COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

HEARING CHARTER

Learning from 9/11: Understanding the Collapse of the World Trade Center

Wednesday, March 6, 2002

Noon to 2:00 p.m.

2318 Rayburn House Office Building

1. Purpose

On Wednesday, March 6, at noon the House Committee on Science will hold a hearing on the investigation into the collapse of the World Trade Center (WTC). Witnesses from industry, academia, and government will testify on the catastrophic collapse of the WTC complex and subsequent efforts by federal agencies and independent researchers to understand how the building structures failed and why. By scrutinizing the steel and other debris, blueprints and other documents, and recorded images of the disaster, engineers, designers, and construction professionals may learn valuable lessons that could save thousands of lives in the event of future catastrophes, natural or otherwise.

The Committee plans to explore several overarching questions raised by the collapse and the ensuing investigation:

1. What have we learned about how the federal government investigates catastrophic building collapses, and are any changes warranted?

2. What have we learned about the collapse of the World

Trade Center, including which structural elements failed first, and why?

3. How will we know what changes, if any, are warranted in building and fire codes as a result of lessons learned from the World Trade Center's collapse?

4. Has the World Trade Center disaster exposed any gaps in our understanding of buildings and fire, and are changes needed in the federal government's research agenda?

2. Background

At 8:47 a.m. on the morning of September 11, 2001, terrorists crashed a fuel-laden Boeing 767 into the north tower (Tower 1) of the World Trade Center (WTC) complex. Approximately 16 minutes later, a second Boeing 767 slammed into the south tower (Tower 2), exploding upon impact and engulfing several of the building's upper floors in flames. While the performance of both towers exceeded their design specifications – the buildings were designed to withstand the force from the initial impact of a 707 jet – the subsequent structural and fire damage still caused the buildings to fall. Tower 2 collapsed in less than an hour, killing victims trapped above the flames and rescue workers in and around the building. Thirty minutes later, Tower 1 met the same fate. While more than 25,000 people were successfully evacuated from the towers, nearly 3,000 people and emergency responders were killed in the collapses. As the day progressed, the remaining WTC buildings collapsed as well, including Building 7, which burned for 8 hours before crumbling to the ground. Fortunately, the later building collapses produced no casualties.

In the wake of the collapses, search and rescue workers launched an around-the-clock recovery effort to find and recover survivors and victims who perished. To make way, literally tons of twisted steel and fractured concrete were removed from the rubble pile and loaded onto convoys of bulldozers and flatbed trucks to be carried away to recycling plants and landfills.

Researchers also began to respond immediately. Among the first were National Science Foundation (NSF)-funded social scientists and engineers who arrived at the WTC site within 48 to 72 hours after the tragedy to begin collecting data. Similarly, the American Society of Civil Engineers (ASCE) formed a Disaster Response Team within hours of the first plane strike. On September 12th, the Federal Emergency Management Agency (FEMA) and its contractor, Greenhorne and O'Mara, Inc., located in Greenbelt, Maryland, commenced the development of a Building Performance Assessment Team (BPAT; explained more fully on the next page) to conduct a formal analysis of the progressive collapses and produce a report of its findings. A variety of other engineering researchers and professionals, including members of the Structural Engineering Association of New York, also engaged in the monumental task of collecting data that could lead to a better understanding of the collapse of the buildings themselves and to the development of mitigation strategies to prevent a similar tragedy in the future.

Concerns Related to the Engineering Investigation

Though many of the individuals who have participated in the WTC building performance investigation are architects and engineers with experience investigating other structural collapses – including those resulting from natural causes as well as terrorist attacks – nothing had prepared these investigators for a disaster of this magnitude and complexity. Unlike the destruction caused by an earthquake, which may affect several buildings across an expansive area, this disaster involved many buildings and a massive debris pile in a small, confined area. Also unlike most earthquakes, the WTC disaster caused significant casualties and prompted a prolonged search and rescue effort. In addition, the concurrent criminal investigation by the Federal Bureau of Investigation and a separate investigation by the National Transportation Safety Board further frustrated the building performance investigators.

The investigation has been hampered by a number of issues, including:

- **No clear authority and the absence of an effective protocol for how the building performance investigators should conduct and coordinate their investigation with the concurrent search and rescue efforts, as well as any criminal investigation:** Early confusion over who was in charge of the site and the lack of authority of investigators to impound pieces of steel for examination before they were recycled led to the loss of important pieces of evidence that were destroyed early during the search and rescue effort. In addition, a delay in the deployment of FEMA's BPAT team may have compounded the lack of access to valuable data and artifacts.

- **Difficulty obtaining documents essential to the investigation, including blueprints, design drawings, and maintenance records:** The building owners, designers and insurers, prevented independent researchers from gaining access – and delayed the BPAT team in gaining access – to pertinent building documents largely because of liability concerns. The documents are necessary to validate physical and photographic evidence and to develop computer models that can explain why the buildings failed and how similar failures might be avoided in the future.

- **Uncertainty as a result of the confidential nature of the BPAT study:** The confidential nature of the BPAT study may prevent the timely discovery of potential gaps in the investigation, which may never be filled if important, but ephemeral evidence, such as memories or home videotapes, are lost. The confidentiality agreement that FEMA requires its BPAT members to sign has frustrated the efforts of independent researchers to understand the collapse, who are unsure if their work is complementary to, or duplicative of, that of the BPAT team. In addition, the agreement has prevented the sharing of research results and the ordinary scientific give-and-take that otherwise allows scientists and engineers to winnow ideas and strengthen results.

- **Uncertainty as to the strategy for completing the investigation and applying the lessons learned:** The BPAT team does not plan, nor does it have sufficient funding, to fully analyze the structural data it collected to determine the reasons for the collapse of the WTC buildings. (Its report is expected to rely largely on audio and video tapes of the event.) Nor does it plan to examine other important issues, such as building evacuation mechanisms. Instead, FEMA has asked the National Institute of Standards and Technology (NIST) to take over the investigation. Yet so far, NIST has not released a detailed plan describing how it will take over the investigation, what types of analyses it will conduct, how it will attempt to apply the lessons it learns to try to improve building and fire codes, and how much funding it will require.

Role of the Federal Emergency Management Agency

The Federal Emergency Management Agency is charged with supporting the nation's emergency management system. FEMA intervenes at all stages of disaster management including preparation, response, recovery, mitigation, risk reduction, and prevention. In the case of the World Trade Center attack, FEMA dispatched Urban Search and Rescue Teams and established a disaster field office at the site within hours of the first strike to assist in New York City's rescue effort. At the same time, the FEMA Building Performance Assessment Team (BPAT) began their important work of initiating an analysis that could ultimately yield valuable information about the sequence of events and failures that resulted in progressive building collapse.

BPATs are routinely deployed by FEMA following disasters caused by events such as floods and hurricanes. The teams are formed by, and operate under the direction of the Mitigation Directorate's Program Assessment and Outreach Division and comprise such individuals as regional FEMA staff, representatives from state and local governments, consultants who are experts in engineering, design, construction, and building codes, and other technical and support personnel. A contractor for FEMA, Greenhorne & O'Mara, Inc., maintains a roster of hundreds of mitigation specialists from across the United States. BPAT teams are typically deployed within seven days of any disaster event.

Generally, a BPAT conducts field inspections and technical evaluations of buildings to identify design practices, construction methods, and building materials that either failed or were successful in resisting the forces imposed by the event. A major objective of the BPAT's findings and recommendations are aimed at improving design, construction and enforcement of building codes to enhance performance in future disasters. The culmination of the BPAT's efforts is a report that presents the team's observations, conclusions, and recommendations for improving building performance in future natural disasters.

The BPAT team deployed to the WTC site was assembled by the American Society of Civil Engineers and is headed by W. Gene Corley, Ph.D., P.E, Senior Vice President of Construction Technologies Laboratory in Skokie, Illinois. He was also the principal investigator in the FEMA study of Oklahoma City's Murrah Federal Office Building. On September 11th, ASCE, in partnership with a number of other professional organizations, commenced the formation of an independent team of experts to conduct a building performance assessment study at the WTC site as part of ASCE's Disaster Response Procedure. In late September, this team, the ASCE Disaster Response team, was officially appointed as the BPAT team and was funded by FEMA to assess the performance of the buildings and report its findings. The BPAT team received $600,000 in FEMA funding in addition to approximately $500,000 in ASCE in-kind contributions.

The 23-member BPAT team conducted an analysis of the wreckage on-site, at Fresh Kills Landfill and at the recycling yard from October 7-12, 2001, during which the team extracted samples from the scrap materials and subjected them to laboratory analysis. Why the analysis was conducted only after a delay of three weeks after the attacks remains unclear. Since November, members of the Structural Engineers Association of New York (SEAoNY) have volunteered to work on the BPAT team's behalf and are visiting recycling yards and landfills two to three times a week to watch for pieces of scrap that may provide important clues with regard to the behavior of the buildings.

In the month that lapsed between the terrorist attacks and the deployment of the BPAT team, a significant amount of steel debris – including most of the steel from the upper floors – was removed from the rubble pile, cut into smaller sections, and either melted at the recycling plant or shipped out of the U.S. Some of the critical pieces of steel – including the suspension trusses from the top of the towers and the internal support columns – were gone before the first BPAT team member ever reached the site. Fortunately, an NSF-funded independent researcher, recognizing that valuable evidence was being destroyed, attempted to intervene with the City of New York to save the valuable artifacts, but the city was unwilling to suspend the recycling contract. Ultimately, the researcher appealed directly to the recycling plant, which agreed to provide the researcher, and ultimately the ASCE team and the SEAoNY volunteers, access to the remaining steel and a storage area where they could temporarily store important artifacts for additional analysis. Despite this agreement, however, many pieces of steel still managed to escape inspection.

The BPAT team is expected to release its report in April. Because FEMA requires the members of its BPAT team to sign a confidentiality agreement until the report is released, the exact scope of the report is unknown. But it appears from the role that BPAT teams normally play and general comments ASCE members of the BPAT team have made that the report is likely to include an examination of how the buildings behaved leading up to the collapse, hypotheses for which structural elements failed and thereby initiated the collapse, and recommendations for additional research and analysis.

For example, ASCE has said that the study will rely primarily on audio and video recordings, interviews with survivors, blueprints and design drawings of the World Trade Center, and evidence they or the SEAoNY volunteers have collected from the rubble. The BPAT team has access to more than 120 hours of high quality film footage and audiotapes of 911 communications with trapped victims. The BPAT team initially had difficulty in obtaining building blueprints and design drawings from either the City of New York, the Port Authority, the building owners, or the building designers due primarily to liability concerns on the part of the building owners and insurers. Belatedly, however, the team was provided access to these documents in early January.

ASCE has said that the BPAT study will not include an analysis of the evacuation or rescue procedures and may not be able to validate definitively any of a number of hypotheses regarding the collapse. But because of the confidentiality of the report, it is unclear whether the it will provide answers or simply lay out more questions. It is unknown, for example, to what degree the BPAT report will compare video evidence with that collected from the steel beams from the floors that were hit by the planes.

As a result, independent researchers are unsure how they can contribute to the understanding of how the buildings fell without unnecessarily duplicating work. Others fear that the BPAT's silence on the scope of its report may allow critical aspects of the picture to be missed, and that, by the time the report is released and any such gaps are discovered, the trail of evidence that could provide answers may have grown cold.

The National Science Foundation

Researchers supported by the National Science Foundation are used to mobilizing rapidly after an earthquake and arriving on scene soon after the event to begin collecting data. Recognizing the similarities between the WTC disaster and earthquakes, NSF program managers awarded nearly $300,000 to experienced earthquake researchers, including engineers and social scientists, to begin an analysis of the 9/11 terrorist attacks within 72 hours of the events. In an effort to quickly deploy researchers to the site, awards were made through the Small Grants for Exploratory Research Program, a supplemental award program that enables NSF program managers to award additional support to currently-funded investigators through an abbreviated internal review process (see Appendix A for a list of awards).

The efforts of NSF-funded researchers were impeded by the same obstacles the BPAT team encountered: an inability to examine the steel, either removed from the site during the early search and rescue work or shipped to recycling plants, and the denial of access to building design, construction and maintenance documents. Interestingly, it was an NSF-funded researcher who ultimately negotiated the arrangements by which he and others investigating the disaster were provided access to the remaining pieces of steel at the recycling plant.

To date, the NSF-funded researchers continue to face problems. They continue to be denied access to important building diagrams and blueprints, and so are unable to complete their analyses or develop the computer models necessary to better understand the failure of the buildings structural elements. Perhaps more importantly, without these computer models, engineering researchers will be unable to develop effective mitigation strategies.

The National Institute of Standards and Technology

NISTs Building and Fire Research Laboratory carries out research in fire science, fire safety engineering, and structural, mechanical, and environmental engineering. It is the only federal laboratory dedicated to research on building design and fire safety. In the past, the lab has investigated several structural failures using authority Congress made explicit in 1985. (15 U.S.C. 282a). The goals of its previous investigations were to determine the probable technical causes of the failures, examine what lessons could be learned from those determinations, and help develop improved building codes, standards, and practices. The investigations also identified areas of research that needed further study.

Shortly after the attack, NIST appointed an employee of the Building and Fire Research Laboratory to serve on the 23-member BPAT team. While this partnership lent some of NIST's resources and expertise to the BPAT study, NIST did not immediately launch a formal investigation into the technical causes that led to the collapse of the World Trade Center buildings.

NIST believes that the World Trade Center collapse raises difficult and technical questions regarding building codes and standards, justifying the redirection of funds to its building and fire lab. For example, standards for concrete design, building loads, and structural integrity may need revision. In response, NIST has redirected $2 million of its fiscal year 2002 internal discretionary funds to the lab to supplement its current building engineering and standards work. NIST has also requested permission to reprogram from the rest of its laboratories another $2 million in fiscal year 2002 funds for these efforts. The reprogramming request is currently pending before the Office of Management and Budget and will ultimately need approval from Congress. NIST did not need Congressional review to redirect its discretionary funds.

In January, after a delay of three months since the terrorists' attacks, FEMA asked NIST to take over the next phase of the investigation of the collapse. Yet neither NIST nor FEMA has released details as to what that next phase would entail (other than the general outline NIST has provided below). In addition, the Administration has not yet indicated whether FEMA, NIST, or a supplemental funding request to Congress would provide funds for such an investigation, nor has it identified how much it would cost.

Administration officials and outside parties are weighing whether a formal arrangement should be made for NIST to serve as FEMA's research arm in the event of future catastrophic building failures. Currently, there is no formal relationship between the two agencies regarding these matters.

Based on some initial planning, NIST has preliminarily identified the following general areas for investigation:

- Determine technically, why and how the buildings collapsed (WTC 1 and 2, and possibly WTC 7);

- Investigate the technical aspects of fire protection, response, and evacuation, and occupant behavior and response;

- Determine whether state-of-the-art procedures were used in the design, construction, operation, and maintenance of the WTC building;

- Determine whether there are new technologies and procedures emerging that could be employed in the future to reduce the potential risks of collapse; and

- Identify building and fire codes, standards, and practices that warrant revision.

3. Questions

Please see Appendix A for copies of letters to witnesses and the questions each was asked to address in testimony at the hearing.

4. Witnesses

The following witnesses will address the subcommittee:

Mr. Robert Shea, Acting Administrator Federal Insurance and Mitigation Administration, and, Mr. Craig Wingo, Director of Division of Engineering Science and Technology, Federal Emergency Management Administration

Dr. W. Gene Corley, P.E., S.E., American Society of Civil Engineers, Chair of the Building Performance Assessment Team reviewing the WTC disaster

Professor Glenn Corbett, Assistant Professor of Fire Science at John Jay College, New York City

Dr. Abolhassan Astaneh-Asl, Professor, Department of Civil and Environmental Engineering University of California, Berkeley

Dr. Arden Bemet, Director, National Institute of Standards and Technology

5. Additional Reading

Glanz, J. (2001, December 4). Wounded Buildings Offer Survival Lessons. The New York Times, p. F1

Glanz, J., & Lipton, E. (2001, December 25). A National Challenged: The Towers; Experts Urging Broader Inquiry in Towers' Fall. The New York Times, p. A1

Glanz, J., & Lipton, E. (2002, January 17). New Agency to Investigate the Collapse of Towers. The New York Times, p. B3

Glanz, J., & Lipton, E. (2002, February 2). At Scrapyards, as Search for Clues in the Towers' Collapse. The New York Times, p. B1

Sherwood L. Boehlert
Chairman

2320 Rayburn House
Office Building
Washington, DC 20515

House Committee on Science

Hearings

Search Science Committee Pages

Search Clear

Select number of results displayed per page

10

Congress Online Bronze Mouse Award Winner 2003

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Learning from 9/11:
Understanding the Collapse of the World Trade Center

Wednesday, March 6, 2002

Noon - 2:00 PM
2318 Rayburn House Office Building

Witness List

Mr. Robert Shea
Acting Administrator
Federal Insurance and Mitigation Administration

Mr. Craig Wingo
Director
Division of Engineering Science and Technology
Federal Emergency Management Administration

Dr. Abolhassan Astaneh-Asl
Professor
Department of Civil and Environmental Engineering
University of California, Berkeley

Dr. W. Gene Corley
American Society of Civil Engineers
Chair of Building Performance Assessment Team reviewing the WTC disaster

Dr. Arden Bemet
Director
National Institute of Standards and Technology

Professor Glen Corbett
Assistant Professor of Fire Science
John Jay College, New York City

CONGRESSMAN SHERWOOD BOEHLERT (R-NY) OPENING STATEMENT FOR WORLD TRADE CENTER HEARING March 6, 2002

I want to welcome everyone to this hearing on a most important, but difficult subject – the investigation into the collapse of the World Trade Center.

It is indeed a difficult subject because it is, at once, emotionally rending and intellectually complex. And it's also difficult because it forces us to cast a critical eye on the dedicated work of public servants and public-spirited volunteers who were taking action amid chaos brought on by an unforeseen and unprecedented tragedy.

But despite these difficulties and the discomfort they may engender, we felt we needed to put together this hearing. The Committee decided to move forward for two fundamental reasons. First, we believe that we owe it to the victims and their families to learn everything possible about what happened in those horrifying first hours of September 11th – not just to satisfy their immediate needs and yearnings, but to ensure that such a catastrophic building failure, and the resulting loss of life, never happen again.

I must say that the current investigation – some would argue that “review” is the more appropriate word -- seems to be shrouded in excessive secrecy. This has unnecessarily increased the families’ anxiety while actually complicating matters. I hope this hearing, by airing the facts of the investigation, will dispel unnecessary concerns while allowing legitimate ones to be pursued more productively.

But perhaps even more important for the Committee, we need to have this hearing because the Trade Center collapse raises questions about federal responsibilities and federal policies – responsibilities and policies that have broader application than this one terrifying – and, we pray, unique -- incident.

The federal government, as a matter of course, takes on investigations of catastrophic building failures, whatever their cause. That’s the only way we, as a nation, can learn from building failures and change our building and fire codes to prevent future ones. Indeed, the engineering of buildings to withstand earthquake damage has improved markedly as a result of federally supported efforts.

Yet in this case, the investigation has faced numerous obstacles. Federal agencies did not coordinate sufficiently, some were slow to react; no organized team was at the site for weeks; potentially valuable evidence has been lost irretrievably, and blueprints were unavailable for months. What this experience clearly points up is that the federal government needs to put in place standard investigative protocols and procedures right now, so we don't have to "reinvent the wheel" each time we face a building failure. That's one change in federal policy that ought to result from the World Trade Center experience.

Another significant lesson of the Trade Center collapse is that we need to understand a lot more about the behavior of skyscrapers and about fire, if we are going to prevent future tragedies. All of our witnesses today will call for an expanded federal research effort into the details of what happened at the World Trade Center and what that means for buildings generally. I wholeheartedly endorse that call. My colleagues and I will have many questions today about the nature, scope and financing of that follow-up effort, but I, for one, think we need to move forward with it.

We'll also do some of our own following up. I expect that the Committee will have a hearing on the report of the current Trade Center report when it is released in April, and we'll obviously continue to oversee the related activities of the agencies in our jurisdiction, and we'll pursue any federal issues that merit further review.

So, all of us here, I believe, understand that we are undertaking a heavy responsibility today by reviewing the response to the World Trade Center collapse. September 11th is still a fresh wound. But this hearing is not so much about the past, as it is about ensuring that we protect lives in the future. We are not here to point fingers, but to ensure that any problems that occurred in the wake of the Trade Center collapse do not hamper future investigations. We are here because the only way to move forward is to try to understand what happened on a day that was so incomprehensible.

Statement of

Mr. Robert F. Shea
Acting Administrator
Federal Insurance and Mitigation Administration
Federal Emergency Management Agency

Before the

Committee on Science
House of Representatives
United States Congress

March 6, 2002

Mr. Chairman, members of the Committee, I appreciate the opportunity to appear before you today to discuss FEMA's response to the World Trade Center attacks. My name is

Robert Shea, Acting Administrator for the Federal Insurance and Mitigation Administration, and I am here representing Joe Allbaugh, the Director of the Federal Emergency Management Agency.

On September 11, 2001, the United States of America was suddenly and savagely attacked by terrorists precipitating the worst disaster in the history of our nation. The tragic loss of life in the collapse of the World Trade Center towers and the destruction at the Pentagon exposed many vulnerabilities to our population and infrastructure within our borders which could be exploited by terrorists and others seeking to harm our country.

Within hours of the terrorist attacks, President Bush had mobilized the Federal government and declared disasters, making Federal support and assistance immediately available to the City and State of New York as well as to the Commonwealth of Virginia. As you know, FEMA helps the nation prepare for, respond to, and reduce the impact of, man-made, natural, and technological hazards including catastrophic events, such as the Alfred P. Murrah Building bombing, the Northridge Earthquake and preparing for Y2K and the Winter Olympics. September 11th was a “wake up” call for our nation and the entire world. In the war on terrorism, FEMA has a clear mission: to make certain that the United States of America becomes “A Nation Prepared”.

FEMA’s role as an emergency responder was tested but we were able to draw upon decades of experience in hundreds of disasters and the solid relationships that we have forged with States and local governments and other Federal agencies. That experience and those relationships were vital during the first days and weeks following September 11th and enabled FEMA to provide the critical support requested by the City and State of New York to local emergency responders and law enforcement officials. This support included the critical urban search and rescue, debris removal, technical assistance and other emergency measures. The U.S. Fire Administration, an integral part of FEMA, has been providing training to firefighters and emergency responders in initial disaster response and incident command and control -- skills that were fully evident at ground zero.

Under the Robert T. Stafford Disaster Relief and Emergency Assistance Act, as amended, FEMA has the lead coordination role for Federal disaster response, which is managed through the Federal Response Plan (FRP), involving the 27 Federal agencies, local agencies, and other groups. This national plan, perfected during the last decade, made it possible to effectively support local law enforcement and supplement the response activities undertaken by the City and State of New York. As for the World Trade Center disaster, the City and State of New York drew upon as many assets as they could, both governmental and private, to rescue and protect their citizens. FEMA has acted in its traditional support role, mindful of the extensive capabilities and the sovereignty of the City and State of New York.

The Federal Response Plan establishes a process and structure for the systematic, coordinated, and effective delivery of supplemental assistance to address the consequences of any major disaster or emergency declared by the President. Within hours of the September 11th attacks, the FEMA Emergency Support Team center was up and running and, implementing the 12 Emergency Support Functions (ESF's) described in the FRP, already coordinating and organizing the Urban Search and Rescue teams, and setting up the Disaster Field Office on-site in New York City.

The most vital Emergency Support Function in response to this tragedy was Urban Search and Rescue (US&R). Because the mortality rate among trapped victims rises dramatically after 72 hours, search and rescue must be initiated without delay. US&R rapidly deploys components of the National US&R Response System to provide specialized lifesaving assistance to State and local authorities in the event of a major disaster or emergency. US&R operational activities include locating, extricating, and providing on-site medical treatment to victims trapped in collapsed structures, and engineering evaluation of structures for safety and building integrity.

A key member of the US&R team is the structural engineer, who must make constant judgments about the structural stability of debris and damaged buildings as the team rescues trapped individuals. As the US&R teams searched through the mountains of twisted steel and concrete, these engineers made safety judgments related to the creation of access points. With engineering expertise coming to New York City from across the country and present within city agencies of New York, the initial response activities were able to pull from an extraordinary pool of local engineering support. During the initial response, engineering support included:

1. Ensuring equipment, such as cranes, was safely located on stable bases to support rescue efforts;
2. Quick and continuing evaluation of the safety of surrounding buildings, infrastructure and the site;
3. Monitoring changes at the site through surveying; and
4. Remote sensing using satellites, and supporting rescue workers on the site by continually reporting this information at shift briefings, site inspections and visits, and through sophisticated Geographical Information Systems producing up-to-date information and maps.

FEMA's United States Fire Administration also responded to directly assist the New York City Fire Department to re-establish its Incident Command structure, had been tragically lost when the towers collapsed. The forward deployed team assisted in coordinating daily mission planning and logistics for the first three weeks until FDNY was ready to fully resume that role. USFA is also working with the fire department on a training needs analysis to help restore FDNY to its full capacity as it takes on over 400 new firefighters. This, in addition to the US&R, demonstrates FEMA's linkage to the first responders in a catastrophic event.

FEMA's singular goal in the immediate aftermath of the attack was to support local jurisdictions in the rescue of trapped firefighters and workers. As soon as practicable, and without impeding the rescue effort, FEMA began coordinating with State and local governments and private organizations on the next important steps: the short-term and long-term recovery.

FEMA has an established role in recovery: to provide grants to State and local agencies and individuals, as well as coordinating the efforts from other Federal agencies with State, local and charitable organizations in order to help communities and individuals rebuild their lives. Another critical component is the technical assistance that FEMA can bring to bear to not only facilitate a quick recovery but to influence the recovery by giving special consideration to particular aspects of a building or the infrastructure. Although meeting the human needs is paramount, investigating and understanding this enormous and complex disaster can provide benefits for the City of New York's recovery as well as the entire nation.

FEMA has long been an advocate of conducting engineering studies to learn lessons from disasters, whether man-made or natural. In response to hurricanes, floods, earthquakes, and other disasters, including man-made disasters, FEMA often deploys Building Performance Assessment Teams (BPATs) to conduct field investigations at disaster sites. The BPAT is typically employed to determine failure mechanisms of buildings in the aftermath of a disaster so strategies can be developed to increase the disaster-resistance of structures. However, since this event was larger and more complex than any we have ever experienced, the objective of this BPAT is to probe the numerous issues related to structural collapse and fire so that we may make preliminary conclusions and recommendations for more intensive investigation and research.

Immediately following the September 11th attacks, FEMA reached out to the engineering and fire communities to coordinate any post-event studies or evaluations of building performance, incident command, communications or other similar efforts. Within 24 hours, FEMA was in contact with the American Society of Civil Engineers, which was already assembling a team of national experts, drawing talent from a variety of engineering, research and scientific groups that had volunteered to help. This team approach, which is frequently utilized for disasters, has been highly effective for ensuring a multidisciplinary approach with equal voices and inputs from the various sectors. For our World Trade Center evaluation, FEMA and ASCE immediately collaborated on the development of the team analogous to our approach during our study of building performance after the Northridge earthquake. The team of experts was assembled based on what appeared to be the likely failure mechanisms for the World Trade Center towers, namely, fire and structural collapse. There are over twenty national and international experts on this team with knowledge in: building and fire testing; computer modeling of structures and fire; design of tall buildings; steel construction; concrete construction; fire safety; fire protection; and codes and standards. As you know, the National Institute of Standards and Technology (NIST) has a long-established history of investigating building collapses and fires and a mission of research and testing that results in standards and guidance that makes the United States safer and its industries more competitive. FEMA asked NIST to join the BPAT during its formation in September because of NIST's technical expertise and to ensure a smooth transition between FEMA's short-term study and any long-term investigation and research conducted by NIST.

Because of the importance of the rescue effort at the World Trade Center complex, it was clear that information would have to be gathered without interfering with response and rescue activities. Based on this fact, the FEMA-ASCE team first visited the site on October 6, but gathered information from others who had been on-site before this date. This information included plans, photographs, videotapes, eyewitness accounts from rescue workers and reports from the New York City Department of Design and Construction. In addition

, the Structural Engineers Association of New York, in support of the City and as a formal member of the BPAT, located and identified specimens of steel for use in future studies. FEMA is coordinating with NIST to make sure that these specimens are properly stored and available for future testing. Also, it is important to note that there are, literally, thousands of plans, specifications and other documents for the World Trade Center. Although it took some weeks to obtain the plans, the owners were fully cooperative with our requests.

Focusing on the areas of fire protection and structural performance, the BPAT team has been gathering evidence and studying designs so that when the report is published, its conclusions and recommendations will help guide future investigative and research efforts connected primarily to understanding the performance of buildings when subjected to extreme conditions.

This study represents an important first step in suggesting how the technical resources of the nation can be brought to bear on protection of lives and property. Because of the importance of this initial report, FEMA and ASCE have compressed in half a schedule that normally takes over a year to complete, which will result in the issuance of a report in early spring. The report will not only make preliminary observations and conclusions about the structural and fire related performance of the World Trade Center towers, but will have six additional chapters that discuss damages and lessons learned from surrounding buildings such as World Trade Center 7, as well as numerous technical appendices.

The National Institute of Standards and Technology (NIST) has the authority and technical expertise to conduct investigative studies of the causes of the collapse and other related matters. The USFA and the Federal Insurance and Mitigation Administration of FEMA will work closely with NIST as it undertakes this ambitious agenda.

U

SFA will also be looking at the lessons that can be learned from this incident by the nation's first responders. USFA has a long history of doing reports on major incidents and their impacts on the fire service, with a special emphasis on incident command, fire protection systems, evacuation planning and response, communications, and overall fire fighting and rescue response.

Finally, FEMA is currently working with NIST to develop a Memorandum of Understanding (MOU), which will help to guide our future collaborations on similar types of studies. For these types of extreme events, whether natural or man-made, the MOU will serve as a road map to establish protocols for future collaboration of our two agencies under our respective authorities.

I would now be pleased to answer any questions that the Committee may have.

Statement of

Professor Glenn P. Corbett
John Jay College of Criminal Justice

Before the

Committee on Science
House of Representatives
United States Congress

"Learning From 9/11: Understanding the Collapse of the World Trade Center"

March 6, 2002

Good afternoon Chairman Boehlert and Members of the House Committee on Science. I want to thank you for inviting me to speak on the topic of the World Trade Center disaster investigation. This is an issue of national importance, and I speak for many who understand that importance.

I would like to discuss three issues with you today: an analysis of the current building performance assessment study of the World Trade Center collapse, a proposal for a national disaster investigation response protocol for future disasters, and a recommendation for a *Commission on the World Trade Center Disaster.*

In the wake of the loss of the World Trade Center, many questions began to arise as to the cause of the collapse of the twin towers. We know, of course, that the towers collapsed catastrophically in a very short time. We know that there is no precedent for this event. And we in the fire protection engineering community know that building failures result directly from very specific causal factors and structural behavioral characteristics that, in the case of the WTC, have yet to be determined.

What role did the planes play in destroying the structural integrity of the towers? What was the impact of the jet fuel fires upon the steel trusses and columns? How long did the jet fuel fires burn? What were the specific causal factors of collapse and what was the exact sequence of events that led to the collapse?

These are important questions that impact national security. We are a nation at risk. There are many high-rise structures in the United States—and more on the way—that demand that we learn from the disaster on 9-11 and apply the lessons learned.

As engineers, as architects, as builders, as firefighters, as citizens who occupy high-rises, and as those who are in a position to protect those citizens, there are critical questions regarding this collapse that need answering. We must extract the lessons for future generations who will live and work in high-rise structures.

The building performance assessment currently being conducted of the World Trade Center collapse is just that: an assessment, not an investigation. While the Building Performance Assessment Team (BPAT) is composed of an elite group of engineers and scientists, the standard procedures used by the BPAT have proven to be inadequate. Handling the collapse study as an assessment has allowed valuable evidence—the steel building components—to be destroyed. The steel holds the primary key to understanding the chronology of events and causal factors resulting in the collapse.

Without an *investigative* presence, the FEMA-sanctioned assessment team did not have the authority—nor the organizational wherewithal—to ensure that *all* of the structural steel was thoroughly examined and the crucial steel from the points of impact saved for examination. Only a handful of pieces of steel from the points of impact have been secured to date. In addition, the BPAT studying the collapse has apparently been hampered in accessing building construction documents.

These hindrances will have an impact on the BPAT report, due to be released in April. The lack of significant amounts of steel for examination will make it difficult, if not impossible, to make a definitive statement as to the *specific* cause and chronology of the collapse.

The collapse of the World Trade Center towers were the largest structural collapses in world history. A disaster of such epic proportions demands that we fully resource a comprehensive, detailed investigation. Instead, we are staffing the BPAT with part-time engineers and scientists on a shoestring budget.

The current World Trade Center disaster inquiry has exposed a gaping hole in the way that we investigate disasters. We don't have a *comprehensive* plan for disaster investigations (other than plane crashes) and we don't apply the necessary resources for complete and thorough investigations of disasters.

We must have a comprehensive plan in place to handle such large-scale investigations. We need to have a greatly enhanced national disaster investigation response protocol, providing for a systematic approach. We must bring in the 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.

I recommend that a task force be impaneled to develop such a protocol. In my opinion, FEMA would be the best organization to organize the task force, given their role in disaster response and their critical disaster mitigation responsibilities. ***[Witness would like to submit, for the record, a document entitled Appendix A "PROPOSAL FOR AN ENHANCED DISASTER INVESTIGATION PROTOCOL"]***

The collapses of the World Trade Center structures are not the only areas of concern. There are five other very important areas of study concerning the World Trade Center disaster need to be explored. In addition to the collapse study, we should be analyzing the building designs themselves, the firefighting procedures, the building evacuations, the search and rescue operations, and the impact on building and fire codes.

These six primary focus areas would form the basis of a complete World Trade Center study. Since these focus areas are multi-disciplinary, it is critical that the experts in each of these areas be permitted to come together under one roof, so to

speak. This will ensure coordination, avoid duplication, verify that all areas of concern are covered, and ensure that the essential process of information sharing
takes place.

The World Trade Center disaster must be analyzed as a total event, using an integrated, scientifically rigorous approach. Studying the issues individually minimizes the effect on the whole. There are interrelationships among these areas that must be combined and the lessons applied for future generations.

I recommend that a *World Trade Center Disaster Commission* be immediately organized to initiate a comprehensive investigation and to coordinate the existing public and private World Trade Center research projects currently underway. For example, an ad hoc committee entitled the *World Trade Center Evacuation Study Initiative* (composed of life safety experts from many different organizations) has been meeting for several months to study the issues of the World Trade Center building evacuations. It is important that this group and other World Trade Center research projects come together to allow for a coordinated approach to studying this disaster.

The *Commission* should be given the appropriate authority and staff to ensure that a viable investigation plan is created and implemented, with the ultimate goal of producing a comprehensive report that details the findings of the investigation, the "lessons learned," and, finally, the "needs for further research."

Some of the lessons that will emerge in the *Commission* report will apply directly to our building codes and the way that we build new structures. Of particular importance are the regulations covering fire protection of high-rise buildings.
[Witness would like to submit, for the record, a document entitled Appendix B "PROPOSAL FOR A WORLD TRADE CENTER DISASTER COMMISSION]

Our current high-rise code requirements do not address the real world issues encountered when fighting fires in high-rise buildings. For example, our model building codes treat a 15-story building exactly the same as a 100-story building in terms of fire protection—we apply the same level of structural fire resistance, the same fire protection systems, the same everything. We place heavy reliance on automatic sprinkler systems, with little redundancy in terms of structural fire resistance to ensure that the building will stay up long enough to allow for firefighters to reach the fire area, rescue trapped inhabitants, and generally deal with the situation. Automatic sprinklers are *the* best protection against fire, but we need to have a backup when we are 1,000 feet high in a building on fire. We need a proper balance of passive and active protection in larger high-rise structures.

An example of the crucial need for research is found when we analyze the current test used to establish the fire resistance various structural members used in buildings. This test, commonly known as A.S.T.M. E-119, was developed to provide assurance that the fire protection coating/encasement provided for beams and columns would allow them to be subjected to high temperatures and not collapse. This test, however, dates back to the 1920's and is based upon the temperatures recorded when a set of buildings were burned back then for study purposes. Today, we basically still use the same test with the same "fire" temperature and exposure conditions developed over 75 years ago. I would argue that the fires of the 1920's are different than those of today, and that this nationally accepted test needs to be thoroughly reexamined in light of what happened on 9-11.

We can learn many lessons from the disaster at the World Trade Center. In fact, we *must* learn these lessons. The lessons may take the form of better building code regulations, enhanced building design methodologies, improved emergency procedures, and enhanced protection against terrorist attacks. We must assure that these lessons are actually applied, thus improving the level of safety and security for American citizens.

I thank you, Congressman Boehlert and honorable members of the Science Committee, for giving me the opportunity to share my thoughts with you. I would be happy to answer any questions that you may have.

Appendix A

PROPOSAL FOR AN ENHANCED DISASTER INVESTIGATION PROTOCOL

Prepared by Professor Glenn P. Corbett

John Jay College of Criminal Justice

Need for an Enhanced Protocol:

When a major disaster strikes in the United States, very important questions typically arise: What happened? Why were so many lives lost? How can we prevent this from happening in the future?

These questions need answers. If we are to protect ourselves and future generations, we must learn the lessons of the disaster and apply them

For past disasters like the Oklahoma City bombing and the Northridge earthquake, a variety of research projects were undertaken. While these research projects produced very useful information, they were conducted independently, without the benefit of a central coordinating body to integrate all of the information. In addition, it has become apparent that some of the very critical lessons never found their way into general design practice – there is a disconnect between the private sector code-writing organizations and the lessons coming out of the research projects .

Since disasters are multi-disciplinary, they require an integrated and comprehensive approach. The disaster must be investigated as a whole, following standard investigative procedures. A single standardized model can be developed for all disasters, with a specific set of "adaptable" procedures for each type of disaster.

Development of an Enhanced Disaster Investigation Protocol

Since FEMA has responsibilities for disaster response and disaster mitigation, it is suggested that the development of an enhanced disaster investigation protocol be initiated within FEMA. Other Federal agencies and private sector organizations with disaster responsibilities/interest would obviously need to participate in the development of the protocol. The National Transportation Safety Board's investigation procedures provide a very useful model for which to begin the development of an enhanced disaster investigation protocol.

"Organizational" Details of a Enhanced Disaster Investigation Protocol

Organizationally, an enhanced disaster investigation protocol:

- Utilizes an *investigative* "lessons learned" approach to analyzing disasters.
- Provides a detailed investigation "command structure" to establish which agency is in charge and the limits of its investigative authority.
- Details the responsibilities of each participating organization.
- Establishes the specific types of disasters that will be investigated and the necessary resources needed for each type of disaster.

"Functional" Details of an Enhanced Disaster Investigation Protocol

Functionally, an enhanced disaster investigation protocol:

- Incorporates a "rapid response" capability, allowing for the immediate deployment of a initial set of investigators to plan the investigation, secure evidence, and to begin the documentation process.

- Ensures the deployment of self-sufficient, disaster-specific "specialist teams" to the scene to conduct the detailed investigation work (similar to USAR organization).

- Ensure that periodic press releases are issued to inform the public of the investigation and its progress.

“Coordination” Details of an Enhanced Disaster Investigation Protocol

In order to assure coordination, an enhanced disaster investigation protocol:

- Ensures that liaisons are appointed to the local incident commander’s command post, search and rescue teams (e.g. USAR), and criminal investigation organizations (e.g. FBI) to ensure coordination with their efforts.
- Ensures that the appropriate “specialist teams” are deployed and are working together efficiently.
- Ensures that additional “outside” research efforts are integrated into the investigation.
- Ensures that a regimented set of meetings with specialist team leaders and staff are held to review progress and to keep investigation on course.

“Final Report” Details of an Enhanced Disaster Investigation Protocol

In order to produce a comprehensive report, an enhanced disaster investigation protocol:

- Ensures that the specialist team leaders are assembled to provide oral presentations to other team leaders/staff and to provide written draft reports for inclusion in Final Report.
- Ensures that the staff support collates the team reports and configures them into a standardized, “single author” report format.
- Ensures that long-term research needs are identified and documented for inclusion in the Final Report.

“Applied Lessons” Details of an Enhanced Disaster Investigation Protocol

To ensure the application of the “lessons learned,” an enhanced investigation protocol:

- Appoints code-writing organization representatives to investigative “specialist teams.”
- Establishes a “formal agreement” with the private sector code-writing bodies that ensures every recommendation for a change in the codes will be formally reviewed by the code-writing body. Final disposition of “disaster” code change proposals (including rationale if code change is rejected) will be formally documented and issued back to the affected disaster investigation organizations.

Appendix B

PROPOSAL FOR A WORLD TRADE CENTER DISASTER COMMISSION

Prepared by Professor Glenn P. Corbett

John Jay College of Criminal Justice

Need for the Commission:

In the wake of the World Trade Center disaster, it has become readily apparent that many issues involving high-rise building construction, emergency evacuation procedures, firefighting operations, and other important concerns must be analyzed collectively in order to learn from the disaster and apply the lessons to the future. Many Americans live and work in high-rise buildings, so it is essential that we learn as much as possible about this disaster.

The establishment of a Commission will allow for the various public and private research efforts currently underway to come together “under one roof” and share information, a critical issue when studying a disaster as complex as the collapse of the World Trade Center towers. The multi-disciplinary aspects of the World Trade Center necessitate that the disaster be investigated in that context, allowing for the identification of interrelationships between the areas of concern.

Commission Objectives:

- The Commission will direct an investigation and coordinate a comprehensive review of all aspects of the World Trade Center disaster. The Commission will take a "lessons learned" type of approach in its review and analysis of the disaster.

- The Commission will utilize the expertise of nationally recognized individuals in the fields of architecture, engineering, forensic investigation, construction methods and materials, fire protection and life safety, human behavior, firefighting, search and rescue, terrorism, building/fire code development and emergency management.

- The Commission will prepare a set of detailed recommendations for the improvement of building designs, building materials, safety regulations and building codes, as well as emergency response procedures.

- The Commission could form the model for a portion of an enhanced disaster investigation protocol.

Establishment of the Commission:

Given the role of FEMA in disaster response and hazard mitigation, it is logical to have the Commission operate under the auspices of FEMA. FEMA would play the role of coordinator and provide staff and facility support (including the development of a final report).

The Commission should have a "core" of eight primary members, including a Chairman, a Vice Chairman, and designated leaders from each of the six focus areas identified below. All eight of the Commissioners would meet on a regular basis to share information, identify needs, and to direct the overall activities of the Commission.

Six Primary "Focus Areas" of Commission:

- *Building Design*
- *Building Collapse*
- *Firefighting Procedures*
- *Building Evacuation*
- *Search and Rescue Operations*
- *Building Codes and Regulations*

Examples of "Focus Area" Inquiries:

Building Design

- Identify general design concepts ("lightweight" construction, loads, etc.).
- List fire protection features in original design and improvements.
- Describe fire protection and life safety upgrades after 1993 attack.
- Establish means of egress design objectives.

Building Collapse

- *Create chronology of events leading to collapse.*
- Examination of physical evidence to identify failure mode(s) leading to collapse.
- Examination of physical evidence to assess material behavior.
- Model fire behavior (temperature, heat release rate, etc.), including contribution of jet fuel.
- Create fire and structural models to illustrate building conditions for duration of incident.

Firefighting Procedures

- Interview surviving firefighters, review radio transmissions, and analyze reports to create as complete a "picture" of firefighting response as possible.
- "Map" and analyze incident command structure.
- Establish the overall goals of incident command officers, including use of "standard" high-rise firefighting strategies.
- Enumerate tactical problems encountered by fire companies.
- Detail radio transmission problems at incident.

Building Evacuation

- Analyze building evacuation procedures, including directions given to occupants by building staff.
- Interview evacuees to collect their observations and experiences during evacuation.
- Model the evacuation including time of egress, points of constriction, crossovers delays, etc.
- Highlight the effects of improvements made after 1993 attack.

Search and Rescue Operations

- Detail coordinated effort between FDNY and USAR teams.
- Establish impact of "self-responders" on rescue operations.
- Analyze performance of "tools and technologies" used in search efforts (robots, "listening devices," cutting equipment, etc.).
- Detail efforts of maintaining "scene safety."

Building Codes and Regulations

- Establish national standards/codes in effect at time of construction.
- Identify the deficiencies of ASTM E-119 (a national test standard that establishes structural fire resistance of various fire resistive materials) when compared with the fire conditions experienced during the incident.
- Review the high-rise requirements found in current national building codes in context of this incident.
- Correlate accepted terrorism design strategies with this incident and develop design criteria for inclusion in building codes.

The Final Report of the Commission:

Upon completion of the investigation and research efforts, a final report should be issued. The report will tell the story of the disaster, highlight the lessons learned, identify additional research needs, and provide a set of specific recommendations. General examples of recommendations could include the following:

- Identification of building/fire code provisions that need to be added/updated/deleted.
- Procedural changes for fire service response to high-rise and terrorist incidents
- Changes in evacuation procedures and egress capacity criteria

Testimony of Dr. W. Gene Corley

Senior Vice President
CTL Engineering
Chicago, IL

On behalf of the

American Society of Civil Engineers

Before the
Subcommittee on Environment, Technology and Standards
&
Subcommittee on Research

Committee on Science
U.S. House of Representatives

March 6, 2002

The tragic events of September 11 have served as a grim reminder that there is no limit to the destructive forces than man can use to damage or destroy our nation's infrastructure. The civil engineering profession, as stewards for our nation's infrastructure, feels obligated to make certain the critical public works our communities and nation depend on are protected. Through the American Society of Civil Engineers (ASCE), the profession has taken a leading role in addressing infrastructure vulnerability and is developing both short- and long-term strategies to mitigate the impact of future disasters on our critical civil infrastructure.

Founded in 1852, ASCE represents more than 125,000 civil engineers worldwide and is the country's oldest national engineering society. ASCE members represent the profession most responsible for the nation's built environment. Our members work in consulting, contracting, industry, government and academia. In addition to developing guideline documents, state-of-the-art reports, and a multitude of different journals, ASCE, an American National Standards Institute (ANSI) approved standards developer, establishes standards of practice such as the document known as ASCE 7 which provides minimum design loads for buildings and other structures. ASCE 7 is used internationally and is referenced in all of our nation's major model building codes.

In response to the events of September 11th, ASCE is implementing a multifaceted response plan, significant elements of which are outlined here. Following this abbreviated outline of our initiative is a more detailed discussion of ASCE's efforts related to the World Trade Center.

ASCE's Critical Infrastructure Response Initiative

On October 9, 2001, the ASCE Board of Direction voted to expend money from reserves on a Critical Infrastructure Response Initiative (CIRI). The objective of CIRI is to establish strategies and guidelines for:

1. Assessing U.S. infrastructure vulnerability.
2. Using the results of vulnerability assessments to prioritize infrastructure renovation.
3. Identifying research and development needs for new approaches to protecting critical infrastructure.
4. Developing retrofit designs to mitigate damage from disasters.
5. Developing new approaches to design and construction.
6. Improving disaster preparedness and response.

To accomplish the CIRI objectives, ASCE has undertaken the following activities:

1. Review and evaluate existing and pending legislation regarding infrastructure, and provide appropriate input.

2. Identify existing and pending infrastructure initiatives by other professional and technical associations to identify opportunities for partnering, and to avoid duplication of efforts. For example, EPA has several water supply initiatives underway with AMWA. These initiatives, however, are currently focused on operations and management, and ways will be sought to provide input regarding design and construction issues.
3. Identify existing and pending infrastructure initiatives by federal agencies to identify opportunities for partnering.
4. Create a liaison or partnership with the Office of Homeland Security regarding the assessment of infrastructure vulnerability and the design and construction of mitigation measures.

In each of these areas, ASCE stands ready to assist other organizations, both public and private, to reduce the vulnerability of our nation's infrastructure.

ASCE's Efforts Related to the World Trade Center

Building Performance Study Teams

On the afternoon of September 11, 2001, the Structural Engineering Institute of ASCE (SEI/ASCE) began assembling two teams of experts to study the performance of the buildings at the World Trade Center Complex and the Pentagon. The goal of the studies is to increase our knowledge and understanding of how buildings subject to extreme forces, such as those caused by the crash and resulting fires, perform under these unusual circumstances.

The scope of the WTC study team is quite broad. Although much of the nation's attention has been riveted to the collapse of the twin 110-story towers, the WTC team is also examining several of the buildings in the surrounding area to determine what lessons might be learned from the performance of those structures as a result of their being impacted by falling debris and ensuing fires. Of particular interest to the engineering community is the performance of WTC 7 and the Banker's Trust Building.

Studies of this type have been performed by ASCE following other disasters under the authority of ASCE's Disaster Response Procedure, which provides the internal mechanism to organize and fund these studies. This was the fifth time in 2001 that the procedure was used to create study teams. Earlier teams, whose members were experts in earthquakes and lifeline engineering, were dispatched to study and document the damage from the earthquakes in El Salvador, India, Seattle, and Peru. In 1995, ASCE, in partnership with FEMA, organized a team to examine the Murrah Federal Office Building in Oklahoma City and surrounding area after the bombing.

<u>Team Members and Partnering Organizations</u>

The teams assembled by SEI/ASCE are comprised of leading experts in the fields of structural analysis and design, fire engineering, blast effects, and building materials. On October 1st, the WTC study became a joint effort between ASCE and the Federal Emergency Management Agency (FEMA), a partnership, which continues to this day.

The partnership with FEMA has proven to be extremely beneficial to the overall success and progress of the WTCteam. In addition to providing funds, FEMA has provided logistical assistance, organizational and operational guidance, assistance in obtaining and organizing the needed data, and will provide the resources to publish the report. Utilizing the FEMA standard operation procedure for post-disaster engineering studies, managed through a contract with the architecture and engineering firm, Greenhorne & O'Mara, Inc., FEMA helped organize and coordinate the on-site operation of the BPS Team as they performed their initial data-collection efforts in New York City.

The WTC team is headed by W. Gene Corley, Ph.D., P.E., a preeminent expert on building collapse investigations and building codes. A full list of team members and an indication of their areas of expertise is attached. Dr. Corley, whose biography is attached, was the team leader and principal author of the ASCE/FEMA Murrah Federal Office Building Study Report in 1995.

The Pentagon team is headed by Paul Mlakar, Ph.D., P.E., of the U.S. Army Corp of Engineers Waterways Experiment Station in Vicksburg, Mississippi. Dr. Mlakar is a preeminent expert in blast engineering and was also a member of the ASCE/FEMA team, which examined the Murrah Federal Office Building.

In addition to assembling the teams of experts, SEI/ASCE has also organized a coalition of professional organizations to participate and support the work. These partnering organizations include: the Society of Fire Protection Engineers (SFPE), which provided recommendations of team members; the National Fire Protection Association (NFPA), which provided counsel on the fire engineering aspects of the study; and the Structural Engineers Association of New York (SEAoNY), which provided on-going assistance in the examination of the debris. It should be noted that SEAoNY, on its own initiative, was instrumental in providing assistance to the rescue and recovery operations immediately after the attacks. Additional members of the coalition are the American Institute of Steel Construction, Inc. (AISC), the American Concrete Institute (ACI), the Council of American Structural Engineers (CASE), the Council on Tall Buildings and Urban Habitat (CTBUH), the International Code Council (ICC), the Masonry Society (TMS) and the National Council of Structural Engineering Associations (NCSEA).

To increase our knowledge and understanding of the performance of the structures, the study is focusing on the response of the buildings, including fire behavior, structural design, fireproofing characteristics, and damage resulting from the aircraft impacts. As a result of this study, the structural and fire protection engineers comprising the team hope to provide an accurate description of the events and a preliminary assessment of the behavior of the affected buildings.

Data Collection

Simultaneous with the efforts to assemble the team and organize the supporting coalition, work began to collect data and information pertinent to the study. A significant part of this data collection phase was holding a meeting of the team in New York City to examine the wreckage and the surrounding buildings impacted by the collapse. On September 29th, the City of New York granted the team access to the World Trade Center site and from October 7th to the 12th, the entire team was on site. The team was provided with unrestricted access to all areas of the site except for areas where their presence might have impeded the on-going rescue and recovery efforts and areas which were determined to be extremely hazardous. To aid the team in this intense 6-day effort, FEMA made its Regional Operation Center (less that 8 blocks form the WTC site) available for use by the team on a 24-7 basis.

During this time period, team members also examined structural debris at the Fresh Kills Landfill on Staten Island and at the two recycling yards in New Jersey. Samples of structural steel were obtained and have since been subjected to laboratory analyses. Under the guidance of selected team members, numerous professional engineers who are members of SEAoNY are continuing this work on the team's behalf and have been visiting recycling yards and landfills regularly since the beginning of November. Additional samples of the structural steel have been obtained and are presently being stored at the National Institute of Standards and Technology in Gaithersburg, Maryland for use in future studies.

Unlike other structural collapses, there is an unprecedented volume of photographic and video evidence available for the team to review, including more than 120 hours of network and private video footage. Individual team members have viewed every foot of this videotape and provided information on the available data to the team at large.

Beyond the information and data pertaining to the events on September 11th, there is also a need to establish, as accurately as possible, the physical attributes of the towers and surrounding buildings prior to the impact of the airplanes. Doing this is a monumental task. The construction of the towers was documented by literally thousands of engineering drawings. In addition, there were numerous changes to the towers over their life. This effort is also being conducted for WTC 7, which is of considerable interest to the team. These data, together with the data previously described will be used to construct detailed computer models of the structures.

Impediments Encountered by the Building Performance Study Teams

In the 10 years in which ASCE has been conducting studies of disasters we have learned that our teams will always encounter impediments. It is therefore not surprising that the study team has encountered some difficulties in their data collection activities. However, we have also learned that with time and persistence these difficulties are either overcome or an alternate approach is found to enable the team to satisfactorily complete their study as described below.

When studying damaged structures it is important to understand the physical nature of the original structure as soon as possible. Commonly this is accomplished by obtaining and studying the engineering plans of the structures. Because the team did not have the engineering plans of the affected structures during the site visit in early October, arrangements were made to have several of the principal designers make presentations to the team. These briefings enabled the team to conduct their site visit more efficiently and to better understand the structure of the affected buildings. The delay in the receipt of the plans hindered the team's ability to confirm their understanding of the buildings. Through the efforts of

FEMA and others, the team received the engineering plans for the WTC Towers on January 8, 2002, and work is proceeding.

As noted previously, there is an enormous volume of video and photographic documentation of the events of September 11th. This type of evidence can often yield significant insights into the failure mechanisms but it is imperative that the highest quality video footage be used. The team did experience some difficulty in obtaining video footage from the various television networks.

Obtaining access to the site of a disaster is always difficult and clearly the search and rescue efforts and any criminal investigation must take first priority. However, in all studies of this nature, gaining access to the site as soon as possible is important in order to observe and document the debris and site conditions. For the future, it may be useful to consider some protocol or process whereby selected individuals from the BPST would be allowed on site in the initial days after a catastrophic event to gather critical data.

There has been some concern expressed by others that the work of the team has been hampered because debris was removed from the site and has subsequently been processed for recycling. This is not the case. The team has had full access to the scrap yards and to the site and has been able to obtain numerous samples. At this point there is no indication that having access to each piece of steel from the World Trade Center would make a significant difference to understanding the performance of the structures.

Resources are always an issue with building performance studies, particularly for one whose magnitude and scale is unprecedented. The total amount of resources being dedicated to support the team's activities is approximately $1 million, which has allowed the team to do the initial reconnaissance of the site and the building materials, begin the process of hypothesis setting, and conduct some limited testing. This raises the question of what amount of money would be sufficient. It is our opinion that $40 million would be a sufficient amount to fully fund a comprehensive study of an event of this magnitude and complexity.

A Protocol for Future Building Performance Study Teams

The Building Performance Assessment Team program in place within the Federal Emergency Management Agency (FEMA) has a long and distinguished history of providing excellent information to the engineering profession. The BPAT program has a detailed protocol in place which has been continually refined and improved upon throughout its use.

Similarly, ASCE's Disaster Response Procedure has been successfully used by ASCE to conduct important studies of significant disasters. ASCE's procedure also has been refined and improved upon through its history.

The history of both of these programs however has been predominantly with natural disasters such as hurricanes, earthquakes or floods. While it is certainly our sincere hope that the anti-terrorist efforts of our government will prove successful, it may be useful to review the existing protocols from the perspective of their application to major, unprecedented events such as the terrorist attack on the World Trade Center. This could address some of the impediments that were discussed above.

A Case Study for Improved Building Practices?

As many in the United States and the world examine the future of tall buildings it is important to look at how well these buildings performed under extreme circumstances. It must be remembered that large commercial aircraft hit the World Trade Center Towers, yet both withstood the initial impact. Additionally, as has been widely reported, almost all of the individuals in the buildings below the impact zone were able to get out of the buildings to safety. Efforts such as that being conducted by the Building Performance Study teams and studies emanating from this initial study will seek to extend the performance of structures to allow occupants ample time to reach safety.

Because there is no limit to the destructive forces which terrorists can bring to bear against our built infrastructure it is impossible to design a building to withstand such an attack. The multi-faceted approach presently being pursued, that being to prevent the attack initially and pursue rational, scientifically based methods to improve structural performance, is both sound and prudent.

Future Research Needs for Civil Engineering

As has occurred throughout the world, the events of September 11th have created new challenges for the civil and structural engineering communities. Solving the problems presented by these challenges will be neither easy nor quick, and will require the collective efforts from a broad range of engineering and scientific disciplines.

While there will be a number of specific issues and recommendations in the reports being issued by the ASCE/FEMA WTC study team and the ASCE Pentagon study team later this spring, there are several high priority needs from the structural engineering community to which I would like to draw your attention:

> **Progressive Collapse:** The likelihood of a building or structure collapsing progressively is dependent upon two inter-related through separate behaviors: the event or load to which the structure is subjected and the strength or redundancy of the structure. At present, there is no rational technical basis to specify the initiating event or conversely to evaluate the

effectiveness of alternative mitigation strategies, either alone or in combination. While virtually all structures contain some degree of redundancy, we must now live, build and function in a world where the performance demands placed on our built infrastructure have been altered, thereby necessitating the development of engineering-based tools to guide our profession in the future.

Fire-Structure Interaction: While events such as those of September 11th are rare, and through the efforts of the President and Congress will be even less likely in the future, normal fires in buildings and other structures are not rare events. To continue to improve the performance of structures in a fire environment will require the development of new tools and design methods through the collaboration of the fire engineering and structural engineering communities for application to both new and existing buildings. This work should include tools by which to address fire as a structural design load, understanding the behavior of structural connections under fire conditions, and a coupling between fire dynamics and structural response.

We believe that each of these needs are crucial to advancing the health, safety, and welfare of the citizens of our nation. Each of these priorities are also highly complex and will require a substantial partnership between public agencies and private organizations to accomplish this work.

In the private sector, ASCE has begun this work through the establishment of a multi-disciplinary coalition of engineering organizations. This coalition, led by the Structural Engineering Institute of ASCE, includes the Society of Fire Protection Engineers, the National Fire Protection Association, the Structural Engineers Association of New York, and the International Code Council. Taken in combination, this coalition represents over 250,000 architects, engineers and scientists who stand ready to bring their talents and expertise to meeting the needs of our nation.

In the public sector, the National Institute of Standards and Technology's (NIST) Building and Fire Research Laboratory (BFRL), as the only federal laboratory dedicated to both building and fire research, BFRL can play a key role in assessing and addressing the vulnerability of the nation's buildings and physical infrastructure. The public-private response program that has been established with significant NIST leadership encompasses the critical needs identified above. We urge you to provide the support and resources sought by NIST so that together we can continue to provide the reliability and performance which our country expects from our physical infrastructure.

Conclusion

Thank you for the opportunity to express ASCE's views. We offer you and all of the agencies involved in the recovery efforts ASCE's full resources to manage the nation's critical infrastructure needs. We are ready to help in any way possible, and I am eager to hear from you regarding ways that ASCE's CIRI can support you as you examine our infrastructure needs in the coming months.

ASCE/FEMA World Trade Center Building Performance Assessment Study Team Members

W. Gene Corley, Ph.D., P.E., S.E. (Team Lead)
Senior Vice President
Construction Technologies Labor
Skokie, Illinois
Expert in building collapse investigations; principal investigator, Murrah Federal Office Building Study

William Baker, P.E., S.E.
Partner, Skidmore Owings & Merrill LLP
Chicago, Illinois
Expert in tall-building design

Jonathan Barnett, Ph.D.
Professor, Center for Fire Safety Studies
Worcester Polytechnic Institute
Worcester, Massachusetts
Expert in building fire safety design and fire computer modeling

David T. Biggs, P.E.
Ryan-Biggs Associates
Troy, New York
Expert in facades

Bill Coulbourne, P.E., S.E.

Principal, URS Corporation
Gaithersburg, Maryland
Expert in BPAT Studies

Edward M. DePaola, P.E.
Partner, Severud Associates
Consulting Engineers
New York, New York
Expert in structural engineering

Robert F. Duval
Senior Fire Investigator
National Fire Protection Association
Expert in fire investigations

John W. Fisher, P.E.
The Joseph T. Stuart Professor of Civil & Environmental Engineering
Lehigh University
Bethlehem, Pennsylvania
Expert in metallurgy and connections

Richard G. Gewain
Senior Engineer, Hughes Associates, Inc.
Baltimore, Maryland
Expert in fire engineering

Ramon Gilsanz, P.E., S.E.
Parner, Gilsanz Murray Steficek, LLP
New York City
Expert in structural engineering

John L. Gross, Ph.D., P.E.
Leader, Structural Systems and Design Group
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, Maryland
Expert in steel design and fire-structure interaction

Ronald Hamburger, P.E., S.E.
Senior Vice President,
EQE Structural
Engineers Division
ABS Consulting
Belmont, California
Expert in structural analysis and design

Nestor Iwankiw
Vice President, Engineering and Research
American Institute for Steel Construction
Chicago, Illinois
Expert in steel design

Venkatesh Kodur, Ph.D., P.E.
Institute for Research in Construction
National Research Council of Canada
Ottawa, Ontario
Expert in fire resistance design and fire effects on materials

Eric Letvin
Department Head, Hazards Engineering Group
Greenhorne & O'Mara
Greenbelt, Maryland
Project Manager

Jon Magnusson, P.E.
Chairman of the Board, Chief Executive Officer
Skilling Ward Magnusson Barkshire, Inc.
Seattle, Washington
Expert in structural analysis and high-rise design

Christopher E. Marrion, P.E.
Fire Strategist, Arup Fire
New York, New York
Expert in fire engineering

Therese P. McAllister, Ph.D., P.E.
Senior Structural Engineer
Greenhorne & O'Mara
Greenbelt, Maryland
Team Coordinator

James Milke, Ph.D., P.E.
Associate Professor & Associate Chair, Department of Fire Protection Engineering
University of Maryland
College Park, Maryland
Expert in fire resistance analysis

Harold E. "Bud" Nelson
Consultant
Annandale, Virginia
Expert in fire engineering

James A. Rossberg, P.E.
Director, Structural Engineering Institute
ASCE
Reston, Virginia
ASCE Staff Lead

Saw-Teen See, P.E.
Managing Partner
Leslie E. Robertson Associates
New York, New York
Expert in structural analysis and high-rise design

Robert Smilowitz, Ph.D., P.E.
Principal, Weidlinger Associates
New York City
Expert in blast effects

Bruce Swiren
Hurricane Program Manager, Region II
Federal Emergency Management Agency
New York, New York
FEMA Region II Contact

Paul Tertell, P.E.
Program Manager, Building Performance Assessment Team
Federal Emergency Management Agency
Washington, D.C.
FEMA BPAT Project Officer

W. Gene Corley

Senior Vice President
gcorley @ c-t-l.com

Educational Background •

University of Illinois

B.S. Civil Engineering, 1958
M.S. Structural Engineering, 1960
Ph.D. Structural Engineering, 1961

Registration •

Licensed Structural Engineer - Illinois
Licensed Professional Engineer - Illinois

Registered Civil Engineer - California, Hawaii
Registered Professional Engineer - Alabama,
Florida, Kansas, Louisiana, Michigan, Mississippi, Missouri, Pennsylvania,
South Dakota, Tennessee, Texas, Utah, Virginia, Washington
Chartered Engineer, FI Struct E, UK

CTL Experience • Dr. Corley has served as CTL Vice President since 1987. In this position, he serves as CTL's managing agent for professional and structural engineering and leads structural evaluation projects related to industrial, transportation and parking facilities, bridges and buildings. He also is active in projects related to earthquake engineering. His wide range of experience includes evaluation of earthquake and blast damaged buildings and bridges; investigation of distress in prestressed concrete structures; repair of parking garages damaged by corrosion; evaluation and repair of high rise buildings, stadiums, silos and bridges; design and construction of repairs for prestressed and conventionally-reinforced, precast and cast-in-place concrete and structural steel facilities. In 1995, Dr. Corley was selected by ASCE to lead a Building Performance Assessment Team investigating the bombing of the Murrah Federal Building in Oklahoma City.

Prior Experience • After receiving his B.S. degree, Dr. Corley worked for the Shelby County, Illinois highway department where he designed highways and bridges. He then returned to the University of Illinois as a research assistant and National Science Foundation teaching fellow while pursuing his graduate studies.

Upon completion of his Ph.D., he served as a commissioned officer in the U.S. Army from 1961 until 1964. During this period, Dr. Corley was a research and development coordinator with the U.S. Army Corps of Engineers at Fort Belvoir, Virginia. His duties included bridge design, acceptance testing of mobile floating assault bridge equipment, design of tank launched bridges and fatigue testing of bridges fabricated from high strength steel, aircraft aluminum and titanium alloys.

In 1964, Dr. Corley began work as a development engineer with the Portland Cement Association. While serving in successively more responsible positions, he was directly involved in the development of improved design procedures for structural concrete, concrete pavement, railroads and structures subjected to fire loads. In addition, he served on an earthquake damage investigation team, carried out investigations of damaged or deteriorated structures and developed repair procedures for numerous buildings and bridges.

Publications and Professional Activities •
W. Gene Corley has authored more than 150 technical papers and books. He frequently lectures to technical and non-technical groups on the subjects of prevention of failures, effects of earthquakes and design and repair of structures. He regularly presents training courses on reinforced concrete design and teaches the seismic design portion of a refresher course to candidates for the Illinois Structural Engineering License examination.

Dr. Corley chaired ACI Committee 318 for six years as the committee developed the 1995 Building Code Requirements for Structural Concrete. He also serves on several other national and international committees that prepare recommendations for structural design and for design of earthquake resistant buildings and bridges. His professional activities resulted in his receiving 11 national awards including the Best Structural Publication Award from NCSEA, Outstanding Paper from the ASCE Journal of Performance of Constructed Facilities, the Wason Award for research from ACI, the T.Y. Lin

Award from ASCE and the Martin Korn Award for PCI. He also has received several regional awards, including the UIUC Civil Engineering Alumni Association's Distinguished Alumnus Award, the SEAOI Service Award, Illinois ASCE Structural Division's Lifetime Achievement Award, the Henry Crown Award, and the SEAOI John Parmer Award.

Dr. Corley serves or has served in leadership roles for numerous professional organizations, both national and international, including the following:

American Society of Civil Engineers (Fellow)

National Society of Professional Engineers (Member)

National Council of Structural Engineers Associations (Founding Member, Board of Direction, Former President)

American Concrete Institute (Fellow) Former Chairman, Committee on Standard Building Code

American Railway Engineering Association (Member)

Building Seismic Safety Council (Former Vice-Chairman and Founding Member, Board of Direction)

Chicago Committee on High Rise Buildings (Member and Former Chairman)

Earthquake Engineering Research Institute (Member and Former President, Great Lakes Chapter)

Institution of Structural Engineers, UK (Fellow)

International Association for Bridge and Structural Engineering (Member)

National Academy of Engineering (Member)

National Association of Railroad Safety Consultants and Investigators (Member)

NACE International (Member)

Prestressed Concrete Institute (Member)

RILEM (Member)

Post Tensioning Institute (Member)

Transportation Research Board (Member)

Structural Engineers Association of Illinois (Member, Former President)

Governor’s Earthquake Preparedness Task Force (Illinois)

Testimony of

Dr. Abolhassan Astaneh-Asl
Professor
Department of Civil and Environmental Engineering
University of California, Berkeley

Before the Committee on Science of the U.S. House of Representatives

March 6, 2002 Hearing on

"Learning from 9/11: Understanding the Collapse of the World Trade Center"

It is a great honor for me to testify here today and address specific questions listed in your letter (in *Italic below)* regarding my involvement in the post disaster investigation of the World Trade Center.

- *What role did you play in the investigating the collapse of the WTC buildings and what do you expect to produce from your effort? How did you arrange NSF funding for your work, and how was that arranged so quickly?*

My involvement in the investigation of the collapse of the World Trade Center is to conduct a reconnaissance of the collapsed and damaged WTC buildings and to collect the perishable data. The main objectives of the reconnaissance are to learn as much as possible from the actual collapsed structures and to document the failure modes and performance of the members and connections as well as quality of the construction. The purpose of collecting the perishable data is to collect material samples, photographs, videotapes, drawings and data on design, construction and collapse. Using the information collected and by conducting the necessary analyses and research, we try to establish probable causes of the collapse and most likely scenario for such collapse.

Our project was funded by the Directorate of Engineering of the National Science

Foundation as one of the eight Quick Response Research Awards in the aftermath of the WTC collapse. These projects focus on structural engineering (our project at UC-Berkeley), fire engineering, social aspects and response and recovery. More information on these projects can be found at www.nsf.gov. We prepared and submitted our proposal to the National Science Foundation three days after the 9/11 events and it was reviewed and funded by the end of the week. The credit for such a fast preparation, submittal, review and funding of these research projects should be given equally to the staff at the universities involved as well as the Program Directors and staff of the National Science Foundation. The use of "Fastlane" electronic submittal process of the NSF also expedited the process tremendously.

So far, I have made three trips to NYC and spent a total of about 25 days there conducting field investigation and collecting data. Upon arrival to NYC on September 19, and after visiting Ground Zero and paying my respects and prayers to the victims, I started my reconnaissance and collection of the perishable data. I have collected some data on design and construction of the WTC and have met and discussed the case with the structural engineers who have designed the WTC Buildings. Thanks to cooperation of the HSNE recycling plant, I have been able to study the steel from the WTC before recycling. I have identified and saved some components of the structures that appear to have been subjected to intense fire or impact of fast moving objects. Figures 1 through 4 show examples of inspected structures. These critical pieces are saved as perishable data and can be used in future research.

- *Please describe the impediments that you encountered during the investigation of the collapse of the WTC buildings, such as the loss of material from the WTC site and any effects of such impediments on your work.*

I wish I had more time to inspect steel structure and save more pieces before the steel was recycled. However, given the fact that other teams such as NIST, SEAONY and FEMA-BPAT have also done inspection and have collected the perishable data, it seems to me that collectively we may have been able to collect sufficient data. The main impediments to my work were and still are:

1. Not having a copy of the engineering drawings and design and construction documents.
2. Not having copies of the photographs and videotapes that various agencies might have taken during and immediately after the collapse.

Such data has already been made available to ASCE Building Performance Assessment Team. If those are also available to us, we will be able to proceed further with our research. Figure 5 shows an example of analysis of performance of generic steel high-rise structure subjected to the impact of a 747 jetliner and the ensuing fire. The example demonstrates the power of advanced technology developed in aerospace and mechanical engineering that can be brought to bear on this problem. We plan to use the drawings and the data and the software used in the example to build a computer based realistic model of the World Trade Center towers and analyze their response to simulated impact of the 767 planes that crashed into them on 9/11 and the ensuing fire.

- *should the Federal Emergency Management Agency (FEMA) and/or Congress develops a more comprehensive protocol for how to conduct investigations in response to natural disasters and/or terrorist attacks?*

The earthquake engineering community has conducted post disaster investigations very successfully and systematically within the Earthquake Engineering Research Institute and funded by NSF and FEMA for several decades. As a result of such post-disaster investigations, the lessons learned and the continued research and technology developments, great advances have been made in mitigating earthquake hazard. The approach taken in earthquake engineering can equally be applied to investigation of damage due to terrorist attacks as well as to minimizing consequences of such attacks. Due to criminal nature of terrorist attacks and higher priority placed on criminal investigation over engineering investigation, it appears that there is a need for a protocol to govern the availability of information and access to the site as well as interaction of the crime investigators and researchers investigating the scientific and engineering aspects of the terrorist attacks.

- *what areas of research into the WTC collapse still need to be addressed, and what is the most appropriate way to handle these needs?*

There are short term and long-term research needs into the WTC collapse. In short term, there is a need for a comprehensive, in-depth and research-oriented study of the WTC buildings from the time of plane impact, through the ensuing fire and the final collapse. Such studies not only should focus on structural and fire engineering aspects, but also social and human aspects of the tragedy as well. A broad based team of researchers and engineers from academia, government agencies and private sector, with expertise in various aspects of the problem need to be assembled to conduct such studies. In my opinion, such studies need to be directed by federal entities such as National Science Foundation (NSF) and/or National Institute of Standards and Technology (NIST) that are involved in directing and conducting scientific and engineering research. In December, the National Science Foundation sponsored a workshops organized by the Institute for Civil Infrastructure Systems of the New York University to identify research needs for future research related to WTC. A list of workshop recommendations can be found at www.nsf.gov. I participated at the workshop and feel that funding research in those areas will result in learning many valuable lessons from this tragedy and will result in significant improvements in the structural design, construction, fire protection, evacuation, fire fighting, rescue and recovery efforts, debris removal and many other aspects of protection of buildings and occupants against terrorist attacks.

In the long term, there is a need for major and sustained funding to conduct basic and applied research on various aspects of terrorist attacks. Such research activities can result in development of scientific methods and technologies to assure life safety, prevent catastrophic collapses and massive loss of lives and minimize the impact of such attacks on the national economy and security. Last months, NIST held a workshop to identify research needs related to evaluation of performance and protection of buildings during intense fires. I also participated at this workshop and feel that the research areas identified at the workshop are very important in providing engineers and architects with the technologies to protect tall buildings, their occupants and firefighter and rescuers against catastrophic fires and resulting collapse.

In the aftermath of 9/11 tragedy and the hazard posed by terrorist attacks to public safety and the economical well being of the U.S. is not much different than the hazard posed by other "extreme events' such as major earthquakes three or four decades ago. In the case of seismic hazard mitigation, Congress, by providing sufficient funding to the National Science Foundation and other agencies involved, has enabled research and engineering community to develop efficient and economical technologies to mitigate seismic hazard and to prevent catastrophic loss of lives. To prevent catastrophic consequences of terrorist attacks, we need to develop and fund a long-term plan of research, perhaps modeled after seismic research programs developed and supported over the years by NSF and FEMA, and in the field of protection of built environment against terrorist attacks.

- *has the confidential nature of the FEMA's Building Performance Assessment Team investigation made it more difficult to gain access to materials that might be useful, such as private videotapes?*

I have not been provided with the information made available to the FEMA Building Performance Assessment Team. This includes, videotapes and photographs taken on 9/11and the following days and copies of the engineering drawings. At this time, having the videotapes, photographs and copies of the drawings not only is useful, but also is *essential* in enabling us to conduct any analysis of the collapse and to formulate conclusions from our effort.

I have been the Principal Investigator in conducting research on damage and collapse of several major buildings and bridges in the aftermath of earthquakes. I understand and respect the concerns of owners, designers, builders and those who are responsible for safe operation of these structures for possible legal ramifications of findings of our research investigations. However, the main objective of our research is to understand how the WTC buildings failed and learn lessons that can be used to prevent such collapses in the future. Never before my research results have been used in any legal proceedings. However, to allay any concerns that any findings of our research project might increase the liabilities of the City, Port Authority or Silverstein, the data on these structures could be provided to the Principal Investigator (myself) on a propriety basis. The Principal Investigator would keep the data and provide the other members of the research team with the information on a need-to-know basis. I have followed similar procedures to the satisfaction of parties involved in conducting research on major buildings and bridges subjected to earthquakes and blasts due to terrorist attacks.

I would like to take this opportunity and thank Chairman Boehlert and members of the Committee on Science for inviting me to testify. I would like now to welcome any questions that you may have.

Abolhassan Astaneh-Asl, Ph.D., P.E.
Professor
Department of Civil and Environmental Engineering
781 Davis Hall, University of California, Berkeley, CA 94720-1710
e-mail: astaneh@ce.berkeley.edu, Phone: 510/642-4528

EDUCATION: M.S.E. (1979) and Ph.D. (1982) from the University of Michigan, Ann Arbor

CURRENT POSITION: Professor, University of California at Berkeley.

PROFESSIONAL MEMBERSHIP: American Society of Civil Engineers (ASCE), Council on Tall Buildings and Urban Habitat (CTBUH), Earthquake Engineering Research Institute (EERI), Structural Stability Research Council (SSRC), Research Council on Structural Connections (RCSC), Consortium of Universities for Research in Earthquake Engineering (CUREE), Advisory Committee AC4 and Technical Committee TC8 of Eurocode Europe, Structural Engineers Association of Northern California, (SEAONC), Structural Steel Educational Council, (SSEC), Committee on Design of Blast-Resistant Steel Structures (AISC)

PROFESSIONAL REGISTRATION: Registered Professional Engineer, P.E. (California)

MAJOR AWARD: Winner of 1998 ,T.R. Higgins Award, American Institute of Steel Construction

TEACHING: Has taught courses since 1982 on Engineering Mechanics, Static, Design of Steel Structures, Advanced Steel Design, Design of Steel and Composite Structures, Inelastic Behavior and Plastic Design of Steel Structures, Comprehensive Design of Structures. He has also taught a number of short courses to professionals on design of structures and earthquake engineering particularly on bridges to Caltrans engineers and others.

MAJOR RESEARCH & DEVELOPMENT PROJECTS DURING LAST 5 YEARS:

1. "Tests of Critical members of the Golden Gate Bridge", (Funded by Golden gate Bridge), 95-96
2. "Shake-table Tests of Computers with and without Support Restrainers", 96-97.
3. "Cyclic Behavior and Seismic Design of Steel Piles", (Funded by Caltrans), 96-98.
4. "Nonlinear Analyses of the Suspension Spans of the Bay Bridge", (Funded by LLNL & UCB, 95-98.
5. "Seismic Behavior and Design of Shear Connections", (Funded by FEMA/SAC), 97-98.
6. "Cyclic Tests and Seismic Design Provisions for Steel Shear Walls", (Funded by GSA),99-01.
7. "Cyclic Tests of Traditional and Innovative Composite Shear Walls", (Funded by NSF) 98-present.
8. "Testing and Studying Blast-Resistant Structures", (Funded by GSA and AISC) 97-present.
9. "Studies of Collapse of the World Trade Center",(Funded by NSF) ,01-present

PUBLICATIONS

Has published more than 150 papers, reports and other publications on the behavior and design of steel structures subjected to seismic, gravity and blast loads.

Statement of

Dr. Arden L. Bement, Jr.

Director
National Institute of Standards and Technology
United States Department of Commerce

Before the

Committee on Science
House of Representatives
United States Congress

"Learning from 9/11: Understanding the Collapse of the World Trade Center"

March 6, 2002

Good afternoon Chairman Boehlert, Ranking Member Hall, and Members of the Committee. I want to thank you for this opportunity to testify on the investigation into the collapse of the World Trade Center Towers. The tragedy that the United States experienced on September 11, 2001, was unprecedented when compared with any prior accident, natural disaster, or terrorist/war attack. The collapse of the twin World Trade Center towers was the worst building disaster in human history. Engineers, emergency responders, and the nation did not anticipate, and were largely unprepared for, such a catastrophe. Among other national needs, these events highlight the following technical priorities:

- To establish the probable technical causes of the collapses and derive the lessons to be learned;
- To develop and disseminate immediate guidance and tools to assess and reduce future vulnerabilities; and
- To produce the technical basis upon which cost-effective changes to national practices and standards can be developed.

Shortly after the attacks on the World Trade Center, NIST's building and fire researchers began assisting federal and local agencies in many ways to investigate the spread of fire through the buildings and their subsequent collapse. Our researchers used previously developed models along with preliminary information from videos of the attack and other sources to simulate the spread of fire and smoke in the buildings. At the request of the Federal Emergency Management Agency (FEMA), NIST conducted a comparison and analysis of the current building and fire codes of New York City with national codes, and we contributed to the Army Corps of Engineers' study of the structural and fire damage to the Pentagon. In addition, NIST experts participated in the initial assessment of the collapse conducted by the American Society of Civil Engineers (ASCE) Coalition that comprised a Building Performance Assessment Team (BPAT) funded by FEMA. The ASCE Coalition Team also included professional members of the Society of Fire Protection Engineers (SFPE), the National Fire Protection Association (NFPA), the American Institute of Steel Construction (AISC), and the Structural Engineers Association of New York (SEAoNY).

NIST is lending its expertise in structural disasters to ASCE and the Structural

Engineers Association of New York (SEAoNY) to store WTC steel at its Gaithersburg, MD, headquarters for further scientific study.

However, more needs to be done. A growing number of technical experts, industry leaders, and families of victims are pressing for a broad-based Federal investigation to study the building construction, the integrity of the materials used, and all the technical conditions that combined to cause the building disaster at the World Trade Center ***[Witness would like to submit for the record, letters received supporting a federal investigation]***. NIST has begun working informally with a coalition of organizations – representing key industry, standards, codes, and professional groups – in an effort to launch a comprehensive public-private response program that includes such an investigation. NIST is also working very closely with FEMA, since an in-depth technical investigation would go well beyond the scope of the building performance assessments conducted by FEMA following major disasters. The implementation of the results of such an investigation would be critical to restore public confidence in the safety of tall buildings nationwide, enhance the safety of fire and emergency responders, and better protect people and property in the future. To cite one example, the February 4th issue of "Crain's New York Business" reports that an increasing number of tenants are leaving the Empire State Building, which is again the tallest building in New York City, because of fears of another terrorist attack. Anecdotal evidence also suggests that building vacancy rates have doubled in Manhattan, despite the 15 million square feet of space that was lost on September 11th.

NIST has received policy approval from the Secretary of Commerce to initiate and, after consultation with local officials, to conduct an independent and comprehensive "National Building and Fire Safety Investigation of the World Trade Center Disaster" under NIST's existing legislative authorities (15 U.S.C. 281a).

Among Federal laboratories, NIST is uniquely qualified to conduct such a comprehensive investigation. The Building and Fire Research Laboratory is the foremost fire research laboratory in the United States, and through the National Earthquake Hazards Reduction Program (NEHRP) NIST is the principal agency for research and development to improve building codes and standards. NIST has extensive experience and expertise in conducting disaster investigations following structural/construction failures, fires, earthquakes, hurricanes, and tornadoes. These have included the well-known investigations into the 1981 collapse of a walkway in the Kansas City Hyatt Regency Hotel, the 1986 Dupont Plaza Hotel fire in San Juan Puerto Rico, the 1994 Northridge earthquake collapses, and the 1995 Kobe, Japan earthquake building collapses, to name just a few. In compliance with statutory requirements NIST has already consulted with local authorities in New York, including the Port Authority of NY & NJ, the Mayor's Office of Emergency Management, the New York City Department of Design and Construction, and the Fire Department of New York. These organizations have expressed support for NIST and agreed to cooperate in it's investigation.

The proposed investigation would involve world-class experts from industry, academia, and other laboratories to complement NIST's excellent in-house technical expertise. Supplementing the outstanding work done through the building performance assessment team initially assembled through FEMA, NIST would delve deeper into the factors related to the collapse. NIST would use the results of the soon to be released ASCE Coalition team's study as a valuable source of input into the investigation. The objectives of the NIST investigation would be to determine technically:

- Why and how the World Trade Center buildings collapsed following the impacts of the planes;
- Why the injuries were so high or low depending on location, including all technical aspects of fire protection, response, evacuation, and occupant behavior and emergency response;
- Whether or not state-of-the-art procedures and practices were used in the design, construction, operation, and maintenance of the World Trade Center Buildings; and
- Whether there are new technologies or procedures that should be employed in the future to reduce the potential risks of such a collapse.

The NIST investigation would focus primarily on World Trade Center Buildings 1 and 2 (the Twin Towers) for several reasons. First, the collapse of the Towers was the triggering event that caused much of the collateral damage to the adjacent properties. Second, many structural and fire protection design features and construction details found in the Towers are widely used in the building construction industry. Third, to study procedures and practices used to assess the safety of innovative structural systems and building designs not covered by existing building codes or prior in-use experience as was the case of the twin towers, and whether such practices are adequate to detect and remedy inherent vulnerabilities. Fourth, to study procedures and practices used to provide adequate structural reserve capacity to resist abnormal loads (e.g. blast, explosion, impact due to aircraft or flying debris from tornadoes, accidental fires, and faulty design and construction), especially those that can be anticipated prior to construction (e.g. impact of a Boeing 707). Fifth, the Twin Towers would provide the opportunity to study the effectiveness of fire protection and firefighting technologies and practices for tall buildings, including emergency mobility and egress, and communication systems. And lastly, the analytical tools used in these investigations would be experimentally verified and widely applicable to other building types. Besides the Towers, the investigation would possibly consider examining WTC Building 7, which collapsed later in the day.

NIST would use an open and inclusive process in formulating its work plan for the investigation. This would involve the participation of technical experts from industry, academia, and other laboratories as well as liaison with federal, state, and local authorities. NIST would expect to complete its investigation and issue a final report in 24 months.

The results of the proposed investigation would be extremely valuable in establishing the probable technical causes of the disaster and deriving the lessons to be learned, but it would be meaningless unless we take the knowledge gained and put it to practical use. That is 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. The events of September 11th have brought even more focus and priority to this already important issue.

The goal of this broader program would be to produce cost-effective retrofit and design measures and operational guidance for building owners and emergency responders. 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.

Over the course of the proposed investigation and broader program there would be a number of short-term and interim work products that would provide guidance, tools, and technical assistance to better prepare facility owners, contractors, designers, and emergency personnel for future disasters. Some of these products, based on prior NIST work, would be disseminated broadly as soon as possible. Others that need further refinement would be disseminated within a year, and the rest after the completion of the investigation. I would like to note that the President's FY 2003 budget request for NIST contains a $2 million funding increase, which will go towards this effort and related research.

Let me now give you three examples of work that would be accomplished through this broader program.

First, fire played a critical and visible role in the collapse of the WTC buildings and contributed to damage to the Pentagon buildings. Current building design practice does not consider fire as a design condition. Instead, structural fire endurance ratings are prescribed in building codes using standard tests on individual components. The current testing standards are based on work carried out at NIST in the 1920s. They do not represent real fire hazards in modern buildings. They also do not 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. The proposed work would expand on this core competence in computational methods, and adapt measurement techniques and test methods to support the prediction of performance of building materials, products, structural elements, and systems up to the point of the collapse of a tall building due to fire. In short, NIST would provide the technical basis and guidance for fire safety design and retrofit of structures, the predictive tools and test methods for fire resistance determination, and the performance criteria for fireproofing materials. In addition, NIST proposes to develop guidance and retrofit technologies to enhance building egress in emergencies, practical tools and guidance to enhance the safety and effectiveness of fire and emergency responders, and improved models of occupant behavior and response to enhance evacuation and communication in emergencies.

Second, progressive collapse – which refers to the spread of failure by a chain reaction that is disproportionate to the triggering event – was also responsible for the extraordinary number of deaths in the 1995 bombing of the federal building in Oklahoma City. Yet, the United States has not developed standards, codes, and practices to assess and reduce this vulnerability. Adding to the problem for modern structures is their smaller margin of safety – and the reserve capacity to accommodate abnormal loads – due to increased efficiency in the use of building materials and refinements in analysis techniques. The work carried out at NIST in the early 1970s continues to provide the basis for the extremely limited guidance that is available in current United States standards. NIST would develop cost-effective solutions to reduce building vulnerability to progressive collapse using a multi-hazard approach that exploits synergies in resisting extreme loads from blast, impact, earthquakes, and fires.

Third, vulnerability reduction of commercial and institutional buildings and facilities. The overwhelming majority of buildings in public use today are vulnerable to terrorist attack on a number of fronts. Most lack state of the art sensing and information management systems. Few have electronic representations of the building documents or models, and standards do not exist for such representations. Most are not protected against chemical, biological, and radiological (CBR) threats. While efforts are underway to protect military buildings through Department of Defense's "immune buildings" program, there are no standards and practices for civilian buildings. 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 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 final program element supports a construction-industry-led roadmapping effort to reflect changed priorities for development and deployment of safety and security standards, technology, and practices. It would also support the delivery and dissemination of practical guidance, tools, and technical assistance to better prepare facility owners, contractors, designers, and emergency personnel to respond to future disasters and to speed economic recovery within the industry following disasters. The effort would complement and support parallel efforts of technical organizations to improve standards, codes, and practices.

In conclusion, I believe it is imperative for the U.S. to learn from the worst-ever building disasters in human history and take aggressive remedial action to minimize future losses. As the events of September 11 demonstrated, the very stability of U.S. commerce and our economy depends upon major buildings and critical facilities that provide a key part of our Nation's physical infrastructure. In the wake of September 11th, the private sector's willingness to take necessary corrective action to strengthen building codes and standards is extraordinarily strong. So with the envisioned Federal technical leadership and partners from the private sector, changes can be made to minimize the likelihood and consequences of future disasters. Thank you, Mr. Chairman. I would be happy to take questions from the Committee.