Historical Survey of Multi-Story Building Collapses Due to Fire

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Introduction

This project was conducted for the National Institute for Standards and Technology (NIST) under Contact Number NA1341-02-W-0686. It was commissioned to assess the needs and existing capabilities for full-scale fire resistance testing of structural connections under the direction of NIST Program Manager, William Grosshandler. The Scope of Work consisted of three separate Tasks, one of which was to conduct a survey of historical information on fire occurrences in multi-story buildings, which resulted in full or partial structural collapse. The results of this individual Task are the subject of this paper.

Either partial or total failure of the structural framing, members, and/or connections was considered to have met the definition of "collapse." A multi-story building was defined to consist of 4 or more stories.

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. 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.

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)
National Institute for Fire and Research (Japan)
National Research Council of Canada (NRCC)
Nucor-Yamato Steel Corp.
Society for Fire Protection Engineers (SFPE)
Victoria University of Technology, Australia

In addition, a survey request for information was sent to several prominent engineers and consulting firms.

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. It was equally difficult to evaluate the separate effects of the many fires in buildings that are known to have occurred after major earthquakes.

Survey Results

In summary, a total of 22 cases from 1970-2002 are presented in Table 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 Trace 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

The events related to the September 11, 2001 terrorist attacks on the World Trade Center (WTC) complex in New York were the dominant fire and collapse events of this survey (represented as 4 separate incidents). The extent of the tragedy and devastation on this day were unprecedented. The Federal Emergency Management Agency (FEMA) report (FEMA 403) published in May, 2002, is a notable reference that provides an excellent overview of the day's chronology and each of the directly affected structural steel buildings (WTC 1, WTC 2, WTC 5, WTC 7). On September 11, 2001 the 5-story Pentagon building in Washington, DC, was also struck by a hijacked aircraft, resulting in extensive damage and fire. The Pentagon was constructed between 1941 and 1943 of hardened, cast-in-place reinforced concrete. The Pentagon Building Performance Report was released in February, 2003 by ASCE/SEI.

Among the other prior fire events of interest, Sao Paulo experienced one of the biggest fires in Brazil on May 21, 1987, which precipitated a substantial partial collapse of the central core of the CESP Building 2, see Figure 1. 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.

Figure 1 CESP 2 Core Collapse in Sao Paulo, Brazil

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 shows a photograph of this collapse.

Figure 2 Collapsed Textile Factory in Alexandria, Egypt

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 American (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.

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. The significance of the selected 7 major fire events in Table 2 was that even though there was no associated structural collapse, numerous casualties had occurred in some cases (MGM Grand Hotel, Las Vegas, 1980 and the Joelma Building, Sao Paulo, 1972 fires), and there was generally significant fire damage and enormous property loss in every instance.

Just as for other natural hazards (wind or earthquake), the time, location, and characteristics of the fire are critical in determining the resulting human and property losses. The total deaths reported for the events in Table 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 for all building materials. Connections are generally recognized as the critical link in the collapse vulnerability of all structural framing systems, whether or not fire is involved.

Table 1 Summary of Multi-Story Building Fires With Collapses

(4 or more stories)

Building Name	Location	Type of Construction, Material, and Fire Resistance	# Of Floors and Occupancy	Date, Approximate Time of Collapse, and References	Nature and Extent of Collapse (Partial or Total)
Santana Row, Bldgs. 7	San Jose, CA, USA	Wood frame, still under construction, fire protection and sprinklers not completed/functional	5 Commercial/residential	August 19, 2002 Chui; Gathright	Total collapse and destruction
Apartment block	St. Petersburg, Russia	Concrete	l9 Residential	June 3, 2002, starting at 1 hour fire duration BBC News Online	Total
Jackson Street Apartments	Hamilton, Ontario Canada	Concrete	21 Residential	February 8, 2002, News	Partial collapse of concrete floor-ceilings
WTC 7	New York, NY, USA	Steel moment frame with composite steel beam and deck floors; fire resistive with sprinklers	47 Office	Sept. 11, 2001 FEMA 403	Total
WTC 2	New York, NY, USA	Structural steel tube lateral system with composite floor truss system; fire resistive with retrofitted sprinklers	110 Office	Sept. 11, 2001, after 1 hour of fire following jet impact and damage FEMA 403	Total
WTC 1	New York, NY, USA	Structural steel tube lateral system with composite floor truss system; fire resistive with retrofitted sprinklers	110 Office	Sept. 11, 2001, after 1.5 hours of fire following jet impact and damage FEMA 403	Total
WTC 5	New York, NY, USA	Steel moment frame with composite steel beam and deck floors; fire resistive with sprinklers	9 Office	Sept. 11, 2001, unknown time, fire burned uncontrolled for more than 8 hours FEMA 403	Partial collapse of 4 stories and 2 bays
Pentagon	Washington, DC, USA	Reinforced Concrete	5 Office	Sept. 11, 2001, 30 minutes after jet impact Official report release pending	Partial collapses of floors and members
Faces Nightclub and Memories Lounge Bar	Motherwell, Lanarkshire UK	Unknown	4 Commercial/residential	February 27, 2001, after 2 hours News	Total
Textile Factory	Alexandria, Egypt	Reinforced Concrete. no sprinklers	6 Commercial	July 21, 2000, after 9 hours of fire Reuters News	Total

Building Name	Location	Type of Construction, Material, and Fire Resistance	# Of Floors and Occupancy	Date, Approximate Time of Collapse, and References	Nature and Extent of Collapse (Partial or Total)
Apartment in Vandergrift	Pittsburgh, PA, USA	Wood	6 Residential	May 7, 2000, few hours after fire started News	Back wall fell, initiating progressive collapse
Commercial complex (near Chestnut Hill Mall)	Newton, MA, USA	Brick/masonry	4 Commercial	February 9, 2000, after slightly more than a 1 hour fire News	Collapse started at upper story and progressed
Effingham Plaza Nursing Home	Portsmouth, VA, USA	Unknown	Multi-story Residential	April 6, 1998, fire started on top floor News	Roof collapsed in places
Coeur de Royale Condominium I-270 and Olive Blvd.	Creve Coeur, MO, USA	Unknown	4 Residential	August 25, 1994 News	Partial collapses of roofs
Apartments, Brooke Ave and 138th St.	Bronx, NY, USA	Brick	5 Residential	April 5, 1994 News	Rear of the building collapsed.
Central Square Apt. Massachusetts Ave. and Douglas St.	Cambridge, MA, USA	Brick	8 Residential	October 1, 1993 News	Collapse of several floors
CESP, Sede 2	Sao Paulo, Brazil	Reinforced concrete frame, with ribbed slabs; no sprinklers	21 Office	May 21, 1987, after 2 hour fire Berto and Tomina	Partial, full height interior core collapse
Alexis Nihon Plaza	Montreal, Canada	Steel frame with composite steel beam and deck floors; fire resistive without sprinklers	15 Office	Oct. 26, 1986, after 5 hour fire, which then continued for 13 hours Isner, NFPA Fire Investigation Report	Partial 11th floor collapse
Katrantzos Sport Department Store	Athens, Greece	Reinforced concrete	8 Commercial	Dec. 19,1980 Papaioannou	Partial collapses of 5-8th floor, together with various other members, during a 2-3 hour fire
Military Personnel Record Center	Overland, MO, USA	Reinforced concrete, without expansion joints, no sprinklers above 2nd floor	6 Office	July 12, 1973 1974 Fire Journal	Roof and supporting columns partially collapsed 12 hours after fire began
Hotel Vendome	Boston, MA, USA	Masonry with cast iron	5-6 Residential	June 17, 1972, after almost a 3 hour fire News	All five floors of a 40 by 45 ft section collapsed
One New York Plaza	New York, NY, USA	Steel framing with reinforced concrete core, fire resistive with no sprinklers.	50 Office	August 5, 1970 Abrams	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.

Table 2 Selected Multi-Story Building Fires With No Collapses

(4 or more stories)

Building Name	Location	Type of Construction, Material, and Fire Resistance	# Of Floors and Occupancy	Date of Fire Incident, and References	Nature and Extent of Fire
One Meridian Plaza	Philadelphia, PA, USA	Steel frame with composite steel beam and deck floors; fire resistive, but sprinklers not operational (retrofit in process)	38 Office	Feb. 23-24, 1991 Klem, 1991	Started Saturday and burned for a total of 18 hours, causing significant structural damage to 9 floors
Mercantile Credit Insurance Building	Churchill Plaza, Basingstoke, UK	Steel frame with composite floor beams; fire resistive, but no sprinklers	12 Office	1991 Newman, et al., 200	Fire burnout of 8th to10th floors
Broadgate Phase 8	London, UK	Steel composite trusses and beams; mostly not fire protected and without sprinklers	14 Office	1990 Newman, et al., 200	During construction, 4.5 hour fire duration and temperatures reached 1000 ºC
First Interstate Bank	Los Angeles, CA, USA	Steel frame with composite steel beam and deck floors; fire resistive; sprinklers not operational	62 Office	May 4, 1988 Klem, 1988	Lasted for about 3.5 hours, causing major damage to four floors
MGM Grand Hotel	Las Vegas, Nevada, USA	Mixed, no sprinklers	26 Resort and casino	Nov. 21, 1980 Misc. News & Clark County Report	Burned for hours
Andraus Building	Sao Paulo, Brazil	Reinforced concrete	31 Office	Feb. 24, 1972 Hall, 2001	Spalling of exterior walls, joists, and columns, exposing reinforcing.
Joelma Building (Crefisul Bank)	Sao Paulo, Brazil	Reinforced Concrete	25 Office	Feb. 1, 1974 Hall, 2001	Spalling of exterior walls