ASCE

American Society of Civil Engineers

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.

Team Members and Partnering Organizations

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 WTC team. 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.

<u>Data Collection</u>

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.

<u>Impediments Encountered by the Building Performance Study Teams</u>

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

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

W. Gene Corley
Senior Vice President
gcorley @ c-t-l.com

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)