Learning from 9-11

Research organizations and other agencies eye wide-ranging safety improvements.

PAMELA R. WEIGER AND JOHN NICHOLSON

Last summer, Ken Catlow, operations group leader at the Pentagon Renovations Project, had a clear vision of the future of the Pentagon's renovations: nine uninterrupted years of strengthening the blast resistance of one of the world's biggest office structures. On September 11, however, all that changed.

In the wake of the tragedies at the Pentagon and the World Trade Center (WTC), Catlow and many other architects, structural engineers, fire protection engineers, and emergency response officials put their plans on hold to participate in numerous studies and investigations designed to assess the structural and fire protection performance of both targets and to define the lessons learned from the emergency response and evacuations. While recommendations from the teams studying the WTC collapse are expected to be more extensive than previously anticipated, thus delaying their release, many recommendations from the early Pentagon studies have been implemented.

NFPA JOURNAL'S COVERAGE OF THE WTC AND PENTAGON ATTACKS CAN BE READ ONLINE AT WWW.NFPA.ORG/NFPAJOURNAL.

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Studying damage

Spurred by the urgent need to rebuild in the days following the attack, designers and engineers launched several preliminary structural-performance investigations of the Pentagon, independent of the long-range plans to renovate the 6.5-million-square-foot (604,000-square-meter) structure by the end of 2010. Among these was a 30-day Pentagon Rebuild Retrofit Study of the Pentagon's blast resistance undertaken by members of the U.S. Army Corps of Engineers, who took advantage of the fact that the hijacked Boeing 757 hit the building between the already-renovated Wedge 1 and the older Wedge 2 to analyze the effectiveness of the renovations made before September 11. Wedge 1 was the only one of the building's five wedges reinforced after the 1995 Oklahoma City bombing.

The study showed that Wedge 1's newer windows and walls withstood the attack much better than Wedge 2's structural components. Floor-to-floor, interconnected vertical steel beams, sturdier windows, and armored panels in the exterior wall are credited for slowing the plane as it slammed into the building and mitigating the effects of the explosion, saving lives by keeping more of the building intact.

"The new windows were superior and saved many lives," says Catlow. The attack "validated a lot of the design in Wedge 1, and we felt good about that."

Part of the design the engineers and designers were pleased with were the new strobe lights and sirens and Wedge 1's new sprinkler system. They performed so well that officials are considering dividing the sprinkler areas into zones to keep portions of the system intact in the event of another attack.

With reports of concrete spalling at temperatures of 1,800˚F (982˚C) in some parts of the building, team members are investigating the feasibility of fireproofing the structural members and installing an automated smoke control system. Also under consideration are a river-water supply system that can be brought on line should the domestic water supply fail, as well as the standardization of office density and space.

In addition to the Pentagon Rebuild Retrofit Study, another Pentagon task force compiled a list of 105 areas of concern by interviewing those who escaped when the plane hit. The list was pared to 26 recommendations in the areas of fire protection, blast resistance, and chemical, biological, and radiological resistance. Some of these, such as the installation of photoluminescent signage, have already been implemented.

"When the plane hit, it took out our secondary power source, an emergency generator, so we lost primary and secondary power, making it very dark in parts of the building," Catlow says.

The new photoluminescent signs, installed in the building's baseboards, provide direction at floor level for people crawling through dense smoke. This recommendation was deemed so critical that baseboard lighting was installed in all portions of the Pentagon, even those not in the process of being renovated.

"We can't ignore the rest of the building for eight years," says Catlow.

Other life safety improvements include issuing flashlights, respirators, and exit directions to Pentagon employees; upgrading the building's firefighting equipment and emergency notification system; establishing a fire

warden system; and strengthening the Pentagon's Incident Response Teams to ensure the availability of trained people who can help the fire department.

Overall, the reconstruction of Wedge 1, known as the Phoenix Project, continues at a rapid pace. It's scheduled to be completed by September 11, 2002.

Arlington County response

In the community around the Pentagon, located in Arlington, Virginia, across the Potomac River from Washington, D.C., the lessons taught by September 11 are also being heeded.

Arlington County Fire Chief Edward Plaugher, who has believed for years that the Pentagon would someday be the target of terrorists, commanded the fire department response for 10 days and calls the Pentagon "a stodgy old building that could, should, and did perform well."

The logistics of the response alone were overwhelming. Plaugher cites the "miles of six-by-six timbers" needed for perimeter fencing, along with the boots, helmets, coats, and a "truckload of latex gloves that came with a police escort." He'd like to see the creation of a Northern Virginia logistics response team that would be in charge of "just this sort of thing and would be available for anything."

Plaugher, whose department was on site planning responses to the renovated portion when the terrorists struck, also envisions the creation of a system to guide a fire department's interaction with the many players involved in incidents of this magnitude. Although his department responds to the Pentagon daily and works regularly with Defense Protective Services officials, the number of people from the federal, state, local, military, non-profit, and private sectors who came to assist overwhelmed him.

"There are so many more players, and a structured interaction with those players is where we're headed," says Plaugher.

To determine the impact of the incident on his personnel, Plaugher mounted a review of what happened. The investigation, funded by a Technical Assistance Grant from the U.S. Department of Justice, began immediately and focused on the performance of his firefighters and emergency personnel.

He hired an outside consultant to debrief all fire service personnel once the department cleared the incident, and asked a facilitator from the International Association of Fire Chiefs to lead the firefighters in a critique that excluded chief officers. Plaugher wanted to ensure that his personnel felt free to speak candidly about the incident without being influenced by their supervisors.

"Emotions were huge, and we needed to bring in someone from the outside to steer us in a non-emotional direction," says Plaugher. "I'm hoping to have an after-action report that provides a blueprint to prepare the fire service for [future] catastrophic incidents, particularly terrorist-related incidents."

Congress spurs action

Because the scope of the WTC disaster far exceeded that of the Pentagon disaster in terms of both lives lost and property destroyed, the investigations into it are expected to take much longer and be much more complicated than originally anticipated.

The House Committee on Science, chaired by New York Republican Sherwood Boehlert, recommended in March that a more comprehensive study of the WTC be undertaken and that enough federal funding be allocated to support it. Members of Congress particularly wanted an organization in charge that could produce a study leading to an evaluation and possible improvements in existing building codes, fire-testing standards, and fire codes. This lead agency is the National Institute of Standards and Technology (NIST).

NIST Director Arden L. Bement, Jr., told committee members that his agency has policy approval to undertake a national building and fire safety investigation of the World Trade Center and that NIST researchers will also conduct a series of short-term WTC studies. Both short- and long-term studies are supported by Secretary of Commerce Donald L. Evans, the Port Authority of New York and New Jersey, New York City Mayor's Office of Emergency Management, the New York City Department of Design and Construction, and the Fire Department of New York.

PHOTOGRAPH: AP/WIDEWORLD

Work continues at the Pentagon attack site. The interior and exterior of the building are shown after the areas were stabilized by shoring structures.

As part of the national building and fire safety investigation of the World Trade Center, NIST researchers will examine why and how the WTC buildings collapsed; the technical aspects of fire protection, response, evacuation, and occupant behavior and emergency response; and procedures and practices used in the design, construction, operation, and maintenance of the buildings. They will also look at new technologies and procedures that might reduce the potential risks of such a collapse.

"The goal of this broader program is to produce cost-effective retrofit and design measures and operational guidance for building owners and emergency responders," Bement told committee members. "The program would develop and disseminate guidance and tools to assess, and produce the technical basis and recommendations for cost-effective changes to reduce vulnerabilities."

Bement explained that the NIST study will focus on the Twin Towers, not only because their collapse triggered the damage done to the surrounding structures, but also because many of the towers' design features are still used by the construction industry. The NIST study will try to determine what measures are needed to give buildings the strength to resist abnormal loads, such as the impact of an airplane and an ensuing fire. Researchers will also study the effectiveness of fire protection and firefighting technologies and practices for tall buildings.

WTC Building 7 may also be included in the study because it, too, collapsed.

NIST is expected to incorporate into its study information collected by the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers (ASCE) Building Performance Assessment Team (BPAT), which is expected to be released soon. The national building and fire safety investigation of the World Trade Center is expected to be released in 2004.

"The results of the proposed investigation would be…meaningless unless we take the knowledge gained and put it to practical use," according to Bement. "That's why NIST, in partnership with FEMA and a number of private-sector organizations, has developed a broader response program.

"This broader program would address critically and urgently needed improvements to national building and fire standards, codes, and practices that have begun to be recognized in recent years."

While the NIST-led national building and fire safety investigation of the World Trade Center is being conducted, short-term and interim projects will be undertaken to provide facility owners, contractors, designers, and emergency personnel with guidance, tools, and technical assistance to prepare them better for future disasters.

Some of these projects are already underway. In February, for example, John Gross, leader of the structural systems and design group at NIST's Building and Fire Research Laboratory, and three private-sector and academic experts visited four scrapyards in New York and New Jersey where steel from the WTC is being stored to identify samples to be sent to NIST's Gaithersburg, Maryland, facility. NIST will store the samples to ensure that any future investigation, whether conducted by NIST or another organization, has secure steel samples ready for scientific study.

The short-term studies NIST is undertaking will focus on fire, the buildings' progressive collapse, and threats to commercial and institutional buildings and facilities.

According to Bement, fire played a critical role in the collapse of the WTC buildings and contributed to the damage done at the Pentagon. Current building design practice doesn't consider fire a design condition. Instead, he says, building codes prescribe structural fire-endurance ratings based on standard tests of individual components.

"The current testing standards are based on work carried out at NIST in the 1920s," said Bement. "They don't represent real fire hazards in modern buildings. They also don't consider the fire performance of structural connections or of the structural system as a whole, or the multiple performance demands on fire-proofing materials. NIST now has the capability to simulate building fires on the computer to explain critical events and outcomes to an extent previously not possible."

Interim NIST studies will also examine progressive collapse, which refers to the spread of failure by a chain reaction that's disproportionate to the triggering event. According to Bement, current U.S. standards, codes, and practices don't address this type of collapse.

Finally, NIST will investigate ways of reducing the vulnerability of commercial and institutional buildings to chemical, biological, and radiological attack.

"Most (buildings) aren't protected against chemical, biological, and radiological (CBR) threats. While efforts are underway to protect military buildings through the Department of Defense's (DoD) 'immune buildings' program, there are no standards and practices for civilian buildings," Bement said. "NIST proposes to work with the DoD to develop guidelines and advanced technologies to reduce the vulnerability of such buildings to CBR attacks.

"NIST also proposes to work with industry

PHOTOGRAPHS: FEMA

Crews continue the reconstruction at the Pentagon on the areas damaged by the terrorist attack. The job is expected to be done by September 11, 2002.

to develop standards for building information models and information exchange, and practicable tools for helping building owners make reasoned economic choices in reducing the vulnerabilities of their buildings."

The results of some of these studies will be disseminated within a year, and the rest when the investigation is completed, says Bement.

Future studies

Many, like Professor Glenn Corbett of John Jay College of Criminal Justice in New York City, agree that we need a governmental structure or protocol to investigate terrorist attacks.

In his testimony before the House Committee on Science, Corbett, who is also an engineer, recommended that to better assess the events of September 11 and produce meaningful future actions, a comprehensive plan to handle large-scale investigations is needed.

"We need to have a greatly enhanced national disaster investigation response protocol, providing for a systematic approach," he said. "We must bring in experts in a rapid, organized manner to extract all of the lessons from a disaster. Finally, and most importantly, we need to ensure that the lessons are actually applied."

According to Corbett, a variety of research projects undertaken for disasters, such as the Oklahoma City bombing and the Northridge earthquake produced very useful information, but were conducted independently, without the benefit of a central coordinating body to integrate all the information.

"In addition, it has become apparent that some of the very critical lessons never found their way into general design practice," Corbett said.

Furthermore, Corbett said, issues involving high-rise building construction, emergency evacuation procedures, firefighting operations, and other important concerns must be analyzed collectively so we can learn from the disaster and apply the lessons to the future.

Corbett recommends the establishment of a World Trade Center Disaster Commission, organized and led by FEMA, that would allow the various public and private research efforts currently underway to come together "under one roof," facilitating the sharing of information, a critical issue when studying a disaster as complex as the collapse of the WTC towers. The complexity of the WTC itself necessitates that the disaster be investigated in a multi-disciplinary context, allowing the interrelationships among the areas of concern to be identified.

National Science Foundation grants

Also playing a part in the WTC investigation is the National Science Foundation (NSF), which awarded engineers and social science researchers eight grants within weeks of the terrorist attacks to conduct post-disaster assessments. For the most part, the grants went to teams already in place as part of NSF's ongoing disaster response program, so funding was immediately supplied to quick-response research.

The teams funded by the eight grants produced their first findings at the end of 2001.

Among those receiving NSF grants was Frederick Mowrer, associate professor in the Department of Fire Protection Engineering at the University of Maryland, who used the funding to look into the performance of fire protection materials and systems during the WTC fires and collapse of the Twin Towers.

Dr. Mowrer, who began by studying photographs taken during an inspection of the building's fireproofing between 1992 and 1996, drew public attention when his preliminary report suggested that this was an area that warranted further study.

"There are some indications that there were some deficiencies, but at this point we don't know if [the deficiencies] were corrected between the time they were observed and the 9-11 incident," Mowrer says. "We also don't know how many of the deficiencies were in the area of impact or the areas affected."

Within the next year, Mowrer plans to compare the WTC incident to two other multi-floor burnouts in high-rise buildings, the 1988 First Interstate Bank building fire in Los Angeles, California, and the 1991 fire at One Meridian Plaza in Philadelphia, Pennsylvania. Neither of these buildings collapsed, despite fire on multiple floors (see "Looking Back" on page 160).

Mowrer would like to analyze the effects the jets' impact, the jet fuel, and the structural design of the WTC had on the outcome on September 11, as compared to the outcomes of the 1988 and 1991 fires.

In other NSF-funded research, Abolhassan Astaneh-Asl of the University of California at Berkeley and a colleague are collecting data on the mechanical and structural properties of the WTC towers, particularly the steel, to determine how they were affected by heat, fire, and impact.

Like many of the researchers looking into the collapse of the WTC towers, Mowrer refuses to accept what he calls an "attitude of inevitability": if a plane hits a building, collapse is inevitable.

PHOTOGRAPHS: FEMA

"I'm saying it may not be [inevitable], and we won't know without a thorough analysis," he said. "Clearly, these were extreme events and it's impractical to design a building for no damage, but perhaps we could make improvements to reduce the probability."

Learning from the lessons

In the months following the attacks, a number of engineers stated that they believed each tower could have withstood the impact of a single large airplane, as it was designed to. Once the aviation fuel in each Boeing 767 exploded into flames, however, it was just a matter of time before the towers collapsed.

The heat from the jet fuel fires, which are estimated to have reached temperatures of 2,000˚F (1,093˚C) are above temperatures that can reduce the structural strength of steel trusses used to hold up the concrete slab floors. The supports may have pulled away from the walls as the steel began to weaken.

The skyscrapers had two means of defense against normal fire damage. One, thick layers of insulation sprayed onto the steel beams, could have been breached by the initial crash. The other, the building's sprinkler system, may have been disabled as well, or it may simply have been useless in the heat of the fire. In a conventional fire, the towers' sprinkler systems could have been sufficient to control the blaze, but these unconventional fires would have overwhelmed the suppression systems if they were still operational.

The initial impacts probably rendered the sprinkler and standpipe systems inoperative on the fire floors and displaced any fire-resistance coatings on the structural steel. This exposed the steel to temperatures in the range of 1,600˚F (871˚C) and higher. Even if the fire protection systems had remained operative, it's unlikely they'd have discharged enough water to protect the structural steel.

WHAT NFPA IS DOING

Two representatives of NFPA serve on international teams examining the September 11 collapse of the WTC towers. Robert E. Solomon, P.E., NFPA's assistant vice-president of Building and Life Safety Codes, is a member of the special task force on the Future of Tall Buildings, formed by the Council on Tall Buildings and Urban Habitat (CTBUH). And Robert F. Duval, NFPA's senior fire investigator, serves on the American Society of Civil Engineers (ASCE)/Federal Emergency Management Agency (FEMA) Building Performance Assessment Team (BPAT) for the WTC.

The BPAT team is examining building performance in the towers and surrounding buildings. Duval serves on BPAT's support team, collecting and organizing data related to several buildings in the WTC complex. He's also a liaison with the New York fire service and responsible for gathering relevant information from past NFPA studies.

Other BPAT team members include representatives of various structural and fire protection engineering groups, as well as the concrete, steel, and masonry industries.

BPAT report

According to Dr. W. Gene Corley, WTC BPAT team leader, the collection of data and information pertinent to the study began while the team was assembled and the supporting coalition organized. A significant part of this data collection took place from October 7 to 12, when the team conducted an on-site examination of the debris and the buildings affected by the collapse. The City of New York granted the team access to the site on September 29.

The team was provided with unrestricted access to all areas of the site, except those in which their presence might have impeded rescue and recovery efforts and those that had been determined to be too hazardous.

Team members also examined structural debris at the Fresh Kills Landfill on Staten Island and at the two recycling yards in New Jersey, where they obtained samples of structural steel that have since been subjected to laboratory analysis.

The team has an unprecedented volume of photographic evidence available for review, including more than 120 hours of network and private videotape footage. Team members have viewed all the videotape and provided information on the data gleaned from it to the team at large.

The final report, which will include preliminary observations and conclusions about the structural and fire-related performance of the WTC towers, will have six additional chapters that discuss damage to surrounding buildings, such as WTC 7, and lessons learned from their performance, as well as numerous technical appendices, says FEMA's acting administrator Robert F. Shea of the Federal Insurance and Mitigation Administration.

Because of a confidentiality agreement between NFPA and FEMA, however, NFPA can't comment on the final report until it's released to the public.

BPAT background

The BPAT program uses teams of experts brought together from federal, state, local, and private-sector agencies to study building performance in response to natural and man-made hazards as part of FEMA's national mitigation effort. FEMA has deployed BPATs since the early 1990s in response to Hurricanes Andrew, Iniki, Opal, and Fran; floods in California, Georgia, North Dakota, Minnesota, and Texas; and the bombing of the Alfred P. Murrah Federal Building in Oklahoma City. The most recent deployments were in response to Hurricane Georges in Puerto Rico and in the Gulf Coast.

Experts in the field are optimistic that some of the lessons learned from the attacks on the WTC and the Pentagon may translate into changes and refinements of life safety and fire prevention codes and standards.

According to David A. Lucht, P.E., professor and director of the Center for Firesafety Studies at Worcester Polytechnic Institute in Worcester, Massachusetts, the evacuation of the WTC on September 11 was a remarkable affirmation of NFPA 101®, *Life Safety Code®*.

"The evacuation was remarkable and a tribute to the *Life Safety Code*. It's remarkable that those on the floors below the areas of impact made it out; it shows that the exiting system works. The evacuation of the World Trade Center is a validation of the work being done, not simply a lesson learned," says Lucht.

One area that engineers will likely explore, Lucht says, is fireproofing.

"I'm sure it will be an area that NFPA technical committees will examine and review," says Lucht, who has also served on the NFPA Board of Directors and is a Fellow and past president of the Society of Fire Protection Engineers. "If the studies being done conclude there's a problem (with fireproofing) how could you avoid it?"

He says the technical committee members will probably begin asking themselves whether the existing fuel loads for a normal fire pose a risk that fireproofing can't address.

"I believe the answer is 'No' because we've never experienced a structural collapse of a high-rise building (due to a normal fire situation)," says Lucht.

He notes that the structural steel of the Meridian Plaza fire showed evidence of extreme stress, but there was no collapse.

"I think all the technical committees will look at the normal worst case scenarios and take it a step further and look at terrorism," says Lucht.

Duval explains that the WTC BPAT is much different that those traditionally deployed following natural disasters. For example, the BPAT sent to Puerto Rico following the Hurricane Georges inspected damage to residential and commercial buildings and other structures; evaluated local design practices, construction methods and materials, building codes, and building inspection and code enforcement processes; and made recommendations on design, construction, and code issues.

The WTC BPAT is taking the methods used for research and survey after a natural disaster and applying them to a terrorist attack. Unfortunately, the size and scope of the WTC is more complicated than most natural disasters.

As for the impact of the BPAT's report on U.S. building and fire codes, Duval says it's too early to tell what changes might result.

"Each [NFPA code] committee will have to decide if this is a watershed incident for code changes," he says. "Codes change to address a few individual incidents, but this is so extraordinary."

CTBUH response

Some groups are looking ahead. One such group is a task force of 24 leading building industry experts formed by the CTBUH, which is looking into actions that can be taken to enhance the emergency performance of buildings. NFPA has been a member of CTBUH, which comprises the architectural, engineering, and building profession communities, since 1997.

The task force, composed of architects, security officials, engineers, and property owners and managers, is finishing up an overview of items of which high-rise building operators need to be aware in the areas of physical properties, safety systems, and the education of building occupants. The resulting guide is expected in early summer.

"It's a reinforcement of things we've known for a long time," says Solomon.

Solomon says the task force is focusing on new strategies that may be considered in the design of tall building, including performance-based design, in hopes of increasing the performance of tall buildings subjected to extreme events. Also of interest to the task force are global changes for building design, the potential for enhanced use of vertical transportation systems, and the practicality of incorporating these measures in buildings in the future.

When the task force met last October, it concluded that there are several actions that can be taken to enhance the emergency performance of buildings, including the design of explicit egress strategies, the installation of multiply-redundant building systems and integrated building control systems, the use of performance-based design, education, and research.

NFPA's own studies

With funding from NIST, NFPA will undertake three studies of its own of the evacuation of the WTC. Rita F. Fahy, Ph.D., NFPA's manager of Fire Databases and Systems, will work on these studies with Guylène Proulx, Ph.D., a researcher at the National Research Council of Canada. NFPA and NRCC conducted a similar study of the WTC evacuation in the wake of the 1993 bombing.

The three studies will cover the evacuation of the towers; the evacuation of Building 7; and a comparison of the 1993 and 2001 evacuations, using first-person accounts taken from the media. Fahy and Proulx will present the results of the third study at the NFPA World Safety Conference and Exposition™ in May.