Errata

Replace

NIST GCR 02-843 with NIST GCR 02-843-1, (Revision 2008)

The Building and Fire Research Laboratory has made corrections to NIST GCR 02-843, December 2002.


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Corrections:

September 2008: Made changes to Table 2.1, Summary of Multi-Story Building Fires with Collapses (4 or more Stories), page 24 and continuing on page 25.

October 2008: Inserted Note page ii, and made a change to section, 2.4 Conclusions, first paragraph, last sentence, page 22.
Analysis of Needs and Existing Capabilities for Full-Scale Fire Resistance Testing

Prepared for
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Note

This report uses the term "fire-induced collapse" to indicate the failure of a structure, or significant portion of a structure, that could be attributable directly to a fire event in the building. In some cases, the building may have been under construction or in process of renovation, or it may have experienced significant damage prior to the fire caused by a blast, impact, or an earthquake. A subsequent report on the collapse of the WTC towers (NIST NCSTAR 1, September 2005) found that WTC 1 and WTC 2 collapsed due to aircraft impact damage to the structure and fireproofing as well as to fire. Both effects (damage and fire) were equally important. In the absence of structural and insulation damage, a fire substantially similar to or less intense than the fires encountered on September 11, 2001, likely would not have led to the collapse of a WTC tower. On the other hand, it was concluded in NIST NCSTAR 1A (October, 2008) that WTC 7 would have collapsed from fires having the same characteristics as those experienced on September 11, 2001, even without the initial structural damage to the building initiated by the collapse of WTC 1. The Building Performance Study conducted by the Federal Emergency Management Agency (FEMA 403, May 2002) refers to the partial collapse of WTC 5 as "fire-induced." No analysis was conducted to determine the relative roles of the initial structural damage and the subsequent fires that led to the fate of WTC 5.

The number of historical building collapses that are identified in this report as "fire-induced" (a total of 22) includes WTC 1, WTC 2, WTC 5 and WTC 7, consistent with the above definition of the term. This does not imply that WTC 1, WTC 2 or WTC 5 would have collapsed due to a severe, uncontrolled fire had the structure and/or insulation not been severely damaged prior to the outbreak of fire.
EXECUTIVE SUMMARY

This program\(^1\) was conducted for The National Institute For Standards and Technology under Contact Number NA1341-02-W-0686. Hughes Associates, Inc. performed this work with assistance from Greenhorne & O’Mara, Inc. and Thornton-Tomasetti-Cutts, LLC. The study was commissioned to analyze the needs and existing capabilities for full-scale fire resistance testing of structural connections. The Scope of Work consisted of three separate tasks. The tasks were:

**Task 1. Identification Of Building Collapse Incidents** - The objective of this Task was to conduct a survey of historical information on fire occurrences in multi-story (defined as four or more stories) buildings, which resulted in full or partial structural collapse.

**Task 2. Survey Of Fire Resistance Test Facilities** - The objective of this Task was to perform a survey of private and public facilities capable of testing the structural integrity of building elements under fire conditions.

**Task 3. Needs Assessment** - The objective of this Task was to perform an assessment of the need for additional testing and/or experimental facilities to allow the performance of structural assemblies and fire resistance materials to be predicted under extreme fire conditions within actual buildings; and if a need does exist, options for meeting those needs.

In Task 1, the search for this data was conducted using three principal sources: news databases, published literature, and direct inquiries to key individuals and organizations. Even though the task objective was to identify multi-story fire-induced collapses, other useful and pertinent information on major multi-story fires without collapses, but with major structural damage was obtained. The results of the world-wide survey indicated that a total of 22 fire-induced collapses were identified spanning from 1970 to the present. The 2001 World Trade Center (WTC) collapses accounted for four of these events. Seven major multi-story fire events were also identified as having significant structural damage due to a fire, but did not exhibit collapse. While this total number of fire events may appear low (average of one/year) these fire events are high consequence events with respect to economic costs and potential for loss of life and/or injuries.

In Task 2, the survey of the potential testing laboratories was conducted via questionnaires sent to various laboratories, organizations, and individuals. The responses were collated and reported. In general, the existing facilities can perform the standardized fire resistance tests which generally limit the various test parameters with respect to testing individual building elements, size of elements, fire exposure conditions, downward live loading, and measurements obtained. The survey did identify that to some limited extent, some combinations of building elements may be evaluated in the existing test furnaces but no one laboratory can provide all of the combinations of size, capabilities, etc. Also, no facility readily exists that can provide full- or real-scale tests of combinations of building elements or their connections and interactions.

Task 3, the needs assessment found that a more complete understanding of structural performance of building elements when exposed to a fire is required. Structural fire protection

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\(^1\) HAI Project #5243, Hughes Associates, Inc.
has largely been ignored as a research area in the past 25 years and the WTC collapses have renewed interest in this area of research. It is apparent that research into structural fire protection performance will require unique test facilities to be developed. Specialized test apparatus and instrumentation for large structural assemblies, for real-scale building elements and their connections, and full- or real-scale combinations of elements will need to be constructed. Specialized and enhanced instrumentation will also be needed.

**DISCLAIMER**

Certain companies and commercial products are identified in this report in order to specify adequately the source of information or of equipment used. Such identification does not imply endorsement or recommendation by the National Institute of Standards and Technology, nor does it imply that this source or equipment or services is the best available for the purpose.
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1.0 INTRODUCTION

This study reported here was conducted for the National Institute of Standards and Technology (NIST) under Contact Number NA1341-02-W-0686. Hughes Associates, Inc. performed this work with assistance from Greenhorne & O’Mara, Inc. and Thornton-Tomasetti-Cutts, LLC.

The study was commissioned to analyze the needs and existing capabilities for full-scale fire resistance testing of structural connections.

The Scope of Work consisted of three separate tasks.

Task 1. Identification of Building Collapse Incidents

The objective of this Task was to conduct a survey of historical information on fire occurrences in multi-story (defined as four or more stories) buildings, which resulted in structural collapse. Either partial or total failure of the structural framing, members, and/or connections was considered to have constituted a collapse.

Task 2. Survey of Fire Resistance Test Facilities

The objective of this Task was to survey private and public facilities (for-profit, not-for-profit; academic, local, state and federal government; military and civilian; domestic and international) capable of testing structural integrity of building elements under fire conditions to establish the current global research capabilities in structural fire protection.

Task 3. Needs Assessment

The objective of this Task was to perform an assessment of the need for additional testing and/or experimental facilities to support the development of predictive structural fire protection methods within actual buildings; and if a need does exist, options for meeting those needs.
2.0 TASK 1: IDENTIFICATION OF BUILDING COLLAPSE INCIDENTS

2.1 Objective

The objective of this Task was to survey historical information on fire occurrences in multi-story (defined as four or more stories) buildings, which resulted in structural collapse. Either partial or total failure of the structural framing, members, and/or connections was considered to have met the definition of “collapse.”

Information sought included:

- Date and location of fire;
- Type of building, its occupancy use, construction type, number of stories, etc.;
- Cause and extent of the fire event;
- Description of the structural collapse;
- Additional information concerning the event, as available; and
- Reference for the fire event information to include literature citations, etc.

2.2 Survey Scope and Methodology

The historical search for catastrophic multi-story fires included incidents dating back to the 1950’s, or earlier, with emphasis on those which occurred in North America. In addition, similar events that occurred throughout the world were also solicited and captured as available. The search for this data was conducted using three principal sources: news databases, published literature, and direct inquiries to key individuals and organizations. Even though the task objective was to identify multi-story fire-induced collapses, other useful and pertinent information on major multi-story fires without collapses was obtained during the normal course of this survey process. For the sake of completeness, there is also a short presentation and discussion of low-rise (less than 4 story buildings) fires with structural collapses.

2.2.1 News Sources

With the volume of information reported electronically concerning the collapse of the World Trade Center (WTC), it was necessary to filter much of the web-based information to find the additional cases. Standard Internet search engines did not yield many specific fires with collapse. Consequently, news sources were consulted for their record of major fire events. LexisNexis™, a powerful full text news database, provided the ability to search for occurrences where both fire and collapse appeared in the same sentence. The keyword story was also included to determine whether the case fit the desired multi-story profile. The WTC Towers were removed from the search in news articles after September 11, 2001. Major world news sources, as well as local US sources, were searched from 1997 to present, the primary time frame included by electronic database sources.
The news sources that were searched included:

LexisNexis™ Academic Universe News Category Online

World News (various news sites outside U.S)
General News>Major Newspapers> 1997 to present

US News (various news sites in U.S.)
Midwest > 1997 to present
Northeast > 1997 to present
Southeast> 1997 to present
Western> 1997 to present

ABC News
www.abcnews.com

NBC News
www.msnbc.com

BBC News
http://news.bbc.co.uk /

NIOSH Firefighter Fatality Investigation Reports
http://www.cdc.gov/niosh/facerpts.html

California Occupational Health Surveillance and Evaluation Program
http://www.dhs.cahwnet.gov/ohb/OHSEP/FACE/97CA003.htm

US Fire Administration

Interfire.org

NFPA
www.NFPA.org

The world search was divided into North/South America, Europe, Asia/Pacific, and Middle East/Africa. The US was divided into Midwest, Northeast, Southeast, and West regions.

Commercial news websites did not provide much useful fire data. The one exception was the BBC, from which two major fire-induced collapses were identified. Other news websites did not have powerful search capabilities.
Data sources focused on firefighter and other fatalities were also searched for fire-induced structural failures. The National Institute for Occupational Safety & Health (NIOSH) Firefighter Fatality/Injury Investigation Reports online included some fire-induced structural collapses. The US Fire Administration National Fire Incident Reporting System (NFIRS) database was general in nature and did not indicate whether structural failures had occurred. It was apparent that within the fire community’s reporting and tabulation of fire events and fatalities, the occurrence of either partial or total collapse of a structure was not specifically recorded or reported. This seriously limited our ability to understand the nature and extent of fire-induced structural collapses.

2.2.2 Literature

The engineering literature database “Compendex” was searched using the keyword collapse, but most documents covered only analytical simulation or modeling work. NIST’s FireDoc database similarly did not provide any actual cases.

Many National Fire Protection Association (NFPA) reports and other available publications were reviewed. The most pertinent survey references are given in Section 5.0. There is no single, or central systematic repository of data on the fire-induced structural collapse, either in the US or abroad.

2.2.3 Direct Inquiries

To supplement the broad and extensive news and literature searches, direct contacts were made with individuals and organizations that were expected to have authoritative information on historical fire-induced collapses. The list of domestic and international professional organizations, companies, and/or governmental agencies contacted included:

- ABS-EQE
- American Concrete Institute (ACI)
- American Institute of Steel Construction (AISC)
- American Iron and Steel Institute (AISI)
- American Society of Civil Engineers (ASCE)
- Arbed Steel
- British Constructional Steel Association (BCSA)
- Canadian Institute of Steel Construction (CISC)
- Construction Technology Laboratory (CTL)
- Corus-British Steel
- CTICM, France
- Disaster Prevention Institute, Kyoto University, Japan
- Factory Mutual Research Corporation (FMRC)
- Institute for Business and Home Safety
- International Association For Fire Safety Science (IAFSS)
- Isolatek International
- Mexican Institute of Steel Construction (IMCA)
- National Fire Protection Association (NFPA)
In addition, a survey request for information was sent to several prominent engineers and consulting firms.

Special acknowledgment for their contributions of pertinent papers, reports, and other information in response to these direct requests is given to Dr. Rosario Ono, Institute for Technological Research, Dr. Farid Alfawakhir, American Institute of Steel Construction (AISC), Mr. John Dowling, Corus-British Steel, Mr. Manny Herrera of Isolatek International, and Mr. Robert Duval and Ms. Teresa Frydryk of NFPA.

2.3 Survey Results

The results of this study for fire-induced collapses of multi-story buildings are given in Section 2.3.1. Section 2.3.1 includes a summary table and further discussion of these important incidents. In Sections 2.3.2 and 2.3.3, ancillary information on fire damage and casualties is also presented for major multi-story fires without collapses, and for low-rise building fires with collapses. Section 2.3.4 discusses fires after major earthquakes and conclusions are given in Section 2.4.

2.3.1 Multi-story Buildings with Fire-induced Collapses

Table 2.1 presents the summary findings of the survey for this category of fire incidents in chronological order, starting with the most recent events (all tables found at the end of each Section). A total of 22 fire-induced collapses were found. Table 2.1 contains the basic highlights of the building fire and further explanations and descriptions of most of these catastrophic events are included in this section.

The events related to the September 11, 2001 terrorist attacks on the World Trade Center (WTC) complex in New York are the dominant fire and collapse events of this survey (represented as 4 separate incidents). The Federal Emergency Management Agency (FEMA) report (FEMA 403) published in May, 2002 is a notable reference that provides an overview of each of the directly affected buildings (WTC 1, WTC 2, WTC 5, WTC 7). The FEMA report also contains the structural, architectural, and fire resistance design characteristics of the various WTC buildings and the nearby damaged structures. Even though the fires were the final destructive force in the collapse of the WTC Towers, their pre-fire condition with extensive structural and fire protection system damage due to the unprecedented impacts by the two large commercial aircraft presented a unique hazard.

The 9-story WTC 5 building suffered extensive structural damage due to WTC 1 debris, which subsequently led to partial collapses of 4 floors due to fires. Interior floor beam splices
between supporting column-tree stubs and beams were identified as the point of fire-induced failure of these several floor bays.

Figure 2.1a shows the fires in the damaged WTC 1 and 2 Towers before collapse, while Figure 2.1b shows the blaze in WTC 5. The representative fire damage in WTC 5 is given in Figure 2.1c, while the aforementioned column tree connection and floor failures are pictured in Figure 2.1d.

The full collapse of the 47-story steel-framed WTC 7 has been attributed to fire causes, which occurred approximately eight hours after the collapse of WTC 1. The structural steel framing and fire protection in WTC 7 were quite conventional, when the building was placed into service in 1987. Perimeter steel moment frames, 2-story belt trusses, and an interior braced core at the lower levels provided lateral resistance features. The floors were typical steel beams with composite deck and concrete topping. The nature of the September 11th fires and their destructive structural effects are the subject of an ongoing investigation by National Institute of Standards and Technology (NIST).

On September 11, 2001 the 5-story Pentagon building in Washington, DC, was struck by an aircraft, resulting in extensive damage and fire (see Figure 2.2). The Pentagon was constructed between 1941 and 1943 of hardened, cast-in-place reinforced concrete. News, anecdotal and visual observations indicate that there were some partial structural collapses in the Pentagon due to the ensuing fires approximately 30 minutes after the jet impact. An official investigation of the incident is being prepared but has not yet been released. There is no other publicly available information on the nature and progression of the structural damage in the Pentagon resulting from the jet crash and subsequent fire.

The remainder of this Section will focus on the less publicized, but still significant, fire-induced collapses of multi-story buildings. Brief overviews of these incidents are provided to supplement the Table 2.1 summary. The information on the following incidents was obtained from news media reports, unless otherwise noted with particular citations or references. Longer narratives are provided for the more significant events.
Figure 2.1a  Damaged and Burning WTC 1 (right) and WTC 2 (left) on Sept. 11, 2001

Figure 2.1b  Fires in WTC 5
Figure 2.1c  Fire Damage in WTC 5

Figure 2.1d  Partial Connection and Floor Failures in WTC 5
The most recent incident reported was the destruction of the Santana Row, Building 7 in San Jose, CA on August 19, 2002 (Chui, 2002; Gathright, et.al., 2002). This structure was a 5-story wood frame retail and residential complex that was under construction. With incomplete fire protection systems, the building was much more susceptible to fire spread and damage. Witnesses state that the fire started on the roof, where construction work was underway. The entire complex collapsed due to the fire.

Another recent fire-induced building collapse occurred in St. Petersburg, Russia on June 3, 2002 (BBC News Online, 2002; Ottawa Citizen, 2002). This building was a 9-story concrete apartment block that totally collapsed after about a one hour fire (See Figure 2.3). The news services reported only 1 related casualty, with about 400 other residents safely evacuating the burning building prior to collapse. It was reported that ongoing reconstruction work at this site had accidentally ruptured a gas line, which ignited and fueled this fire.

A severe fire in the 21-story Jackson Street Apartment building in Hamilton, Ontario on February 8, 2002 (Stephan, 2002) caused partial collapse of a floor/ceiling assembly. Fragments of concrete, as well as lath and plaster, were reported to have injured several firefighters, but no fatalities were reported.

On February 27, 2001, the 4-story Faces Nightclub and Memories Lounge Bar building in Motherwell, Lanarkshire, UK experienced a total collapse after burning for approximately 2 hours (The Herald (Glasgow), 2001).
A fire-initiated collapse of a 6-story reinforced concrete textile factory occurred in Alexandria, Egypt on July 19, 2000 (Reuters News, 2000; BBC News, 2000). The fire started in the storage room at the ground floor. Fire extinguishers were non-functional, and the fire spread quickly before firefighters arrived. Approximately nine hours after the start of the fire, when the blaze seemingly was under control and subsiding, the building suddenly collapsed, killing 27 people. Figure 2.4 shows a photograph of this collapse.

Between 1993 and 2000, six other fire-induced collapses were reported in the news media (Table 2.1). The buildings were all four to eight story, mostly residential, buildings in the USA. The "old" wood Vandergrift apartments in Pittsburgh, PA (Belser, 2000) totally collapsed on
May 7 2000. The collapse was initiated by a back wall failure, causing several fatalities. On February 9, 2000 in Newton, MA (Burke, 2000), a 4-story, brick commercial building collapsed about one hour after the start of the fire, with the upper stories collapsing onto the floors below. One casualty resulted, probably due to the fire itself. This building had been undergoing roof, facade, and electrical renovations. The remaining incidents between 1993 and 2000 caused partial structural collapses with no reported fatalities, such as the roof and/or floor collapses in the Effingham Plaza Nursing Home in Portsmouth, VA on April 6, 1998 (Portsmouth Times, 1998), in the Coeur de Royale Condominium in Creve Coeur, MO on August 25, 1994 (Bell, 1994), and in the Central Square Apartments in Cambridge, MA on Oct. 4, 1993 (Tong, 1993). Apartments in Bronx, New York experienced collapse of the entire rear of the building on April 5, 1994 (Onishi, 1994), killing three people.

On May 21, 1987, Sao Paulo experienced one of the biggest fires in Brazil, which precipitated a substantial partial collapse of the central core of the CESP Building 2. This was a 21-story office building, headquarters of the Sao Paulo Power Company (CESP). Buildings 1 and 2 of this office complex were both constructed of reinforced concrete framing, with ribbed slab floors. According to Berto and Tomina (1988), these two buildings had several unique internal features and contents. Both buildings retained their original wood forms used for pouring the concrete floor slabs. Low-height plywood partition walls were also installed in the interiors. The ceiling in CESP 1 was made of plywood attached to the wood forms, while plaster tiles covered the ceiling in Building 2. Both buildings had automatic fire detection and manual fire alarms, but no automatic sprinkler system. Six footbridges connected these 2 buildings to permit convenient pedestrian access at various levels across a separation distance of 9.5 m.

The CESP fire started on the fifth floor of Building 1 from electrical causes, and progressed rapidly upward due to the combustible (wood) ceilings, the underlying formwork, and lack of adequate compartmentalization. Due to the severity of the Building 1 fire and other factors, it not only spread within this building, but also to the companion Building 2. The subsequent fires in CESP 2 ignited simultaneously on several floors due to the high thermal radiation from the original CESP 1 fire. In the presence of similar combustible partition walls and wood floor formwork, the CESP 2 fire also spread quickly. Firefighting efforts in both buildings were unsuccessful. Approximately two hours after the beginning of the fire in CESP 2, its structural core area throughout the full building height collapsed. This collapse was attributed to the thermal expansion of the horizontal concrete T-beams due to fire exposure. This led to the fracture of the vertical framing elements and their connections in the middle of the building, and the subsequent progressive loss of gravity load-carrying capacity (Figure 2.5). After the Building 2 collapse, the fire in Building 1, which was burning out, then re-ignited in floors 1-4 due of the flaming debris pile on the lower levels from Building 2. It was reported that this entire incident, from the original fire ignition in Building 1, spread to Building 2, the collapse of CESP 2 core, and the final re-ignition and burning of the lower floors of Building 1 lasted a total of about seven hours. The fire occurred in the evening and no casualties were reported.
The Alexis Nihon Plaza fire in Montreal, Canada occurred on October 26, 1986 (Isner, 1986). The building was a 15-story steel-framed office building that was built atop a wide 5-story concrete mall and parking garage. This complex included an adjacent 23-story office building and a 32-story apartment building, all supported by this concrete plaza. The 15-story office tower had conventional steel framing, consisting of steel beam and deck floors and steel columns. The beams and floors had a 3-hour fire rating, while the columns had a 2.5-hour rating. All building elements were insulated with spray-applied mineral fiber. There was no automatic sprinkler system installed in the building. On October 26, 1986 a fire began on the 10th floor, then spread to the 11th and 12th floors, and later to the top floor. Approximately five hours after the fire started, a section of the 11th floor collapsed onto the 10th floor. The fire was declared out the following morning. There were no fatalities or injuries.

Isner stated that the partial collapse involved the failure of the ends of several steel girders supporting the 11th floor, as well as an entire 9.1 m by 12.2 m floor section. Isner reported that these partial collapses resulted from weld fractures of clip angles that connected the floor girders to the columns. It was noted that the steel girders and beams of the collapsed floor section were virtually straight and un-deformed, suggesting that the structural members were not exposed to excessively high fire temperatures or stresses.

As a postscript to this incident, Isner indicated that a smaller second fire occurred in this same building almost one year later during its reconstruction. On November 16, 1987 a fire occurred on the 9th floor, which had received little damage during the initial fire. Firefighters successfully extinguished this fire in approximately 45 minutes. Similar to the previous 1986
fire, several floor girders and beams in the area exposed to the fire collapsed locally, due to weld fractures in the clip angle connections between the beams and columns. The steel members themselves were again observed to be straight and undistorted.

Papaioannou (1986) documented two large department store fires in Athens, Greece in 1980. These suspected arson fires occurred on December 19, 1980. The Katrantzos Sport Department Store was an 8-story reinforced concrete building. Its fire started at the 7th floor and rapidly spread throughout the building, due to lack of vertical or horizontal compartmentalization and the absence of an automatic sprinkler system. Collected evidence indicated that the fire temperatures reached 1000 °C over the 2-3 hour fire duration, and the firefighters concentrated on limiting fire spread to the adjacent buildings. Upon extinguishment of these fires, it was discovered that a major part of the 5th through 8th floors had collapsed. Various other floor and column failures throughout the Katrantzos Building were also observed, (see Figure 2.6). The cause of these failures was considered to be restraint of the differential thermal expansion of the structure that overloaded its specific elements or connections.

Figure 2.6 Katrantzos Department Building in Athens after the 1980 Fire

A partial roof and column collapse of the Military Personnel Record Center occurred on July 12, 1973 (Sharry, et.al., 1974). This was a large 86 m by 222 m, 6-story office building constructed of reinforced concrete. The building was located in Overland, MO and was built in the late 1950’s. Sprinklers were present only on the first and second floors. The fire was reported to have started on the 6th floor. Due to the high fuel load of 21.7 million record files stored on the 6th floor, the fire burned out of control for 20 hours. The fire was finally extinguished after 4 days. The roof collapse began after approximately 12 hours of fire exposure, and involved 30% of the roof slab above the estimated point of fire origin. Subsequently, most of the remaining freestanding columns on the 6th floor collapsed. Minimal fire damage was experienced below the 6th floor. The collapse and damage were later attributed
to the large horizontal expansion of the 18 cm thick, conventional concrete roof slab that was supported by 41 cm reinforced square-tied columns. There were no expansion joints in the floors or roof. Lateral roof displacements of almost 60 cm occurred in one corner. Figure 2.7 shows the extent of the sixth floor horizontal deformation and damage to the concrete columns due to thermal expansion of the roof. The damage to the columns appeared to be analogous to the brittle column failures that have often occurred during earthquakes.

![Figure 2.7](image)

**Figure 2.7** Large Lateral Deformations and Failure of Columns at Sixth Floor of Military Personnel Records Center

Another fire collapse occurred at the historic Hotel Vendome in Boston, MA. Built in the late 19th century of masonry and cast iron, this 5-story building was being renovated when a fire started at on June 17, 1972. After burning for almost 3 hours, all five floors in a 12 m by 13.7 m section collapsed (See Figure 2.8). This incident and the subsequent investigation were described in the *NFPA Fire Journal,* (January, 1973). Ongoing renovation work had caused excessive stresses on the bearing wall under a cast iron column, which was apparently already on the verge of overloading before the fire event.

The One New York Plaza fire occurred on August 5, 1970 (N.Y. Board of Fire Underwriters, 1970) in a 50-story office building constructed of structural steel floor and column framing with a reinforced concrete core. The steel beams and columns were fire protected. The fire started on the 33rd floor and lasted for about 5 hours. The resulting damage was restricted to the 33rd and 34th floors, wherein beams were visibly twisted and deflected. More significantly, filler beams in several sections of these floors dropped onto their supporting girders due to the fracture of the end connection bolts. These local connection failures were attributed to isolated unprotected areas of the steel connections, either due to localized removal of the spray-applied steel fireproofing materials to accommodate certain construction details, accidental
localized fireproofing application omissions, or material fall-off. There were no further collapses of the structural framing during this fire. These localized steel connection failures which occurred in the fire at the One New York Plaza were somewhat similar to those that occurred in the 1986 Alexis Nihon Plaza fire and in the 2001 WTC 5 fire.

In order to have been included in this incident tabulation, fire needed to have been judged the proximate cause for the building collapse (partial or total). Hence, any collapses due primarily to explosions, impacts, earthquakes, wind, and other construction or design factors were beyond the scope of this survey, even if fires had developed during the course of these events.

This survey was restricted only to building fires, so fires in such non-building structures as tunnels, bridges, transmission towers, storage tanks, etc. were excluded. Given these restrictions, the major damage and apparently incipient collapse conditions due to the August 27, 2000 fire in the Ostankino Tower in Moscow, Russia was omitted. This 539 m high Tower was Europe’s tallest structure used for broadcasting and communications, but technically not a building. It endured a 24 hour fire with four casualties. According to the news sources, much of the prestressed concrete Tower’s steel tendons were compromised. Because of this structural
damage, some have claimed that the Tower was on the verge of collapse during and immediately after the fire.

Also, the aggregated building destruction and damage in Kuwait due to the 1990 Iraqi occupation documented by Al-Mutairi and Al-Shaleh (1997) was not included in this survey. This paper was vague with respect to cause and effect documentation, and lacked specific data on any individual buildings. Similarly, the recent incident on July 12, 2002 of a structural collapse and fire of the 10-story storage facility owned by Quad/Graphics Inc. in Fond du Lac, WI, USA was omitted from the survey results. There are major open questions whether a rack system structural failure precipitated the subsequent collapse and fire, or vice versa. There is a private engineering investigation of this event being conducted at this time.

It was equally difficult to evaluate the separate effects of the many fires in buildings that are known to have occurred after major earthquakes. This subject is addressed later in Section 2.3.4.

In summary, a total of 22 cases from 1970-2002 are presented in Table 2.1, with 15 from the US and two from Canada. The number of fire-induced collapse events can be categorized by building construction material as follows:

- Concrete: 7
- Structural steel: 6
- Brick/masonry: 5
- Unknown: 2
- Wood: 2

Three of these events were from the 1970’s, three were from the 1980’s, four were from the 1990’s, and twelve occurred in 2000 and beyond. This temporal distribution was skewed towards more recent occurrences both due to the magnitude of the WTC collapses (4 collapse events) and the enhanced availability of computerized news media data.

The collapse distribution by building story height was as follows:

- 4-8 stories: 13
- 9-20: 3
- 21 or more: 6

Almost 60% of the cases occurred in the 4-8 story building height range, with the remainder affecting much taller buildings. Six collapses occurred in buildings over 20 stories, with three of these occurring at the World Trade Center complex (WTC 1, WTC 2 and WTC 7).

At least four of these fire-induced collapses occurred during construction or renovations, when the usual architectural, structural and fire protection functions were incomplete or temporarily disrupted. Partial collapses (14 events) were the most frequent occurrences, and the three World Trade Center complete collapses dominated the full collapse event total of eight
cases. Office and residential were the primary occupancy types in these 20 buildings, as would be expected in multi-story construction. The occupancy distribution is as follows:

- Office: 9
- Residential: 8
- Commercial: 3
- Combined commercial/residential: 2

Among the general observations from this survey of fire-induced collapses of multi-story buildings was that while they are relatively few in number, the consequences were significant, and could have been even worse in terms of human fatalities and economic losses. The fire risk appeared to be slightly higher during building construction and renovation work. Of the 17 fire incidents in the US and Canada, only the Santana Row development collapse in San Jose, CA, occurred outside the northeastern quadrant of North America (North and East of Missouri).

This data demonstrated that buildings of all types of construction and occupancies, in North America, and abroad, are susceptible to fire-induced collapse, particularly older buildings. The annual fire occurrences in the US, according to Hall, (2001), exceeded 10,000 in buildings that were 7-stories or taller. Those that were undergoing repairs or renovations appeared to further increase the fire and collapse risk. If the fire could not be quickly contained and suppressed by sprinklers, firefighters, or other fire protection measures, it posed a serious life safety hazard for any of the building occupants present. Continued fire spread can lead to a partial or total collapse in a multi-story building, compounding occupant losses, as in some of the cases described above.

Difficulties were encountered during this survey in readily identifying news, and other credible sources of historical and technical information on the fire-induced collapses of buildings. The potential data sources were fragmented, often incomplete, and sometimes conflicting. This lack of data and information significantly hampered the development of a more complete understanding of the magnitude and nature of fire-induced collapse. A centralized reliable body of catalogued information on fire-induced building collapses is needed.

The building code and design objectives are to provide sufficient warning and egress time during a fire emergency that would enable the building occupants to safely evacuate, even if there was an eventual structural collapse. Just as for other natural hazards (wind or earthquake), the time, location, and characteristics of the fire are critical in determining the human and property losses. The total deaths reported for the events in Table 2.1 were over 3,000. Over 2,800 occurred in the recent 2001 collapses of WTC 1 and WTC 2.

A fire-induced collapse in a multi-story building can be classified as a low frequency, high-consequence event. Modern society draws much attention to these and attempts to prevent them, much as it does for earthquakes and windstorms. Given that there can be no guarantee that a fire will not occur in a given building, or that it will be successfully contained and suppressed, the fire resistance of the building structure must be duly assessed in its design in order to avoid local and progressive collapses. Since several of these documented cases demonstrated various member and structural connection failures, a better understanding of the response of various
building connections to fire is needed. The effects of elevated temperatures on the strength of connectors themselves and on their ductility, as well as how thermal expansion of adjacent heated members affects the stress redistribution in a floor and framing sub-assemblage through its connections, are important issues yet to be resolved. Connections are generally recognized as the critical link in the collapse vulnerability of all structural framing systems, whether or not fire is involved.

2.3.2 Selected High-Rise Building Fires Without Collapses, But With Major Structural Damage

To complement the fire-induced collapse cases described previously, a summary of selected major recent fires in high-rises that did not suffer collapse, but did incur significant structural fire damage, are presented in Table 2.2. The significance of the selected 7 major fire events in Table 2.2 was that even though there was no associated structural collapse, there was significant fire damage and enormous property loss.

Hall tabulated several hundred high-rise structural fires from 1911-present with fatalities in his 2001 NFPA report, using the NFPA high-rise definition of a building of 7 stories or more. Table 2.3 (Hall, 2001) reported all high-rise fire occurrences in the US (by year) from 1985-1998 for four occupancy (property) classes: apartments, hotels and motels, hospitals and care facilities, and offices. The annual fire occurrences in such high-rises ranged from 10,000 to 17,200 per year, with annual civilian deaths between 23 and 110, annual civilian injuries between 554 to 950, and annual direct property damage between $24.9 million to $150.1 million. It would appear that based on the direct property damage estimates, the majority of these fires were small in nature. To include the fires from other high-rise property classes and in residences with unreported heights, a multiplication factor of approximately 33% was suggested by Hall. This increased the annual range of actual high-rise fire occurrences in the US from 10,000-17,200 to 13,330-22,900. If one were to further adjust this historical fire data for the difference in number of stories between NFPA’s high-rise statistics and the NIST multi-story definition as being 4 stories or more (i.e., add 4-6 story buildings to the NFPA summary of 7-story and higher), the number of incidents would be higher.

The 1980 MGM Grand Hotel fire in Las Vegas (Clark County Fire Department, 1981) killed 84 people, injured another 679 people, and caused hundreds of millions of dollars worth of property damage (Clark County Report). The First Interstate Bank (Klem, 1988) (4 floors burned out) and One Meridian Plaza (Klem, 1991)(9 floors burned out) in the US, and the Mercantile Credit Insurance Building and Broadgate fires in the UK (Newman, et al., 2000) are notable examples of excellent overall structural integrity under adverse fire conditions. Some casualties and major economic losses were still incurred in these steel-framed buildings. Complete burnouts of several floors destroyed the interior contents and caused substantial and permanent floor sagging and steel beam distortions, as would be expected after a long, severe fire exposure. In the One Meridian Plaza fire, deflection of main support beams were recorded as large as 46 cm, and one entire area of the 22nd floor had deformed by 1.2–1.5 m. (See Figure 2.9). All the buildings listed in Table 2.2, with the exception of One Meridian Plaza, were repaired and returned to service. After extensive investigations and studies, One Meridian Plaza was dismantled for economic reasons.
Sao Paulo, Brazil had two major high-rise fires in the 1970s. The 31-story Andraus building fire on Feb. 21, 1972 resulted in 16 casualties, while the 25-story Joelma fire caused 189 deaths on Feb. 1, 1974. (Hall, 2001 and Willey, 1972.) Both of these office buildings were constructed of reinforced concrete framing, and contained much of the same nonstructural wood combustibles (floor forms, ceiling tiles, and floor covering) as was previously discussed for the 1987 CESP Building collapse in Sao Paulo. The fires caused severe spalling of large portions of the exterior concrete walls, joists, and columns, exposing the reinforcing steel, due to the severe fire temperatures. Nevertheless, both the Andraus and Joelma buildings remained standing without any collapses. The building were subsequently repaired and returned to service.

Two major fire test programs have been conducted in the UK on full-scale, multi-story and multi-bay structures exposed to fires, at the Building Research Establishment (BRE) Laboratories in Cardington. The first series of tests was conducted on a representative 8-story composite steel-framed office building in September, 1996, (Newman, et. al, 2000). Significant fire damage occurred, as expected, but there were no progressive failures, even with unprotected steel floors. Many other technical observations on the overall high temperature behavior of entire steel structures, as opposed to just isolated individual elements of the structure, were also made. During the summer of 2001, BRE performed another major fire test of a 7-story concrete building (Bailey, 2001). Extensive spalling of the floors and significant lateral displacements of the external columns were experienced, but again without failures, as the compressive slab membrane action provided a secondary strength mechanism.

Both of these research programs strongly suggest that further work on the structural fire response of the entire building framing should be conducted to develop a better understanding of structural fire safety, both in steel and concrete construction.
2.3.3 Low-Rise Buildings with Collapse

Fifty-nine low-rise (2-3 stories in height) building fires with structural collapse, shown in Table 2.4, were found using a world-wide newspaper search dating back five years. This number of entries were assumed to be only a subset of the total number of actual occurrences in this category based upon the limitations of the time frame of the search. As indicated low-rise, multi-story incidents (2-3 stories) with some type of collapse occur frequently. Because of their smaller size and occupancies, they had relatively less catastrophic outcomes per incident.

Of the 59 low-rise fires identified in Table 2.4, 49 occurred in North America (45 in the US and 4 in Canada). The vast majority of the low-rise fire collapses were apartments and residential dwellings constructed of wood or brick construction. Generally, three modes of partial collapse were present: floor, wall, and roof. There were only 5-6 cases (or about 10% of these 59 incidents) that led to a total collapse of the structure. Floor and roof collapse were the most common types of partial failures. The information found in the news report was generally provided by fire department personnel. Casualty data ranged from injuries to multiple deaths. Some collapses caused the residents and firefighters to become remotely trapped, or instantly buried. This survey focused on merely identifying these representative collapse incidents, considering the large number of records reviewed and others that were available for low-rise incidents.

2.3.4 Fires after Earthquakes

A fire by itself presents a serious emergency condition, but it can be further exacerbated by another hazardous event(s), such as an earthquake, war, explosions or impact. It is well recognized that a cluster of building fires occurs immediately after most major earthquakes in urban areas. The post-earthquake fire losses can sometimes be comparable to those created by the ground movement alone. Under these circumstances, there is an increased risk of fire sources, reduced or strained firefighting capabilities, the presence of structural damage, and damage to the buildings’ fire protection systems.

The 1906 San Francisco earthquake was the signature destructive event of the early 20th century that first emphasized the urgent need for additional seismic structural design criteria for buildings in the US. Likewise, the 1906 earthquake brought to light the danger of the many large fires in the city that added numerous, undocumented, structural failures. Over 3000 individuals died, and the earthquake and fires destroyed large areas of San Francisco. Post-earthquake fire danger has long been acknowledged and has often been repeated.

For this reason, the following general data is provided on the fire effects after the more recent strong earthquakes (Sugahara, 1997; NISTIR 6030, 1996; EQE website):

- October 17, 1989 Loma Prieta Earthquake
  San Francisco experienced 22 structural fires and over 500 reported incidents during the seven hours after the earthquake began. It appeared that all of these affected low-rise buildings (with less than 4 stories), and mostly residential buildings.
• January 17, 1994 Northridge, CA Earthquake

The Los Angeles Fire Department reported 476 fire incidents during almost a 20-hour period following the earthquake, in contrast to a normal daily count of 50-100 incidents. Other surrounding jurisdictions also reported large numbers of post-earthquake fire calls on that day, including 300 from the Ventura County Fire District, of which 20 were reported to be structural fires, 16 from Santa Monica, and one from Burbank.

• January 17, 1995 Kobe Earthquake

Approximately 100 fires started within minutes of the quake, primarily in the densely populated, low-rise residential areas of Kobe, Japan. It was reported that several large conflagrations had developed within 1 to 2 hours, with a total of 142 fires and numerous collapses and destruction of mostly low-rise, residential/commercial buildings of simple wood construction. Figure 2.10a and 2.10b shows pictures of the many fires in Kobe and their vast destruction after the 1995 earthquake (EQE Website).

![Post-earthquake Fires in Kobe, Japan on Jan. 17, 1995](image)
Available historical records do not clearly indicate any specific multi-story building failures due to post-earthquake fires. This may be the result of a lack of disaster data and precise accounting for the resultant building damage or collapses between the earthquake and fire causes. Nevertheless, these types of fires pose a severe risk to all types of construction in their potentially damaged post-earthquake state, both in terms of their reduced structural and fire resistance. While past experience does not provide any direct evidence of such occurrences in multi-story buildings, the possibility for this combined extreme hazard from both earthquake and fire exposures does exist.

2.4 Conclusions

Fire-induced collapse poses a serious risk in low-rise and multi-story buildings, in terms of life safety and property damage. The Great Chicago Fire of 1871 first exposed the enormity and severity of the fire problem on the US. As demonstrated in this survey of the more modern era, the fire-induced collapse hazard is present in all construction types and construction materials, and in various occupancies. The risks associated with a fire in a high-rise building are greater, though, because of the increased population typically associated with high-rise buildings and the increased difficulty in carrying out a full-building evacuation.

It is well known that the largest number of fires occurs in low-rise and residential construction (Hall, 2001). However, more than 10,000 fires per year in the US have been historically reported in high-rise buildings. While this survey confirms that relatively few of these fires caused subsequent structural collapses in multi-story buildings, the consequences of
those fire-induced collapses can be enormous. Fire damage to structural members in multi-
story buildings can result in large deflections an order of magnitude greater than the elastic
defections normally contemplated for serviceability design.

A central repository of well-documented information on building collapses would be
highly desirable in order to more readily enable understand the nature and extent of fire-induced
collapses, and further engineering and construction advancements for the enhanced protection of
public safety.

Proper fire protection design in compliance with the current, building codes is one
obvious necessity to help preserve life safety. Besides adequate provisions for automatic
suppression systems, egress, compartmentalization, etc., the fire resistance of the structural frame
itself must be adequately provided. In order to minimize the possibility of fire-induced structural
collapse of significant proportions, additional structural and fire engineering advancements may
be warranted for use in multi-story buildings, and other critical facilities, where such collapses
would cause unacceptably large consequences. In particular, as emphasized in FEMA 403 and
reflected in this survey, more information should be developed with respect to the structural fire
performance of various structural framing and connections as part of entire systems in order to
assure overall integrity at elevated temperatures for the sake of enhanced public safety.
Table 2.1  Summary of Multi-Story Building Fires With Collapses  
(4 or more stories)$

<table>
<thead>
<tr>
<th>Building Name</th>
<th>Location</th>
<th>Type of Construction, Material, and Fire Resistance</th>
<th># Of Floors and Occupancy</th>
<th>Date, Approximate Time of Collapse, and References</th>
<th>Nature and Extent of Collapse (Partial or Total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santana Row, Bldgs. 7</td>
<td>San Jose, CA, USA</td>
<td>Wood frame, still under construction, fire protection and sprinklers not completed/functional</td>
<td>5 Commercial/residential</td>
<td>August 19, 2002</td>
<td>Total collapse and destruction</td>
</tr>
<tr>
<td>Apartment block</td>
<td>St. Petersburg, Russia</td>
<td>Concrete</td>
<td>19 Residential</td>
<td>June 3, 2002, starting at 1 hour fire duration</td>
<td>Total</td>
</tr>
<tr>
<td>Jackson Street Apartments</td>
<td>Hamilton, Ontario Canada</td>
<td>Concrete</td>
<td>21 Residential</td>
<td>February 8, 2002,</td>
<td>Partial collapse of concrete floor-ceilings</td>
</tr>
<tr>
<td>WTC 7</td>
<td>New York, NY, USA</td>
<td>Steel moment frame with composite steel beam and deck floors; fire resistive with sprinklers</td>
<td>47 Office</td>
<td>Sept. 11, 2001</td>
<td>Total</td>
</tr>
<tr>
<td>WTC 5</td>
<td>New York, NY, USA</td>
<td>Steel moment frame with composite steel beam and deck floors; fire resistive with sprinklers</td>
<td>9 Office</td>
<td>Sept. 11, 2001, unknown time, fire burned uncontrolled for more than 8 hours</td>
<td>Partial collapse of 4 stories and 2 bays</td>
</tr>
<tr>
<td>Pentagon</td>
<td>Washington, DC, USA</td>
<td>Reinforced Concrete</td>
<td>5 Office</td>
<td>Sept. 11, 2001, 30 minutes after jet impact</td>
<td>Partial collapses of floors and members</td>
</tr>
<tr>
<td>Faces Nightclub and Memories Lounge Bar</td>
<td>Motherwell, Lanarkshire UK</td>
<td>Unknown</td>
<td>4 Commercial/residential</td>
<td>February 27, 2001, after 2 hours</td>
<td>Total</td>
</tr>
<tr>
<td>Textile Factory</td>
<td>Alexandria, Egypt</td>
<td>Reinforced Concrete, no sprinklers</td>
<td>6 Commercial</td>
<td>July 21, 2000, after 9 hours of fire</td>
<td>Total</td>
</tr>
<tr>
<td>Apartment in Vandergrift</td>
<td>Pittsburgh, PA, USA</td>
<td>Wood</td>
<td>6 Residential</td>
<td>May 7, 2000, few hours after fire started</td>
<td>Back wall fell, initiating progressive collapse</td>
</tr>
<tr>
<td>Commercial complex (near Chestnut Hill Mall)</td>
<td>Newton, MA, USA</td>
<td>Brick/masonry</td>
<td>4 Commercial</td>
<td>February 9, 2000, after slightly more than a 1 hour fire</td>
<td>Collapse started at upper story and progressed</td>
</tr>
<tr>
<td>Effingham Plaza Nursing Home</td>
<td>Portsmouth, VA, USA</td>
<td>Unknown</td>
<td>Multi-story</td>
<td>April 6, 1998, fire started on top floor</td>
<td>Roof collapsed in places</td>
</tr>
</tbody>
</table>

§
Table 2.1  Summary of Multi-Story Building Fires With Collapses (Cont.)
(4 or more stories)$

<table>
<thead>
<tr>
<th>Building Name</th>
<th>Location</th>
<th>Type of Construction, Material, and Fire Resistance</th>
<th># Of Floors and Occupancy</th>
<th>Date, Approximate Time of Collapse, and References</th>
<th>Nature and Extent of Collapse (Partial or Total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apartments, Brooke Ave and 138th St.</td>
<td>Bronx, NY, USA</td>
<td>Brick</td>
<td>5 Residential</td>
<td>April 5, 1994</td>
<td>Rear of the building collapsed.</td>
</tr>
<tr>
<td>Central Square Apt. Massachusetts Ave. and Douglas St.</td>
<td>Cambridge, MA, USA</td>
<td>Brick</td>
<td>8 Residential</td>
<td>October 1, 1993</td>
<td>Collapse of several floors</td>
</tr>
<tr>
<td>CESP, Sede 2</td>
<td>Sao Paulo, Brazil</td>
<td>Reinforced concrete frame, with ribbed slabs; no sprinklers</td>
<td>21 Office</td>
<td>May 21, 1987, after 2 hour fire</td>
<td>Partial, full height interior core collapse</td>
</tr>
<tr>
<td>Alexis Nihon Plaza</td>
<td>Montreal, Canada</td>
<td>Steel frame with composite steel beam and deck floors; fire resistive without sprinklers</td>
<td>15 Office</td>
<td>Oct. 26, 1986, after 5 hour fire, which then continued for 13 hours</td>
<td>Partial 11th floor collapse</td>
</tr>
<tr>
<td>Katrantsos Sport Department Store</td>
<td>Athens, Greece</td>
<td>Reinforced concrete</td>
<td>8 Commercial</td>
<td>Dec. 19,1980</td>
<td>Partial collapses of 5-8th floor, together with various other members, during a 2-3 hour fire</td>
</tr>
<tr>
<td>Military Personnel Record Center</td>
<td>Overland, MO, USA</td>
<td>Reinforced concrete, without expansion joints, no sprinklers above 2nd floor</td>
<td>6 Office</td>
<td>July 12, 1973</td>
<td>Roof and supporting columns partially collapsed 12 hours after fire began</td>
</tr>
<tr>
<td>Hotel Vendome</td>
<td>Boston, MA, USA</td>
<td>Masonry with cast iron</td>
<td>5-6 Residential</td>
<td>June 17, 1972, after almost a 3 hour fire</td>
<td>All five floors of a 40 by 45 ft section collapsed</td>
</tr>
<tr>
<td>One New York Plaza</td>
<td>New York, NY, USA</td>
<td>Steel framing with reinforced concrete core, fire resistive with no sprinklers.</td>
<td>50 Office</td>
<td>August 5, 1970</td>
<td>Connection bolts sheared during fire, causing several steel filler beams on the 33-34th floors to fall and rest on the bottom flanges of their supporting girders.</td>
</tr>
</tbody>
</table>

§ WTC 1 and WTC 2 were deleted from this table on August 25, 2008. The two WTC towers collapsed due to aircraft impact damage to the structure and fireproofing as well as to fire. Both effects (damage and fire) were equally important. In the absence of structural and insulation damage, a fire substantially similar to or less intense than the fires encountered on September 11, 2001, likely would not have led to the collapse of a WTC tower. (NIST NCSTAR 1, September 2005)
<table>
<thead>
<tr>
<th>Building Name</th>
<th>Location</th>
<th>Type of Construction, Material, and Fire Resistance</th>
<th># Of Floors and Occupancy</th>
<th>Date of Fire Incident, and References</th>
<th>Nature and Extent of Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>One Meridian Plaza</td>
<td>Philadelphia, PA, USA</td>
<td>Steel frame with composite steel beam and deck floors; fire resistive, but sprinklers not operational (retrofit in process)</td>
<td>38 Office</td>
<td>Feb. 23-24, 1991</td>
<td>Started Saturday and burned for a total of 18 hours, causing significant structural damage to 9 floors</td>
</tr>
<tr>
<td>Mercantile Credit Insurance Building</td>
<td>Churchill Plaza, Basingstoke, UK</td>
<td>Steel frame with composite floor beams; fire resistive, but no sprinklers</td>
<td>12 Office</td>
<td>1991</td>
<td>Fire burnout of 8th to 10th floors</td>
</tr>
<tr>
<td>Broadgate Phase 8</td>
<td>London, UK</td>
<td>Steel composite trusses and beams; mostly not fire protected and without sprinklers</td>
<td>14 Office</td>
<td>1990</td>
<td>During construction, 4.5 hour fire duration and temperatures reached 1000 ºC</td>
</tr>
<tr>
<td>First Interstate Bank</td>
<td>Los Angeles, CA, USA</td>
<td>Steel frame with composite steel beam and deck floors; fire resistive; sprinklers not operational</td>
<td>62 Office</td>
<td>May 4, 1988</td>
<td>Lasted for about 3.5 hours, causing major damage to four floors</td>
</tr>
<tr>
<td>MGM Grand Hotel</td>
<td>Las Vegas, Nevada, USA</td>
<td>Mixed, no sprinklers</td>
<td>26 Office</td>
<td>Nov. 21, 1980</td>
<td>Burned for hours</td>
</tr>
<tr>
<td>Joelma Building (Crefisul Bank)</td>
<td>Sao Paulo, Brazil</td>
<td>Reinforced Concrete</td>
<td>25 Office</td>
<td>Feb. 1, 1974</td>
<td>Spalling of exterior walls</td>
</tr>
</tbody>
</table>
Table 2.3  High-Rise Building Fire Experience Selected Property Classes, by Year 1985-98 Structure (Reproduced from Hall, 2001)

<table>
<thead>
<tr>
<th>Year</th>
<th>Fires</th>
<th>Civilian Deaths*</th>
<th>Civilian Injuries</th>
<th>Direct Property Damage (in Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>17,200</td>
<td>66*</td>
<td>665</td>
<td>$24.9</td>
</tr>
<tr>
<td>1986</td>
<td>15,000</td>
<td>37*</td>
<td>554</td>
<td>$41.5</td>
</tr>
<tr>
<td>1987</td>
<td>13,000</td>
<td>55</td>
<td>635</td>
<td>$36.2</td>
</tr>
<tr>
<td>1988</td>
<td>14,600</td>
<td>93</td>
<td>778</td>
<td>$102.3*</td>
</tr>
<tr>
<td>1989</td>
<td>14,800</td>
<td>110</td>
<td>798</td>
<td>$58.1*</td>
</tr>
<tr>
<td>1990</td>
<td>13,300</td>
<td>83</td>
<td>625</td>
<td>$48.3</td>
</tr>
<tr>
<td>1991</td>
<td>13,100</td>
<td>23</td>
<td>747</td>
<td>$150.1*</td>
</tr>
<tr>
<td>1992</td>
<td>13,600</td>
<td>34*</td>
<td>827</td>
<td>$75.4</td>
</tr>
<tr>
<td>1993</td>
<td>12,400</td>
<td>43</td>
<td>701*</td>
<td>$60.8*</td>
</tr>
<tr>
<td>1994</td>
<td>11,300</td>
<td>51</td>
<td>950</td>
<td>$56.9</td>
</tr>
<tr>
<td>1995</td>
<td>10,000</td>
<td>55*</td>
<td>688</td>
<td>$44.5</td>
</tr>
<tr>
<td>1996</td>
<td>12,100</td>
<td>64*</td>
<td>790</td>
<td>$69.1</td>
</tr>
<tr>
<td>1997</td>
<td>11,400</td>
<td>33</td>
<td>560</td>
<td>$43.4</td>
</tr>
<tr>
<td>1998</td>
<td>10,000</td>
<td>37</td>
<td>680</td>
<td>$41.1</td>
</tr>
</tbody>
</table>

* In 1985, 1986, 1989, 1991, and 1992, there were 24 total office building fire deaths, all in buildings with unreported height. Since high-rise buildings account for about one-eighth of all office fires, it was estimated that high-rise office buildings had three deaths, allocated as one of the eight 1985 deaths; one of the eight 1986 deaths; and one of the eight 1989, 1991 and 1992 deaths to high-rise buildings, choosing 1992 for the latter as four of the eight deaths occurred in 1992. In 1995 and 1996, deaths in facilities that care for the sick were allocated based on the high-rise share of fires. Property damage figures for apartments in 1991 are inflated by problems in handling the Oakland wildfire in the estimates. Property damage figures for office buildings are underestimated due to problems in handling some large-loss fires, such as a $50 million California fire in 1988, a $50 million Pennsylvania fire in 1989, the $325 million One Meridian Plaza fire in Pennsylvania in 1991, and the $230 million World Trade Center incident in 1993, whose more than 1,000 injuries also are not properly reflected in national estimates.

Note: These are fires reported to U.S. municipal fire departments and so exclude fires reported only to Federal or state agencies or industrial fire brigades. Fires are rounded to the nearest hundred, civilian deaths and injuries are rounded to the nearest one and direct property damage is rounded to the nearest hundred thousand dollars. Property damage has not been adjusted for inflation.

Source: National estimates based on NFIRS and NFPA survey.
<table>
<thead>
<tr>
<th>Building Name or Occupancy</th>
<th>Location</th>
<th>Construction</th>
<th>Stories</th>
<th>Date</th>
<th>Nature and Extent of Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daycare/ Factory</td>
<td>Dromore, Ireland</td>
<td>Unknown</td>
<td>3</td>
<td>May 30, 2002</td>
<td>Fire in a former factory at Castle Street in Dromore left the building unstable when internal floors collapsed.</td>
</tr>
<tr>
<td>House</td>
<td>Carterton, New Zealand</td>
<td>Wood</td>
<td>2</td>
<td>May 27, 2002</td>
<td>Fire caused the center of the building to collapse</td>
</tr>
<tr>
<td>Apartment</td>
<td>Houston, TX</td>
<td>Unknown</td>
<td>2</td>
<td>May 26, 2002</td>
<td>Fire was contained to one building, where flames caused the roof to collapse.</td>
</tr>
<tr>
<td>Apartment</td>
<td>Owings Mills, MD</td>
<td>Unknown</td>
<td>3</td>
<td>April 13, 2002</td>
<td>Fire caused a partial collapse of the third floor.</td>
</tr>
<tr>
<td>Shopping</td>
<td>Elveden Forest, Suffolk, UK</td>
<td>Unknown</td>
<td>2</td>
<td>April 4, 2002</td>
<td>Early partial structural collapse</td>
</tr>
<tr>
<td>Apartment</td>
<td>New Orleans, LA</td>
<td>Wood</td>
<td>2</td>
<td>March 15, 2002</td>
<td>Fire damaged the attic of the building and caused a partial collapse of the floor in the apartment where the fire began.</td>
</tr>
<tr>
<td>Apartment over Business</td>
<td>Carthage, NY</td>
<td>Unknown</td>
<td>2</td>
<td>March 1, 2002</td>
<td>Fire resulted in heavy damage to at least four buildings, two collapsed.</td>
</tr>
<tr>
<td>Apartment</td>
<td>Dallas, TX</td>
<td>Unknown</td>
<td>2</td>
<td>February 10, 2002</td>
<td>Wall collapsed.</td>
</tr>
<tr>
<td>Grocery</td>
<td>Kenosha, WI</td>
<td>Unknown</td>
<td>2</td>
<td>January 1, 2002</td>
<td>Fire in a two-story corner grocery store building resulted in structural collapse.</td>
</tr>
<tr>
<td>House</td>
<td>Ottawa, Canada</td>
<td>Unknown</td>
<td>2</td>
<td>December 26, 2001</td>
<td>Fire destroyed the garage and reached the second story, eventually causing the roof to collapse</td>
</tr>
<tr>
<td>Apartment</td>
<td>Chicago, IL</td>
<td>Brick</td>
<td>3</td>
<td>December 6, 2001</td>
<td>A two- to three-foot concealed space between the old roof and the new third floor contributed to the rapid spread of the fire and led to the partial collapse.</td>
</tr>
<tr>
<td>House</td>
<td>South Wales, UK</td>
<td>Wood</td>
<td>2</td>
<td>November 26, 2001</td>
<td>The roof collapsed.</td>
</tr>
<tr>
<td>House</td>
<td>Wales, UK</td>
<td>Wood</td>
<td>2</td>
<td>November 26, 2001</td>
<td>Roof collapsed of a semi-detached home.</td>
</tr>
<tr>
<td>Duplex</td>
<td>Pittsburgh, PA</td>
<td>Wood</td>
<td>2</td>
<td>September 12, 2001</td>
<td>Fire caused floors to collapse.</td>
</tr>
<tr>
<td>House</td>
<td>Spotswood, NJ</td>
<td>Wood</td>
<td>2</td>
<td>August 11, 2001</td>
<td>Entire kitchen floor collapsed into the basement.</td>
</tr>
</tbody>
</table>
### Table 2.4 Recent Low-Rise Building Fires With Collapses (Cont.)

<table>
<thead>
<tr>
<th>Building Name or Occupancy</th>
<th>Location</th>
<th>Construction</th>
<th>Stories</th>
<th>Date</th>
<th>Nature and Extent of Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>House</td>
<td>Pittsburgh, PA</td>
<td>Wood</td>
<td>2</td>
<td>August 8, 2001</td>
<td>Fire, located mainly on the second floor of the building, caused the roof of the home to collapse.</td>
</tr>
<tr>
<td>House</td>
<td>Irvine, CA</td>
<td>Unknown</td>
<td>2</td>
<td>July 6, 2001</td>
<td>Fire captain was injured after the burned-out second floor collapsed.</td>
</tr>
<tr>
<td>Apartment</td>
<td>Passaic, NJ</td>
<td>Brick</td>
<td>3</td>
<td>May 9, 2001</td>
<td>Third floor collapse in building</td>
</tr>
<tr>
<td>Row House</td>
<td>Baltimore, MD</td>
<td>Unknown</td>
<td>3</td>
<td>January 3, 2001</td>
<td>A man fell two or three stories when one floor of the burning row house gave way.</td>
</tr>
<tr>
<td>House</td>
<td>Smithfield, PA</td>
<td>Wood</td>
<td>2</td>
<td>September 12, 2000</td>
<td>Fire caused floors to collapse.</td>
</tr>
<tr>
<td>Store</td>
<td>Hopewell, VA</td>
<td>Unknown</td>
<td>2</td>
<td>June 4, 2000</td>
<td>Fire fueled by recycled clothes consumed a two-story building, which collapsed.</td>
</tr>
<tr>
<td>Apartment</td>
<td>Strathmore, UK</td>
<td>Unknown</td>
<td>3</td>
<td>April 8, 2000</td>
<td>Fire spread quickly to the roof area, causing the ceilings to collapse into the six adjoining units.</td>
</tr>
<tr>
<td>House</td>
<td>Stigler, Tulsa, OK</td>
<td>Unknown</td>
<td>2</td>
<td>February 15, 2000</td>
<td>House collapsed into the full basement.</td>
</tr>
<tr>
<td>House</td>
<td>Baltimore, MD</td>
<td>Unknown</td>
<td>3</td>
<td>December 24, 1999</td>
<td>Three-story frame house partially collapsed during the fire.</td>
</tr>
<tr>
<td>Country Club</td>
<td>Lewisburg, VA</td>
<td>Unknown</td>
<td>2</td>
<td>December 19, 1999</td>
<td>Fire apparently began on an open porch and spread through the attic of the 12,750-square foot, two-story building, resulting in the roof collapsing.</td>
</tr>
<tr>
<td>Apartment</td>
<td>Niagara Falls, NY</td>
<td>Brick</td>
<td>2.5</td>
<td>October 5, 1999</td>
<td>Fire spread quickly through the 2 1/2-story brick building and causing the roof and attic to collapse into the second floor</td>
</tr>
<tr>
<td>Apartment</td>
<td>San Francisco, CA</td>
<td>Unknown</td>
<td>3</td>
<td>July 20, 1999</td>
<td>Fire burned undetected in this area for a significant amount of time, eventually causing a second-floor collapse.</td>
</tr>
<tr>
<td>Apartment</td>
<td>Cunningham, Denver, CO</td>
<td>Unknown</td>
<td>3</td>
<td>July 4, 1999</td>
<td>Fire gutted the building's attic and caused the roof to collapse.</td>
</tr>
<tr>
<td>House</td>
<td>Cederburg, WI</td>
<td>Wood</td>
<td>2</td>
<td>April 29, 1999</td>
<td>Fire spread across the roof, and into the basement, causing the first floor in the kitchen and dining room to collapse.</td>
</tr>
<tr>
<td>House</td>
<td>Chingford, London, UK</td>
<td>Wood</td>
<td>2</td>
<td>March 6, 1999</td>
<td>Fire caused the roof and floors of the house in Bellamy Road to collapse.</td>
</tr>
<tr>
<td>Building Name or Occupancy</td>
<td>Location</td>
<td>Construction</td>
<td>Stories</td>
<td>Date</td>
<td>Nature and Extent of Fire</td>
</tr>
<tr>
<td>----------------------------</td>
<td>---------------------------</td>
<td>--------------</td>
<td>---------</td>
<td>--------------------</td>
<td>------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Bar/Apartment</td>
<td>North Oakland, CA</td>
<td>Wood</td>
<td>2</td>
<td>January 10, 1999</td>
<td>Firefighters became trapped when the second floor of a nightclub collapsed during an interior fire attack.</td>
</tr>
<tr>
<td>House</td>
<td>Malden, Boston, MA</td>
<td>Wood</td>
<td>2</td>
<td>January 1, 1999</td>
<td>Large of fire related rubble caused the collapse of floor and ceiling, unable to determine the exact point of origin</td>
</tr>
<tr>
<td>Store</td>
<td>Glasgow, Scotland</td>
<td>Unknown</td>
<td>2</td>
<td>December 18, 1998</td>
<td>Fire caused the roof to collapse</td>
</tr>
<tr>
<td>House</td>
<td>Bayside, WI</td>
<td>Wood</td>
<td>2</td>
<td>October 31, 1998</td>
<td>Fire destroyed the home, causing the second floor to collapse.</td>
</tr>
<tr>
<td>Apartment/Commercial</td>
<td>Brooklyn, NY</td>
<td>Brick</td>
<td>3</td>
<td>June 5, 1998</td>
<td>Rear of the second floor of building #2 collapsed.</td>
</tr>
<tr>
<td>House</td>
<td>Golden Valley, MN</td>
<td>Wood</td>
<td>3</td>
<td>March 12, 1998</td>
<td>Fire on all three levels resulted in partial wall collapses.</td>
</tr>
<tr>
<td>Apartment</td>
<td>Medford, MA</td>
<td>Wood</td>
<td>3</td>
<td>December 28, 1997</td>
<td>Partial collapse of second floor.</td>
</tr>
<tr>
<td>House</td>
<td>Toronto, Ontario, Canada</td>
<td>Unknown</td>
<td>2</td>
<td>November 21, 1997</td>
<td>Fire led to seconds floor collapse.</td>
</tr>
<tr>
<td>Row House</td>
<td>Pittsburgh, PA</td>
<td>Unknown</td>
<td>3</td>
<td>April 6, 1997</td>
<td>Fire weakened structure collapsed.</td>
</tr>
<tr>
<td>Apartment</td>
<td>Earlington, KY</td>
<td>Unknown</td>
<td>3</td>
<td>April 1, 1997</td>
<td>Top two floors collapsed.</td>
</tr>
<tr>
<td>Apartment</td>
<td>St. Henri, Montreal, Canada</td>
<td>Unknown</td>
<td>3</td>
<td>March 6, 1997</td>
<td>Walls began to collapse while firefighters were bringing the fire under control.</td>
</tr>
<tr>
<td>House</td>
<td>Stockton, CA</td>
<td>Wood</td>
<td>2</td>
<td>February 6, 1997</td>
<td>Second story floor toppled.</td>
</tr>
<tr>
<td>House</td>
<td>Jamaica, Queens, NY</td>
<td>Wood</td>
<td>2</td>
<td>December 31, 1996</td>
<td>Burn through of basement floor beams led to collapse of floor slabs.</td>
</tr>
<tr>
<td>House</td>
<td>Scituate, MA</td>
<td>Wood</td>
<td>2</td>
<td>September 15, 1996</td>
<td>Second-floor bedroom fire caused floor to collapse into the living room below.</td>
</tr>
<tr>
<td>Store</td>
<td>Bangkok, Thailand</td>
<td>Unknown</td>
<td>3</td>
<td>November 27, 1995</td>
<td>Complete structural collapse</td>
</tr>
<tr>
<td>House</td>
<td>Edwardsville, MO</td>
<td>Wood</td>
<td>2</td>
<td>October 9, 1995</td>
<td>Fire gutted the attic of the two-story home and caused the roof to collapse.</td>
</tr>
</tbody>
</table>
Table 2.4  Recent Low-Rise Building Fires With Collapses (Cont.)

<table>
<thead>
<tr>
<th>Building Name or Occupancy</th>
<th>Location</th>
<th>Construction</th>
<th>Stories</th>
<th>Date</th>
<th>Nature and Extent of Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial/Apartment</td>
<td>Los Angeles, CA</td>
<td>Wood</td>
<td>2</td>
<td>July 30, 1995</td>
<td>Burning two-story building collapsed.</td>
</tr>
<tr>
<td>Apartment</td>
<td>Calgary, Canada</td>
<td>Unknown</td>
<td>3</td>
<td>May 28, 1995</td>
<td>Ceiling on third floor started to collapse.</td>
</tr>
<tr>
<td>Apartment</td>
<td>West Palm Beach, FL</td>
<td>Unknown</td>
<td>2</td>
<td>April 21, 1995</td>
<td>Partial collapse of the second floor.</td>
</tr>
<tr>
<td>Apartment</td>
<td>Lynn, Boston, MA</td>
<td>Unknown</td>
<td>3</td>
<td>February 10, 1995</td>
<td>Roof and floors of three-story apartment building collapsed.</td>
</tr>
<tr>
<td>Warehouse</td>
<td>Seattle, WA</td>
<td>Unknown</td>
<td>2</td>
<td>January 5, 1995</td>
<td>Top floor collapsed onto lower floor, where the fire initiated.</td>
</tr>
<tr>
<td>Chalet</td>
<td>Granges-sur-Salvan, Switzerland</td>
<td>Wood</td>
<td>2</td>
<td>October 16, 1994</td>
<td>Progressive inward collapse of structure</td>
</tr>
<tr>
<td>Vacant</td>
<td>Washington, DC</td>
<td>Unknown</td>
<td>2</td>
<td>September 18, 1994</td>
<td>Exterior walls collapsed causing ceiling collapse.</td>
</tr>
<tr>
<td>Supply</td>
<td>Allentown, PA</td>
<td>Unknown</td>
<td>3</td>
<td>May 11, 1994</td>
<td>Total building collapse.</td>
</tr>
<tr>
<td>House</td>
<td>Roswell, GA</td>
<td>Wood</td>
<td>2</td>
<td>December 14, 1992</td>
<td>Total house collapse.</td>
</tr>
<tr>
<td>Vacant</td>
<td>Lawrence, MA</td>
<td>Unknown</td>
<td>3</td>
<td>July 6, 1992</td>
<td>Total building collapse.</td>
</tr>
<tr>
<td>Apartment</td>
<td>Brackenridge, PA</td>
<td>Concrete/unprotected steel</td>
<td>2</td>
<td>December 20, 1991</td>
<td>Section of the first-story floor assembly fell into the basement.</td>
</tr>
</tbody>
</table>
3.0 TASK 2. FIRE RESISTANCE TESTING LABORATORY SURVEY

3.1 Objective

The objective of this task was to survey the private and public facilities (for-profit, not-for-profit; academic, local, state and federal government; military and civilian; domestic and international) capable of testing the structural integrity of building elements under fire conditions. This survey was to determine their specific capabilities in this area and provide an understanding of the global capabilities for fire resistance testing.

3.2 Survey Scope and Methodology

The survey was limited to laboratories or facilities that could perform fire resistance testing. Fire resistance testing was defined as evaluating the structural integrity and/or the flame or temperature transmission through structural building elements. Structural building elements are defined as floors, roofs, ceilings, beams, columns, walls and their connections. Other test capabilities on fire performances characteristics such as flame spread, heat release rate, ignition resistance, smoke generation, etc. were not included in this survey.

The list of the test laboratories was developed based on personal knowledge, references from several of the laboratories, listings from various standards organizations (e.g. American Society for Testing and Materials (ASTM), International Standards Organization (ISO)) or approval organizations (e.g., International Conference of Building Officials (ICBO), Asia Pacific Laboratory Accreditation Cooperative (APLAC)). Table 3.1 provides a summary of the various laboratories and other contacts that were surveyed.

Each of the laboratories or contacts was initially contacted via E-mail and provided a questionnaire to complete and return. Follow-up contacts were performed as required.

The questionnaire was designed to provide a short yet complete description of the fire resistance testing capabilities of the various organizations. In general, the questionnaire requested information such as:

- Information on the location of the laboratory or facility
- Contact information
- Capability to test vertical building elements
  - What type
  - Size of elements / apparatus
  - Exposure conditions
  - Loading capabilities
- Capability to test horizontal building elements
  - What type
  - Size of elements / apparatus
  - Exposure conditions
  - Loading capabilities
3.3 Survey Responses

The various responses were collected and tabulated. In some cases, the contact or laboratory did not have existing fire resistance test facilities and thus they were eliminated from further consideration. In some cases, the laboratory or facility responded that that they were private facilities and did not accept outside testing and thus did not complete the form. Table 3.2 provides a summary of the responses received to date.

The responses from the laboratories that completed the questionnaire are summarized in Tables 3.3, 3.4, 3.5, and 3.6. Table 3.3 provides basic contact information for each laboratory. Tables 3.4 and 3.5 provide summaries of the test capabilities for vertical and horizontal elements, respectively. Table 3.6 provides additional information concerning testing restrictions and availability of other non-standard test capabilities. A copy of each of the completed questionnaires is provided in Volume II of this report.

3.4 Discussion of Survey

Currently, fire resistance testing is primarily performed to evaluate materials, products or assemblies with respect to their ability to maintain structural integrity or retard the passage of flames, or heat when exposed to a specified fire condition. The time that the test article exhibits this performance is known as its fire endurance or fire resistance rating. For example, a wall may attain a fire resistance rating of 1-hour, 2-hour or greater. This fire resistance rating, expressed in a time increment is typically specified in the building codes such that each structural building element for a particular building is required to have a rating that can vary from 0-hours to 4-hours or greater depending on the building requirements.

In order to attain a fire resistance rating, the material, product or assembly is evaluated using existing standard fire resistance tests. The most common fire resistance standards throughout the world are:


All of these tests are standardized fire resistance tests that have been used for many years. In general, they use similar fire exposure conditions as measured and controlled by the air
temperature within the furnace. For some specific applications, a “hydrocarbon pool fire” exposure is also used. This test uses a heat flux to the test article as the exposure criteria but is controlled using the air temperature in the furnace. Typical “hydrocarbon pool fire” test methods followed in North America are:

- UL 1709 – “Rapid Rise Fire Tests of Protection Materials for Structural Steel”
- ASTM E 1529 – “Determining Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies”

Figure 3.1 provides a plot of the fire exposure conditions for ASTM E119 (North America), ISO 834 (International) and the “hydrocarbon pool fire”. All of the testing laboratories reported that they could perform the standard fire exposures (ASTM and ISO). Several of the laboratories can also perform fire exposures that are similar to the “hydrocarbon pool fire” exposure or greater.

Over the years, the fire test methods have standardized many of test details such as sample size, measurement of temperatures, loading, etc. As such, the majority of test laboratories have designed and built their current fire resistance test furnaces to meet the standard test methods.

The responding laboratories have various sized vertical and horizontal furnaces that can be used for fire resistance testing. In some cases, they also have small-scale furnaces that are used for scoping/R&D testing even though they do not meet the requirements of the standard tests with respect to the minimum size of the samples. In most of the laboratories, full-scale furnaces that can evaluate the standard sample sizes are available.

The standard practice in fire resistance testing is to test each building element individually. For example, roofs or floors are not tested in combination with walls or columns. Thus, the roof assembly is tested as an individual element and the column or the wall is also tested as an individual item. Connections between building elements are not necessarily evaluated under the existing fire resistance test methods. In some cases, such as with floors, the ends of beams may be restrained, but they are typically not exposed to the actual fire environment.

Full-scale vertical furnaces can typically evaluate samples approximately 3 m high x 3 m wide. The largest (ULC) can evaluate samples 4.6 m high x 4 m wide. Most vertical furnace are shallow (e.g. 0.6 m deep or less) but several (OPL, LGU) have depths up to 1.2 m to 1.5 m. Some of the test facilities can also provide expansion collars that will increase the depth of the furnace as well as the size (height & width) of the test sample.

Full-scale horizontal furnaces can evaluate samples up to approximately 4 m long x 5.5 m wide. The largest furnace (ULC) can accommodate a sample that is 10.5 m. long x 4 m. wide. Generally, the depth of the full-scale furnaces is approximately 1.8 m. The largest furnace described above, however, has a depth of 2.4 m. Most laboratories can build-up the sides of the horizontal furnaces such that deeper or taller samples, such as columns, can be tested.
Figure 3.1 Fire Exposure Conditions
Testing combinations of structural elements can be conducted, but one must be careful with respect to the type and size of combinations. For example, it may be possible to test a full-scale floor and a column together within some limits on the size, but most laboratories cannot test a full-scale roof and wall combination. The horizontal furnace at ULC may have this capability, since they can shut down parts of the furnace and thus build a wall inside the furnace such that it will meet a floor. Also, OPL has a medium scale furnace that can potentially expose a wall (3 m tall x 3.6 m wide) in conjunction with a floor (3.6 m wide x 4.9 m long).

Loading of test assemblies is accomplished in various ways depending on the orientation of the test sample. Most of the laboratories load walls using hydraulic jacks such that the wall is in compression during the test. Columns are typically tested without load, since most of the testing involves fire protection materials on the columns and thus limiting temperatures are used rather than structural integrity. Several laboratories (NRC, LGU, BRI) have the capability to test columns under load.

In horizontal testing, loading is typically limited to live loads placed on top of the test assembly. The live loading is typically accomplished using water tanks or hydraulic jacks. Loading with respect to tension, shear, etc. is not typically done. One test laboratory (FPL) can perform tension loading in their small-scale horizontal furnace.

Generally, instrumentation in fire resistance testing is limited to:

- Temperatures / heat flux of exposing fire
- Temperatures on the test sample (interior and exterior)
- Deflection of the test sample
- Limited data on load history by some laboratories
- Pressure in the furnace with respect to atmosphere near the sample location

In some cases, research testing was conducted wherein load cells or strain gauges were used, but this is very rare. Some of the laboratories have the capability to use these devices but many experimental problems exist with their use. For example, at high temperatures these devices will be destroyed.

Most of the responding laboratories will perform testing for clients and there are few reported issues with respect to contracts and regulations. The largest concerns center on testing of potentially hazardous materials, such as asbestos.

The cost to perform fire resistance testing varies considerably depending on the type of assembly and its construction, instrumentation, loading, etc. In general, standard wall tests are in the range of $5,000 to $8,000 (US) while floor tests can range from $25,000 to $50,000 (US). Test scheduling is totally dependent upon the construction and instrumentation requirements for the test. For example, a simple wall test without the need for curing materials can be conducted within two weeks of receipt of materials.
while tests that may involve materials such as concrete may require a minimum of four to six months due to curing of the concrete.

Several laboratories have large, enclosed areas whereby specialized testing can be conducted. While not totally defined, several laboratories, (UL, SWR, SP) have facilities wherein a test structure can be constructed and potentially evaluated under real-scale fire conditions. While the overall space exists, the exact nature of the capabilities would be undefined until an actual proposed test is provided.

In summary, most of the responding laboratories have the capability to perform the standard fire resistance tests with respect to size, type of exposure, loading, and measurements. In some cases, laboratories can subject samples to a variety of fire exposures and several fairly large furnaces exist that may be used to evaluate, within some size limitations, connections or a combination of building elements. No single laboratory stands out as having all combinations of facilities such as largest size, capabilities of testing connections or combination of elements, loading, exposure conditions, etc. In general, the large commercial laboratories (e.g., ULC, UL, OPL, SWR, BRE, BRI, VTT) have greater than normal capabilities. The selection of a particular laboratory would depend on the specific objective of the test program and the test requirements. Real-scale size facilities and loading conditions and instrumentation other than those used or specified in the standard test methods is not be readily available.
### Table 3.1 List of Laboratories/Contacts

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underwriters Laboratories, Inc</td>
<td>USA</td>
</tr>
<tr>
<td>Underwriters Laboratories of Canada</td>
<td>Canada</td>
</tr>
<tr>
<td>Southwest Research Institute</td>
<td>USA</td>
</tr>
<tr>
<td>Intertek Testing – US &amp; Canada</td>
<td>USA/Canada</td>
</tr>
<tr>
<td>Armstrong World Industries</td>
<td>USA</td>
</tr>
<tr>
<td>Factory Mutual Research Corporation</td>
<td>USA</td>
</tr>
<tr>
<td>SGS/US Testing Laboratory – LA</td>
<td>USA</td>
</tr>
<tr>
<td>Omega Point Laboratories</td>
<td>USA</td>
</tr>
<tr>
<td>3M Company</td>
<td>USA</td>
</tr>
<tr>
<td>Carboline</td>
<td>USA</td>
</tr>
<tr>
<td>National Research Council</td>
<td>Canada</td>
</tr>
<tr>
<td>US Forest Product Laboratory</td>
<td>USA</td>
</tr>
<tr>
<td>Western Fire Center</td>
<td>USA</td>
</tr>
<tr>
<td>US Gypsum – Research Facility</td>
<td>USA</td>
</tr>
<tr>
<td>Guardian</td>
<td>USA</td>
</tr>
<tr>
<td>NGL Testing Services</td>
<td>USA</td>
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<tr>
<td>VTEC Labs</td>
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<tr>
<td>Commercial Testing</td>
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<tr>
<td>UC Berkeley</td>
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<tr>
<td>Intertek – WI</td>
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<tr>
<td>INTI</td>
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<tr>
<td>IPT</td>
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<tr>
<td>REDCO</td>
<td>Belgium</td>
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<tr>
<td>Univ. of Ghent</td>
<td>Belgium</td>
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<tr>
<td>SP</td>
<td>Sweden</td>
</tr>
<tr>
<td>Danish Institute of Fire Technology</td>
<td>Denmark</td>
</tr>
<tr>
<td>VTT</td>
<td>Finland</td>
</tr>
<tr>
<td>SINTEF</td>
<td>Norway</td>
</tr>
<tr>
<td>Institute for QC of Bldg</td>
<td>Hungary</td>
</tr>
<tr>
<td>Lorient</td>
<td>UK</td>
</tr>
<tr>
<td>BRE</td>
<td>UK</td>
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<tr>
<td>Warrington</td>
<td>UK</td>
</tr>
<tr>
<td>Warrington (Australia)</td>
<td>Australia</td>
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<td>Lorient (Australia)</td>
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<tr>
<td>CSIRO</td>
<td>Australia</td>
</tr>
<tr>
<td>Tianjin Fire Research Institute</td>
<td>China</td>
</tr>
<tr>
<td>China Nat. Center for QC &amp; Testing of Bldg</td>
<td>China</td>
</tr>
<tr>
<td>Sichuan Fire Research Institute</td>
<td>China</td>
</tr>
<tr>
<td>Architecture &amp; Building Research Institute</td>
<td>Taiwan</td>
</tr>
<tr>
<td>PSB/SISIR</td>
<td>Singapore</td>
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<tr>
<td>SIRIM</td>
<td>Malaysia</td>
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<tr>
<td>CTICM</td>
<td>France</td>
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<td>CSTB</td>
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<td>Building Res. Institute</td>
<td>Japan</td>
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<tr>
<td>Res. Institute of Marine Engineering</td>
<td>Japan</td>
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<tr>
<td>Gen Building Res. Corp</td>
<td>Japan</td>
</tr>
<tr>
<td>Japan Testing Center for Building Const.</td>
<td>Japan</td>
</tr>
<tr>
<td>Fire Research Institute</td>
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<tr>
<td>Univ. of Canterbury</td>
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<td>BRANZ</td>
<td>New Zealand</td>
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<tr>
<td>BAM</td>
<td>Germany</td>
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<tr>
<td>MPA – Materialprüfungsamt</td>
<td>Germany</td>
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<td>TNO</td>
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## Table 3.2 Summary of Responses

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<th>Laboratory</th>
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<th>Capabilities</th>
<th>Remarks</th>
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<tr>
<td>Underwriters Laboratories, Inc</td>
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<tr>
<td>Underwriters Laboratories of Canada</td>
<td>Canada</td>
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<tr>
<td>Southwest Research Institute</td>
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<td>Yes</td>
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<tr>
<td>Armstrong World Industries</td>
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<td>Private</td>
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<tr>
<td>Factory Mutual Research Corporation</td>
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<tr>
<td>SGS/US Testing Laboratory – LA</td>
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<tr>
<td>Omega Point Laboratories</td>
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<td>Yes</td>
<td></td>
</tr>
<tr>
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<td>Carboline</td>
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<tr>
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<td>US Forest Products Laboratory</td>
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<td>US Gypsum – Research Facility</td>
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<tr>
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</tr>
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<td>Finland</td>
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<td></td>
</tr>
<tr>
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</tr>
<tr>
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<td>Yes</td>
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<tr>
<td>CSIRO</td>
<td>Australia</td>
<td>Yes</td>
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</tr>
<tr>
<td>PSB/SISIR</td>
<td>Singapore</td>
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<tr>
<td>SIRIM</td>
<td>Malaysia</td>
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<td></td>
</tr>
<tr>
<td>Building Res. Institute</td>
<td>Japan</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Res. Institute of Marine Engineering</td>
<td>Japan</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Gen Building Res. Corp</td>
<td>Japan</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>SP Swedish National Testing and Res. Institute</td>
<td>Sweden</td>
<td>Yes</td>
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</tbody>
</table>

Private = while some facilities exist, they did not wish to complete the form since they only do in-house testing.
## Table 3.3  General Testing Laboratory Information

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Location</th>
<th>Contact Person</th>
<th>Contact Information</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSB Corporation Pte Ltd</td>
<td>Singapore</td>
<td>Joseph Chng</td>
<td>Tel: (65) 6865 3778; (65) 6862 1433</td>
<td>PSB</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fax: <a href="mailto:joseph.chng@psbcorp.com">joseph.chng@psbcorp.com</a></td>
<td></td>
</tr>
<tr>
<td>USG Research &amp; Technology Center</td>
<td>Libertyville, IL, USA</td>
<td>Rich Kaczkowski</td>
<td>Tel: 847-970-5255; 847-970-5299</td>
<td>USG</td>
</tr>
<tr>
<td>Guardian Fire Testing Laboratory, Inc</td>
<td>Buffalo, NY, USA</td>
<td>R. Joseph Pearson</td>
<td>Tel: 716-835-6880; 716-835-5682</td>
<td>GFT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fax: [email]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Email: <a href="mailto:gftli@earthlink.net">gftli@earthlink.net</a></td>
<td></td>
</tr>
<tr>
<td>Carboline Co.</td>
<td>Saint Louis, Mo, USA</td>
<td>Chris Magdalin</td>
<td>Tel: 314-644-1000; 314-644-4617</td>
<td>CBL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fax: [email]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Email: <a href="mailto:chris_Magdalin@Carboline.com">chris_Magdalin@Carboline.com</a></td>
<td></td>
</tr>
<tr>
<td>Laboratorio de Segurança ao Fogo/ Instituto de Pesquisas Tecnológicas</td>
<td>Sao Paulo, Brazil</td>
<td>Antonio Fernando Berto</td>
<td>Tel: 55 11 37674675; 55 11 37674682</td>
<td>LSF</td>
</tr>
<tr>
<td>do Estado de Sao Paulo SA</td>
<td></td>
<td></td>
<td>Fax: <a href="mailto:alberto@ipt.br">alberto@ipt.br</a></td>
<td></td>
</tr>
<tr>
<td>Laboratorio de Ensayo de Resistencia al Fuego DICTUC</td>
<td>Santiago, Chile</td>
<td>Pablo Matamala</td>
<td>Tel: (56 2) 686 4626; (56 2) 686 6226</td>
<td>LER</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fax: <a href="mailto:pmatamal@ing.puc.cl">pmatamal@ing.puc.cl</a></td>
<td></td>
</tr>
<tr>
<td>Omega Point Laboratories, Inc</td>
<td>San Antonio, TX, USA</td>
<td>Deg Priest</td>
<td>Tel: 210-635-8100; 210-635-8101</td>
<td>OPL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fax: dn <a href="mailto:priest@ix.netcom.com">priest@ix.netcom.com</a></td>
<td></td>
</tr>
<tr>
<td>NGC Testing Services</td>
<td>Buffalo, NY, USA</td>
<td>Robert Menchetti</td>
<td>Tel: 716-873-9750 ext.341; 716-973-9753</td>
<td>NGC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Email: ngctestingservices.com</td>
<td></td>
</tr>
<tr>
<td>NRC, Canada</td>
<td>Ottawa, Ontario, Canada</td>
<td>Mohamed A. Sultan</td>
<td>Tel: 613-993-9771; 613-954-0483</td>
<td>NRC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fax: <a href="mailto:Mohamed.sultan@nrc.ca">Mohamed.sultan@nrc.ca</a></td>
<td></td>
</tr>
<tr>
<td>Commercial Testing Co., Inc</td>
<td>Dalton, GA, USA</td>
<td>Jonathon Jackson</td>
<td>Tel: 706-278-3935; 706-278-3936</td>
<td>CTC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fax: <a href="mailto:Jjackson@commercialtesting.com">Jjackson@commercialtesting.com</a></td>
<td></td>
</tr>
<tr>
<td>Research Institute of Marine Engineering</td>
<td>Tokyo, Japan</td>
<td>Tatsushihiro Hiraoka</td>
<td>Tel: 81 42 394 3611; 81 42 394 1119</td>
<td>RIM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fax: <a href="mailto:hiraoka@rime.jp">hiraoka@rime.jp</a></td>
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<tr>
<td>Laboratory</td>
<td>Location</td>
<td>Contact Person</td>
<td>Contact Information</td>
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<td>------------</td>
<td>----------</td>
<td>----------------</td>
<td>---------------------</td>
<td>------</td>
</tr>
<tr>
<td>USDA, Forest Service, Forest Products Laboratory</td>
<td>Madison, WI, USA</td>
<td>Robert White</td>
<td>Tel: 608-231-9265 608-231-9508 Fax: <a href="mailto:rhwhite@fs.fed.us">rhwhite@fs.fed.us</a></td>
<td>FPL</td>
</tr>
<tr>
<td>Laboratory for Heat Transfer and Fuel Technology – Ghent Univ.</td>
<td>Ghent, Belgium</td>
<td>Prof dr ir P Vandevelde</td>
<td>Tel: 32-9-243 77 55 32-9-243 77 51 Fax: <a href="mailto:paul.vandevelde@rug.ac.be">paul.vandevelde@rug.ac.be</a></td>
<td>LGU</td>
</tr>
<tr>
<td>General Building Research Corporation of Japan</td>
<td>Osaka Prefecture, Japan</td>
<td>Masatomo Yoshido*</td>
<td>Tel: 81 6872-0391 81 6872-0784 Fax: <a href="mailto:tasaka@gbrc.or.jp">tasaka@gbrc.or.jp</a></td>
<td>GBR</td>
</tr>
<tr>
<td>BRE: Centre for Fire Performance and Suppression</td>
<td>Hertfordshire, UK</td>
<td>Dick Jones*</td>
<td>Tel: 01923 665021 01923 665197 Fax: <a href="mailto:jonesr@bre.co.uk">jonesr@bre.co.uk</a></td>
<td>BRE</td>
</tr>
<tr>
<td>VTT Technical Research Centre of Finland</td>
<td>Espoo, Finland</td>
<td>Matti Lanu</td>
<td>Tel: 358 9 456 6935 358 9 456 4815 Email: <a href="mailto:tasaka@gbrc.or.jp">tasaka@gbrc.or.jp</a></td>
<td>VTT</td>
</tr>
<tr>
<td>Underwriters Laboratory</td>
<td>Northbrook, IL, USA</td>
<td>Robert Berhinig</td>
<td>Tel: 847-664-2292 847-509-6392 Email: <a href="mailto:Robert.m.berhinig@us.ul.com">Robert.m.berhinig@us.ul.com</a></td>
<td>UL</td>
</tr>
<tr>
<td>Underwriters Laboratory Canada</td>
<td>Ontario, Canada</td>
<td>G. Abbas Nanji</td>
<td>Tel: 416-757-3611 416-757-1781 Email: <a href="mailto:Garry.Collins@csiro.au">Garry.Collins@csiro.au</a></td>
<td>ULC</td>
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<tr>
<td>Fire Engineering Testing Section, Testing Services Dept., SIRIM QAS Sdn. Bhd.</td>
<td>Selangor, Malaysia</td>
<td>Rohaya Ibrahim</td>
<td>Tel: 603-5544 6456 603-5544 6454 Email: <a href="mailto:rohaya@sirim.my">rohaya@sirim.my</a></td>
<td>FET</td>
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<tr>
<td>Building Research Institute</td>
<td>Tsukuba, Japan</td>
<td>Dr. Mamoru Kohno</td>
<td>-</td>
<td>BRI</td>
</tr>
<tr>
<td>Fire Technology Laboratory, CSIRO Manufacturing and Infrastructure</td>
<td>Sydney, Australia</td>
<td>Garry E. Collins</td>
<td>Tel: 61 2 9490 5408 61 2 94905528 Email: <a href="mailto:Garry.Collins@csiro.au">Garry.Collins@csiro.au</a></td>
<td>FTL</td>
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<tr>
<td>Warrington Fire Research Centre</td>
<td>Cheshire, UK</td>
<td>Niall Rowan</td>
<td>Tel: 44 1925 655116 44 1925 655419 Email: <a href="mailto:niall.rowan@wfrc.co.uk">niall.rowan@wfrc.co.uk</a></td>
<td>WFR</td>
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<tr>
<td>Southwest Research Institute, Dept. of Fire Technology</td>
<td>San Antonio, TX, USA</td>
<td>James R. Griffith</td>
<td>Tel: 210-522-3716 210-522-3377 Email: <a href="mailto:jgriffith@swri.org">jgriffith@swri.org</a></td>
<td>SWR</td>
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<tr>
<td>SP Swedish National Testing and Res. Institute</td>
<td>Boras, Sweden</td>
<td>Ulf Wickstrom</td>
<td>Tel: +46 33 165194 46 33 165194 Email: <a href="mailto:ulf.wickstrom@sp.se">ulf.wickstrom@sp.se</a></td>
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* indicates one of multiple contact persons provided
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<tr>
<th>Lab</th>
<th>Vertical FR Tests If Yes, Sizes</th>
<th>Combination Elements</th>
<th>Restrictions</th>
<th>Loading If Yes, How</th>
<th>Fire Exposure</th>
<th>Pressure (Pos., Neg., Combo)</th>
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<tr>
<td>USG</td>
<td>Max 10’x10’</td>
<td>No</td>
<td>No</td>
<td>Mechanical Jacks</td>
<td>Max Temp of 1200 ºC</td>
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<td>PSB</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>GFT</td>
<td>3m x 3.7m</td>
<td>Yes but unwilling</td>
<td>No plastics or woods with arsenic</td>
<td>Hydraulic Jacks</td>
<td>ASTM E119</td>
<td>Yes</td>
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<tr>
<td>CBL</td>
<td>Columns – 1.5m only</td>
<td>Second Furnace Top Load</td>
<td>No</td>
<td>No</td>
<td>All</td>
<td>Column Furn. Pos. Topload Furn Neg</td>
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<td>LSF</td>
<td>2.8m x 2.8m</td>
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<td>No</td>
<td>Axial Compression</td>
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<td>3m x 3m or 4.3m x 3.7m 2.7m columns</td>
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<td>No</td>
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<td>LGU</td>
<td>3m x 3m</td>
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<td>No</td>
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<td>3m x 3m</td>
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<td>Lab</td>
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<td>Combination Elements</td>
<td>Restrictions</td>
<td>Loading If Yes, How</td>
<td>Fire Exposure (Pos., Neg., Combo)</td>
<td>Pressure (Pos., Neg., Combo)</td>
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<td>No</td>
<td>Water Containers</td>
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<td>Toxic Materials</td>
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<td>Tensile Load Only</td>
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<td>Hydraulic Jacks</td>
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<td>No</td>
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<td>Hydraulic Jacks</td>
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<td>4.3m x 5.3m</td>
<td>Yes</td>
<td>No</td>
<td>Water Tanks/Hydraulic Jacks</td>
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<td>10.5m x 4m x 2.4m</td>
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<td>No</td>
<td>Jacks with dead weights</td>
<td>ASTM E119, ISO 834</td>
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<td>4m x 8m</td>
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<td>No</td>
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<td>Combo</td>
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<td>No</td>
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<td>ISO 834, ASTM E119, Pool Fire, and EN 1363-2</td>
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<td>Weights &amp; Hydraulic Jacks</td>
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### Table 3.6 Additional Information

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<th>Outside Party Testing</th>
<th>Contractual Concerns</th>
<th>Turn-Around Time</th>
<th>Costs (US $)</th>
<th>Safety and Env. Regulations</th>
<th>Full-Scale Non-Std. Tests</th>
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<td>GFT</td>
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<td>1-2 months</td>
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4.0 TASK 3. ASSESSMENT OF NEEDS

4.1 Objective

The objective of this task was to perform an assessment of the need for additional testing and/or experimental facilities to allow the performance of structural assemblies and fire resistance materials to be predicted under realistic fire conditions within actual buildings; and to develop options for meeting identified needs.

4.2 Assessment

The survey of the fire history of partial or total collapse of buildings identified 22 fire-induced collapses. These collapses, when combined with fire events that caused major structural damage without collapse, result in a significant number of fire events. The costs, both economic and human, of these events are considerable. It is also apparent that significant damage or collapse occurs in all types of construction and is not limited to a particular building method or material. One must therefore, consider the entire range of building materials and construction methods as exhibiting the potential for fire-induced collapse.

One important finding is the lack of systematically collected information about partial or total collapse due to fire. Generally, very little structural collapse information was available, especially for events that occurred outside North America. Even in North America, there was no specific reporting of collapse via NFIRS, or other reporting system. Therefore, it is recommended that a structural damage and collapse reporting method be developed or be incorporated into existing databases whereby structural damage and collapse can be reported in the future. Without this information, the full scope of this problem cannot be understood.

Except for several recent research studies (Bailey, 2002; Newman, et al., 2000; Bailey, 2001) current fire resistance testing is limited to qualifying materials or assemblies using the standard fire resistance tests. When viewed from a whole building perspective, the standard fire testing has the following limitations:

- Tests are conducted on individual building elements of limited size.
- Tests do not evaluate the connections of one building element to another.
- Tests demonstrate the fire resistance capability based typically on limited temperature measurements and limited load carrying capability
- Other than significant deflections, no other structural measurements or data are obtained
- Tests typically use a similar but single fire exposure (i.e., ASTM E 199 and ISO 834)
- The test assembly is exposed from only one side, except for columns (i.e., all sides) and beams (i.e. typically 3 sides)
- Tests are typically not conducted to ultimate failure. Tests are stopped when the required rating period is attained, or when the appropriate temperature or deflection limit is observed.

This type of standardized fire resistance testing has been used for many years. It appears that it has provided some measure of safety, since most buildings that have a significant fire do
not exhibit collapse. This may be due to many factors such as a limited fire spread area so that load is transferred to elements not exposed to the fire, redundancy and/or operation of fire protection features and over-design of the structural components, their fire protections and the other fire protection features within the building. However, despite these general successes, notable failures identified in this report have occurred. Based on the history, these failures will continue to occur.

Methods and tools need to be developed to provide an engineering basis for structural fire resistance. It is readily apparent that the current state-of-the-art in fire resistance testing does not address the “whole building” as a single entity. In this regard, the WTC collapses have highlighted the lack of communication between the structural engineering community and the fire protection community when designing buildings. Also, the issue of a single mode of failure (i.e., loss of some structural stability) resulting in collapse has arisen.

If a column is exposed to a fire, how its behavior or failure will affect the structural elements that it supports is unknown. Currently, we would test the column with protection such that the element will not exceed pre-defined critical temperatures below which its structural capability is assumed to be adequate. Even though the column is connected to a beam or floor, we do not evaluate the connection method, nor its protection, to assure that the connection will perform as designed. Also, if the column was to fail, the impact of this failure on the rest of the structure is unknown. It has always been assumed that if each individual element performs well by itself, then the whole will perform successfully. In some cases, this may be a faulty assumption.

It has been assumed in standard tests, that the actual fire will expose one side of an assembly. For example, a floor is tested with the fire under the floor. The connection of the floor to exterior columns or spandrel beams may be exposed both from the fire below and an exterior fire plume from window openings on the fire floor below. Thus, all of the elements are exposed and stressed simultaneously.

Structural performance at elevated temperatures except for the support of some live load or the attainment of a critical temperature, are typically ignored in current fire resistance testing. In effect, an assembly or element is evaluated for its structural performance by attainment of a critical temperature or its support of a live load based on some requirement for the amount of the load to be imposed during the test. In many cases, the live load used in the test may not be the maximum design load. Other loads or stresses may also be imposed on a structural element that may affect its structural performance during a fire event that may need to be considered. Thus, the combination of thermal load effects and structural load-carrying performance is ignored.

The existing fire test facilities evaluate building elements with specific size limitations such as length of beams (3.7 m), height of columns (2.7 m), etc. In real-world applications, building elements are significantly larger that those tested. This raises potential concerns of the structural performance on the large members when they are exposed to a fire. In these cases, the performance under a specific load on a shorter member will not reflect the same loading on a longer member.
In the standardized fire tests, the measurements and data collected are minimal. To understand how structural elements behave in a fire, greatly enhanced and unique instrumentation will be required. This will include monitoring the structural members for movement, state of stress, and temperature distribution within the elements. Without this information, it will be impossible to predict the performance of the building elements or systems when exposed to a fire.

The history of fire-induced building collapse coupled with identified concerns surrounding the existing fire resistance test methods clearly indicate that there is a need for reliable structural fire protection that goes beyond what is practiced today. In order to accomplish this goal of advancing our understanding and knowledge along with enhancing the combination of fire protection and structural engineering, empirical data developed from research-based, realistic tests must be generated. These data will be necessary to provide the basis for future analytical models and structural fire protection design methods.

Since our concerns center on a greater understanding of the impact of fire on the building elements, combination of building elements, their connections to each other and on real-scale size of building elements, most of our existing test facilities may be inadequate. Newer or unique facilities will be required to appropriately address these issues. If a connection, such as a column to a beam is to be evaluated, even the existing larger furnaces will have to be adapted to provide the appropriate exposure and loading systems. The current limitations on the size of the members that can be tested in existing furnaces remain a concern. In testing a combination of walls, exterior columns and floors, a unique test facility will have to be constructed to accommodate the required size, appropriate loading and the fire exposures needed. For longer, wider or taller members, a unique facility will again be required.

Currently, the path to the design, construction, and operation of a unique facility to provide the required research-based information is unclear. Future discussions within the fire protection and the structural engineering communities are required so as to begin to build a consensus with respect to the path forward. Deliberations with respect to developing a research plan for the future must continue and the plan developed. The Fire Resistance Determination and Performance Prediction Research Needs Workshop (Grosshandler, 2002) was a significant step in this direction. Along with the research plan, implementation strategies with respect to identification of stakeholders, investments of time and funding must be discussed and determined.

In summary, it is clear that to provide reliable structural fire protection for buildings, the future research needs will dictate that one or more unique facilities will be required. Specialized test apparatus, loading methods and instrumentation for large sizes, real-scale building elements and their connection, and full- or real-scale combinations of elements will be required as well as providing specialized and enhanced instrumentation to determine the structural performance of the building elements in a more quantitative manner. With the information and data that this type of unique facility can provide, both the fire protection and the structural engineering professions can be provided with an advanced understanding of the performance of fire exposed building elements such that improvements in the design and use of construction materials and techniques as well as the development of analytical models and design tools can be attained. This advanced
knowledge can then be moved into actual design practice and future codes and standards so that fire-induced building collapse in buildings can be prevented.

5.0 REFERENCES


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Questionnaire Concerning Fire Resistance Testing
Of Structural Building Elements

PART I – GENERAL

Name of Laboratory

Location – City, State, Country

Type of Organization – Government, Private, Industry, Non-profit, etc.

Contact information – Person, address, E-mail address, phone number, and fax number.

Can the laboratory perform fire resistance testing of structural building elements? These include walls, columns, floors, ceilings, beams, trusses, connections etc.

If no – so state, complete Part I and return the form to Hughes Associates, Inc. as shown in Section V at the bottom of this Questionnaire.

If yes – please continue and address the parts that are applicable to your laboratory.

PART II – VERTICAL STRUCTURAL BUILDING ELEMENTS

Can you test for fire resistance of vertical building elements such as walls/columns, etc.?

Can you perform standard fire tests and nonstandard fire resistance tests on these elements?

How many furnaces for vertical element tests do you have and what elements can be tested in each?

Besides testing discrete building elements such as walls or columns by themselves, can your furnace(s) accommodate combinations of elements such as wall-floor combinations, column-beam connections, etc.?

What are the largest dimensions of test samples that you can test in each furnace for each type or combination of building element?

Do you have any restrictions with respect to what type of materials can be tested (i.e., wood, steel, concrete, composites, aluminum, fire-proofing materials, etc.)?

What type for fire exposure can your furnace(s) generate (i.e., ISO 834, ASTM E119, Hydrocarbon pool fire simulations, others)?

Do you have any limitations on the fire exposure?
Do you control the furnace exposure via temperatures and/or heat flux?

How are these parameters measured (i.e., thermocouples, heat flux gauges, plate thermometers, etc.) and recorded (i.e., computer, strip charts, etc.)?

Can your furnace(s) run positive, negative or a combination of both with respect to pressure inside the furnace? Do you have any limitations with respect to the pressure or the position of the neutral plane?

Do you measure and record the furnace pressure?

Can you apply a load to the test sample?

If so, can this be done on each furnace?

Provide a brief description of the load mechanism (i.e., compression, tension, shear, axial, load limits, use load beam w/ jacks, etc.) for each furnace and/or type of building element.

How is the load carrying capability monitored during the test?

PART III – HORIZONTAL STRUCTURAL BUILDING ELEMENTS

Can you test for fire resistance of horizontal building elements such as floors, ceilings, beams, trusses, etc.?

Can you perform standard fire tests and nonstandard fire resistance tests on these elements?

How many furnaces for horizontal element tests do you have and what elements can be tested in each?

Besides testing discrete building elements such as floors or beams by themselves, can your furnace(s) accommodate combinations of elements such as floor-wall combination, column-beam connections, etc.?

What are the largest dimensions of test samples that you can test in each furnace for each type or combination of building element?

Do you have any restrictions with respect to what type of materials can be tested (i.e., wood, steel, concrete, composites, aluminum, fire-proofing materials, etc.)?

What type for fire exposure can your furnace(s) generate (i.e., ISO 834, ASTM E119, Hydrocarbon pool fire simulations, others)?

Do you have any limitations on the fire exposure?
Do you control the furnace exposure via temperatures and/or heat flux?

How are these parameters measured (i.e., thermocouples, heat flux gauges, plate thermometers, etc.) and recorded (i.e., computer, strip charts, etc.)?

Can your furnace(s) run positive or negative with respect to pressure inside the furnace? Do you have any limitations with respect to the pressure or the position of the neutral plane?

Do you measure and record the furnace pressure?

Can you apply a load to the test sample?

If so, can this be done on each furnace?

Provide a brief description of the load mechanism (i.e., compression, tension, shear, axial, load limits, dead load, live load, use loading jacks/frame, water containers, etc.) for each furnace and/or type of building element.

How is the load carrying capability monitored during the test?

**PART IV – ADDITIONAL INFORMATION**

Is your laboratory capable of and willing to performing tests for outside parties or do you test only for yourself or your industry?

Do you have any restrictions on doing testing for outside parties?

Are there any specific contractual concerns with respect to performing testing for outside parties?

What is the typical turn-around time for conducting tests? We realize that cure times, construction, etc. may affect this but in general what is the timing.

Could you please provide a range of costs for some typical tests such as walls, columns, or floors? We realize many factors will influence this, but we are only looking for some general cost information.

Besides normal safety and environmental regulations, does your laboratory have any special regulations or rules concerning such items as testing, materials or disposal? If so, briefly details these.

Besides, the furnaces described above, does your laboratory have the capability to perform full-scale, nonstandard, fire resistance tests of structures such as rooms or small buildings?
Any other information that may assist us in our survey.

SECTION V – SUBMITTAL INFORMATION

Feel free to answer each question using this form and then submit the completed form.

This form can be submitted via Fax or E-mail. Please submit the completed form to:

Jesse J. Beitel  
Senior Scientist  
Hughes Associates, Inc.  
3610 Commerce Drive, Suite 817  
Baltimore, Maryland 21227 USA

Phone – 410-737-8677  
Fax – 410-737-8688

E-mail – jbeitel@haifire.com

Thank you for your assistance and time, and if you have any questions, please feel free to contact me.
**APPENDIX B**

**SAMPLES* OF LABORATORY QUESTIONNAIRES**

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*Permission obtained from listed laboratories to release details of survey. Contact other laboratories directly to request their additional information.*
PART I – GENERAL

Name of Laboratory:

Laboratorio de Ensayo de Resistencia al Fuego
DICTUC

Location – City, State, Country:

Santiago, Chile

Type of Organization – Government, Private, Industry, Non-profit, etc.

Private. It is owned by the Catholic University of Chile (non profit).

Contact information – Person, address, E-mail address, phone number, and fax number:

Pablo Matamala P.
Vicuña Mackenna 4860, Macul, Santiago, Chile
pmatamal@ing.puc.cl
Phone number: (56 2) 686 4626 – 686 4265
Fax number: (56 2) 686 6226

Can the laboratory perform fire resistance testing of structural building elements?
These include walls, columns, floors, ceilings, beams, trusses, connections etc.

Yes.

If no – so state, complete Part I and return the form to Hughes Associates, Inc. as shown in Section V at the bottom of this Questionnaire.

If yes – please continue and address the parts that are applicable to your laboratory.

PART II – VERTICAL STRUCTURAL BUILDING ELEMENTS

Can you test for fire resistance of vertical building elements such as walls/columns, etc.?

Yes.

Can you perform standard fire tests and nonstandard fire resistance tests on these elements?
Yes.

How many furnaces for vertical element tests do you have and what elements can be tested in each?

We have one furnace, capable of performing test for walls and columns.

Besides testing discrete building elements such as walls or columns by themselves, can your furnace(s) accommodate combinations of elements such as wall-floor combinations, column-beam connections, etc.?

We have not performed such a test, but a column – beam connection could be accommodated.

What are the largest dimensions of test samples that you can test in each furnace for each type or combination of building element?

Walls: 3.3 meters high and 3.2 meters wide (3.1 meters x 3.0 meters exposed to the fire)  
Columns: 3 meters long (2.7 meters exposed to the fire)

Do you have any restrictions with respect to what type of materials can be tested (i.e., wood, steel, concrete, composites, aluminum, fire-proofing materials, etc.)?

We do not have any restriction. The only concern would be the emission of dangerous substances: we have an incinerator to burn out the combustion gases, keeping them at 850°C during 2 seconds at least.

What type for fire exposure can your furnace(s) generate (i.e., ISO 834, ASTM E119, Hydrocarbon pool fire simulations, others)?

ISO 834 and ASTM E119. Hydrocarbon pool could be done, but we have not tested it yet.

Do you have any limitations on the fire exposure?

Hydrocarbon pool could be done, but we have not tested it yet. It would depend on the type of testing specimen: probably with a column we would not have problems, but regarding a wall we are not sure yet.

Do you control the furnace exposure via temperatures and/or heat flux?

We control it via temperature.

How are these parameters measured (i.e., thermocouples, heat flux gauges, plate thermometers, etc.) and recorded (i.e., computer, strip charts, etc.)?
Thermocouples and we are going to implement plate thermometers as well. We record all the information via a computer. We read temperatures every one second.

**Can your furnace(s) run positive, negative or a combination of both with respect to pressure inside the furnace? Do you have any limitations with respect to the pressure or the position of the neutral plane?**

We can run positive, negative or a combination of both. We have not run it to the limits: we can get full positive pressure, but we have not tested the maximum height of the neutral plane.

**Do you measure and record the furnace pressure?**

We measure it and then record it via a computer. We can read the pressure every 1 second.

**Can you apply a load to the test sample?**

Only to walls; not columns.

**If so, can this be done on each furnace?**

Yes. (We have only one furnace.)

**Provide a brief description of the load mechanism (i.e., compression, tension, shear, axial, load limits, use load beam w/ jacks, etc.) for each furnace and/or type of building element.**

For walls only: It is done in compression using an external frame and jacks. We can apply up to 30 tons of load.

**How is the load carrying capability monitored during the test?**

It is read from the jacks (related to the oil pressure).

**PART III – HORIZONTAL STRUCTURAL BUILDING ELEMENTS**

**Can you test for fire resistance of horizontal building elements such as floors, ceilings, beams, trusses, etc.?**

Yes.

**Can you perform standard fire tests and nonstandard fire resistance tests on these elements?**

Yes.
How many furnaces for horizontal element tests do you have and what elements can be tested in each?

We have only one furnace. We can test floors, ceilings and floor – beams arrangements.

Besides testing discrete building elements such as floors or beams by themselves, can your furnace(s) accommodate combinations of elements such as floor-wall combination, column-beam connections, etc.?

We can arrange and test column – beam arrangements.

What are the largest dimensions of test samples that you can test in each furnace for each type or combination of building element?

The fire exposed surface of the element is 4,5 meters by 3,75 meters. The element should be of 4,05 meters x 4,8 meters to fit into the frame.

Do you have any restrictions with respect to what type of materials can be tested (i.e., wood, steel, concrete, composites, aluminum, fire-proofing materials, etc.)?

We do not have any restriction. The only concern would be the emission of dangerous substances: we have an incinerator to burn out the combustion gases, keeping them at 850ºC during 2 seconds at least.

What type for fire exposure can your furnace(s) generate (i.e., ISO 834, ASTM E119, Hydrocarbon pool fire simulations, others)?

ISO 834 and ASTM E119. Hydrocarbon pool could be done, but we have not tested it yet.

Do you have any limitations on the fire exposure?

Hydrocarbon pool could be done, but we have not tested it yet. It would depend on the type of testing specimen: probably with a column we would not have problems, but regarding a wall we are not sure yet.

Do you control the furnace exposure via temperatures and/or heat flux?

We control it via temperature.

How are these parameters measured (i.e., thermocouples, heat flux gauges, plate thermometers, etc.) and recorded (i.e., computer, strip charts, etc.)?

Thermocouples and we are going to implement plate thermometers as well. We record all the information via a computer. We read temperatures every one second.
Can your furnace(s) run positive or negative with respect to pressure inside the furnace? Do you have any limitations with respect to the pressure or the position of the neutral plane?

We can run positive, negative or a combination of both. We have not run it to the limits: we can get full positive pressure, but we have not tested the maximum height of the neutral plane.

**Do you measure and record the furnace pressure?**

We measure it and then record it via a computer. We can read the pressure every 1 second.

**Can you apply a load to the test sample?**

Yes.

**If so, can this be done on each furnace?**

Yes. (We have only one furnace.)

**Provide a brief description of the load mechanism (i.e., compression, tension, shear, axial, load limits, dead load, live load, use loading jacks/frame, water containers, etc.) for each furnace and/or type of building element.**

We put dead loads over the test specimen. The maximum capacity is 500 Kg/m².

**How is the load carrying capability monitored during the test?**

We use dead load; they are weighted before. Deflection is monitored during the test.

**PART IV – ADDITIONAL INFORMATION**

**Is your laboratory capable of and willing to performing tests for outside parties or do you test only for yourself or your industry?**

We perform tests for outside parties. We are also available to perform tests for the university for investigation purposes.

**Do you have any restrictions on doing testing for outside parties?**

No.

**Are there any specific contractual concerns with respect to performing testing for outside parties?**
What is the typical turn-around time for conducting tests? We realize that cure times, construction, etc. may affect this but in general what is the timing.

After the specimen is finished, the test is performed in one day and the report is available two weeks after this.

For example: we tested some cardboard/gypsum and glass fiber arranged partition walls: they were built in one day each, and 3 days after letting them dry, we run the test. We could perform 3 tests in one week.

A horizontal floor assembly had to be built in 2 days, cured in 28 days and tested in two days.

Could you please provide a range of costs for some typical tests such as walls, columns, or floors? We realize many factors will influence this, but we are only looking for some general cost information.

Vertical Elements: US$ 1500 - 2000
Horizontal Elements: US$ 2000 - 2500

These prices do not consider the building costs of the specimen (materials and work hours)

Besides normal safety and environmental regulations, does your laboratory have any special regulations or rules concerning such items as testing, materials or disposal? If so, briefly details these.

No.

Besides, the furnaces described above, does your laboratory have the capability to perform full-scale, nonstandard, fire resistance tests of structures such as rooms or small buildings?

No.

Any other information that may assist us in our survey.

No.
PART I – GENERAL

Name of Laboratory

LABORATORY FOR HEAT TRANSFER AND FUEL TECHNOLOGY – GHENT UNIVERSITY

Location – City, State, Country

OTTERGEMSESTEENWEG 711, 9000 GHENT, BELGIUM

Type of Organization – Government, Private, Industry, Non-profit, etc.

GOVERNMENT

Contact information – Person, address, E-mail address, phone number, and fax number.

PROF DR IR P Vandevelde, Laboratory for Heat Transfer and Fuel Technology – Ghent University, Ottergemsesteenweg 711, 9000 Ghent, Belgium, Paul.Vandevelde@rug.ac.be, tel. +32-9-243 77 55, fax +32-9-243 77 51

Can the laboratory perform fire resistance testing of structural building elements? These include walls, columns, floors, ceilings, beams, trusses, connections etc.

YES

If no – so state, complete Part I and return the form to Hughes Associates, Inc. as shown in Section V at the bottom of this Questionnaire.

If yes – please continue and address the parts that are applicable to your laboratory.

PART II – VERTICAL STRUCTURAL BUILDING ELEMENTS

Can you test for fire resistance of vertical building elements such as walls/columns, etc.? YES

Can you perform standard fire tests and nonstandard fire resistance tests on these elements? YES

How many furnaces for vertical element tests do you have and what elements can be tested in each? 1 – Doors, walls, loaded and unloaded columns, lift landing doors, glazed elements, linear gap seals, dampers.
Besides testing discrete building elements such as walls or columns by themselves, can your furnace(s) accommodate combinations of elements such as wall-floor combinations, column-beam connections, etc.? **To a limited extent.**

What are the largest dimensions of test samples that you can test in each furnace for each type or combination of building element? The furnace dimensions are 3 m width, 3 m height and ± 1.5 m depth for doors, walls, lift landing doors, glazed elements, linear gap seals and dampers. The furnace dimensions are 3 m width, ± 4 m height and 3 m depth for loaded and unloaded columns.

Do you have any restrictions with respect to what type of materials can be tested (i.e., wood, steel, concrete, composites, aluminum, fire-proofing materials, etc.)? **No.**

What type for fire exposure can your furnace(s) generate (i.e., ISO 834, **YES** ASTM E119 **YES**, Hydrocarbon pool fire simulations **NO**, others **YES**, hydrocarbon curve)?

Do you have any limitations on the fire exposure? **Six hours duration.**

Do you control the furnace exposure via temperatures and/or heat flux? **Thermocouple plus plate thermometers (European standards).**

How are these parameters measured (i.e., thermocouples, heat flux gauges, plate thermometers, etc.) and recorded (i.e., computer, strip charts, etc.)?

Can your furnace(s) run positive, negative or a combination of both with respect to pressure inside the furnace? Do you have any limitations with respect to the pressure or the position of the neutral plane? **The neutral plane within the furnace height if the pressure is negative in the furnace.** The pressure in the furnace is up to circa 50 Pa.

Do you measure and record the furnace pressure? **YES**

Can you apply a load to the test sample? **YES**

If so, can this be done on each furnace? **YES**

Provide a brief description of the load mechanism (i.e., compression, tension, shear, axial, load limits, use load beam w/ jacks, etc.) for each furnace and/or type of building element. **We can charge loaded columns up to 5.000 kN.**

How is the load carrying capability monitored during the test? **Pressure of hydraulic rams and/or load cells.**

**PART III – HORIZONTAL STRUCTURAL BUILDING ELEMENTS**

Can you test for fire resistance of horizontal building elements such as floors, ceilings, beams, trusses, etc.? **YES**
Can you perform standard fire tests and nonstandard fire resistance tests on these elements? **YES**

How many furnaces for horizontal element tests do you have and what elements can be tested in each? **One. Floors, beams, trusses, ceilings, ventilation ducts, stairs, columns.**

Besides testing discrete building elements such as floors or beams by themselves, can your furnace(s) accommodate combinations of elements such as floor-wall combination, column-beam connections, etc.? **To a limited extent.**

What are the largest dimensions of test samples that you can test in each furnace for each type or combination of building element? **Furnace = 6 m long, 3 m wide, 2 m deep.**

Do you have any restrictions with respect to what type of materials can be tested (i.e., wood, steel, concrete, composites, aluminum, fire-proofing materials, etc.)? **NO**

What type for fire exposure can your furnace(s) generate (i.e., ISO 834 **YES**, ASTM E119 **YES**, Hydrocarbon pool fire simulations, others **YES**)?

Do you have any limitations on the fire exposure? **Duration < 6 hours**

Do you control the furnace exposure via temperatures and/or heat flux? **As above.**

How are these parameters measured (i.e., thermocouples, heat flux gauges, plate thermometers, etc.) and recorded (i.e., computer, strip charts, etc.)? **As above.**

Can your furnace(s) run positive or negative with respect to pressure inside the furnace? **As above.**
Do you have any limitations with respect to the pressure or the position of the neutral plane? **As above.**

Do you measure and record the furnace pressure? **YES**

Can you apply a load to the test sample? **YES**

If so, can this be done on each furnace? **YES**

Provide a brief description of the load mechanism (i.e., compression, tension, shear, axial, load limits, dead load, live load, use loading jacks/frame, water containers, etc.) for each furnace and/or type of building element. **We can charge beams up to 800 kN.**

How is the load carrying capability monitored during the test? **As above.**

**PART IV – ADDITIONAL INFORMATION**
Is your laboratory capable of and willing to performing tests for outside parties or do you test only for yourself or your industry? **YES**

Do you have any restrictions on doing testing for outside parties? **NO**

Are there any specific contractual concerns with respect to performing testing for outside parties? **Normal commercial conditions.**

What is the typical turn-around time for conducting tests? We realize that cure times, construction, etc. may affect this but in general what is the timing.

**Three to six months, depending on complexity and availability of furnace.**

Could you please provide a range of costs for some typical tests such as walls, columns, or floors? We realize many factors will influence this, but we are only looking for some general cost information.

Besides normal safety and environmental regulations, does your laboratory have any special regulations or rules concerning such items as testing, materials or disposal? If so, briefly details these.

Besides, the furnaces described above, does your laboratory have the capability to perform full-scale, nonstandard, fire resistance tests of structures such as rooms or small buildings? **To a limited extent. The tests are done in the open air.**

Any other information that may assist us in our survey.
PART I – GENERAL

NGC Testing Services

1650 Military Road, Buffalo, NY 14217

Private

Robert J. Menchetti, email@ngctestingservices.com, 716 8739750 ext. 341, 716 973-9753 (fax)

Can the laboratory perform fire resistance testing of structural building elements? These include walls, columns, floors, ceilings, beams, trusses, connections etc. Yes

If no – so state, complete Part I and return the form to Hughes Associates, Inc. as shown in Section V at the bottom of this Questionnaire.

If yes – please continue and address the parts that are applicable to your laboratory.

PART II – VERTICAL STRUCTURAL BUILDING ELEMENTS

Can you test for fire resistance of vertical building elements such as walls/columns, etc.? Yes

Can you perform standard fire tests and nonstandard fire resistance tests on these elements? Yes

How many furnaces for vertical element tests do you have and what elements can be tested in each? 1 vertical furnace, 3 test movable 10’x10’ frames

Besides testing discrete building elements such as walls or columns by themselves, can your furnace(s) accommodate combinations of elements such as wall-floor combinations, column-beam connections, etc.? Yes

What are the largest dimensions of test samples that you can test in each furnace for each type or combination of building element? 10’ x 10’

Do you have any restrictions with respect to what type of materials can be tested (i.e., wood, steel, concrete, composites, aluminum, fire-proofing materials, etc.)? NO

What type for fire exposure can your furnace(s) generate (i.e., ISO 834, ASTM E119, Hydrocarbon pool fire simulations, others)? E119

Do you have any limitations on the fire exposure? NO
Do you control the furnace exposure via temperatures and/or heat flux? Temp.

How are these parameters measured (i.e., thermocouples, heat flux gauges, plate
thermometers, etc.) and recorded (i.e., computer, strip charts, etc.)? Computer

Can your furnace(s) run positive, negative or a combination of both with respect to
pressure inside the furnace? Do you have any limitations with respect to the pressure or
the position of the neutral plane? Yes, no limitations

Do you measure and record the furnace pressure? Yes

Can you apply a load to the test sample? Yes

If so, can this be done on each furnace? Yes

Provide a brief description of the load mechanism (i.e., compression, tension, shear,
axial, load limits, use load beam w/ jacks, etc.) for each furnace and/or type of building
element. Axial load utilizing hydraulic jacks

How is the load carrying capability monitored during the test? Pressure gauges /
deflection gauges

PART III – HORIZONTAL STRUCTURAL BUILDING ELEMENTS

Can you test for fire resistance of horizontal building elements such as floors, ceilings,
beams, trusses, etc.? YES

Can you perform standard fire tests and nonstandard fire resistance tests on these
elements? YES

How many furnaces for horizontal element tests do you have and what elements can be
tested in each? 2

Besides testing discrete building elements such as floors or beams by themselves, can
your furnace(s) accommodate combinations of elements such as floor-wall combination,
column-beam connections, etc.? YES

What are the largest dimensions of test samples that you can test in each furnace for each
type or combination of building element? 14’ x 18’

Do you have any restrictions with respect to what type of materials can be tested (i.e.,
wood, steel, concrete, composites, aluminum, fire-proofing materials, etc.)? NO

What type for fire exposure can your furnace(s) generate (i.e., ISO 834, ASTM E119,
Hydrocarbon pool fire simulations, others)? E119
Do you have any limitations on the fire exposure?  NO

Do you control the furnace exposure via temperatures and/or heat flux?  Temp.

How are these parameters measured (i.e., thermocouples, heat flux gauges, plate thermometers, etc.) and recorded (i.e., computer, strip charts, etc.)?  Computer

Can your furnace(s) run positive or negative with respect to pressure inside the furnace?  
Do you have any limitations with respect to the pressure or the position of the neutral plane?  Yes, no limitations

Do you measure and record the furnace pressure?  YES

Can you apply a load to the test sample?  YES

If so, can this be done on each furnace?  YES

Provide a brief description of the load mechanism (i.e., compression, tension, shear, axial, load limits, dead load, live load, use loading jacks/frame, water containers, etc.) for each furnace and/or type of building element.  WATER CONTAINERS

How is the load carrying capability monitored during the test?  Deflection gauges

**PART IV – ADDITIONAL INFORMATION**

Is your laboratory capable of and willing to performing tests for outside parties or do you test only for yourself or your industry?  We perform tests for outside parties.

Do you have any restrictions on doing testing for outside parties?  NO

Are there any specific contractual concerns with respect to performing testing for outside parties?  NO

What is the typical turn-around time for conducting tests? We realize that cure times, construction, etc. may affect this but in general what is the timing.  Within 2 weeks after receiving test materials

Could you please provide a range of costs for some typical tests such as walls, columns, or floors? We realize many factors will influence this, but we are only looking for some general cost information.  Walls: $5,000 +/-,  Floor – ceiling +/- $10,000.

Besides normal safety and environmental regulations, does your laboratory have any special regulations or rules concerning such items as testing, materials or disposal? If so, briefly details these.  NO
Besides, the furnaces described above, does your laboratory have the capability to perform full-scale, nonstandard, fire resistance tests of structures such as rooms or small buildings? NO, not beyond room corner burns

Any other information that may assist us in our survey.

Our web site: ngctestingservices.com

We also have a full building acoustics laboratory within the same facility
PART I – GENERAL

Name of Laboratory: PSB Corporation Pte Ltd

Location – No 10 Tuas Avenue 10 Singapore 639134

Type of Organization – Government Linked Company

Contact information – Joseph Chng
Tel: (65) 6865 3778
Fax:(65) 6862 1433
Email: joseph.chng@psbcorp.com

Can the laboratory perform fire resistance testing of structural building elements? These include walls, columns, floors, ceilings, beams, trusses, connections etc.

Yes, only on non-load bearing elements.

If no – so state, complete Part I and return the form to Hughes Associates, Inc. as shown in Section V at the bottom of this Questionnaire.

If yes – please continue and address the parts that are applicable to your laboratory.

PART II – VERTICAL STRUCTURAL BUILDING ELEMENTS

Can you test for fire resistance of vertical building elements such as walls/columns, etc.?

Yes

Can you perform standard fire tests and nonstandard fire resistance tests on these elements?

Yes

How many furnaces for vertical element tests do you have and what elements can be tested in each?

2 number of vertical furnaces of size 3.2m x 3.2m and 1 number of cube furnace of size 1.5m x 1.5m, for testing of wall partition, fire doors, dampers, lift landing doors, refute chute hopper, etc.

Besides testing discrete building elements such as walls or columns by themselves, can your furnace(s) accommodate combinations of elements such as wall-floor combinations, column-beam connections, etc.?
No

What are the largest dimensions of test samples that you can test in each furnace for each type or combination of building element?

3m x 3m

Do you have any restrictions with respect to what type of materials can be tested (i.e., wood, steel, concrete, composites, aluminum, fire-proofing materials, etc.)?

No

What type for fire exposure can your furnace(s) generate (i.e., ISO 834, ASTM E119, Hydrocarbon pool fire simulations, others)?

ISO 834, ASTM E119, BS 476 Part 20/22, AS 1530.4

Do you have any limitations on the fire exposure?

No

Do you control the furnace exposure via temperatures and/or heat flux?

Temperature

How are these parameters measured (i.e., thermocouples, heat flux gauges, plate thermometers, etc.) and recorded (i.e., computer, strip charts, etc.)?

Thermocouples are used for measurements and recorded on computer.

Can your furnace(s) run positive, negative or a combination of both with respect to pressure inside the furnace? Do you have any limitations with respect to the pressure or the position of the neutral plane?

A combination of both. No limitation to the neutral plane.

Do you measure and record the furnace pressure?

Yes

Can you apply a load to the test sample?

No
If so, can this be done on each furnace?

Not applicable

Provide a brief description of the load mechanism (i.e., compression, tension, shear, axial, load limits, use load beam w/ jacks, etc.) for each furnace and/or type of building element.

Not applicable

How is the load carrying capability monitored during the test?

Not applicable

PART III – HORIZONTAL STRUCTURAL BUILDING ELEMENTS

Can you test for fire resistance of horizontal building elements such as floors, ceilings, beams, trusses, etc.?

No

Can you perform standard fire tests and nonstandard fire resistance tests on these elements?

How many furnaces for horizontal element tests do you have and what elements can be tested in each?

Besides testing discrete building elements such as floors or beams by themselves, can your furnace(s) accommodate combinations of elements such as floor-wall combination, column-beam connections, etc.?

What are the largest dimensions of test samples that you can test in each furnace for each type or combination of building element?

Do you have any restrictions with respect to what type of materials can be tested (i.e., wood, steel, concrete, composites, aluminum, fire-proofing materials, etc.)?

What type for fire exposure can your furnace(s) generate (i.e., ISO 834, ASTM E119, Hydrocarbon pool fire simulations, others)?

Do you have any limitations on the fire exposure?

Do you control the furnace exposure via temperatures and/or heat flux?

How are these parameters measured (i.e., thermocouples, heat flux gauges, plate thermometers, etc.) and recorded (i.e., computer, strip charts, etc.)?
Can your furnace(s) run positive or negative with respect to pressure inside the furnace? Do you have any limitations with respect to the pressure or the position of the neutral plane?

Do you measure and record the furnace pressure?

Can you apply a load to the test sample?

If so, can this be done on each furnace?

Provide a brief description of the load mechanism (i.e., compression, tension, shear, axial, load limits, dead load, live load, use loading jacks/frame, water containers, etc.) for each furnace and/or type of building element.

How is the load carrying capability monitored during the test?

PART IV – ADDITIONAL INFORMATION

Is your laboratory capable of and willing to performing tests for outside parties or do you test only for yourself or your industry?

Yes, we do conduct tests for overseas clients beside the local industries.

Do you have any restrictions on doing testing for outside parties?

No

Are there any specific contractual concerns with respect to performing testing for outside parties?

No

What is the typical turn-around time for conducting tests? We realize that cure times, construction, etc. may affect this but in general what is the timing.

4 to 6 weeks

Could you please provide a range of costs for some typical tests such as walls, columns, or floors? We realize many factors will influence this, but we are only looking for some general cost information.
Test fees of between US$2300 to US$3300.

Besides normal safety and environmental regulations, does your laboratory have any special regulations or rules concerning such items as testing, materials or disposal? If so, briefly details these.

We are expected to comply with the Ministry of Manpower and Ministry of Environment regulations, beside the laboratory accreditation under ISO/IEC 17025.

Besides, the furnaces described above, does your laboratory have the capability to perform full-scale, nonstandard, fire resistance tests of structures such as rooms or small buildings?

No.

Any other information that may assist us in our survey.

Our fire test laboratory is accredited by Singapore Accreditation Council (SAC) under the Singapore Laboratory Accreditation Scheme (SINGLAS). SAC is an independent organisation.
PART I – GENERAL

Name of Laboratory

UNDERWRITERS LABORATORIES, INC

Location – City, State, Country

333 Pfingsten Road
Northbrook, IL 60062

Type of Organization – Government, Private, Industry, Non-profit, etc.

Not for profit

Contact information – Person, address, E-mail address, phone number, and fax number.

Robert M. Berhinig
333 Pfingsten Road
Northbrook, IL 60062

robert.m.berhinig@us.ul.com

Phone: +1 847-664-2292

Fax: +1-847-509-6392

Can the laboratory perform fire resistance testing of structural building elements? These include walls, columns, floors, ceilings, beams, trusses, connections etc.

Yes

If no – so state, complete Part I and return the form to Hughes Associates, Inc. as shown in Section V at the bottom of this Questionnaire.

If yes – please continue and address the parts that are applicable to your laboratory.

PART II – VERTICAL STRUCTURAL BUILDING ELEMENTS

Can you test for fire resistance of vertical building elements such as walls/columns, etc.?
Yes

Can you perform standard fire tests and nonstandard fire resistance tests on these elements?

Yes. There are temperature and pressure limits associated with each piece of test equipment. These conditions would need to be defined for the nonstandard tests.

How many furnaces for vertical element tests do you have and what elements can be tested in each?

Three

Column furnace: Inside dimensions of approximately 8 feet by 10 feet wide by 10 feet high.

Vertical Panel Furnace: Inside dimensions of sample test frame is approximately 15 feet wide by 10 feet high. This furnace is to test load and nonload bearing walls and fire door assemblies.

Vertical Panel Furnace: Inside dimensions of sample test frame is approximately 4.5 feet wide by 5.5 feet high.

Besides testing discrete building elements such as walls or columns by themselves, can your furnace(s) accommodate combinations of elements such as wall-floor combinations, column-beam connections, etc.?

The combinations of wall-floors and column beams may better be handled within our floor furnace. It is planned to add loading equipment to the column furnace during 2003. Presently only unloaded specimens can be tested in the column furnace.

What are the largest dimensions of test samples that you can test in each furnace for each type or combination of building element?

Column furnace – Approximately 9 feet long.

Vertical Panel Furnace – Approximately 14 feet wide by 10 feet high

Do you have any restrictions with respect to what type of materials can be tested (i.e., wood, steel, concrete, composites, aluminum, fire-proofing materials, etc.)?

No. All our furnaces are connected to smoke abatement equipment.
What type of fire exposure can your furnace(s) generate (i.e., ISO 834, ASTM E119, Hydrocarbon pool fire simulations, others)?

*The large panel furnace is limited to ISO 834 / ASTM E119 exposures or lower temperature and pressure levels.*

*The column furnace is frequently used for hydrocarbon pool fire simulations. It was used to develop the requirements for Standard UL 1709.*

Do you have any limitations on the fire exposure?

*None other than the upper limits of the fuel source which excludes the large panel furnace from the rate of temperature rise required by the hydrocarbon pool fire simulation.*

Do you control the furnace exposure via temperatures and/or heat flux?

*Furnaces are controlled by temperatures because of test standard requirements. Heat flux measurements could be made.*

How are these parameters measured (i.e., thermocouples, heat flux gauges, plate thermometers, etc.) and recorded (i.e., computer, strip charts, etc.)?

*Temperatures are measured by thermocouples and recorded in a centralized data logging system. The data logging system is capable of handling 300 channels and is updated at a frequency of 1 second / iteration. Final processing of data is typically in Excel spreadsheet format.*

Can your furnace(s) run positive, negative or a combination of both with respect to pressure inside the furnace? Do you have any limitations with respect to the pressure or the position of the neutral plane?

*The furnaces can comply with the pressure requirements of ISO 834.*

Do you measure and record the furnace pressure?

*Yes*

Can you apply a load to the test sample?

*Yes*

If so, can this be done on each furnace?

*Samples on the large panel furnace can be loaded. These samples are usually 10 feet by 10 feet. Samples on the smaller vertical panel furnace can not be loaded.*
Presently, samples in the column furnace cannot be loaded. It is anticipated loading equipment will installed in the column furnace during 2003.

Provide a brief description of the load mechanism (i.e., compression, tension, shear, axial, load limits, use load beam w/ jacks, etc.) for each furnace and/or type of building element.

Load is applied to wall by a series of hydraulic jacks.

How is the load carrying capability monitored during the test?

The load carrying capability of the sample is monitored by visual observations and by deflection measurements.

PART III – HORIZONTAL STRUCTURAL BUILDING ELEMENTS

Can you test for fire resistance of horizontal building elements such as floors, ceilings, beams, trusses, etc.?

Yes

Can you perform standard fire tests and nonstandard fire resistance tests on these elements?

Nonstandard tests can be conducted but there are limits to the capabilities of the furnace.

How many furnaces for horizontal element tests do you have and what elements can be tested in each?

Three.

One furnace can accommodate samples approximately 14 feet wide by 17.5 feet long. The depth of the furnace can vary but the most common depth is approximately 6 feet.

The other two furnaces are smaller with sample sizes approximately 3 feet by 3 feet. Loads cannot be applied on these smaller samples.

Besides testing discrete building elements such as floors or beams by themselves, can your furnace(s) accommodate combinations of elements such as floor-wall combination, column-beam connections, etc.?

Yes, although this would not be a typical test sample. We have tested floor wall combinations in our large horizontal furnace.
What are the largest dimensions of test samples that you can test in each furnace for each type or combination of building element?

**The largest floor samples are approximately 14 feet by 17 feet. The longest beam samples are approximately 17 feet.**

Do you have any restrictions with respect to what type of materials can be tested (i.e., wood, steel, concrete, composites, aluminum, fire-proofing materials, etc.)?

**None. All furnaces are connected to smoke abatement equipment.**

What type for fire exposure can your furnace(s) generate (i.e., ISO 834, ASTM E119, Hydrocarbon pool fire simulations, others)?

**ISO 834 and ASTM E119. It is planned to expand the capabilities of the large horizontal furnace to be able to conduct hydrocarbon pool fire simulations during 2003.**

Do you have any limitations on the fire exposure?

**The limitations are controlled by the fuel supply. It is anticipated that by mid-2003, the floor furnace will be able to provide the temperature rate of rise required by the hydrocarbon pool fire simulation. The furnaces can provide any fire exposure that requires a time–temperature less than that required by ISO 834 or ASTM E119.**

Do you control the furnace exposure via temperatures and/or heat flux?

_**Furnaces are controlled by temperatures because of test standard requirements Heat flux measurements could be made.**_

How are these parameters measured (i.e., thermocouples, heat flux gauges, plate thermometers, etc.) and recorded (i.e., computer, strip charts, etc.)?

_**Temperatures are measured by thermocouples and recorded in a centralized data logging system. The data logging system is capable of handling 300 channels and is updated at a frequency of 1 second / iteration. Final processing of data is typically in Excel spreadsheet format.**_

Can your furnace(s) run positive or negative with respect to pressure inside the furnace? Do you have any limitations with respect to the pressure or the position of the neutral plane?

_**The large furnace can comply with the requirements of ISO 834. The neutral pressure plane can be located close to exposed surface of the test specimen.**_

Do you measure and record the furnace pressure?
Yes.

Can you apply a load to the test sample?

Yes

If so, can this be done on each furnace?

Only the large horizontal furnace.

Provide a brief description of the load mechanism (i.e., compression, tension, shear, axial, load limits, dead load, live load, use loading jacks/frame, water containers, etc.) for each furnace and/or type of building element.

A combination of methods are used depending the requirements of the sample being tested. Equipment varies from concrete blocks, water containers and hydraulic jacks.

How is the load carrying capability monitored during the test?

For the hydraulic system, the pressure is monitored. When using water containers or other somewhat static means monitoring is by visual observations.

PART IV – ADDITIONAL INFORMATION

Is your laboratory capable of and willing to performing tests for outside parties or do you test only for yourself or your industry?

We are willing to conduct tests for outside parties.

Do you have any restrictions on doing testing for outside parties?

No. UL has no general restrictions on doing testing for outside parties (other than those foreign entities with whom U.S. corporations are barred from doing business by government regulations).

Are there any specific contractual concerns with respect to performing testing for outside parties?

No. UL typically employs its standard form contracts to support its testing services.

What is the typical turn-around time for conducting tests? We realize that cure times, construction, etc. may affect this but in general what is the timing.
Within two weeks upon receiving the materials necessary to construct the sample. There is no delay in testing the sample when the sample has reached required curing.

Could you please provide a range of costs for some typical tests such as walls, columns, or floors? We realize many factors will influence this, but we are only looking for some general cost information.

*Concrete floors with protected steel* - $48,000.00

*Walls* - $22,000.00

*Columns* - $9,000.00

These costs assume UL staff will construct the assemblies except for the application of spray applied fire resistive coatings which would be by an outside contractor. The contractor’s fee is included in the cost estimates.

Besides normal safety and environmental regulations, does your laboratory have any special regulations or rules concerning such items as testing, materials or disposal? If so, briefly details these.

UL follows MSDS regulations.

Besides, the furnaces described above, does your laboratory have the capability to perform full-scale, nonstandard, fire resistance tests of structures such as rooms or small buildings?

Yes. UL has several rooms dedicated to fire testing. The most versatile is 120 feet long by 120 feet wide with a ceiling height that can vary from 5 feet to 48 feet.

Any other information that may assist us in our survey.

Please see the attached folder. UL’s fire testing services go well beyond the typical test equipment associated with testing fire resistive building assemblies. The enclosed “fact sheets” highlight several additional areas such as performance of sprinkler systems and their components, flammability of materials, extinguishing systems and large-scale fire research.
PART I – GENERAL

Name of Laboratory USG Research & Technology Center

Location – City, State, Country Libertyville, IL USA  60048

Type of Organization – Government, Private, Industry, Non-profit, etc. Private (Corporate Research Facility)

Contact information – Person, address, E-mail address, phone number, and fax number. Rich Kaczkowski, 700 N. Highway 45, Libertyville, IL 60048, PH 847-970-5255, FAX 847-970-5299

Can the laboratory perform fire resistance testing of structural building elements? These include walls, columns, floors, ceilings, beams, trusses, connections etc. Yes – as described below

If no – so state, complete Part I and return the form to Hughes Associates, Inc. as shown in Section V at the bottom of this Questionnaire.

If yes – please continue and address the parts that are applicable to your laboratory.

PART II – VERTICAL STRUCTURAL BUILDING ELEMENTS

Can you test for fire resistance of vertical building elements such as walls/columns, etc.? Yes – both load bearing and non load bearing walls can be tested

Can you perform standard fire tests and nonstandard fire resistance tests on these elements? Yes – our wall furnace complies with ASTM E119

How many furnaces for vertical element tests do you have and what elements can be tested in each? One vertical furnace for wall testing

Besides testing discrete building elements such as walls or columns by themselves, can your furnace(s) accommodate combinations of elements such as wall-floor combinations, column-beam connections, etc.? No

What are the largest dimensions of test samples that you can test in each furnace for each type or combination of building element? Wall size is limited to 10’ x 10’

Do you have any restrictions with respect to what type of materials can be tested (i.e., wood, steel, concrete, composites, aluminum, fire-proofing materials, etc.)? No. The only limitations are safety and practicality.
What type for fire exposure can your furnace(s) generate (i.e., ISO 834, ASTM E119, Hydrocarbon pool fire simulations, others)? Any time-temperature curve can be programmed, but max temp is limited to 2200 deg F.

Do you have any limitations on the fire exposure? See above

Do you control the furnace exposure via temperatures and/or heat flux? Furnace exposure is temperature controlled.

How are these parameters measured (i.e., thermocouples, heat flux gauges, plate thermometers, etc.) and recorded (i.e., computer, strip charts, etc.)? Measured via thermocouples, recorded via computerized data acquisition system.

Can your furnace(s) run positive, negative or a combination of both with respect to pressure inside the furnace? Do you have any limitations with respect to the pressure or the position of the neutral plane? Yes. Neutral plane can vary from lower 1/3rd point to slightly above top of test assembly.

Do you measure and record the furnace pressure? Yes

Can you apply a load to the test sample? Yes

If so, can this be done on each furnace? N/A. We only have one wall furnace.

Provide a brief description of the load mechanism (i.e., compression, tension, shear, axial, load limits, use load beam w/ jacks, etc.) for each furnace and/or type of building element. Load beam with mechanical jacks.

How is the load carrying capability monitored during the test?

**PART III – HORIZONTAL STRUCTURAL BUILDING ELEMENTS**

Can you test for fire resistance of horizontal building elements such as floors, ceilings, beams, trusses, etc.? Yes – but size is limited and horizontal furnace does not comply with ASTM E119 size requirements.

Can you perform standard fire tests and nonstandard fire resistance tests on these elements? Furnace size does not meet ASTM E119 requirements.

How many furnaces for horizontal element tests do you have and what elements can be tested in each? One. It has been used to test floor-ceiling and roof-ceiling assemblies.

Besides testing discrete building elements such as floors or beams by themselves, can your furnace(s) accommodate combinations of elements such as floor-wall combination, column-beam connections, etc.? No.
What are the largest dimensions of test samples that you can test in each furnace for each type or combination of building element? Approximately 7’-6” by 8’-6”

Do you have any restrictions with respect to what type of materials can be tested (i.e., wood, steel, concrete, composites, aluminum, fire-proofing materials, etc.)? No. The only limitations are safety and practicality.

What type for fire exposure can your furnace(s) generate (i.e., ISO 834, ASTM E119, Hydrocarbon pool fire simulations, others)? Any time-temperature curve can be programmed, but max temp is limited to 2200 deg F.

Do you have any limitations on the fire exposure? See above.

Do you control the furnace exposure via temperatures and/or heat flux? Furnace exposure is temperature controlled.

How are these parameters measured (i.e., thermocouples, heat flux gauges, plate thermometers, etc.) and recorded (i.e., computer, strip charts, etc.)? Measured via thermocouples, recorded via computerized data acquisition system.

Can your furnace(s) run positive or negative with respect to pressure inside the furnace? Do you have any limitations with respect to the pressure or the position of the neutral plane? Yes. Neutral plane can vary from lower 1/3rd point to slightly above top of test assembly.

Do you measure and record the furnace pressure? Yes.

Can you apply a load to the test sample? Yes.

If so, can this be done on each furnace? N/A. We only have one wall furnace.

Provide a brief description of the load mechanism (i.e., compression, tension, shear, axial, load limits, dead load, live load, use loading jacks/frame, water containers, etc.) for each furnace and/or type of building element. Dead load is applied via water containers.

How is the load carrying capability monitored during the test? Since load is applied as dead weight, no monitoring is required.

**PART IV – ADDITIONAL INFORMATION**

Is your laboratory capable of and willing to performing tests for outside parties or do you test only for yourself or your industry? We are a corporate Research facility and do testing to support USG Corporation. We typically do not do testing for hire.

Do you have any restrictions on doing testing for outside parties? See above.

Are there any specific contractual concerns with respect to performing testing for outside parties? See above.
What is the typical turn-around time for conducting tests? We realize that cure times, construction, etc. may affect this but in general what is the timing. N/A

Could you please provide a range of costs for some typical tests such as walls, columns, or floors? We realize many factors will influence this, but we are only looking for some general cost information. N/A

Besides normal safety and environmental regulations, does your laboratory have any special regulations or rules concerning such items as testing, materials or disposal? If so, briefly details these. N/A

Besides, the furnaces described above, does your laboratory have the capability to perform full-scale, nonstandard, fire resistance tests of structures such as rooms or small buildings? No.

Any other information that may assist us in our survey.