interior</td>
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<td>1</td>
</tr>
<tr>
<td>Floor Construction</td>
<td>1 1/2</td>
<td>1 1/2</td>
<td>1</td>
</tr>
<tr>
<td>Roof Construction</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Other background information on these topics was excerpted from the AISC publication Facts for Steel Buildings-Fire (2003) written by Iwankiw.
Table 1 (Based on Table 601 from the IBC) gives these fire resistance rating requirements, which are generally representative of construction practices over the last several decades. Types IA and IB in the IBC, as well as the comparable designations in the NFPA 5000, provide the greatest allowed heights and areas, which in many cases are unlimited by the code.

In high-rise buildings, special requirements for automatic sprinklers allow the Type IB construction requirements to be used for a Type IA building, and Type IIA requirements for a Type IB building. The practical implication of this for a Type IA building is a 1-hour reduction, from 3 hours to 2 hours, in the minimum fire resistance for the frame girders and columns; for a Type IB building, it is a 1-hour reduction for both the columns and floors, from 2 hours to 1 hour. These allowable fire resistance reductions are important, and, along with the available Type IIB Construction provisions for zero rating time (unprotected steel) in low-rise buildings, their implementation can result in meaningful cost savings on a given steel project.

### Type of Construction

Type of Construction affects the extent and cost of required structural fire protection, and is the basis on which the building will qualify given its use/occupancy, heights, areas, etc. Type of Construction is usually selected based on the owner’s project objectives (floor area, use and height of building), needs and the constraints of the available property location. However, careful early review of the applicable building code in this regard may reveal some reasonable and manageable substitutions or modifications to the original project plans. These may enable a move to a more favorable construction type designation to optimize the required fire resistance ratings for the structure.

For example, the initial project specifications may call for a building that appears to almost fit a preferred construction type or designation, but falls into the more stringent one that requires more fire protection. In small to medium size buildings of about 6 stories or less, if there is some project flexibility allowing for modifications to qualify for the less demanding construction type classification, then the potential for cost savings can be realized, with even possibly the attainment of unprotected Type IIB construction. However, it should be realized that certain mandatory code provisions, such as fire-rated shaft enclosures, including exits, would require similarly rated construction for its supports, thereby potentially limiting the range of use of Type IIB construction. Some trade-offs between floor area and number of stories, frontage area, or the discretionary use of sprinklers, are the primary means through which this favorable reduction of code requirements can be achieved. As with any major decision, agreement on the Type of Construction selection should be reached on the basis of full knowledgeable input from all the project parties and disciplines.

For high-rise buildings with unlimited heights and areas, Type IA or IB will be necessary per the IBC as the baseline, but the mandated use of sprinklers allows for a one category reduction in fire protection requirements, as previously described, which can translate for up to a 1-hour fire resistance difference in both the beams and columns.

### Product Selection

The common choices for protected steel construction include gypsum board, sprayed fire-resistive materials (SFRM), and intumescents/mastic coatings. New fire protection products and listed assemblies are continually being added to the inventory of available choices, as contained in the Underwriters Laboratory Fire Resistance Directory, Volume 1 and other sources. Timely independent and professional advice on this selection are likely to avoid problems or concerns about the appropriateness of a given structural fire protection product for the intended service and performance.

### Restrained and Unrestrained Ratings

Gewain and Troup (2001) summarized pertinent facts, past research, and historical experience to reinforce assertions that the restrained classification for fire protection design is most appropriate for steel beams, girders, floor and roof assemblies that support concrete slabs.
and that are welded or bolted to integral framing members, as given in ASTM E119-00, Appendix X3. The proposed AISC 2005 Specification for Structural Steel Buildings, in a new Appendix on structural design for fire conditions, is expected to explicitly contain this statement on use of restrained ratings for steel construction in fire design.

### Member Substitutions

In practice, it is common for floor beams to naturally exceed the minimum steel member sizes shown in the fire resistance designs. A heavier steel beam shape, or one with a greater W/D (weight to heated perimeter) ratio, may be conservatively substituted for the lighter members shown in fire-rated designs with the given protection thickness. However, doing so without compensating for the more favorable thermal mass characteristics of the beam with the higher W/D ratio is inefficient. This excessive overprotection of all floor members based on the smallest listed beam shape in the fire rated design occurs frequently, and can be costly. The preferred economical approach is to use the analytical relationships developed from fire test to determine the thickness requirements in SFRM requirements for the actual beams, or several size groupings, as a function of their actual W/D properties.

The fire resistance listings give the minimum steel column size necessary for the applicable fire rating — the member that was tested — comparable to what was done for steel beams. Again, larger members than the minimum steel size may be conservatively used with the fire protection requirements in a given design. However, if a lighter steel section is to be used for the column, more fire protection will be required. As in beams, the reason for this adjustment is the increased thermal mass capabilities of heavier members with larger W/D ratios, which require less insulation than lighter members for the same fire exposure conditions.

### Savings Projections With Prescriptive Criteria

The portion of the total project budget that is typically allocated to structural steel framing is less than 10 percent, and the associated structural fire protection typically comprises no more than roughly 10 to 15 percent of this steel package cost. This approximate 1 to 1½ percent of the overall budget for passive steel fire protection is modest, and seemingly would not appear to be a relatively significant cost factor. However, there is still significant potential to reduce cost without sacrifice of safety as shown in Table 2.

### Fire Engineering

More advanced fire engineering analyses, beyond the given pre-scriptive code requirements, may justify certain building design features or assess factors that are beyond the prescriptive scope of the current codes. These may include, but are not limited to, the need for unprotected or exposed construction due to architectural or other reasons, use of new (or not listed) materials or assemblies, consideration of member load effects and/or of natural (nonstandard) fire exposures. Externally unprotected construction would likewise typically require additional engineering study to verify its fire safety adequacy for the protected, noncombustible Type I or IIA designation of the building. While this work may be also partially motivated by economy, it is probably much more influenced by the non-financial project needs and constraints of the owner or architect, wherein the unique occupancy, appearance, and/or use of the building is expected to be consistent throughout its service life.

### Conclusions

Value engineering could identify meaningful direct cost savings and indirect benefits in the structural fire protection for some buildings and typical conditions, just by implementation of the regular prescriptive ratings and criteria of the current building codes. A suitably scoped peer review or code compliance check performed by an experienced structural fire protection engineering consultant could likewise serve the same purpose. The potential streamlining of common conservative design assumptions and excessive protective material applications can provide improved economy without sacrificing the intended safety objectives of the codes. In select cases, dependent on the exact nature of the encountered initial circumstances and size of the project, it is expected that very tangible passive fire protection cost savings or their reallocation can be realized, even reaching hundreds of thousands or several million dollars, as the example projections illustrated.

Additional engineering analyses of structural fire resistance for unique non-routine conditions (load effects, natural fires, or Architecturally Exposed Structural Steel) could likewise result in enhanced value to the project of terms of safely satisfying the owner’s and/or architect’s special objectives, apart from any economic aspects.

Greater professional engineering attention directed toward structural fire resistance design can safely bring both economic and functional benefits to the completed project.*

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### Table 2: Maximum Estimated Potential Savings in Structural Fire Protection (Passive) Costs (per ft² of floor area) for Steel Buildings

<table>
<thead>
<tr>
<th>Type of Construction</th>
<th>Low-rise (≤ 6 stories)</th>
<th>High-Rise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protected (IA, IB, IIA)</td>
<td>$0.30 - $0.60/ft²</td>
<td>$0.30 - $0.60/ft²</td>
</tr>
<tr>
<td>Unprotected (IIB)</td>
<td>$1.40-$2.00/ft²</td>
<td>N/A</td>
</tr>
</tbody>
</table>

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Arthur Parker, P.E. is a Senior Fire Protection Engineer Hughes Associates, Inc.

Jesse Beitel, is a Senior Scientist and Principal with Hughes Associates, Inc.

Nestor Iwankiw, P.E., PhD, is a Senior Engineer and Director of the Chicago Office, Hughes Associates, Inc.

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### References


International Code Council (2003), International Building Code, Falls Church, VA, 2003

