

**THE IMPORTANCE OF KNOWING YOUR BUILDINGS – AN EXAMINATION
OF THE FDNY STANDARD OPERATING PROCEDURE FOR HIGH-RISE
OFFICE BUILDINGS AS PART OF ITS RISK MANAGEMENT PLAN**

EXECUTIVE ANALYSIS OF FIRE SERVICE OPERATIONS IN EMERGENCY
MANAGEMENT

BY: Richard S. Tobin
Battalion Chief
Fire Department of the City of New York
New York, New York

An applied research project submitted to the National Fire Academy
as part of the Executive Fire Officer Program

June 2002

ABSTRACT

The problem was despite the fact that the FDNY had a Risk Management Program with extensive written standard operating procedures including its high-rise SOP, Firefighting Procedures High-Rise Office Buildings , the FDNY suffered the staggering and unprecedented loss of three hundred and forty-three officers and firefighters at the World Trade Center.

The purpose of this research was to discover the differences that existed in the construction characteristics of the World Trade Center and the other high-rise office buildings in New York City and determine if those differences were presented in FDNY's Firefighting Procedures High-Rise Office Buildings.

Descriptive and historic research methods were used to answer the following questions:

1. Were the twin towers of the World Trade Center representative of most high-rise office buildings in New York City, or were they an anomaly?
2. Did the firefighting procedures manual Firefighting Procedures High-Rise Office Buildings provide sufficient information about the construction characteristics of the World Trade Center?
3. What, if any, were the major differences between the construction techniques used in the World Trade Center towers and the other high-rise office buildings in New York City?
4. What features of the World Trade Center's construction presented the greatest vulnerability to fire?

The procedures used for the research included a literature review of fire service publications, an internet search of pertinent web-sites, interviews with ranking officials of the FDNY and a survey of Battalion Chiefs. As the final step of the procedures, a critical review of the research was conducted by Vincent Dunn, an acknowledged expert in the field of fire protection.

The results of the research indicated that the FDNY had an obligation to maintain up to date and relevant information concerning potential hazards in its SOPs as part of its Risk Management Program. The research also disclosed that the significant findings of others concerning the construction characteristics of the WTC were not included in Firefighting Procedures High-Rise Office Buildings.

It was recommended that the FDNY: revise its SOP Firefighting Procedures High-Rise Office Buildings, consider adding structural engineers to the FDNY's staff, establish heightened awareness of possible terrorist activity, enhance FDNY's capabilities to relay critical information to units through enhancements to its current technology concerning CADS and related systems; increase training for members.

TABLE OF CONTENTS

ABSTRACT	2
TABLE OF CONTENTS	4
INTRODUCTION	5
BACKGROUND AND SIGNIFICANCE	7
LITERATURE REVIEW	13
PROCEDURES.....	35
RESULTS	40
DISCUSSION	47
RECOMMENDATIONS	52
REFERENCES	57
APPENDIX	60

INTRODUCTION

The New York Board of Fire Underwriters (1975) reported that the New York City Fire Department (FDNY) has the most extensive firefighting experience in high-rise office buildings of any fire department in the United States. This experience had been gained because there are over 2,000 high-rise buildings in New York City. Excluding residential occupancies, there are over eight hundred high-rise office buildings in New York City, making it the high-rise capitol of the country.

The purpose of this research was to discover the differences that existed in the construction characteristics of the World Trade Center and the other high-rise office buildings in New York City, in order to identify if deficiencies were present in the FDNY's manual Firefighting Procedures High-Rise Office Buildings. The manual was developed in the mid - 1970's as a result of a high-rise fire that occurred on August 5, 1970 at One New York Plaza.

Ganci (2000) reported, "The fire at One New York Plaza was the first of its kind in a modern commercial high-rise. Two floors involving 40,000 square feet were involved in fire before the FDNY arrived. There were construction deficiencies that caused fire to extend to the floor above the original fire area. FDNY responded with over 50 units and more than 300 personnel to extinguish this fire. As a direct result of this fire high-rise firefighting SOPs were established citywide, and Local Law 5 regarding high-rise safety was enacted" (p.16).

Firefighting Procedures High-Rise Office Buildings has served as FDNY's SOP for high-rise firefighting since 1977; it has undergone several revisions since it was first adopted. The manual's last revision took place in 1997. The manual has served as the basis for many questions on promotional exams given by the FDNY. The manual was serving as FDNY's standard operating procedure for high-rise office building fires on September 11, 2001.

It was designed to provide officers and firefighters with crucial information about the characteristics of high-rise office buildings constructed in New York City. This research sought to determine if Firefighting Procedures High-Rise Office Buildings contained sufficient information to meet the critical need for fire officers to know their buildings. It is hoped that the facts discovered will lead to long range planning by the FDNY resulting in future risk reduction to FDNY members. Hopefully, facts disclosed by this research will lead to the development of more comprehensive SOPs for high-rise firefighting; greater involvement by the FDNY in the planning for future high-rise construction and a resultant risk reduction for FDNY members operating in such buildings.

Descriptive and historical research methods were used to answer the following questions:

1. Were the twin towers of the World Trade Center representative of most high-rise office buildings in New York City, or were they an anomaly?
2. Did the firefighting procedures manual Firefighting Procedures High-Rise Office Buildings provide sufficient information about the construction characteristics of the World Trade Center?

3. What, if any, were the major structural differences between the World Trade Center towers and the other high-rise office buildings in New York City?
4. What features of the World Trade Center's construction presented the greatest vulnerability to fire?

The research began at the Learning Center of the National Fire Academy, progressed to the Mand Library of the New York City Fire Department, and the New Rochelle Public Library. A literature review was conducted from fire service publications and the standard operating procedures of the FDNY. In addition, the internet was searched for web sites of professional organizations that published pertinent material. The archives of the New York Times were also searched for historical information concerning the World Trade Center complex. Interviews were conducted with FDNY's Chief of Operations, Chief of Safety, and Chief of Fire Prevention.

BACKGROUND AND SIGNIFICANCE

The FDNY recognized that fighting fires in high-rise commercial buildings is one of the greatest challenges faced by the department. The variations in construction techniques and the complexity of the high-rise office buildings required standard operating procedures that differed substantially from the SOPs employed by the department in other types of structures.

The multitude of fire problems in these structures, coupled with the fact there could be thousands of occupants trapped on the upper floors, required that all units operate in a controlled and coordinated manner (FDNY, 1997).

The FDNY was established as a fully paid fire department in 1865. The department has been fighting fires in steel framed high-rise office buildings since 1898. Historically, the FDNY had not encountered a high-rise fire that it did not extinguish. The FDNY had never, until September 11, 2001, experienced the total collapse of a high-rise building, despite the fact that many had been exposed to hours of heavy fire conditions.

However, the FDNY realized the potential existed for a high-rise fire that could not be controlled. John J. Fogarty (1982), the Manhattan Borough Commander, wrote, "It is generally agreed upon by professionals in the field of fire safety that it is possible that some day we could have a very serious high-rise office building fire with a large loss of life and with tremendous damage to the building and its contents.

Such a fire could occur if the Fire Department was unable to confine a fire to one floor. A major fire on two floors would increase the possibility of the fire extending to the third floor. A condition might be reached where the fire would be completely out of control" (p.1).

Speaking of the terrorist attack on the WTC, Assistant Chief Salvatore Cassano, the Chief of Operations, stated, "On September 11th the senior staff officers of the FDNY performed a risk assessment of the situation facing the department. The assessment disclosed that upward of 50,000 people were possibly trapped in the towers of the WTC. The FDNY realized that the magnitude of the fire dictated that it could not be fought; as a result, the FDNY confined itself to a rescue operation. The department committed ladder

companies, squads, and rescue companies to their traditional tasks of search and rescue of the floors and stairwells below the fire, as well as, the evacuation of surrounding buildings that appeared threatened. The senior officers of the department also realized that those trapped above the fires were most likely caught in a hopeless situation. However, the FDNY was committed to providing those occupants that had a chance for survival every chance possible. The events of September 11th had no precedent; there was no text or past history to rely on for guidance. No fire department in the history of the United States had faced such a daunting task. While it may be easy for some to criticize, the fact remains that thousands of people owe their lives to the heroic actions of the FDNY” (S. Cassano, personal communication, May 1, 2002).

Prior to the late 1970's, FDNY relied on standard operating procedures issued as Borough or Division Directives. These directives were issued to units in specific geographic areas of the city, such as the 1st Division in lower Manhattan, the 3rd Division in mid-town Manhattan, or the 11th Division in downtown Brooklyn. The directives were based on the experience gained by the FDNY at high-rise fires that had occurred. Articles that critiqued the fires and presented the lessons learned from them were published in WNYF; these articles often served as the basis for SOPs.

In the 1960's, John O'Hagan was the youngest man ever appointed Chief of the New York City Fire Department. O'Hagan has been one of the few men to serve simultaneously as Chief of Department and Fire Commissioner.

He paid particular attention to the problems associated with firefighting in high-rise buildings. He became known nationally and internationally as the author of *High Rise / Fire & Life Safety*, one of the first and most comprehensive books published concerning firefighting in high-rise office buildings.

O'Hagan recognized that in order for FDNY, with over eleven thousand personnel, to operate efficiently at high-rise fires required standard operating procedures.

Firefighting Procedures High-Rise Office Buildings became required study for all members of the FDNY. The SOP was developed to provide all FDNY officers and firefighters with crucial information about the characteristics of high-rise office buildings constructed in New York City, as well as standardized procedures for extinguishing such fires.

The World Trade Center had been the scene of numerous fires since 1975. However, with the exception of several notable multiple alarm fires, most of them were small or inconsequential. In February of 1993, the World Trade Center was bombed by terrorists attempting to topple the buildings. The 1993 bombing of the World Trade Center resulted in the largest response ever by the FDNY; the equivalent of 16 alarms was struck for the explosion, subsequent fires, and evacuation of the towers.

FDNY (1993), Chief of Department Anthony Fusco reported, "The statistics were staggering: six people died and 1,042 were injured. Of those injured 15 received traumatic injuries from the blast itself. Twenty people complained of cardiac problems and thirty pregnant women were rescued.

Eighty-eight firefighters, thirty-five police officers, and one EMS worker sustained injuries” (p.1).

Following the 1993 bombing, no information highlighting the World Trade Center’s vulnerabilities or unique construction features were incorporated into the 1997 revision of Firefighting Procedures High-Rise Office Buildings.

Brannigan (1992) warned, “Above all know your buildings. Make all information and knowledge accessible of building conditions which might be hazardous during a fire. Develop a record and retrieval system which will assure that the necessary information is made known to responding units immediately on dispatch” (p. 559).

He further stated, “It is a serious error to consider all high-rise buildings as a single problem. There are significant construction differences among high-rises. The particular buildings in your area must be studied in detail to determine the particular potential modes of building failure” (p.452).

Brannigan (1992) noted that all high-rise buildings are designed to resist the effects of fire on the structural frame of the building and the floors. Whether the design concepts used are adequate to cope with all these possible effects is quite another matter.

The September 11th attack against the World Trade Center resulted in severe structural damage to the buildings from the impact of the planes. Following the initial impact, uncontrolled fires, fueled by thousands of gallons of jet fuel, raged on numerous upper floors of both towers. Flaming jet fuel

cascaded down the elevator shafts and burned many building occupants attempting to flee. Thousands of occupants were trapped on the upper floors of the buildings. Many of the trapped occupants jumped to their deaths, rather than be incinerated. Two simultaneous fifth alarms were transmitted for the fires that raged out of control in the twin towers of the World Trade Center.

September 11, 2001 exposed members of the FDNY to unprecedented horror, danger and events that had never been experienced by any firefighting force in history. Before the day was over thousands of the civilian occupants of the World Trade Center would be dead, while many thousands more were rescued. Three hundred forty-three members of the FDNY, from the Chief of Department to many of the newest probationary firefighters were killed. Over sixty police officers from the NYPD and Port Authority Police also lost their lives in the collapse of the twin towers.

The World Trade Center was reduced to 6-story piles of rubble and death. The first complete structural failure of a modern high-rise building had occurred.

The course, Executive Analysis of Fire Service Operations in Emergency Management (EAFSOM), of the National Fire Academy's Executive Fire Officer Program, is designed to prepare senior staff officers in the administrative functions necessary to manage the operational component of a fire and rescue department effectively (NFA, 2001, p.SM1-3).

The development and revision of standard operating procedures are an integral part of FDNY's Risk Management Program. Insuring they are relevant to

the challenges facing the department is one of the administrative functions necessary to manage the operational component of the FDNY and, therefore, related to the goals of the EAFSOM course.

This research is related to the operational goals of the United States Fire Administration, in that it seeks to develop heightened awareness among members of the FDNY for the necessity of knowing their buildings. Brannigan (1992) has stated throughout all three editions of *Building Construction for the Fire Service* that every firefighter and officer must study the peculiarities of building construction in their response areas; this will greatly enhance their chance for survival.

Hopefully, the facts disclosed by this research will lead to the development of more comprehensive SOPs for high-rise firefighting and greater involvement by the FDNY in the planning of future high-rise construction that will take place in New York City. Such actions should lead to a resultant risk reduction for FDNY members.

LITERATURE REVIEW

A literature review was conducted in compliance with the applied research guidelines of the Executive Fire Officer Program. The literature review intended to discover the critical findings of others who have published material related to the construction features and vulnerabilities of modern steel framed, high-rise commercial buildings.

Prior to September 11, 2001, FDNY had an enviable record of firefighter safety at high-rise office building fires. New York City is the most vertical city in the world. There are over 800 high-rise office buildings in the city. FDNY's high-rise fire experience goes all the way back to 1898 when the Home Life Insurance building in lower Manhattan went up in flames.

The FDNY's SOP for high-rise fires evolved from the department's experience at high-rise fires over the years. Based on this experience, FDNY (1997) identified three generations of high-rise office buildings:

- 1.) Buildings Built Before 1945
- 2.) Buildings Built Between 1945 and 1968
- 3.) Buildings Built After 1968

The first generation – Buildings Built Before 1945

The first generation of high-rise office buildings was constructed with techniques that resulted in a "heavy-weight" building, usually weighing about 20 to 23 pounds per cubic foot. The steel structural components, girders and columns were encased in concrete or some other form of masonry or tile. The exterior walls were of masonry construction, and were substantially tied to all floors. Plenum type ceilings generally were not found in these buildings.

These buildings were not centrally air-conditioned and were normally steam heated. All of the high-rise buildings erected between 1938 and 1968 were required to have a fire tower. Some built prior to 1938 have fire towers.

The floors were constructed of reinforced concrete and central core construction techniques were not used (FDNY, 1997).

O'Hagan (1977) cited several fires that had occurred in the 1st generation of high-rise buildings constructed before 1945. These fires included the Home Life Insurance Building fire in 1898, the Equitable Building fire in 1926, and the Empire State Building fire in 1945.

The first significant fire in a steel framed high-rise occurred on December 4, 1898 in the 16-story, 190 foot tall, Home Life Insurance Building. At the time of the fire, the building was considered to possess the most advanced design for a protected steel frame skeleton building. The fire originated in an adjacent 5-story, non-fireproof building and spread to the Home Life Building via unprotected glass windows that failed at the 6th floor. Ultimately, ten floors, the 6th to the 16th floors, of the Home Life Building became involved with fire. It was the first fire of this magnitude in a steel frame high-rise and truly tested the fire-resistance capabilities of the fire protected steel columns and girders. Although a few steel beams had to be replaced, the steel structure held up well under a prolonged and intense fire.

In 1926, fire struck the Equitable Building, a 39-story, steel skeleton building. The exterior walls were brick and all columns were encased in brick. The Equitable Building was substantially constructed with all steel structural members protected by masonry, as required by the New York City Building Code. The building's floor area was divided into sections of 12,000 square feet each. Floors were concrete supported by 12-16 inch hollow tile arches. Beams

and girders were protected by hollow tile enclosures; vertical stairs were enclosed in 6 inches of tile to up to 8 or 12 inches of brick, and the elevators were in enclosed shafts of masonry and tile.

The fire proved the design and construction of the building was worthwhile. Despite the fact that a ruptured natural gas line discharged an estimated 9,000 cubic feet of gas and provided additional fuel to the fire, the building held up admirably. The fire extended from the 1st floor to the 35th floor. The outcome was that a serious fire, with a strong origin that exposed every floor of the building, was confined to a limited area. No structural failure occurred in any part of the building.

O'Hagan (1977) noted that the greatest tribute to this generation of high-rise structures was the effectiveness with which the Empire State Building withstood the crash and subsequent fire of an Air Force B-25 bomber.

Exterior walls are of 8 inch brickwork with Indiana limestone facing. Floors are composed of cement finish on 3 inches of cinder fill, on 4 inches of cinder concrete. Beams, girders and interior columns are protected by 1.25 inches to 2 inches of cinder concrete fireproofing.

On Saturday, July 28, 1945 a B-25 bomber crashed into the 78th and 79th floors of the Empire State Building. The plane crashed into the north side of the building and part of it exited through the south wall of the building. One of the motors penetrated the elevator shaft and fell to the sub-cellar where it started a separate fire.

The subsequent fire was fed by over 800 gallons of aviation grade gasoline. Firefighting problems were exacerbated by the fact that the standpipe was severed at the 54th floor. The broken standpipe required the FDNY to isolate the standpipe; bypass its' damaged areas and hand-stretch hose. Fourteen civilians were killed by the crash and subsequent fire at the Empire State Building. No firefighters were killed or severely injured.

“In spite of the severity of the fire, and the handicaps that had to be overcome, it is estimated that the fire was extinguished within 35 minutes after the arrival of the New York Fire Department. This is not only a tribute to the department for their efficiency, but it is also a tribute to the construction and design of the building. Because of the substantial subdivisions inherent in the building, the fire was confined to the westerly half of the 78th and 79th floors” (p.21).

The Second Generation – Buildings Built Between 1945 -1968

O'Hagan (1977) noted that following World War II, builders, developers, and designers complained that existing codes were too restrictive and resulted in buildings being overbuilt with added costs.

“There was a need to create more jobs and a desire to renew some of the older sections of our cities. All of these pressures were directed toward a relaxation of the fire safety requirements contained in building codes. Our efforts to modify the more drastic changes that were demanded were overridden in whole or part. As a result, a new generation of high-rise buildings appeared in the 1950's and 1960's with a new generation of fire problems” (p.23).

According to O'Hagan (1977), "The latest high-rise building has as its primary component a central core of reinforced concrete which contains most of the buildings services and facilities, such as power and water lines, elevators, air supply and return shafts, enclosed stairs and rest rooms. This core is connected to the columns in the exterior walls by steel girders that eliminate the need for intermediate columns, and provide undivided floor space. Floors are described as Q deck or metal deck and consist of metal panels attached to floor beams and girders. The panels provide support for a 2 to 3-inch layer of concrete which becomes the floor ... The floors end at the mid-point of the exterior columns where a short curtain wall is erected to partially enclose the floor area to a height of 24 to 36 inches"(p.24).

Columns, girders, and beams were no longer protected by masonry as they had been in the past. Spray asbestos insulation or a composition material was sprayed onto structural steel to protect it against fire. The sprayed on insulation had been tested to offer 4-hour test ratings for columns and three-hour ratings for beams and girders. Unfortunately, these test conditions did not reflect the actual conditions encountered in the field. As a result the adhesion was often unsatisfactory.

The insulation was often applied to steel that was covered with rust, and not properly prepared. This negatively affected its ability to adhere, and the consistency of application and insulation was sometimes uneven. Workers in the trades frequently dislodged the insulation and seldom replaced it. As a result,

when the time came for the insulation to withstand the prescribed levels of heat, it was often found wanting (pps.23-27).

FDNY (1997) described the second generation of high-rise buildings as mixed. These buildings contained a mix of the features found in pre-1945 buildings and the post 1968 buildings. They were required to conform to the 1938 Building Code, a strict specification code, but because of numerous variances granted they used many of the construction techniques of the post 1968 buildings. The construction techniques used resulted in a “medium-weight” building, usually weighing between 10 and 20 pounds per cubic foot. Fire towers were required in all of these buildings.

A fire at One New York Plaza on August 5, 1970, severely damaged a second generation high-rise building. The fire involved 20,000 square feet of office space on the 33rd and 34th floors of the 50-story building and resulted in several fatalities to building occupants.

O’Hagan (1977) reported, “The fire and life hazards that were present in the building were traceable to features of the building’s design and to some extent the use of unsuitable materials. Each of the following contributed to the destructiveness of the fire and requires close attention in future construction:

1. A central air-conditioning system with common ceiling plenum.
2. Exterior curtain wall construction.
3. Q-deck floor with embedded wire races.
4. Fireproofing of structural members.

5. Workmanship and materials used.
6. Electronic elevator call buttons.
7. Absence of emergency evacuation plan.
8. Highly insulated control design with locked window sash.
9. Central core design
10. Fire loading "(pps.29-30).

O'Hagan (1977) reported that the FDNY fought for more than six hours to bring this fire under control. Unlike those fires described in the previous generation of high-rise buildings, structural damage was extensive. Floors buckled on the northern end of the 34th floor. Deluge guns had to be substituted for hand-lines because of the intense heat generated by the fire and the fear that the buildings structural members might fail. Protection afforded by the new generation of sprayed on fireproofing proved inadequate and damage to the structural steel was extensive.

On June 24, 1980, fire ripped through 299 Park Avenue, another second generation high-rise in Mid-town Manhattan. The fire raged on the twentieth floor of the building and caused extensive structural damage to the building. Whalen (1980) reported for The New York Board of Fire Underwriters, "This will not be the last serious fire in a high-rise structure. These buildings are functional and suggest a strong appearance but, by reason of their unique construction, each of them will react to fire differently.

What will happen when a high-rise fire encompasses two stories? Will the suppression forces be able to extinguish the fire before extreme structural damage is created" (p.1)?

Whalen (1980) also reported that numerous steel beams and girders protected by sprayed on insulation and a membrane ceiling were damaged beyond repair and had to be replaced and that the heat generated deflected steel beams and caused cracks in the concrete of the 21st floor. In one area, the floor actually measured 8" below floor level.

One hundred twenty-seven members of the FDNY were injured; seventeen required hospitalization. The fire took hours to bring under control and required a five-alarm assignment of hundreds of firefighters and equipment.

The 3rd Generation - Buildings Built After 1968

FDNY (1997) reported that the construction techniques used in these buildings resulted in a "lightweight" building. These buildings usually weigh about 8 to 10 pounds per cubic foot. These buildings lacked compartmentation. The protection of the structural steel components was usually done by spraying on a fireproofing material. Exterior walls were curtain walls constructed of metal and glass. The method of securing the exterior curtain wall left a space of 6 to 12 inches which required additional fire stopping.

Fire towers are not required. The floors are light in weight usually consisting of lightweight concrete, "Q-decking", and core construction techniques are used extensively.

Corcoran (1993) reported that ground was broken for the WTC in 1966, the first buildings opened in 1970 and the center was completed in 1974. A key element to understanding the characteristics of the WTC complex is the fact that it was not built to the specifications of the New York City building code. The Port Authority of New York and New Jersey, a bi-state agency, owned the Trade Center and was not required to comply with the building and fire prevention codes of New York City.

On February 13, 1975, a fire occurred on the 11th floor of Tower 1 of the World Trade Center. Ryder (1975) reported for The New York Board of Fire Underwriters that this was a hot and stubborn fire to extinguish and required 3 alarms.

Ryder stated, "The experience in New York City for almost 75 years has shown that fires can be started from many causes ranging from an Air Force B-25 bomber crashing into the Empire State Building, to a cigarette dropped into an overstuffed chair. Somewhere in between must be placed the incendiary device hidden in a reception room and welders sparks that have been responsible for many fires. However, the list of spectacular high-rise fires in New York City for the fifty-years spanning 1917-1967 was very few and the loss of life was essentially zero in all high-rise fires that had occurred in this period. The exception, of course, is the plane crash, which sprayed over 800 gallons of gasoline on two floors but still did not jeopardize the strength of the Empire State Building"(p.12).

Ryder (1975) also reported that, “Many people have asked – “How safe are the two World Trade Towers?” Realizing that about 65,000 people may be in one tower at any height from ground level to 1,350 feet, it is obvious that there is no margin for error. The New York Board of Fire Underwriters reported that overall, these towers may be considered among the safest buildings in New York City. There are bad points about these towers: fireproofing of the steel may be missing in places; openings have been made in floors and walls while the fire rating of shafts is just above minimum requirements ... Another problem is the entire design of the modern lightweight building. Although the components have passed fire tests, they provide no reserve for unexpected conditions. For example, they reported, a concrete block wall would still be standing and preventing fire spread long after its two hour fire exposure. As a contrast, many modern assemblies would have disappeared only a few minutes after the duration of test fires.

Similarly, sprayed on fireproofing has successfully passed fire tests but conditions in the field are not the same as in the laboratory. Even if the sprayed material is properly formulated and applied to the proper thickness, it may not adhere to the surfaces or may be knocked off as other building services are installed. The result is that the fire resistance is not there when it is needed” (p.14).

Brannigan (1992), in Chapter 11 of *Building Construction for the Fire Service* stated, “This chapter is not intended to present a discussion of all the problems of fires in high-rise buildings. The basic purpose is to direct attention to

the fact that not all high-rise buildings are similar, that in addition to height , the specifics of the construction of the building, and the era in which it was built, are very significant factors in planning to combat the high-rise fire “(p.337).

Brannigan, identified three generations of high-rise:

1. Early Fire Resistive Buildings, 1870-1930
2. Later High-Rise Construction 1920-1940
3. Modern High-Rise Buildings built after the Second World War.

Early Fire-Resistive Buildings, 1870-1930:

Brannigan’s (1992) description of the earliest generation of high-rise buildings was more inclusive than that found in FDNY’s SOP. FDNY (1997) addressed only steel frame buildings. Brannigan included buildings with cast iron frames, many of which still stand today in New York City. According to Brannigan, there were many fire safety defects in buildings of this era. Some of the major defects he cited were:

- There were no standards for the protection of steel.
- Cast iron columns were often unprotected
- Terra Cotta fireproofing was compromised by concealed light-weight conduit, which expanded and tore the tile off columns.
- Segmental (curved) brick or tile arch floors were tied with exposed steel ties.

- Wooden floor beams were placed on piers creating a void under the floor, connected to all other voids by the hollow columns. In some cases, floors were leveled with cinders, often overloading the structure.
- Structures in this era were built without any appreciation of the impact of vertical openings (p.454).

Later High-Rise Construction 1920-1940

Brannigan (1992) described these as excellent buildings. He wrote that the high-rise buildings built before World War II, following the demise of cast iron use, were universally of steel framed construction. Floor construction and fireproofing of steel members was often of concrete or tile, both good heat sinks and slow to transmit heat to the floor above.

Each floor area was a well segregated fire area in these buildings. Wall construction was frequently of wet masonry, joined to the floor so that there was an inherent fire stop at the floor line. In these buildings vertical shafts were enclosed in solid masonry with openings protected with proper closures.

Exterior fire towers, stairways with an atmospheric break between the building and stairway, the finest escape device available, were provided in many of these buildings. Such a stairway can be compared to an enclosed tower located away from the building which is reached by a bridge to the open weather, so smoke cannot pollute the tower (pps. 458-459).

Modern High-Rise Buildings

Brannigan (1992) noted, “After World War II, a number of significant developments occurred. Fire departments apparently bemused by the lack of problems in the previous generation of structures, generally failed to realize the dimensions of the new problem. City administrations, eager to get the spectacular new buildings on the tax rolls, didn’t question the hazard of cramming thousands of people into totally enclosed mega-structures which created a potential for catastrophe “(p.462).

Brannigan (1992) identified significant changes in the construction characteristics of the post World War II modern high-rise buildings. He cited the following:

- “There has been a definite push to lighten and thus reduce the costs of buildings. The Empire State Building weighs about 23 pounds per cubic foot; whereas, a typical modern high-rise weighs approximately 8 pounds per cubic foot.
- Because of the development of better reinforcing steel and new techniques, reinforced concrete became a serious competitor to steel as a construction material. No longer could the building industry be indifferent to the weight penalty caused by concrete fireproofing of steel” (p.462). In addition, the necessity of fireproofing is a cost disadvantage to steel. While concrete has the advantage of being the most permanent fireproofing and difficult to remove, the disadvantage of concrete is its weight. In the ceaseless effort to reduce the weight of a building, and thus its cost, the fireproofing is a

tempting target. In lieu of concrete, encasement systems of gypsum board or wire lathe and plaster were developed to save weight.

- Spray on fireproofing materials using many combinations of asbestos fibers and other materials were developed. While some of these materials can pass laboratory tests, serious questions are raised about their reliability in the field.
- “One of the results of reducing the concrete in the building is the loss of a valuable heat sink. Every Btu that is absorbed into the concrete is one less available to keep the fire from extending” (p.463).
- “Steel truss floor and ceiling assemblies provide useful voids to carry utilities and communications or as a plenum for air conditioned air, and unintentionally for fire and smoke” (p.463).
- Gypsum, rather than masonry, is often used to enclose elevator and other shafts, including stairwells. In the One New York Plaza fire, gypsum enclosures were displaced leaving the shafts unprotected.
- “Not all high-rise buildings are of core construction. Some tall high-rise structures, including the World Trade Center, are of tube construction. In tubular construction the wind load is taken principally on the exterior. However, this does not eliminate the use of a central core for utilities and services “(p. 464).

FDNY (1997) described the construction characteristics of steel skeleton and core constructed high-rise buildings. The department’s manual failed to recognize or describe the characteristics of tubular construction that was used in

the World Trade Center. This oversight existed despite the fact that, as reported by Schwartz (2001), the WTC complex contained, “thirty million square feet of commercial space, the equivalent of all the financial office space in the city of San Francisco”.

Brannigan (1992) noted, “It is a serious error to consider all high-rise buildings as a single problem. There are fire-significant construction differences among high-rises. The particular buildings in your area must be studied in detail to determine the particular potential modes of building failure” (p.452).

Brannigan (1992) wrote “When huge spans are achieved by using rigid frames, trusses, or space frames, collapse can be sudden, general, and tragic. In buildings with huge spans, adjacent bents are tied together to resist wind load. Tying the steel units together, however, means that if one part of the building is distorted by fire, torsional or eccentric loads beyond the designed capacity may be placed on the balance of the building. This can start a progressive collapse of the building, often far beyond the area involved in fire. As a matter of fact the better the building is tied together to resist wind load, the more likely it is to suffer progressive collapse due to fire distortion” (p.267). This is significant because the towers of the WTC were perfect examples of the construction features just noted by Brannigan.

Assistant Chief Michael Butler, commanding officer of FDNY’s Bureau of Fire Prevention, reported that the World Trade Center buildings were the only buildings in New York City constructed using tubular construction methods (M. Butler, personal communication, March 12, 2002). As Brannigan stated, the

towers of the WTC should not have been expected to act in the same manner as the high-rise office buildings described in FDNY's Firefighting Procedures High-Rise Office Buildings because their construction characteristics differed greatly from the core high-rises described by the FDNY (1997).

Snoonian and Czarnecki (2001) reported that the towers of the World Trade Center were classic examples of tube structures, which gained their strength from tightly spaced perimeter columns that provided wind resistance. The perimeter columns were spaced 39 inches on center, and were braced laterally by 40,000 square-foot floor diaphragms of concrete and metal decking on 60 foot horizontal steel trusses extending from the concrete core. The buildings central core carried only the dead load of the elevator bank. The open floor plate was unencumbered by any columns from the perimeter to the core

Clifton (2002) reported for HERA that the construction techniques used in the World Trade Center resulted in towers that were one of the best examples of tube tower construction, a structural form ideally suited to providing the strength and stiffness required for very tall buildings. On each facade a rigid moment-resisting frame was formed consisting of 59 box-section columns, spaced meter 39 inches on center; connected by deep spandrel beams. The frames did not run into the corners however, there a shear connection between the two adjacent frames was provided so that the frames, together with the floors, formed a torsionally rigid framed tube fixed to the foundations. The framed tube carried all wind loads. The floors spanned without intermediate columns to the core, which

was supported on 44 box-section columns designed and detailed to carry vertical loading only.

The floor system was comprised of 900 deep bar joists braced by secondary joists. These secondary joists then supported a profiled deck on which was poured the 100 mm thick light-weight concrete slab. The gravity and lateral load-resisting systems were designed to deliver the strength and stiffness required from a 110-story building with minimum dead load.

He noted that the very light and open structure, superbly engineered to meet the design serviceability and ultimate limit state conditions on a building of this height and size, probably made the buildings more vulnerable to collapse from the aircraft impact than would have been the case for a more inefficient and heavier structural system.

Wilkinson (2001), a lecturer in Civil Engineering at the University of Sydney in Australia, noted that the structural integrity of the World Trade Center depended on the closely spaced columns around the perimeter. Lightweight steel trusses spanned between the central elevator core and the perimeter columns on each floor. These trusses supported the concrete slab of each floor and tied the perimeter columns to the core, preventing the columns from buckling outward.

Schwartz (2001) reported that Hamburger, a member of the Structural Engineers Institute of the American Society of Civil Engineers, cited several features he believed made the World Trade Center buildings vulnerable to the intense fires that ultimately caused their collapse.

Schwartz reported that according to Hamburger, "The floor trusses (joists) were relatively flimsy. As the tower collapsed, the trusses just fell apart," he observed, and noted that steel bar joist trusses are difficult to fireproof. Hamburger stated that each tower was constructed using a novel tube frame system designed to resist winds of up to 80 miles per hour. However, Hamburger commented that he believed the connections of the tube frame were weak, causing them to break apart and become three-pronged missiles that crashed into the street and into nearby buildings.

Crenson (2002) indicated that engineers studying the destruction of the WTC believed inadequate fireproofing may have contributed to the collapse of the World Trade Center. Crenson reported that according to Frederick W. Mowrer, a fire safety expert, inspections performed during the 1990's indicated that at least some of the steel bar joists supporting the floors of the twin towers were not covered with enough fire proofing insulation. Building codes required that each of the 7/8 inch thick steel rods making up the floor joists at the WTC be coated with 2 inches of fire protection. But photographs taken during inspections showed only a spattering of spray-on fireproofing.

He reported that Abolhassan Astaneh-asl, an engineering professor at the University of California in Berkeley, has examined twisted and broken steel beams from the twin towers in the New Jersey scrap yard where they are being recycled. He reported that Astaneh-asl believed that as the fires burned, the floor joists were the first elements of the buildings' structures to fail. Their failure

pulled the buildings' exterior columns inward, initiating complete collapse of the structures.

Dunn (2002) wrote, "In terms of structural systems the twin towers departed completely from other high-rise buildings. Conventional skyscrapers since the 19th century have been built with a skeleton of interior supporting columns that support the structure. Exterior walls of glass or synthetic material do not carry any load. The Twin Towers were radically different in structural design as the exterior wall was used as the load-bearing wall. (A load bearing wall supports the weight of the floors.) The only interior columns were located in the core area, which contained the elevators. The outer wall carried the buildings vertical loads and provided all the resistance to wind. The wall consisted of closely spaced vertical columns (21 columns 10 feet apart) tied together by horizontal spandrel beams that girdled the towers at every floor. On the inside of the structure the floor sections consisted of trusses spanning from the core to the outer wall. These horizontal steel trusses, used to support the floors of the World Trade Center's twin towers, spanned 60 feet from the exterior wall to the core.

The World Trade Center had tubular steel bearing walls, fluted corrugated steel flooring and bent bar steel truss floor supports. The fire service believes there is a direct relation of fire resistance to mass of structure. The more mass the more fire resistance "(p.2).

Several authors (Fitzgerald 1997, Brannigan 1992; Dunn 1988, 1999) reported that steel, like all other materials, is adversely affected by fire. Because of its high thermal high thermal conductivity, it can transfer heat away from a

localized heat source rather quickly. This property, in conjunction with its thermal capacity, enables steel to act as a heat sink. When the steel has an opportunity to transfer heat to cooler regions, it can take a relatively long time for a member to reach its critical value. On the other hand, an extensive fire that distributes heat simultaneously over a greater area reduces this time considerably.

Related to this thermal activity is the effect of mass and surface area of structural steel members. Heavy, thick sections have a far greater resistance to the effects of building fires than do lighter ones. Unprotected lightweight sections, such as those found in trusses and open-web joists, can collapse in 5 to 10 minutes of exposure. Brannigan (1982) noted “that at one observed fire in a one-story and basement bar-joist building, the bar-joist supported floor began to collapse before the people could get out of the first floor. On the other hand, very heavy steel sections might survive an hour of the standard test without failure” (p. 223).

Post and Winston (2001) reported that Jon D. Magnusson, the Chairman-CEO of Skilling Ward Magnusson Barkshire Inc., one of the successor firms of Skilling Helle Christiansen Robertson and the original structural engineer for the World Trade Center, cited the weakness of connectors as a vulnerability of the WTC. Magnusson stated, in Engineering News Report, that he believed the floor diaphragm, necessary to brace the exterior columns, had lost connection to the exterior wall. The result of the loss of the connection meant that stability was lost which then caused the exterior columns to buckle outward, allowing the floors

above to drop down onto the floors below, overloading and failing each one as it went down.

Lipton and Glanz (2002) reported for The New York Times that parallels between the demise of the twin towers of the World Trade Center and deadly fires in other high-rises since 1970 are disturbingly apparent and at times, explicitly drawn. After the fire at One New York Plaza in 1970, federal investigators cited flaws in light fireproofing sprayed onto steel structural supports that had fallen off or flaked away from the steel, leaving beams vulnerable to failure and collapse in the super intense heat. The assessment of the WTC collapse by the Federal Emergency Management Agency and the American Society of Civil Engineers cites the same hazards identified by federal authorities in the earlier fire as contributing to the death and destruction on September 11th. “Spray-applied fireproofing may be vulnerable to damage from blasts and impacts”, says a draft of the FEMA report, adding that failure of support structures protected with this fireproofing “is likely critical to the ultimate building failure.”

FDNY officials, beginning with former Commissioner O'Hagan, began questioning the effectiveness of sprayed on fireproofing long before the disaster at the World Trade Center. The events of September 11, 2001 are seen by many in the FDNY as a horrible validation of their long held apprehensions about the dangers of fighting major fires and performing evacuations in modern lightweight high-rises.

In summary, the research indicated that FDNY's standard operating procedures manual, Firefighting Procedures High-Rise Office Buildings, failed to adequately inform members of the FDNY of critical construction features and vulnerabilities that were presented by the twin towers of the World Trade Center. Assistant Chief Albert Turi, the commanding officer of the FDNY's Safety & Inspection Command, agreed with the findings of the research. In a personal communication he stated that he believed the material contained in FDNY's SOP did not provide adequate information about the construction characteristics of the World Trade Center to the members of the department (A.Turi, personal communication, February 22, 2002).

PROCEDURES

A six step process was used to complete this research. These steps were undertaken in the following order:

1. Deputy Assistant Chief Albert Turi, the commanding officer of the FDNY's Safety and Inspection Command was interviewed to determine if he believed that Firefighting Procedures High-Rise Office Buildings provided sufficient information to the members of the FDNY concerning the construction features of the World Trade Center.
2. Twenty-five FDNY Battalion Chiefs were surveyed as to whether or not they believed the material contained in the cited manual was sufficient. Battalion Chiefs were chosen for the survey because, as indicated by O'Hagan (1977), "Traditionally, in the FDNY, the tactical commander has been the Battalion Chief.

Battalion Chiefs organize the individual companies and deploy them in a manner that is designed to accomplish the strategic goals of the department” (p.193).

3. Deputy Assistant Chief Michael Butler, the commanding officer of FDNY's Bureau of Fire Prevention, was interviewed to determine if any other building in New York City shared the construction characteristics of the WTC.

4. Material was selected for the literature review that was relevant to the subject. The literature review began at the Learning Resource Center of the National Fire Academy; progressed to the Mand Library of the FDNY and the New Rochelle Public Library. In addition to the libraries cited, the internet was searched for articles in professional journals relevant to the research subject. The material used for the literature review included material drawn from:

- Architectural Record
- Building Code Of The City Of New York
- Building Construction For The Fire Service (2nd & 3rd Editions)
- Collapse of Burning Buildings A Guide to Fire-ground Safety
- Engineering News Report
- Fighting High-Rise Building Fires
- Fire Engineering
- Firefighting Procedures High-Rise Office Buildings
- Fire Protection Handbook 18th Edition
- High Rise Fire & Life Safety

- New York Board of Fire Underwriters
- The New York Times
- Risk Management Practices in the Fire Service
- Stanford Report
- Why the World Trade Center Buildings Collapsed A Fire Chief's Assessment
- WNYF

5. A draft of the research paper was submitted to Vincent Dunn for critical review. Vincent Dunn retired from the FDNY after 40 years of fire experience. Chief Dunn's credentials as a fire service expert are extensive. Dunn had served as the commander of FDNY's Third Division in Mid-town Manhattan, the high-rise capitol of the world. Chief Dunn served as an adjunct professor at Manhattan College where he taught fire engineering in the Civil Engineering Department. Chief Dunn has also served as an adjunct instructor at the National Fire Academy. He has authored many articles on firefighting safety and collapse for Fire Engineering, Fire Command, and the FDNY publication WNYF. He is the author of three text books: *Collapse of Burning Buildings a Guide to Fireground Safety*, *Safety and Survival on the Fireground*, *Command and Control of Fires and Emergencies* and the critical essay, *Why the World Trade Center Buildings Collapsed a Fire Chief's Assessment*. The review was conducted to assure the accuracy of material concerning building construction and engineering matters discussed.

6. The critical review was examined by the author. The recommendations from the critical review were used to develop the completed text of the research project, which was then submitted for evaluation by the staff of the Executive Fire Officer Program at the National Fire Academy.

Limitations

The research is limited by the following factors:

- The research is limited to an examination of the relevance of FDNY's SOP Firefighting Procedures High-Rise Office Buildings. The research is not intended to critique or evaluate, in any way, the performance of the FDNY on September 11, 2001.
- The research is limited to construction features. Tactical issues are not addressed.
- The author is not a professional engineer.
- There was a lack of willingness by many members of the FDNY to discuss any matter concerning the World Trade Center.
- The events of September 11th are being investigated on many levels. Materials relevant to the construction of the Trade Center such as, original plans etc. were not readily available due to ongoing investigations being conducted by many different organizations.
- Personal biases of those interviewed, whether intentional or not, may be present.

Definition of Terms

Chapter 26, Administrative Code -The official title for the New York City Building Code.

FDNY - Fire Department of the City of New York

Chapter 26, Administrative Code - The official title for the New York City Building Code.

FEMA - Federal Emergency Management Agency

HERA - New Zealand Heavy Industry Research Association

High-Rise Office Building - Chapter 26 of the Administrative Code of the City of New York defines a high-rise office building as a Class E occupancy that is 100 feet or more in height.

Occupancy Group E-Business - According to Chapter 26- Section 306.1, buildings and spaces shall be classified in the business occupancy when they are occupied for transacting business; for rendering professional services; or for performing other commercial services that may incidentally involve the storage of limited quantities of stocks of goods for office use or purposes. Buildings and spaces used for prosecuting public or civic services shall also be classified in this group.

SOP - Standard Operating Procedure

WTC - The World Trade Center Complex

RESULTS

1. ***Were the twin towers of the World Trade Center representative of most high-rise office buildings in New York City, or were they an anomaly?***

A review of the literature, and the interview with Assistant Chief Michael Butler, indicated that the twin towers of the World Trade Center were an anomaly among New York City's high-rise office buildings. Butler indicated that a search of building records by the FDNY's Bureau of Fire Prevention failed to discover any other high-rise office building in New York City that was of tubular construction. However, further research is being conducted to determine if any other building not built to the standards of Chapter 26, such as federal buildings, are of tubular construction (M. Butler, personal communication, March 12, 2002).

As was indicated by Corcoran (1993) the WTC was a creature of the Port Authority of New York and New Jersey, and therefore was not required to be constructed according to the specifications of the New York City Building Code.

While the WTC shared many of the characteristics found in hundreds of modern lightweight high-rise structures that populate the New York City's skyline, such as: a center core for utilities and services; Q deck flooring, etc. they were unique buildings, in fact, an anomaly because they were the only tubular buildings in New York City.

2. ***Did the standard operating procedures manual Firefighting Procedures High-Rise Office Buildings provide sufficient information about the construction characteristics of the World Trade Center?***

The research indicated the FDNY's standard operating procedure failed to provide adequate information about the construction characteristics of the World Trade Center. The WTC's unique construction; its vulnerabilities and fire protection features, crucial knowledge for a fire officer, were not addressed by the manual. The WTC's unique features presented vulnerabilities to fire that were not known by many members of the FDNY. The lack of knowledge concerning the vulnerabilities present in the WTC can be traced, in large part, to the fact that they were not presented to members of the department by its SOP, Firefighting Procedures High-Rise Office Buildings.

Brannigan (1992) stressed that it is critical to know your buildings. He stated that, "every firefighter and officer must study the peculiarities of building construction in their response areas; this will greatly enhance their chance for survival "(p. 452).

3. ***What were the major structural differences between the World Trade Center towers and the other high-rise office buildings in New York City?***

The literature review revealed that the twin towers of the World Trade Center possessed unique structural characteristics that were not found in any other high-rise office building in New York City. Among the WTC's unique features were:

- The construction of the WTC was not core construction as defined by FDNY (1997). Although a center core for services and utilities was present, the buildings were described by engineers (Brannigan, 1992; Clifton 2002) as classic examples of tubular construction.

- The WTC's center core carried only 60% of the vertical load (that created by the stairwells, elevators, building services, standpipes etc). In a core constructed building the core carries 100% of the building's load; the outer walls are non-bearing curtain walls.
 - The outer wall of the WTC was a bearing wall that carried 40% of the load. They were the highest bearing walls in New York City. The WTC buildings resisted the wind load via their unique tubular construction and the presence of a vierendeel truss system. This construction method placed wind resistance at the most efficient spot, the outside of the building.
 - The floors of the WTC were supported by steel bar joist trusses. There were no steel girders supporting the floors of the WTC. This is in complete contrast to the core buildings described in Firefighting Procedures High-Rise Office Buildings that have their floors supported by solid steel girders and beams.
4. ***What features of the World Trade Center's construction presented the greatest vulnerability to fire?***
- The sprayed on fireproofing was cited by many, including the American Society of Civil Engineers, Brannigan, Dunn, FEMA, Lucht, the New York Board of Fire Underwriters and O'Hagan, as a critical element in the WTC's vulnerability to the fires that raged out of control. Federal investigators raised concerns about the inadequacy of sprayed on fireproofing as early as 1970.

- The presence of lightweight steel bar joists, the only support for the floor system, left the WTC extremely vulnerable to fire. Several authors (Dunn 1988, Brannigan 1992, and the NFPA 1997) all reported that lightweight steel bar joist trusses could be expected to collapse in 5 to 7 minutes when exposed to high heat conditions. It was readily apparent that on September 11, 2001, the trusses were exposed to extreme heat. Schwartz (2001) reported that the floor trusses were relatively flimsy and just fell apart while noting that steel bar joist trusses are difficult to adequately fireproof.
- The connectors were fragile. Schwartz (2001) reported that the construction of the towers employed a novel tube frame system that was designed to resist winds of up to 80 miles per hour but, the connections of the tube frame were weak, causing them to break apart and become three pronged missiles that crashed into the street and into nearby buildings.
- The outside bearing wall was dependent on the integrity of the floor system. Wilkinson (2001) stated that the outside bearing wall depended on the integrity of the floor system. The floors which acted as a diaphragm collapsed and negated the structural integrity of the building.
- Brannigan (1992) reported that the characteristics of tubular construction, used to build the World Trade Center, made it more vulnerable to the possibility of progressive collapse.

The survey (Appendix) of Battalion Chiefs indicated the following:

1. 22 of the 25 chiefs surveyed indicated that FDNY's SOP FFP High-Rise Office Buildings was their primary source of information concerning high-rise construction characteristics.
2. 22 of the 25 chiefs surveyed had no knowledge of tubular construction before 9/11/01.
3. All chiefs surveyed did not believe FDNY's SOP Firefighting Procedures High-Rise Office Buildings provided sufficient information about the WTC or other significant 3rd generation high-rise office buildings.
4. 20 of the twenty-five chiefs surveyed could not identify what a vierendeel truss was.
5. 22 of the 25 chiefs surveyed believed the WTC was a core constructed building as defined in FFP High-Rise Office Buildings.
6. All chiefs were unaware that the floors of the WTC were carried only by bar joists and that no solid beams or girders were present.
7. 22 of the 25 chiefs surveyed indicated that they believed the outside wall of the WTC was a curtain wall and not a bearing wall.
8. 21 of the 25 chiefs indicated that due to the great volume of material the FDNY publishes, they obtained the majority of their information from material that is listed on the bibliography for promotion exams.

Unexpected Findings:

Unexpected findings were derived from the research that is relevant to the problem. The published data served, in some instances, to exacerbate the confusion concerning the characteristics of the construction of the WTC.

- Technically inaccurate information about the construction characteristics of the WTC was distributed by the U.S. Dept. of Commerce (1975). The report, obtained from the LRC at the National Fire Academy, covered a fire that occurred in the south tower of the World Trade Center on April 17, 1975. Item 7 of the report stated, "The World Trade center consists of two 110-story office towers which rise from a large ground level complex. Both towers are approximately 200' x 200'. They are core design of protected steel frame construction." This is contradicted by several authors (Brannigan, 1992, Snoonian and Czarnecki, 2001; Clifton, 2002) that noted the World Trade Center was tubular design, it was not core design.
- O'Hagan (1977) wrote in *High Rise/ Fire & Life Safety*, "Floor plan of the 110-story Tower 1 in the New York World Trade Center. Central core contains most of the building services including elevators, stairs, utilities, air-conditioning shafts and rest rooms. Steel girders connect the core to columns in the exterior walls thus eliminating the need for interior columns and providing an unobstructed floor space" (p.24). Several authors (Snoonian and Czarnecki, 2001, Clifton, 2002; Brannigan,1992) indicated no girders were present to connect the core to the columns in the exterior walls. They noted that the outer columns were connected solely by steel trusses.

- Discussing the 1975 fire at the WTC, O'Hagan (1977) wrote, "Overall construction is superior to the typical lightweight skin construction used in most high-rise structures. Exterior walls have closely spaced columns and are devoid of any continuous openings connecting successive floors. The tower was built with today's typical center core construction and its open floor concept "(p.37). The towers were not typical; they were *atypical* because as noted by several authors (Brannigan, 1992, Snoonian and Czarnecki 2001, and Clifton, 2002) they were tubular construction, not core construction.
- Manning reported in the October, 2001 issue of *Fire Engineering*, Our Most Tragic Day: Initial Report, "No one could have anticipated the collapse window for the towers, given that in the past, similarly constructed high-rise structures have withstood days of heavy fire without total failure" (p.15). Unfortunately, this statement is without merit. The literature review disclosed that the towers of the World Trade Center, due to their unique tubular, lightweight truss construction, were unlike any other high-rise. There is no history of a similarly constructed tubular high-rise building burning for days with heavy fire. No other tubular high-rise building has experienced the type of fire described by Manning. The buildings Manning refers to though not cited are, most probably, the One Meridian Plaza Building in Philadelphia and the First Interstate Building in Los Angeles, California, all are core buildings that had experienced extensive heavy fire conditions for extended periods of time, without collapse. These buildings were built with steel girders and beams supporting the floors, all were core buildings with curtain walls that are

not load bearing, none of them were of tubular construction. Brannigan (1992) wrote, "Because of the duration and intensity of this and the First Interstate Bank fire, attention has been focused on the possible loss of strength and stability of the structural frame of high rises. In both cases the columns of the structural steel frame endured the fire without significant damage. Can we draw from this experience that there is no need to fear collapse even in a raging high-rise fire? I believe the answer is **NO**" (p. 511).

DISCUSSION

This research determined that FDNY's standard operating procedure, Firefighting Procedures High-Rise Office Buildings, when compared to the significant findings of others who have published documents related to the research problem, did not contain adequate information about the construction features and vulnerabilities to fire that were present at the World Trade Center. Brannigan (1992) wrote, "Know your buildings! ... if every fire officer and firefighter took the time to study the peculiarities of how buildings are constructed in their response areas, their chances of coming away alive would be immeasurably improved" (p.XV).

FEMA (1996) reported that risk management and disaster planning are important tasks. Ensuring that risks have been properly identified, resources have been set into place and key personnel have been trained, will not prevent a disaster from occurring, but will reduce losses and ensure that members are adequately prepared with knowledge of possible risks.

An unexpected finding derived from the data in the literature review disclosed that inadequate attention to technical detail in published material studied by members of the fire service can lead to confusion and misunderstanding of critical construction features of buildings. This misunderstanding can hinder the probability of properly identifying risks that may be presented by the construction characteristics of certain buildings.

Brannigan (1992) reported “All fire officers need an accurate knowledge of building terms ... However, the most important reason for knowing building terms is safety. There are too many instances of fatalities that have occurred because fire officers did not recognize construction elements and the conditions under which they are likely to fail” (p.9).

Advancing the professional development of fire service personnel is a mandated goal of the National Fire Academy. The fire service must demand professional standards and technically accurate terminology and descriptions of building characteristics from those who publish data for study by members of the service.

FDNY (1997) provided only two pages, out of a forty-five page manual, dedicated to information about the construction characteristics of high-rise office buildings. This constitutes an insufficient amount of information about such complex structures. The need for restoring standard texts such as *Building Construction for the Fire Service* to the bibliography for promotional exams is strengthened by the results of the survey conducted of Battalion Chiefs. FEMA

(1996) encouraged the use of standard texts such as Brannigan's by fire departments.

O'Hagan (1977) reported, "Traditionally, in the FDNY, the tactical commander has been the Battalion Chief. Battalion Chiefs organize the individual companies and deploy them in a manner that is designed to accomplish the strategic goals of the department" (p.193). Common sense dictates that it is essential for chief officers to be well acquainted with the characteristics of the buildings their personnel are operating in.

The FDNY relies heavily on its SOPs as a source for exam questions. The survey of Battalion Chiefs indicated that few were aware of critical construction characteristics of the WTC. Most of the chiefs surveyed, including this author, had never heard of tubular construction until after September 11th. This fact reinforces the need for more comprehensive knowledge of building construction by members of the FDNY.

Brannigan (1987) has reminded members of the fire service time and again, to know their buildings. He stated the building is your enemy and experience in the fire service is gained through blood, sweat and tears. Competent preplanning and analysis of potential hazards are better options, because it may not be possible to detect the hazards that a building is presenting to firefighters at the time of the fire. Educated preplanning is a must. "It is not easy to always "Know Your Buildings" but it is vital if deadly ambushes are to be avoided" (p.314).

Loflin (1997) reported that NFPA 1500-Standard on Fire Department Occupational Safety and Health Program, required fire departments to adopt an official written risk management plan that addressed all fire department policies and procedures.

FDNY's (1997) standard operating procedure, Firefighting Procedures High-Rise Office Buildings, is an integral part of the department's risk management plan. FEMA (1996) reported that once a risk management plan has been created, the elements of the plan should be periodically updated. It should be considered a dynamic process, not a static event with a single written record. The Risk Management Plan, and all of its integral components including SOPs, should be kept current based on conditions, circumstances and experience.

In order to be effective, risk management decisions must be based on accurate, timely, and complete information about hazards that are present and significant.

The research indicated that the construction characteristics, as defined by Firefighting Procedures High-Rise Office Buildings, had not been added to or updated since the SOP was first issued. The revisions that had been incorporated into the manual concerned only response assignments and tactics. Crucial information concerning building construction techniques and characteristics had not been made. Brannigan (1982) warned fifteen years before the 1997 revision of Firefighting Procedures High-Rise Office Buildings, "Not all high-rises were of core construction, using the term structurally. Some particularly high high-rise structures are of tube construction, that is, the wind

load is taken principally on the exterior. This does not eliminate the use of a central core for utilities and services” (p.349).

The research indicated that the WTC, prior to September 11, 2001, was the scene of the largest evacuation that ever took place in a high-rise office building. Terrorists bombed the basement of the WTC in 1993. FDNY (1993) reported that the event resulted in the largest response ever by the FDNY, with over 16 alarms struck for the fire and evacuation of the twin towers.

The 1993 bombing should have served as the catalyst for providing greater information to the members of the FDNY about the construction characteristics of the World Trade Center. Particular attention should have been directed to the vulnerabilities that were present in the buildings. Historically, in this author’s view, it has been the hidden vulnerabilities of buildings that have caused death and injuries to firefighters. A lack of knowledge about a building’s strength has seldom, if ever, hurt firefighters. Brannigan (1992) noted that every firefighter and officer must study the peculiarities of building construction in their response areas; this will greatly enhance their chance for survival.

The results of the research indicate the FDNY must take steps to upgrade the information that is available to the field units of the FDNY concerning the construction features of significant buildings found in New York City. The events of September 11th indicated that the cities of the United States are the targets of an international group of terrorists. These people are determined to attack significant structures in American cities. Their goal is to kill and maim Americans. The personnel of the FDNY, as protectors of America’s largest city,

will remain on the frontlines of America's war against terrorism. The enemy is a patient foe. It is not a question of whether or not they will strike again; it is only a question of when and where.

Eight years passed between the initial attempt to topple the World Trade Center and the horrific events of September 11, 2001. In that eight year span, critically needed amendments to Firefighting Procedures High-Rise Office Buildings were not developed. The FDNY has, since September 11th, put together a team of chief officers to revise the SOP. In addition, another team is studying what changes must be put into place regarding building code requirements for future high-rise construction that will take place in New York City.

The implications for the FDNY are that, as a result of the studies being conducted, better standards for future high-rise construction should be developed and more comprehensive descriptions of the vulnerabilities in high-rise structures should be made available to department members via enhanced CADS capabilities, greater use of technology, more comprehensive SOPs and greater use of standard texts for study by all members of the FDNY.

RECOMMENDATIONS

The results of this research indicated that the FDNY includes a large number of FDNY publications on its bibliography for promotion exams. The research also indicated a clear need for steps to be taken that will enhance the ability for FDNY's members to know their buildings. The following recommendations are made:

1. The FDNY should continue the ongoing review of its SOP, Firefighting Procedures High-Rise Office Buildings and correct the deficiencies that are present regarding critical information about 3rd generation high-rise office buildings.
2. The FDNY as part of its Risk Management Program should conduct a quadrennial review of its SOPs and pre-plans in order to determine that they are up to date. This is especially crucial given the fact that the threats from terrorist activities are likely to continue into the foreseeable future.
3. FDNY should explore the possibility of adding structural engineers to the civilian staff at headquarters. The engineers should serve in the department's planning section.
4. Due to the complexity of modern engineered buildings, FDNY's firefighting procedures and SOP's should be developed in cooperation with licensed structural engineers. The final draft of the SOP should be reviewed by structural engineers. The engineers should be asked to provide guidelines, based on professional judgments about construction, rather than anecdotal evidence, for windows on collapse time; possibility of progressive collapse etc.
5. FDNY chief officers, while undergoing the 5 week Chief Officers Command Course, should be trained to read and interpret building plans, and made aware of the latest developments in building technology.

6. The FDNY should maintain liaison with law enforcement and anti-terrorist task forces in order to keep its Risk Management Plan up to date on possible terrorist activity that is perceived as a threat to New York City.
7. The FDNY should, as part of its Risk Management Program, develop, in cooperation with terrorism experts from the NYPD and FBI, a list of high profile buildings deemed most probable future targets for terrorism.
8. Once a list of high risk buildings is developed, the FDNY should determine whether any building identified as a potential target does or does not conform to the New York City Building Code, or possesses inherent vulnerabilities, critical information that must be known by operating members.
9. The FDNY should lobby for legislation requiring all structures built in New York City to comply with Chapter 26 of the City's Administrative Code (the New York City Building Code). If the FDNY is to fight the fire, the department should enforce the codes. This will improve and allow for knowledge and standardization of fire protection features.
10. The FDNY should update its CIDS program. Currently, only 160 characters of information can be transmitted to responding units concerning structural hazards and characteristics of buildings. With today's computer technology, the CIDS Program should be enhanced to provide greater information.
"Several systems have been developed as components of computer aided dispatch (CAD) to automatically retrieve information associated with a specific address when a team is dispatched to an incident at that location.
Capabilities currently existing range from New York City's system-which can

print out a few lines to alert responding companies of specific hazards, associated with each address-to the system in Fairfax County, Virginia, which can store several pages of text information and line drawings in a CAD system accessible to mobile digital terminals (FEMA, 1996)". FDNY should explore the possibility of upgrading its CAD capabilities to equal those of Fairfax County.

11. Laptop computers should be issued as replacements for the outdated microfiche used in the past. The laptops should be assigned to each Division and carried in each Division Chief's car. It is now possible to store tens of thousands of pages on electronic media such as CD-ROM disks. This new technology has increased capabilities to store graphic information including thousands of building plans. If a building's construction incorporates trusses or other hazards that are not readily apparent to the responding firefighters that should be prominently noted in a manner that draws the user's attention. Graphics presentations should use standard symbols and color coding to convey important information efficiently (FEMA, 1996).
12. FDNY removed *Building Construction for the Fire Service* from the bibliography of required study material for the last Battalion Chief exam. This material should be reinstated to all promotion exams. FEMA (1996) reported that standard texts such as Francis L. Brannigan's *Building Construction for the Fire Service* provide essential information that enables fire officers to recognize high-risk situations.

13. The FDNY should take steps to insure that the material studied by members of the FDNY is technically accurate. Brannigan (1992) stated, "All fire officers need an accurate knowledge of building terms. If fire officers make glaring errors in terminology... it may be difficult for building professionals or trade persons to believe their fire protection recommendations" (p.9). Building descriptions provided in fire service publications must be correct according to professional engineering standards. A critical review of material that is required for study should be conducted to assure its technical accuracy.

REFERENCES

Brannigan, F. L. (1982). Building Construction for the Fire Service (2nd Edition), Quincy, Massachusetts: National Fire Protection Association

Brannigan, F. L. (1992). Building Construction for the Fire Service (3rd Edition), Quincy, Massachusetts: National Fire Protection Association

Clifton, G.C. (2002). Collapse of the World Trade Center Towers, *TEN LINKS.COM THE WEB ORGANIZED FOR TECHNICAL PROFESSIONALS*, <http://www.tenlinks.com>

Corcoran, D. (1993, December). Fire Prevention and Building Restoration Activities, *FIRE ENGINEERING*, p.94

Crenson, M. (2002). Inadequate Fireproofing May Have Contributed to World Trade Center Collapse, *DESIGN-BUILD*, <http://www.designbuild.com>

Dunn, V. (1988). Collapse of Burning Buildings a Guide to Fire ground Safety, New York, New York: Fire Engineering

Dunn, V. (1999). Command And Control Of Fires And Emergencies, New York, New York: Fire Engineering

Dunn, V. (2002). Why the World Trade Center Buildings Collapsed A Fire Chief's Assessment, <http://vincentdunn.com/wtc.html>

Federal Emergency Management Agency.1996. Risk Management Practices in the Fire Service. Emmitsburg, MD: Federal Emergency Management Agency

Fire Department of New York. (1993). Report from Chief of Department.
Brooklyn, New York: Author

Fire Department of New York. (1997). Firefighting Procedures High-Rise
Office Buildings. Brooklyn, New York: Author

Fitzgerald, R. (1997a). Structural integrity during fire. In A. Cote (Ed.) *Fire
Protection Handbook* (18th ed., pp. 60-63), Quincy, Massachusetts: National Fire
Protection Association

Fogarty, J. (1982). Introduction. MANHATTAN BOROUGH COMMAND
HIGH RISE OFFICE BUILDINGS FIRE SAFETY SEMINAR, January 1982, p.1

Ganci, P. (2000, 1st) Fires that Affected FDNY Firefighting Procedures,
WNYF p. 16

Lipton, E. and Glanz, J. (2002, March 6). New Rules Proposed to Help
High-Rises Withstand Attacks, New York Times, p.1

Loflin, M.E. (1997) Using the Classic Risk Management Model, *FIRE
ENGINEERING*, 150(2), p.62-66

National Fire Academy, (2001, December). Executive Analysis of Fire
Service Operations in Emergency Management, p. SM 1-3 Emmitsburg, MD:
Author

O'Hagan, J. (1977). High Rise / Fire & Life Safety, New York, New York:
Dunn & Donnelley Publishing Corporation

Ryder, E. (1975). One World Trade Center Fire, New York, NY February 13, 1975, High-Rise Fire Safety, New York, New York: The New York Board of Fire Underwriters Bureau of Fire Prevention and Public Relations

Schwartz, M. (2001, December). Structural Engineer Describes Collapse of the World Trade Center Towers, *STANFORD REPORT*, <http://www.news-service/december5/wtc-125html>.

Snoonian, D. and Czarnecki, J. (2001, October). World Trade Center's Robust Towers Succumb to Terrorism, *ARCHITECTURAL RECORD*, <http://www.archrecord.com>

Whalen, E.W. (1980) Anatomy of a Fifth Alarm High- Whalen, E.W. (1980) Anatomy of a Fifth Alarm High-Rise Fire 299 Park Avenue June 23, 1980, New York, New York: The New York Board of Fire Underwriters Bureau of Fire Prevention and Public Relations

APPENDIX

Survey of Battalion Chiefs Re: Construction Characteristics of the WTC

1. Your primary source of information concerning the characteristics of high-rise building construction is?
 - a. FDNY's High-Rise FFP
 - b. Brannigan's Building Construction for the Fire Service
 - c. Fire Protection Handbook
 - d. Other source

2. Prior to the collapse of the World Trade Center had you ever heard of tubular construction? Yes No

3. Do you believe FDNY's High-Rise FFP provided sufficient information concerning the construction characteristics of the World Trade Center? Yes No

4. Do you know what a vierendeel truss is and the purpose it served in the World Trade Center? Yes No

5. Did you believe the World Trade Center was core construction as defined in FFP High-Rise? Yes No

6. Were you aware, prior to 9/11, that the floors of the World Trade Center were supported solely by steel bar joist trusses? Yes No

7. Did you consider the outside wall of the World Trade Center to be a curtain wall as described in FFP High-Rise Office Buildings? Yes No

8. Is it fair to say that because of the great volume of material published by the FDNY, you have devoted most of your study time to official FDNY publications contained on the bibliography for promotion exams? Yes No