Proceedings of the Workshop on Lessons from the World Trade Center Terrorist Attack

Management of Complex Civil Emergencies & Terrorism-Resistant Civil Engineering Design

Edited by

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Sponsored by
Multidisciplinary Center for Earthquake Engineering Research (MCEER)
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This workshop was conducted June 24-25, 2002 at the Elebash Recital Hall, the Graduate Center, City University of New York, New York, and was supported primarily by the Earthquake Engineering Research Centers Program of the National Science Foundation under a supplement to award number EEC-9701471.

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NOTICE

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Image provided by Michel Bruneau, MCEER.

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Held at:
Elebash Recital Hall
The Graduate Center
City University of New York
June 24-25, 2002

Edited by M. Bruneau

Sponsored by:
Multidisciplinary Center for Earthquake Engineering Research
National Research Council
Institute for Civil Infrastructure Systems

Organizing Committee:
George Lee[1], Michel Bruneau[1], Richard Little[2], Kathleen Tierney[3], and Rae Zimmerman[4]

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2 National Research Council
3 Disaster Research Center, University of Delaware
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Introduction

The tragic terrorist attack of September 11, 2001 in New York City resulted in mass casualties, numerous injuries, the collapse of the 110-story World Trade Center twin towers and adjacent buildings, and extensive disruption of business, professional, economic, and social activities within the city and the surrounding area. When the final accounting takes place, this attack will almost certainly constitute one of the most deadly and costly disasters in U. S. history.

The types of damage that occurred and the demands placed on organizational and government emergency response systems, in many ways parallel those that can be expected in the event of a major earthquake in any U. S. urban center. Like an earthquake, the terrorist attack occurred with virtually no warning, creating the immediate demand for lifesaving and emergency health care provisions. Fires broke out and multiple structural collapses occurred. Facilities that perform critical emergency functions were destroyed, heavily damaged, or evacuated for life-safety reasons.

Attempting to respond to the needs of New York State and the Nation, the Multidisciplinary Center for Earthquake Engineering Research (MCEER), in collaboration with the National Research Council (NRC) and the Institute for Civil Infrastructure Systems (ICIS), organized this workshop, *Lessons from the World Trade Center Terrorist Attack: Management of Complex Civil Emergencies & Terrorism-Resistant Civil Engineering Design*.

Objectives

The objectives of the workshop were to review whether knowledge developed during the past decades to enhance seismic resilience can be used to help achieve terrorism resistant communities, and at the same time, investigate whether lessons can be learned from blast-resistant engineering to enhance earthquake engineering practice. Furthermore, the workshop examined the management of complex civil emergencies and terrorism-resistant civil engineering design. Organizers sought participation of experts from throughout the country, to provide the multidisciplinary perspectives required to address this very complex problem.

The workshop aimed to answer three questions using the expert opinion of the participants:

- Can some of the mitigation and emergency response procedures and tools in place to enhance earthquake resilience of the infrastructure be used to enhance resilience against a terrorist attack?
- Can some of the mitigation and emergency response procedures and tools in place to enhance resilience of the infrastructure against a terrorist attack be used to enhance earthquake resilience?
- What common procedures and tools are needed to provide enhanced resilience to both hazards?

The answers will make it possible to identify:

- The current state-of-practice in each discipline
- Knowledge that can be transferred from one field to the other
- How the state-of-the-art and state-of-practice can be further developed to enhance the existing state of resilience
- Foreseeable future developments that are required to achieve such multiple hazards protection

Format

Each day consisted of plenary sessions followed by discussions to allow workshop participants to exchange views on the topic at hand. Plenary sessions featured invited speakers and consisted of general presentations to provide an overview of events related to the WTC attack. Presentations also focused on how knowledge from previous studies and various fields can merge to address new challenges.

This Proceedings summarizes the findings from the workshop and includes, in digital format (attached CD-ROM), the presentations made by most of the speakers. This special format for the Proceedings was designed to share, to the fullest extent possible, the visuals and video-clips that constituted an essential part of some presentations and greatly enriched communication of the concepts presented.

Complementing these electronic presentations that replace the "traditional papers," are abstracts from most presentations and short biographical sketches of most authors. These are grouped under the general session topics under which they were presented, namely:

- How Did 9/11 help NYC to Cope with the Next Disaster?
- Achieving Resilience in the Face of Complex Civil Emergencies
- The Tools to Achieve Resilience—State of the Art
- The Tools to Achieve Resilience—The Future
- The Political, Economic, and Engineering Fusion of Resilience-Enhancing Design

Finally, a few authors volunteered additional longer technical documents, which have been electronically appended to the Proceedings, on the CD-ROM.

Recommendations

Background and Objectives

Multi-hazard approaches have long been proposed as a viable and cost effective means to achieve a greater level of protection of the infrastructure. But which hazards could be combined to achieve benefits in an economical manner? Floods and earthquakes have little in common in terms of their engineering solutions and approaches, and simultaneous protection against both hazards essentially costs the same as the sum of the costs for mitigating each hazard individually. Wind engineering and earthquake engineering are closer, but there are still major significant and conceptual differences in engineering solutions for these two hazards. However, earthquakes and the blast forces from an exploding bomb can both push the structural and non-structural elements of a building to their ultimate, near-collapse limit state. Therefore, the design tools and strategies to enhance building performance in blast or earthquake events are somewhat similar (even if not totally identical). As such, the communities concerned with earthquake-protection and protection from terrorist bombings are today at a critical and strategic juncture, and presented with an opportunity to take a major step toward the implementation of multi-hazard protection for buildings and critical infrastructure. This can only be achieved successfully, however, if the two communities start to work together.

The objective of this workshop was to bring together leaders from the earthquake engineering community, the blast engineering community, the social sciences, and the emergency response community, to identify possible linkages between earthquake-protection and terrorism-protection issues, and how groups focusing on these two different problems could potentially work together. The following conclusions and recommendations provide ideas on how to work toward this objective.

It is important to note that, for purposes of this workshop, the terrorist attacks considered were limited to bombings. Terrorist attacks using biological, chemical, or radiological weapons were beyond the scope of this workshop.

Differences and Possible Synergy in Blast and Earthquake Effects

Significant differences exist between the effects of earthquakes and blasts on a building or infrastructure component.

Earthquake sources are below ground, and transfer energy to infrastructure through ground shaking. These vibrations affect the entire structural system globally, and the source of excitation can last up to a minute, with input frequencies of 1 to 10 hertz. Damage to non-structural components ensues as a consequence of excessive structural behavior. Emergency response activities have to simultaneously address a wide geographical area, as well as rescue and recovery needs and priorities of multiple communities across the impacted region.

To date, terrorist bombing attacks have either been above ground, detonated outside of a building, or in some instances inside a building. In both cases, the effects are localized. Blast forces last a few milliseconds and consist mainly of a strong main pressure wave followed by a slightly longer but less intense reversed pressure. The shock waves travel rapidly from one point of a building to another. Blast forces can directly produce damage to non-structural components, although failure of structural elements can further compound this damage. Disaster response activities are generally confined to the immediate area where the blast has occurred.

Earthquake-resistant design alone does not inherently confer a sizeable measure of blast-resistant design, nor does blast-resistant design automatically provide earthquake-resistance. However, it is conceivable that new types of systems could be developed holistically taking into account both threats, resulting in greater effectiveness than if both hazards were simply considered independently and sequentially using conventional systems. Research is required to better specify the characteristics of such new and innovative systems.

Shared Engineering Objectives

In spite of the differences outlined above, the key engineering objective of preventing catastrophic failure and collapse is common for both earthquake and blast engineers. Similar analysis and design approaches can be used to achieve this objective, such as increased ductility of the structural systems and redundant load paths, to name a few, even though applications may vary in their details. Both the earthquake engineering and blast-resistant design communities have many tools that can be exchanged and shared, and more interaction and cross-pollination of ideas would be helpful. Research would be needed to assess how the many existing engineering analysis methods, design philosophies, structural concepts and retrofit strategies could also be best modified to address both hazards.

Design of Commercial (Non-Mission Critical) Buildings

While blast-resistant design is likely to become a standard requirement for most government buildings and mission-critical infrastructure, it appears that little incentive exists to add such mandatory provisions for other buildings and infrastructure. Some argue that this in fact may not be necessary or desirable. However, building codes should include effective requirements to prevent progressive collapse; to the extent such measures are threat-independent, they can provide protection from multiple hazards. For some types of construction, the cost of protecting against collapse could be relatively small in comparison to potential losses of life and property.

A major difficulty in designing against progressive collapse is the definition of the initial triggering design condition, or the initial tolerable levels of loss of structural elements for which progressive collapse should be prevented. Deliberate airplane collisions are not believed to be a likely design condition for such buildings. Instead, measures to prevent the high jacking of airplanes are more cost-effective by many orders of magnitude than efforts to make the entire infrastructure resistant to such attacks.

Engineers are generally confident that they can satisfactorily execute designs that meet any limit state or specified circumstance, provided that the loads are adequately defined. However, technical design guidance and results from military research and testing would be of great assistance if made more widely available to those with a desire to voluntarily incorporate blast-resistant features into their designs. Although some may argue that such actions could potentially provide terrorists with specific information on design levels, thereby guiding their destructive actions, the benefits of making existing knowledge available to the design community in a secure manner outweigh the potential risks, especially if it can lead to the design and construction of more resilient structures.

Societal Issues

An argument can be made that the collapse of the World Trade Center twin towers were not disproportionate to the damage that caused them. Similarly, the collapse of the Murrah Building in Oklahoma City may not have been disproportionate to the effects of 5,000 pounds of high explosive detonated less than 20 feet from its key structural elements. However, there is a need for broader discussion with all stakeholders and societal actors to assess whether it is desirable to prevent such disastrous outcomes at all costs, whether a balance exists between risks and costs, and, if so, where lies this desired balance-point. As is the case with hazards of all types, the challenge is to better determine what the public and key stakeholder groups consider acceptable levels of risk and how much they are willing to pay to protect themselves against the range of existing and emerging threats. It is quite possible that without a political driving force and leadership, such questions will not be addressed and few incentives will be provided to enhance resilience against terrorist attacks beyond what currently exists (i.e., for mission-critical facilities).

Likewise, measures to improve mitigation, preparedness, response, and recovery require cooperation and trust between government agencies at all levels and between the public and private sectors. Achieving higher levels of protection is not the responsibility of government alone. As demonstrated following 9/11, timely and truthful communication on plans and actions is critical; people need to know why actions are being taken and what the impact will be on their operations. Consequences need to be identified and planned for, and plans must be exercised. Ongoing collaboration breeds trust, and the importance of broad collaboration among various governmental levels and between government, the private sector, and the public cannot be overemphasized.

Fire-Resilience

Structural performance in major fires is relatively uncharted territory. There is a need for extensive focused research on the behavior of different structural systems, both to improve the building stock and to provide better guidance to emergency responders.

Infrastructure Systems

New York City was able to restore critical services and initiate early recovery activities relatively quickly after the terrorist attacks of September 11, 2001 because of the inherent redundancy of many of its physical and institutional infrastructures. Many of the service providers in New York (e.g., Consolidated Edison, Verizon, MTA) possessed sufficient excess capacity in people, equipment, and other resources to provide an effective and relatively rapid restoration of services. Less robust systems, or infrastructure systems in less highly resilient cities, would likely not have fared as well.

Infrastructure systems in major urban areas are inherently interconnected and vulnerable to complex system failures. We do not fully understand all of the vulnerabilities that can cause losses to proliferate and hinder recovery efforts.

Real-Time Sensing Technology

Technology was helpful in managing response, restoration, and early recovery activities following 9/11, and the use of accrued real-time sensing technology has the potential to yield clear benefits. First responders in particular need real-time data on damaged buildings, which when coupled with assessment tools and decision-support systems, can assist in making informed choices about the feasibility of rescue operations and the safety of emergency personnel, as well as supporting other post-disaster response activities. Opportunities exist to incorporate advanced sensing technologies into emergency response activities in a manner that would enhance the safety and survivability of first responders.

Recommendations for Future Research, Knowledge Transfer, and System Development

The following recommendations flow directly from workshop presentations and discussion sessions:

- Research is needed to develop new types of innovative systems than can simultaneously and cost-effectively provide resistance to both earthquake and blast hazards.
- Research should be conducted to assess how to use new advanced materials to provide simultaneous protection for extreme events, earthquakes or blasts.
- Cross-disciplinary research to assess the applicability of earthquake engineering approaches, systems, tools and strategies for blast engineering, and vice versa, would allow us to understand limits in existing technologies and set the stage for new discoveries.
- Advanced analytical approaches and computer models that can address multiple hazards (physical, chemical, etc.) are needed and must be developed. Still needed are highly reliable computer models that can appropriately replicate the behavior of many types of structural systems to blast effects. Such models must be calibrated and verified using experimental approaches on large-scale specimens subjected to realistic load conditions (although smaller models that are easily verifiable may be useful in certain cases).
- Ongoing efforts to make the results of DoD-sponsored research and testing on blast mitigation available to the civilian design community should be accelerated.
- There is a need for relatively simple design tools that can be used broadly by the design community to provide ordinary commercial buildings with some acceptable level of protection against terrorist attack, without having to resort to sophisticated analyses that most owners cannot afford. These tools could be developed from the more sophisticated models described above.

- As soon as possible, commercial building codes should be modified to incorporate known design measures that would reduce the potential for disproportionate collapse, regardless of the initiating event. In the longer term, the phenomenon of disproportionate collapse should be a research topic of high priority.
- A comprehensive and focused research program on the behavior of structural systems in fire should be initiated.
- Efforts should be initiated to couple sensor technology and wireless communications with building damage assessment and decision-support tools, in order to provide real-time assistance to emergency responders. However, problems that occur through the use of such technologies, such as false positives and negatives, must be addresses.
- There is a need to determine the levels of hazard protection society finds acceptable, the factors that influence public perceptions with respect to the terrorist threat and other hazards, and the resources the public is willing to invest to achieve various levels of protection. A process to engage all stakeholders in such as effort is critical.
- Research is needed to determine how new knowledge can be integrated into loss estimation models and decision-support systems, and to develop models and systems that can serve as reliable tools for decision makers.
- Research is also needed to identify lessons learned and best practices for the management of natural and technological disasters, as well as crises produced by intentional acts of terrorism.
- The impacts of privatization, business re-engineering, and corporate streamlining on the ability of systems and institutions to function and recover from high-stress, extreme events need to be better understood. A desire to increase efficiency and profitability may contribute to greatly increased vulnerability and reduced capacity to respond to emergencies.
- Research is needed on the performance of lifeline infrastructure (i.e., electricity, communications, water, etc.) connected to buildings and the impact of their damage on surrounding structures.

Finally, although the attacks of September 11 have focused attention on the severity of the terrorist threat, the engineering and emergency management communities need to continue to focus on the entire range of hazards that threaten the built environment, including natural, technological, and human-induced hazards. With that goal in mind, multi-hazard loss-reduction approaches should receive emphasis in both research and implementation efforts. There is a need to develop overarching approaches focusing on broad improvements that enhance the overall resilience of the civil infrastructure and society more generally, rather than on strategies for coping with specific threats to the built and societal environment, however severe those threats may appear to be. Approaches and strategies that focus on addressing both the earthquake hazards and the blast forces from an exploding bomb are promising, as they both focus on prevention of collapse for structural and structural elements at their extreme limit states.

The events of 9/11 have opened a window of opportunity for the entire disaster loss-reduction community to engage key societal decision makers and convey to them the need to formulate and enact appropriate strategies for preventing extreme events whenever possible, and for limiting damage and responding effectively when such events do occur. The recommendations from this workshop make a useful contribution to such efforts by suggesting how such strategies should be developed.

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New York University

How Did 9/11 Help NYC Cope with the Next Disaster?

Management of Complex Emergencies Perspective
Cruz Russell (New York-New Jersey Port Authority)

Engineering Preparedness Perspective
Gene Corley (CTL Group)

Engineering Response Perspective
Daniel Cuoco (LZA Technologies / Thornton Tomasetti Group)

Engineering Preparedness Perspective of the World Trade Center Collapse

W. Gene Corley, SE, PE
Construction Technology Laboratories, Inc.

On September 11th, 2001 an attack on the World Trade Center resulted in severe structural damage followed by a major fire and complete collapse of the two towers. Surrounding buildings were also severely damaged with some suffering complete or partial collapse.

As the nation watched the attack, the following fires and the eventual collapse of the World Trade Center towers, the engineering community immediately began to respond to the needs on site. This paper describes the response of the engineering community, notes the successes and identifies those things that could have been done better.

Based on experiences with the engineering needs at the World Trade Center and on experiences with previous disasters, recommendations are made for the engineering response to future disasters.

Workshop Discussion Session 1

Achieving Resilience in the Face of Complex Civil Emergencies

Moderator: Kathleen Tierney
MCEER/Disaster Research Center, University of Delaware

Overview of Issues
Richard Little (National Research Council)

Local Government Issues; NYS Perspective
Edward F. Jacoby, Jr. (New York State Emergency Management Office)

Local Government Issues; A FEMA Perspective
Joseph Picciano (Federal Emergency Management Agency - Region II)

Owners' Perspective (large management complex)
Joseph Donovan (Carr America)

Security in the Post 9/11 Environment
Randy Nason (C.H. Guernsey & Company)

The Trade-offs of Handling Risk and Resilience
David Hadden (ARUP)

How NYC Adopted Earthquake-resistant Design Codes
Richard Tomasetti (Thornton Tomasetti Group)

A Unified Technology Transfer Approach to Improve Structural Resiliency for Earthquake, Blast, and Other Extreme Loading Conditions

Richard G. Little
National Research Council

At the conclusion of their 1992 book, Why Buildings Fall Down, Matthys Levy and Mario Salvadori posed the question of whether progress in the field of structures would reduce the number of failures. In light of the devastating collapse of the World Trade Center towers, this question is certainly as relevant today as when first posed a decade ago. However, a series of other structural failures through the 1990's raises the more compelling question of whether the overall state of knowledge regarding the interplay of risk factors in design and construction is adequate to ensure the integrity and safety of buildings and those who inhabit them. For example, the progressive collapse of the Alfred P. Murrah Federal Building in Oklahoma City as a result of the 1995 bombing; extensive and costly damage to steel-frame buildings following the 1994 Northridge earthquake; damage to buildings due to snow loadings in Washington, Oregon and California caused by winter storms in 1996 are examples of failed designs employing what might be reasonably judged to be the best available practice or technology of the time. However, when subjected to extreme loading conditions, the designs proved inadequate.

As isolated events, these examples would traditionally warrant a comprehensive but narrowly focused forensic investigation of the failure modes, their likely causes, and possible remedial actions. However, when considered together, these and other structural failures worldwide suggest the need for a broader, systematic contemplation of structural design and the degree to which the ultimate safety of a building's occupants depends on design assumptions that may or may not be valid under extreme loading conditions. As America moves beyond the events of September 11, 2001, it is important that everything reasonable be done to protect the nation's buildings and the people who use them from possible future attacks. Despite the terrible loss of life, the World Trade Center towers and the Pentagon performed extremely well under circumstances far more severe than anything anticipated in their designs. Thousands of people were able to escape the World Trade Center because the north and south towers withstood the initial impact of the airliners. The recently renovated portion of the Pentagon that was struck did not collapse immediately even though it was damaged extensively. This is validation that buildings can make a real difference in saving lives if appropriately designed and constructed.

A recently completed study by the National Research Council (Protecting People and Buildings from Terrorism: Technology Transfer for Blast-effects Mitigation) evaluated how the results of the extensive research and testing program conducted by the Defense Threat Reduction Agency (DTRA) over the past four years (the Blast Mitigation for Structures Program) could be conveyed to the people who need the information most -- architects, engineers, and builders, as well as students pursuing degrees in these professions. This information transfer is crucial because it will ensure that innovative engineering techniques are used to produce a new generation of architecture -- open, safe, and attractive buildings that are neither bunkers nor fortresses.

Building professionals experienced in hazard mitigation have a real opportunity to take the lead in protecting all types of buildings from terrorism. By translating the findings of government-sponsored research and testing into widely available design guidance, better buildings can become a reality. The information transfer activity should also include information on injuries, illnesses, and casualties stemming from bombing attacks. Knowing the causes of attack-related injuries or illnesses–as well as how people were able to survive blasts–will prove useful for designing buildings and saving lives in the future. Communication between researchers and practitioners can take place in a number of ways, and include active outreach to technical and professional societies to help determine how best to provide information on blast-resistant design and what form it should take.

Security in the Post 9/11 Environment
Presentation Summary

Randall R. Nason, P.E.
C.H. Guernsey & Company

The September 11th attacks on the World Trade Center and the Pentagon had profound effects on society in general as well as the security industry. Issues ranging from threat to workplace productivity face the security industry as we attempt to formulate a long term strategic response to these events. This presentation will discuss these topics as well as issues associated with technology and general security approach in this new environment.

The Trade-Offs of Handling Risk and Resilience

David Hadden
Arup Security Consulting

In this presentation, the author approaches risk and resilience from the viewpoint of a practicing engineer working in the field of protection against terrorist action largely in the commercial buildings sector and drawing on the experience gained of such attacks over many years in the UK.

Observations on the methods of attack favoured by terrorists are related to methods of protecting people and assets from their effects. The relationship between the cost of building enhancements and levels of risk is explored. Minimum requirements to achieve structural resilience are recommended and attention is drawn to the importance of member connections in achieving resilience against explosion, impact and seismic loading.

The effect of 11th September on the UK commercial building market is discussed.

Finally, the author questions the level of protection against terrorist action that society can reasonably expect in the post-11th September world in which attacks of previously unimagined severity have become credible events.

Additional information about Arup is available at *http://www.arup.com*.

How New York City Adopted Earthquake – Resistant Design Codes

Richard L. Tomasetti, P.E.
The Thornton Tomasetti Group Inc

Mr. Tomasetti will discuss the events and process, which led to the adoption of New York City's Earthquake Resistant Design Code. The process was one of the scientific community convincing the engineering community who convinced the Building Department which engaged the entire construction industry. The last step was to convince the political establishment. Rather than starting from scratch, the code was fashioned after the 1988 Uniform Building Code amended appropriately for local seismicity, geology and building industry practices. The process started in the early 1980's and was completed with the issuance of the new seismic requirements in the New York City Building Code in 1995.

The 1988 UBC Code was thoroughly analyzed and digested for its requirements for primary structure, foundations, architectural and mechanical/electrical elements, separation distances, and detailing. The amendments made to the UBC Code are explained in a 1995 NCEER report, "The New York City Seismic Code: Local Law 17/95", edited by Guy J.P. Nordenson. Much thought was also given to economic studies for the potential increases in construction cost as well as defining the requirements for existing buildings under major renovations.

Certainly, such a long process cannot be utilized if modifications are appropriate to the current New York City Building Code to include requirements for protective design due to terrorist threats. The issues concerning the appropriateness of modifying the current code for such threats will be discussed as well as a brief overview of current issues being considered throughout the building industry.

Workshop Discussion Session 2

The Tools to Achieve Resilience - State-of-the-Art

Moderator: Michel Bruneau
MCEER/University at Buffalo

Overview of Issues
Robert Smilowitz (Weidlinger Associates)

Strategies and Tools in Blast Engineering
Joseph Smith (ARA)

Strategies and Tools in Earthquake Engineering
Andrew Whittaker (University at Buffalo)

Easiest and Most Difficult Buildings to Implode
James Redyke (Dykon Blasting)

Anti-terrorism / Force Protection
Harold Sprague (B&V Special Projects)

Advanced Technologies to Achieve Seismic Resilience
Michael Constantinou (University at Buffalo)

Fire-related Issues
Paul Senseny (Factory Mutual Global)

The Tools to Achieve Resilience – State-of-the-Art Overview of Issues

Robert Smilowitz
Weidlinger Associates, Inc.

Progressive collapse analyses are intended to determine the capacity of a structure either to resist an abnormal loading, thereby preserving the load carrying capacity of the critical elements, or to redistribute gravity loads of a critical load-bearing element is removed. While many of the references found in the literature agreed on common features – ductility, continuity, and energy absorption – that structures should possess to help prevent progressive collapse, few of them offered any quantitative analytical approaches for evaluating the potential for progressive collapse. The scarcity of research in the field of progressive collapse prevention and the difficulty for most structural engineering firms to perform advanced (geometric and material nonlinear) finite element computations in an economical and timely manner has led to the development of broad guidelines that are open to many interpretations. For example, ASCE 7-98 [2] describes protection through "an arrangement of the structural elements that provides stability to the entire structural system by transferring loads from any locally damaged region to adjacent regions capable of resisting these loads without collapse." From this approach, ASCE 7-98 discusses three design alternatives that may be part of a multi-hazard design approach. The alternatives are the indirect design approach, the alternate path direct design approach and the specific local resistance direct design approach. The Alternate Path Approach presumes a critical element is removed from the structure, due to an abnormal loading, and the structure is required to redistribute the gravity loads to the remaining undamaged structural elements. The method of Specific Local Resistance requires all critical gravity load-bearing members to be designed and detailed to be resistant to a postulated abnormal loading. Each design approach is based on assumptions and conditions that offer technical advantages and disadvantages. The merit of these approaches and the computational features that are required to perform the required analyses are presented in this overview.

The response of either the elements or the structure to abnormal loading conditions is most likely to be dynamic and nonlinear, both geometrically and in the material behavior. Therefore, the analytical methods that are required to determine the response of the structure must represent the sudden application of the abnormal loading, the dynamic behavior of the materials under very high strain rates, the inelastic post-damage behavior of the materials and the geometric non-linearity resulting from large deformations. Further, the ability of the structural elements to withstand the abnormal loading or the structural system to redistribute the loads depends to a great extent on the behavior of the structural details that define the connections. As a result, the computational tools and modeling constructs that are used to analyze the damage response of structures is often critical to the success of the design approach. Perhaps most critical to the success of the design is the experience of the engineers modeling the structure and materials.

Strategies and Tools in Blast Engineering

Joseph L. Smith
Applied Research Associates, Inc.

This short presentation highlights general areas of blast engineering especially as they relate to seismic engineering. While the tools employed in seismic and blast engineering may be similar, the details of the requirements are, in general, quite dissimilar. The presentation briefly covers Guidelines, Criteria, & Standards, Assessing Risk, Testing Procedures Manuals and Guidelines, Dynamic Response of Building Components, Progressive Collapse and Technology Transfer.

For the consideration of conference participants, it is an interesting exercise to complete a matrix comparing some of the major issues related to blast and seismic engineering. A preliminary draft is included as follows. It is highly recommended that conference participants from both the seismic and blast communities alter, correct and complete this table as it may serve as a vehicle for discussion and for meeting the objectives of the conference.

Component/Item	Earthquake Engineering	Blast Resistant Engineering
Forces	Forces primarily consist of ground motions with periods of 100's of milliseconds. Forces vary spatially but are generally of equal magnitude across the dimensions of a typical building. Forces vary temporally (both in time of arrival and duration time – for most typical buildings the forces are normally assumed to arrive at the global structure at the same time since the variations in arrival time are short compared to the load duration times). Forces are cyclical with the multiple cycles. First load pulse may not be the largest. Loads in both directions can be of equal magnitude.	Ground shock is generally only a concern for extremely large explosion or if structure is close enough to the detonation to be in or near the crater. Forces primarily consist of pressure loadings with durations of 10's of milliseconds. Forces vary spatially (magnitude drops off dramatically with distance) and temporally (both in time of arrival and duration time – variations in arrival times can be equal to or greater than the load duration times). Forces are not generally cyclical. There is normally a blast force acting away from the detonation point and a negative phase acting back towards the detonation point. Multiple load pulses are possible in complex sites with adjacent structures and for interior detonations. First load pulse is invariably the largest. Negative phase generally does not exceed a few psi. Fragment loads (primary or secondary) may be significant in some cases.

Component/Item	Earthquake Engineering	Blast Resistant Engineering
Determination of Threat and Risk	Probabilistically and statistically based methods based on historical events and geographic areas.	Very difficult to assign probabilities. Terrorism is by its very nature random. Use of the concept of "Credible Threats" not as quantifiable as probability of earthquake occurrence. Once "Credible Threats" are determined Risk Ratings are assigned. Risk Ratings are a combination of vulnerability to attack by each credible threat and a measure of target attractiveness.
Location of Facility/Site	Build in low seismic areas or at least in areas not prone to some serious problems (e.g., liquefaction, etc.)	Defend the standoff to the building. Avoid building near other high probability targets in order to avoid collateral damage.
General Affect on Buildings	Global damage due to foundation damage and/or lateral motions of structural framing system.	Localized damage except for large conventional explosives (>1000 lb TNT) or internal explosives detonated near critical elements.
Foundations	Design can be controlled by earthquake requirements.	Design is generally NOT controlled by explosive blast events below ~ 4000 lb TNT as long as structure is outside of the crater.
Frame	Design and connections can be controlled by earthquake requirements. Requirement for preventing progressive collapse can be threat independent. Seismic load can have natural periods on the order of those for typical buildings. Earthquake load durations can be similar to the natural periods of many structures.	Design is generally NOT controlled for small events (<100 lb TNT). Design is influenced for moderate events (500-1000 lb TNT). Design can be controlled for large events (>1000 lb TNT). Requirement for preventing progressive collapse can be threat independent. Blast loads are normally an order of magnitude lower in duration than the natural periods for most building frames.
Exterior Walls	Design of non-vertical load bearing walls can be influenced by earthquake requirements for secondary effects (low velocity debris, etc). Design of load bearing walls and shear walls can be controlled by earthquake load requirements.	Design of non-vertical load bearing walls can be controlled by blast due to load acting perpendicular to the wall. Design of load bearing walls and shear walls are normally controlled by blast around the exterior envelope of the building.
Interior Walls	Design of interior walls can be controlled by seismic if they are part of the lateral load system.	Generally not controlled by blast except in localized areas such as lobbies, mailrooms and loading docks where localized threats may exist.

Component/Item	Earthquake Engineering	Blast Resistant Engineering
Windows	Normally a secondary consideration (low velocity debris, spotty breakage). Breakage normally due to in-plane racking of window and walls.	A primary concern. Glass damage due to blast can be severe and widespread. High velocity fragments may cause injuries and/or death. Breakage normally due to pressure load acting normal to the glass surface.
Roof	Design is normally not significantly affected by seismic design.	Design can be controlled by blast force requirements.

These items are provided for preliminary consideration only and to serve as a talking piece for conference participants.

Easiest & Most Difficult Implosions

Jim Redyke
Dykon Explosive Demolition Corp.

When thinking about a structure for implosion, there are many factors to evaluate in considering whether this structure is a candidate for implosion such as:

1. Location of structure in relation to surrounding structures
2. Utilities & surroundings – structures & types
3. Structural types
   a. Reinforced concrete
   b. Structured steel
   c. Masonry
4. Structural consideration
   a. Vintage or age
   b. Steel configuration & size
   c. Steel strengths & chemical analysis
   d. Reinforced concrete column size & steel size & layout
   e. Spiral wrapping – type of cages and multiple cages
   f. Sheer walls – sizes & location
   g. Elevators & stairs
   h. Beams & columns - beam type & size
   i. Floor slabs – reinforcing pattern – prestressed
   j. Exterior curtain wall construction – type & fill
   k. Special trusses
   l. Large spans
   m. Unusual structure features
5. Structural design as it relates to how you plan for the building to collapse
6. Integrity of structure

A typical implosion is a timed sequential elimination of the support columns to create a planned collapse. In analyzing a structure to create this failure, we must take into account the factors we looked at above to understand what the designer had intended for the structure. Our job is to use the structure's characteristics and strengths to the fullest advantage in planning the blast design for the implosion.

Examples:

1. 12 – story R/C frame single 66 ft span, brick infill, between columns, limited, physical floor above structure, need to drop middle of structure to have ends of structure rotate towards middle.
2. Heavy Steel Tower – Ridge rigid complex framing. – Titan Rocket Launcher – Cape Canaveral, FL

For concrete column removal, a series of holes are drilled horizontal into the column for the placement of explosives to remove the concrete from the reinforcing. This drilling process can be greatly affected by the reinforcing steel. The quantity of explosives needed to remove the concrete from the steel is directly proportional to column size and quantity of steel.

In structural steel columns, cutting torch work is required for placement of special steel cutting charges called Linear Shape Charges. These charges are only for the actual cutting of the steel. A bulk charge must be affixed to the column to displace the column from the vertical. Steel columns need to have protection built around them for two reasons, one to contain shrapnel and, secondly, to protect the charges from being displaced by previous delays.

For me, the easiest structure for implosion is a reinforced concrete frame and simple shaped structure, with a deep basement, tall first floor and tile in fill in frame, stairs and elevators.

Conversely, the most difficult structure is the heavy steel frame with heavy bolted connection, many shear walls, poured concrete stair walls, elevator walls, and large bracing. These structures require substantial preparation for implosion and have proven to be the most difficult challenges.

Lessons to be learned from the WTC and the Oklahoma City Murra building to me are that the greater the stiffness of the frame which allows for greater distribution of stress and building loads, the greater the frame redundancy, the more difficult the building is to implode and will offer greater resistance to terrorist attack.

Anti-terrorism / Force Protection

Harold O. Sprague, Jr., PE
Black & Veatch Special Projects Corp.

The United States has a presence throughout the world. The United States owns and operates facilities in many foreign countries that serve the Department of State and the United States military. Historically, many of the facilities have been the targets of terrorist attacks. Tactics used by terrorists have included assassinations, kidnappings, grenade attacks, arson, and suicide bombings. Some of these tactics can be mitigated operationally, but mitigation for other tactics must employ methods of anti-terrorist / force protection (AT/FP) engineering.

Recently, facilities in the continental United States have been attacked by domestic and foreign terrorists. The Murrah Building and the 1993 bombing of the World Trade Center were tragic events. The September 11, 2001 attacks on the World Trade Center and the Pentagon were the most devastating attacks ever on American soil. The terrorists employed the new tactic of using a commandeered commercial airliner. As tragic as these attacks have been, they must be studied in order to prevent the terrorists from achieving similar results in the future. Lives must be preserved and the mission of our critical facilities must be allowed to continue.

The AT/FP practice of engineering is multidisciplinary. AT/FP engineering involves elements of architecture, structural engineering, mechanical engineering, electrical engineering, fire protection engineering, and civil – site engineering. There are no "building codes" that define how the AT/FP engineer designs a facility. The practitioner must rely on principals of science and fundamentals of engineering to counter the efforts of a potential aggressor.

The AT/FP practitioner must also work closely with the intelligence community to properly develop the design threat which is fundamental in the process. The practitioner must also educate himself on indigenous construction methods and materials to properly assess their resistance to a particular terrorist tactic. While the AT/FP engineer must focus his mitigation efforts on traditional terrorist tactics, he must also be cognizant of other tactics such as chemical, biological, and radiological attacks as well as attacks through our computer systems. The AT/FP engineer must direct resources to mitigate a given threat tactic based on a facility's mission, its criticality, and likelihood of attack.

Compounding the work of the AT/FP engineer is the need for security. There are valuable lessons that can be learned in the public sector. The practice of designing earthquake resistant structures has been greatly enhanced by public efforts and shared knowledge as exemplified by the public work of the Building Seismic Safety Council and the National Institute of Building Sciences. The AT/FP engineer must guard much of his work from the public to keep sensitive information from potential aggressors.

The ability to design resistance to the effects of terrorist attack and explosions is not precluded by secrecy. Black & Veatch designed the NORAD facility in Cheyenne Mountain, Colorado in the 1950's under very tight security, and only recently declassified. But as with earthquake engineering, openness and knowledge dissemination allow for a much more free exchange of information and development of effective mitigation design. The balance of openness and secrecy is an essential element of AT/FP engineering.

Additional information about Black & Veatch Special Projects Corp. is available at: *http://www.bv.com/bv/services/government/facilities/index.htm* .

Advanced Technologies to Achieve Seismic Resilience

Michael C. Constantinou
University at Buffalo, State University of New York

Advanced technologies for seismic resilience include seismic isolation systems, energy dissipation systems, semi-active and active motion control systems and smart materials.

Seismic isolation is a construction technique and a technology for mitigating the damaging effects of earthquakes on structures through the introduction of flexibility and energy absorption capability. Energy dissipation (or damping) systems are introduced to new and existing construction to dissipate much of the earthquake-induced energy in elements not forming part of the gravity framing system. Key to this construction technique is limiting or eliminating damage to the gravity-load-resisting system. Semi-active and active systems and smart materials have been proposed and studied as alternative or supplemental to seismic isolation and energy dissipation systems that may offer versatility, adaptability and increased effectiveness. The presentation will briefly introduce the audience to the different types of advanced technologies hardware and present examples of applications of these technologies. The applicability of these technologies to terrorism-resistant construction will be discussed and an example of conceptual design of energy dissipation systems capable of arresting the collapse of a building will be presented.

Fire-Related Issues

Paul Senseny
Factory Mutual Global Research

This presentation discusses three types of fire-related issues. The first is the fire, itself. The second is fire protection, both passive and active. The third is structural collapse in large fires.

The fire issues can be further broken into ignition issues and fuel issues. Earthquakes, explosions and impacts can create ignition sources by moving or toppling electrical equipment such as transformers and switchgear, equipment with hot surfaces or open flames, molten materials or chemicals, which mix, react and ignite. At the same time these ignition sources are created, there can be release of fuel that greatly increases the fuel load and distribution beyond that expected for the occupancy. Fuel release can occur by damage to piping or tanks, tank overturning or sloshing.

The fire-protection issues can be further divided into passive and active systems. Both can be damaged by earthquakes, explosions and impacts. Passive systems are the protective coatings that are applied to insulate the structural members. They can spall or chip, allowing the temperature in the structure to increase much faster than expected. Active systems comprise the water-based sprinkler systems. Sprinkler piping can be damaged preventing water flow to the sprinklers above the fire. The water supply can be interrupted by damage to the water mains or to the storage tanks so there is no water to fight the fire. Finally, the unexpected conflagration may grow quickly, over a very large area so that the sprinkler system is overwhelmed and the fire is not controlled.

The structural-collapse issues can be further divided into heat transfer, material property and deformation/collapse-mode issues. The issues are central to our ability to model structural deformation and to assess the potential for collapse in large fires. Our current understanding of heat transfer from the fire to the structure is largely empirical, with data limited to relatively few structural components and to only a few fire scenarios. Temperature-dependent material properties are not readily available for structural materials, especially at the high temperatures that produce collapse. Rate-dependent deformation is rarely accounted for. Finally, the ability to model the nonlinear material and structural behavior with enough accuracy to reliably predict structural collapse time and mode is not demonstrated.

Workshop Discussion Session 3

The Tools to Achieve Resilience - The Future

Moderator: Thomas O'Rourke
MCEER/Cornell University

Overview of Issues
John Crawford (Kazagozian and Case)

Performance Based Design for Fire
Brian Meacham (ARUP)

Performance Based Design in Earthquake Engineering
Ronald Hamburger (EQE)

Blast-mitigation Program at DOD
Frank Tyboroski (DOD)

Structural Control
Andrei Reinhorn (University at Buffalo)

Design of Mission-critical Facilities
Robert Bachman (Consultant)

Retrofit for Blast Mitigation Effects
Reed Mosher (USACE/ERDC)

Resilient Design using a Complex Adaptive Systems Approach
Gary Dargush (University at Buffalo)

Comparison of Building Responses under Blast and Earthquake Loadings; A Case Study
George Lee (MCEER/University at Buffalo)

An Overview of the Tools Needed to Achieve Resilient Building Designs, The Future

John E. Crawford
Karagozian & Case Structural Engineers

The ability to produce a resilient design—for new buildings or retrofitting existing buildings—is complicated by the lack of knowledge and analytic tools in the engineering, policy maker, and academic communities related to characterizing and predicting the effects of terrorist attack loads. Much of this is due to the relatively recent need for these types of designs; the unique nature of civilian structures as compared to hardened military structures, where loads like these (e.g., blast loads) have always been a primary concern; and the security concerns related to much of the data and analytic models developed primarily within the DoD community.

Recent efforts by ASCE, ACI, AISC, and others to incorporate terrorist attack effects and related design issues in current practice are a necessary initial step. However, the process is still fragmented and often based on opinions or specific viewpoints versus broad based experience and factual based notions. Much of the problem may be attributed to the dearth of applicable tests, the difficulty of modeling responses caused by terrorist attacks, and the sparse number of structural engineers having experience with terrorist-resistant design. It is critically important that terrorist-resistant design policy-makers, engineering, and other interested communities benefit from the lessons learned from recent terrorist attacks.

Performance-Based Design for Fire

Brian Meacham
Arup Risk Consulting

In the early 1990s, the US building and fire communities began discussing the transition from a prescriptive-based to a performance-based design and regulatory environment (Lucht, 1991). Over the past ten years, considerable research has been conducted into performance-based regulation and fire safety design (e.g., Meacham, 1998a; 1998b; 1998c; 2000), and in 2000, the Society of Fire Protection Engineers (SFPE) published an engineering guide to performance-based fire protection analysis and design of buildings (SFPE, 2000), and in 2001, the International Code Council (ICC) published a model performance building code (ICC, 2001).

As defined by the SFPE (2000), performance-based fire safety design is defined as:

"An engineering approach to fire protection design based on (1) established fire safety goals and objectives; (2) deterministic and probabilistic analysis of fire scenarios; and (3) quantitative assessment of design alternatives against the fire safety goals and objectives using accepted engineering tools, methodologies, and performance criteria."

In brief, the performance-based design process has seven primary steps:

1. Define the scope of the fire safety analysis
2. Define fire safety goals and objectives of the stakeholders
3. Translate stakeholder objectives into design objectives
4. Develop performance (design) criteria
5. Develop design fire scenarios and design fire loads
6. Evaluate design options and select final design, and
7. Document design.

As part of the performance-based design process, several analytical tools and methods are available to the fire protection engineer for assessing the fuel load and likely fire characteristics, the likely development and spread of fire and fire effluents, and the impact of the fire and fire effluents on people, property, structure and mission.

Although the SFPE guide provides a structure process to follow, and a wide variety of tools and methods are available, the key to performance-based analysis and design for fire lies in the ability of the fire protection engineer to understand the interrelationship of the building-people-fire system, to identify appropriate data for use in analysis, and to develop a solution that fits the overall building performance requirements. This is especially important when considering multi-hazard scenarios, or scenarios in which deliberate attack may be a concern, as the mitigation strategy must consider all of the life safety, property protection and mission continuity objectives – some of which may be competing.

Understanding how buildings and people can be expected to perform in the event of a fire is extremely important to design for multi-hazard mitigation. Integrating performance-based design for fire, with performance-based design for other hazard events, will lead to more disaster resilient buildings. However, to get to a point where a majority of engineers can develop such designs, more data, and an integrated multi-hazard framework, will be needed.

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Meacham, B.J. (1998a). *The Evolution of Performance-Based Codes and Fire Safety Design Methods*, NIST-GCR-98-761, National Institute of Standards and Technology, Gaithersburg, MD, November 1998.

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SFPE (2000), *The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*, SFPE and NFPA.

Performance-Based Design in Earthquake Engineering and Applications to Design for Terror Resistant Construction

Ronald O. Hamburger, SE
Simpson Gumpertz & Heger Inc.

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The developing practice of performance-based earthquake engineering must inherently deal with many of the same issues that are of concern and relevance to those interested in designing structures for resilience to terror attack. Both earthquakes and terror attacks are infrequent but high-consequence events. Given the low probability that a structure will actually experience such an event, rather than seeking to avoid damage when the loading event occurs, as is common for other hazards, design practice specifically anticipates the onset of structural damage while seeking to minimize risk to life safety. In both cases the loading is dynamic and a function of the configuration and structural characteristics of the structure, and in both cases, in order to predict structural behavior, engineers must attempt to characterize response of a severely degraded, highly nonlinear structure. In the case of each hazard, structures that are inherently rugged and that have continuous and redundant structural systems with superior toughness and ductility are more likely to survive. Finally, in both cases, the time of occurrence, magnitude and character of the exact loading the structure will experience, as well as the structure's pattern of response, are highly uncertain.

Performance-based earthquake engineering is a young field, having initiated in the late 1980s as corporate, institutional and government owners and operators of buildings sought to reduce their seismic risk through programs of building upgrade. Prior to deciding to upgrade buildings, these owner/operators naturally needed to understand probable building performance if an earthquake occurred and the consequences of this performance on their personnel and operations. They then needed to understand that the resulting risks could be reduced to tolerable levels at a reasonable return on the investment associated with the upgrade program. Over the period of 1985-2000, the Federal Emergency Management Agency (FEMA) has funded the development of a series of guideline methodologies for predicting performance, and upgrading buildings to meet selected performance goals. These methodologies have resulted in standardization of performance measures and design performance objectives, as well as rudimentary procedures to deal with the very large uncertainties associated with performance prediction. FEMA has just initiated a project with the Applied Technology Council, designated ATC-58, that will seek to extend these methods to the design of new buildings and ensure that the performance measures are relevant to the stakeholders.

Although there are many similarities between earthquake and terror-resistant design, there are also many differences. The character of loading is different, as is the structural response. Terror incidents are less probable for an individual building than is earthquake loading and each terror incident effects fewer structures at one time. As a result, more severe damage is generally tolerable. As a result of these differences, it is unlikely that a common design procedure can be used for both hazards. However, the basic approaches to characterizing performance and dealing with uncertainty should be coordinated as design methodologies advance in both arenas.

Blast Mitigation Program at the Department of Defense

Douglas Sunshine and Frank Tyboroski
Defense Threat Reduction Agency, Technology Development Directorate, Structural Dynamics Branch

The objective of the Department of Defense's Blast Mitigation Program is to develop, test and field technologies to mitigate the effects of blast on structures in order to reduce injuries and deaths from terrorist bomb attacks. The program is sponsored by the Technical Support Working Group (TSWG) and managed by the Defense Threat Reduction Agency.

The key issues addressed in the program are the prevention of progressive collapse of multi-story buildings and the reduction of flying debris generated by elements within the structure (e.g., glass, walls, office furnishings). Specific objectives of the program are to:

a. Establish tri-service/interagency workgroups to oversee the program.

b. Develop cost-effective methods to retrofit existing structures to mitigate the effects of blast.

c. Develop design guidance for new construction to mitigate the effects of blast.

d. Test and evaluate commercial-off-the-shelf (COTS) products for their ability to increase the resistance of structures to the effects of blast.

e. Develop industry standard models for the prediction of blast effects on structures and generate computer models for use by the government and industry.

f. Produce joint service/agency design and assessment tools.

g. Develop simplified models to assess the benefits of blast mitigation design in terms of injury avoidance.

The two primary products of the program are vulnerability assessment methodologies and blast mitigation design guidance. The first product is a set of tools to evaluate the vulnerability of buildings and the people in them. The tools include models to calculate blast effects, structural response, and injury to people. The second product is a set of guidelines for designing new and retrofitting existing buildings to reduce injuries and deaths to occupants.

Structural Control for Mitigation of Natural and Human-Made Disasters

Andrei M. Reinhorn
University at Buffalo, State University of New York

Structural control is a relatively new concept applied to buildings, bridges and civil infrastructure. While the electrical, mechanical, and aerospace industries have used the control concept for quite some time, the large size civil and constructed infrastructure industries adopted the concept only recently, after the development of fast acting large-scale devices.

Along with relatively simple devices, which protect the structures by preventing the loads to excite the load supporting systems, more complex devices were developed to dissipate energy before the load resisting structure would have to dissipate it by itself through damage and collapse. Devices, which use braking friction, or yielding sacrificial elements, have been used in addition to devices using fluid flow and pressure changes to reduce the movement of large structural systems, thus preventing damage of main load carrying components. More recently active systems were developed using either large hydraulic or electrical force delivery devices. These active systems modify the load carrying system during the extreme events by an influx of energy directed to mitigate the influence of acting damaging loads. This influx of energy is directed by a predetermined or adaptive logic, implemented by analog or digital computers acting while the system is attacked by the extreme excitations.

The extreme loading leading to collapse can be defined as: (i) direct loading, such as force, base movement, pressure, momentum, fire resulting from windstorms, explosions or direct impact and collisions; and (ii) indirect loading such as waves and inertial response producing vibrations and deformations which may exceed the limits of stability and safety. The first category of loading is more complex and requires protective structural systems, which either can reject or resist the influence of such excitations. The second category of loading produce usually severe vibrations, and it is better understood. Many solutions have been explored, in particular related to seismic loading and wind gusts. Structural control is a technology which uses predefined performance targets and tries to achieve them using either enhancements and modification of the structural system, or adds devices which introduce counteractions to loadings and to response to stay under the performance limits set. As such, structural control was and is at the forefront of newly adopted policy of "performance based engineering".

The presentation will introduce some of the more traditional methods of structural control ranging from conventional passive devices to the newest generation of protective devices, either passive, active, semi-active or hybrid. Among the more modern control techniques are additions of stiff structural walls with enhanced energy dissipation (Bruneau and Berman, 2002), isolation of structures or components using seismic systems or shock protection (Tunnissen, J. T.,1997, Drake J.L. et al.,1989), advanced energy dissipation devices and hybrid systems, and active systems such as active braces or active tuned mass or liquid dampers. The presentation will introduce excitation barriers and trenches, isolation of nuclear power plants using floating structures, suspended structures, etc, or double structural systems (similar concept with double hull used in the ships and tankers). It will be shown that the solutions using control concepts may be restricted and suitable for limited sets of excitations and performance criteria. It is concluded that the technology is ripe to protect the expensive constructed infrastructure, however more research is needed to develop hybrid solutions using a combination of stiffening, strengthening or weakening, and damping.

References:

Bruneau, M. and Berman J. (2002), "Plastic Analysis and Design of Steel Plate Shear Walls", ASCE / JSE (in press).

Drake J.L. et al. (1989), *Protective Construction Manual: Dynamic Response of Structures*, Air Force Engineering and Services Center (AFESC), Tyndall AFB, Florida

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Design of Mission-Critical Facilities

Robert Bachman
Consulting Structural Engineer

Mission-critical facilities consist of a wide array of buildings, structures, non-structural components and equipment which have one thing in common. Because of the essential importance of their mission, they are designed to continue to perform their function after being subjected to the most extreme design events. Examples of mission-critical facilities include certain Department of Defense military facilities (e.g. Cheyenne Mountain), Department of Energy plutonium and nuclear waste handling facilities, critical lifeline structures (e.g. San Francisco-Oakland Bay Bridge), city emergency operations centers, acute care hospitals, liquefied natural gas (LNG) secondary containment structures, blast resistant control buildings in petrochemical plants, nuclear power plants and more recently, data centers and Internet server facilities. For most mission-critical structures, the most extreme design events are earthquakes.

Many of these facilities have specialized design criteria to better assure that they will continue to function when subjected to extreme design events. These specialized design criteria include:

- *Seismic Design for Buildings*, TI 809-04, U.S. Army Corps of Engineers, 1998
- *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*, U.S. Department of Energy Standard (DOE) 1020-94
- *Standard Specification for Highway Bridges*, American Association of State Highway and Transportation Officials (ASSHTO), 1996
- *Design Requirement for LNG Receiving Terminals,* Department of Transportation, 49 CFR Ch 1, Part 193.2155
- *Regulatory Guides and Standard Review Plans,* Nuclear Regulatory Commission

In addition to these specialized criteria, building codes provide structural design loadings and criteria for extreme events for typical mission-critical building structures including hospitals, emergency operation centers and data centers. These codes recognize the critical nature of these facilities by imposing higher design requirements in the form higher design forces (higher importance factor) and more stringent detailing requirements for both structural and non-structural components. Also, critical mechanical and electrical equipment are required to be certified by the supplier that they will be functional based on empirical evidence, shake-table testing or rigorous analysis. The codes also include seismic design criteria and requirements for seismic isolation which is generally only used for mission-critical buildings. In high areas of seismicity, the building codes and standards most commonly being used are:

- *Uniform Building Code*, International Congress of Building Officials, 1997
- *International Building Code*, International Code Congress, 2000 (Based on FEMA-302)
- *Minimum Design Loads for Building and Other Structures,* American Society of Civil Engineers Standard, ASCE 7-98 (Based on FEMA-302)

It is interesting to note that many of these standards and criteria documents have been in existence for over 20 years and that many of the facilities have been designed for a multitude of extreme events. The types of design hazards for which many mission-critical structures have been designed include earthquake, wind, tornado missile impact and extreme fire. But there is one requirement in DOT Part 193.2155 which I believe would be significantly interesting to this audience. It states that a Class I LNG impounding system must be designed to withstand the collision by, or explosion of, the heaviest aircraft which can take off or land at any airport located within 10 miles of the facility. Such a system was actually built across the river in Staten Island in 1974 and was designed to withstand the impact of a Boeing 747. Analytical tools and material codes exist today and have been in practical use for over 20 years to design a variety of mission-critical structures. Many of tools and procedures were actually developed in World War II for military hardening design purposes, but for a variety reasons only became first adopted for mission-critical facilities in the early 1970's. Two important standards in which procedures are included for blast, impact and/or temperature design in addition to other extreme loadings are:

- Appendix A and C, Code Requirements for Nuclear Safety Related Concrete Structures, ACI 349-01, American Concrete Institute (2001)
- Design of Blast Resistant Buildings in Petrochemical Facilities, American Society of Civil Engineers (1997)

In summary, many mission-critical facilities have been designed for a variety of extreme hazards including large commercial aircraft impact for over two decades. Analytical tools and procedures exist which permit design and evaluation of such extreme events. The primary need for mission-critical facility design in the future is to define the threat (or threats), to translate that threat (or threats) into a design event(s) and associated design loadings. In addition, it is necessary to define the desired facility performance when subjected to that design event and providing an acceptable cost/benefit analysis approach and associated decision making procedure for determining whether designing for the threat is a worthwhile goal.

Retrofit for Blast Mitigation Effects

Reed L. Mosher
Geotechnical and Structures Laboratory

A balance between security procedures, including the enforcement of increased standoff distance, and the use of blast-hardening and mitigation techniques, can significantly improve protection of building occupants from terrorist bomb attacks. The goal of our research is to develop technology to protect people inside of buildings from terrorist bombs through blast mitigation techniques. Injuries and deaths come from two primary sources in terrorist bombing incidents. While structural collapse has accounted for the majority of deaths in the past, flying debris has resulted in deaths and is the leading cause of injuries.

One of the major challenges facing security engineering is retrofitting existing buildings to prevent flying debris hazards. These methods must be cost effective and aesthetically pleasing or they will likely not be used. Considering the large variations in construction materials and practices throughout the world, and the wide variety of potential threats (bomb size, type, and standoff), the problem needs to be reduced to a workable level. Since the threat level is uncertain, and varies in different parts of the world, the capability to predict the effects of bombs of different sizes and standoffs is required. Testing every combination of building type, bomb size, and standoff is obviously prohibitively expensive, so a combination of mathematical models and testing is used. A variety of analytical models from very complex first-principle physics-based models, to simplified, quick-running models are used. The simplified models are desired for general use since they are easier and quicker to use. Model development must be validated through a testing program. The models are implemented in both stand-alone computer codes and in modules that can be used by general-purpose vulnerability assessment tools, such as AT Planner or the future BEEM. These models are also used to examine the design of blast-resistant buildings as well as to evaluate retrofit options for existing buildings and ultimately to develop design guidance.

Cost-effective methods that are aesthetically pleasing are particularly challenging for windows. Although glass is the weakest element of a building and typically causes the most injuries in bombings, most building owners and tenants insist on the ability to see outside and allow natural light to come in. Commercial companies have attempted to adapt products that provide ballistic and impact protection to resist blast loads. These products include films, laminated systems, thermally treated glass, and glass fragment catch systems. Many of these products have not been adequately tested but have been marketed as capable of providing protection.

During bombing events, exterior walls often fail and become debris hazards to the occupants of a building. To protect people inside of structures, two solutions exist. First, the exterior walls can be strengthened to withstand the blast pressures. Another solution, for non load-bearing walls, is to allow the wall to fail and to catch the debris. This solution is often much less expensive than strengthening the wall. Various debris catcher systems that use materials such as Kevlar, geofabrics, thin steel plates, and spray-on elastomeric polymers have been developed. Retrofitting walls with windows is a much more difficult problem. Catch mechanisms must be able to catch the wall, glazing, and window frame. In most situations, the building occupants do not want the window covered.

Resilient Design Using a Complex Adaptive Systems Approach

Gary F. Dargush, Mark L. Green, Ramesh S. Sant and Xiangjie Zhao
Department of Civil, Structural and Environmental Engineering
University at Buffalo, State University of New York

This presentation focuses on the application of ideas from complex adaptive systems theory to problems of multi-hazard structural design and retrofit. On-going research supported by MCEER is directed toward the development of a computational framework for aseismic design of passively damped structural systems, based upon evolutionary methodologies. This approach utilizes a genetic algorithm for optimization of damper type, size and location, while considering the uncertain nature of the seismic environment. Several examples are provided to demonstrate the benefits of such an approach. Recent work on the development of a GIS framework for the graphical display of the evolving structural designs and the seismic hazard is also included.

Can this same methodology be applied for blast-resistent design? Preliminary work on this issue is presented for very simple structural idealizations, along with some ideas for retarding mechanical response due to implusive loads. All of these investigations suggest that a complex adaptive systems approach may be attractive for multi-hazard decision support, as one attempts to build toward the goal of disaster-resilient communities.

Comparison of Building Responses under Blast and Earthquake Loadings– A Case Study

George C. Lee
Multidisciplinary Center for Earthquake Engineering Research
University at Buffalo, State University of New York

The tragic event of September 11, 2001 in New York City resulted in numerous casualties and injuries. It also caused significant disruptions to the professional, social and economic functions of the city and of the US. The Multidisciplinary Center for Earthquake Engineering Research (MCEER), with supplemental funding from the National Science Foundation, is carrying out a study to assess whether knowledge developed in recent years to enhance seismic resilience can be used to help achieve terrorist-resistant communities and at the same time, to investigate whether the current state-of-knowledge in blast-resistant engineering can be applied to earthquake engineering practice.

This paper is concerned about a component of this post-WTC project of MCEER to compare the building responses due to impact (blast) and earthquake (ground motion) loadings. A special interest is given to the possibility of applying seismic response modification technologies developed in recent years to blast resistance of structures so that they can provide dual protection purposes. Several different types of buildings are examined in this project. Results of one of them is reported herein.

The building under consideration is a 6-story RC frame building located in New York State with earthquake loading conditions of 10% 50 years and 2% 50 years. For blast loadings, small vapor cloud amount (10 – 1000 kg) of TNT equivalent blasts, and medium amount (5-20 tons) of explosions are used. Based on dynamic pressures, durations of loading, and levels of input energy, comparisons are made for the severity, type and locations of structural damage due to the different loadings. A brief consideration is given to potential applications of some of the various structural response modification technologies, originally developed for earthquake resistance, to blast-resistance of buildings.

Workshop Discussion Session 4

The Political, Economic, and Engineering Fusion of Resilience-Enhancing Design

Moderator: Richard Little, National Research Council

Overview of Issues
Kathleen Tierney

Enhancing Resilience of Integrated Civil Infrastructure Systems
Rae Zimmerman (New York University, ICIS)

Response and Recovery Issues
Brent Woodworth (IBM)

How to Prepare for Anything but a Repeat of the Past
William Wallace (RPI)

MCEER Research to Integrate Multidisciplinary Aspects of Resilience
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Overview: Conceptualizing and Measuring Resilience For Physical and Organizational Systems

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MCEER defines resilience as the ability of physical systems and social units (e.g., organizations and communities) to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future disaster events. Resilient physical and social systems are characterized by reduced failure probabilities; reduced consequences resulting from failure, measured in terms of lives lost, damage, and negative social and economic impacts; and reduced time to recovery—that is, more rapid restoration of systems to their normal, pre-disaster levels of functioning. MCEER has also identified four general properties that can be applied to all systems and to the elements that comprise systems: *robustness*, or the ability to withstand the forces generated by a hazard agent without loss or significant deterioration of function; *resourcefulness*, or the capacity to apply material, informational, and human resources to remedy disruptions when they occur; *redundancy*, or the extent to which elements, systems, or other units of analysis exist that are capable of satisfying the performance requirements of a physical or social unit in the event of loss or disruption that threaten functionality; and *rapidity*, or the ability to contain losses and restore systems or other units in a timely manner. According to MCEER's framework, robustness and rapidity are considered *end*s or goals of resilience-enhancing activities, while redundancy and resourcefulness constitute *means* of achieving those goals.

Resilience can further be conceptualized as encompassing four dimensions: technical, organizational, social, and economic. On the technical side, resilience consists of the ability of physical systems to perform to desired levels when subject to environmental forces—whether achieved through enhancing robustness, creating redundancy, or mobilizing resources rapidly after degradation has occurred. Organizational resilience refers to the same property for organizations—i.e., the ability of critical organizations such as emergency management agencies and hospital organizations to continue to function without significant disruption, or if disrupted, to rapidly restore themselves to performance levels that are sufficient to meet crisis-generated demands. The social and economic dimensions of resilience refer to characteristics of social and economic systems and their constituent units of analysis (e.g. firms, households, economic sectors, neighborhoods) that make them more or less able to resist disruption and loss and to recover following disasters without suffering lasting negative effects.

These resilience concepts can be applied to critical facilities, such as hospitals, emergency operations centers, and other critical structures and groups of structures, as well as to civil infrastructure systems, such as power, water, and other lifelines. This presentation focuses on measures of technical and organizational resilience for local emergency operations centers and emergency management organizations. The grids below contain selected measures and indicators of resilience for emergency operations centers as physical systems, as well as local emergency management agencies as organizational systems. The resilience properties addressed are robustness, redundancy, and resourcefulness:

Technical Dimension:
The EOC as a Physical System

Performance Objective: Continuous Operation and Ability to Perform Functions for Which Facility Was Designated

Resilience Property	**Resilience Measures**
Robustness	*Building Remains Structurally Safe for Use *Nonstructural, Contents Damage, Internal Lifeline Damage Not So Severe As to Impede Performance of Critical Tasks *External Lifelines Provide Uninterrupted Service *Transportation System Damage Not So Severe As to Prevent Access, Egress
Redundancy	*System and Component Design Build in Redundancy *Backup Facility in Case of Structural Failure *Redundancy for Critical Equipment, Lifelines, Communication Systems, Critical Functions
Resourcefulness	*Supplies, equipment, etc. adequate or rapidly available

Organizational Dimension:
Local Emergency Management Agencies As Organizational Systems

Performance Objective: Continuous Operation and Ability to Perform Assigned Organizational Functions

Robustness	*Organization retains capacity to carry out designated emergency functions at time of disaster impact *Organization can take action to protect emergency response personnel against death, injury *Organization maintains coherent management structure *Organization able to identify, mobilize, coordinate, and track resources
Redundancy	*Organization can expand by incorporating other emergency response organizations and personnel *Organization can expand by integrating volunteers into emergency operations as appropriate
Resourcefulness	*Organization has capacity to improvise, innovate, seek creative solutions to compensate for loss of robustness, redundancy

The measures outlined above for EOCs as facilities and emergency management agencies as organizations are by no means exhaustive. Rather, they are intended to illustrate that both the technical and the organizational aspects of resilience can be operationalized and measured using parallel indicators. For example, just as meeting technical resilience criteria for robustness requires that emergency operations centers and their contents are physically able to resist damage that could hamper their operations, meeting organizational resilience criteria for robustness requires that local emergency management agencies, *as organizations*, retain the capacity to carry out their designated emergency management tasks when disasters occur. Similarly, both physical systems and organizations require redundancy; the former require alternate ways of enhancing structural and nonstructural performance when primary systems fail, while the latter require mechanisms to ensure organizational expansion (or redundancy) when personnel and other resources are insufficient to meet disaster-related demands.

The World Trade Center disaster constituted a worst-case scenario for New York City's EOC as a physical system. That facility, which had been located at 7 World Trade Center, was completely destroyed when that structure collapsed late in the afternoon of September 11. However, the city's emergency management agency, the Mayor's Office of Emergency Management (OEM), demonstrated significant resilience as an organization. OEM was able to continue to function despite the loss of the EOC and all its contents. In a remarkable example of organizational resourcefulness and with the help of other agencies, OEM was able to reconstitute its EOC at an alternative site at Pier 92. That facility was better able to accommodate emergency coordination functions than the 7 World Trade Center facility would have been.

For emergency management centers and other critical facilities, the physical and organizational dimensions of resilience are interdependent and mutually reinforcing. Both forms of resilience must be designed into physical and organizational systems prior to the occurrence of a disaster, and both must be sustained at the time of impact and in the days and weeks that follow. Demonstrating empirically how these objectives are accomplished is a major focus of MCEER's research on resilience.

Enhancing Resilience of Integrated Civil Infrastructure Systems

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NYU Robert F. Wagner Graduate School of Public Service

After the attacks on September 11th, the immediacy of the response to restore transportation, power, water, and environmental services was influenced by the initial capability of the infrastructure to respond to normal system disruptions as well as extreme events. Research in progress by the ICIS Director is reported on the various mechanisms used to measure and promote infrastructure resilience. Infrastructure is critical to the support of our quality of life as we know it. In order to address infrastructure resilience, the research evaluates general and specific measures of system behavior before, during and after September 11th. General measures include flexibility, interoperability, and interconnectedness. Examples of initial success stories reflect some of the more specific measures or characteristics:

- Mobile cell towers were brought into the area in order to restore cell phone capability, and the loss of phone service
- Mobile generators were moved in as a short-term solution to the power outages
- Water needed for fire-fighting was restored the day of the attacks
- Ferry service dramatically increased in terms of passengers, trips, etc., to meet the travel demands of people when other modes of transport were unavailable
- Within eight months of the attack, debris removal was equivalent to 1.56 million tons equivalent to the total solid waste generated in the City over a month or the municipal solid wastes (MSW) generated over four months, and the work was completed quicker and less expensively than originally expected with the pace of work largely due to the ability to obtain large earthmoving equipment and excavate nearby ports for rapid removal of material.

Measures of system characteristics, how the system was used, and user and community expectations for infrastructure are presented as a guide for future design and operation of infrastructure for enhanced resiliency and security.

About ICIS: ICIS was created as a multi-university collaboration with National Science Foundation funding to foster innovative, interdisciplinary partnerships and collaborations across engineering, the natural and physical sciences, and the social sciences to enhance communication among those who build and manage infrastructure and the users of that infrastructure about critical problems of developing and managing infrastructure in 21st Century societies. Through workshops, conferences, publications, and outreach, ICIS promotes the development of research agendas in areas such as advanced technologies and performance and educational innovations aimed at a new, cross-disciplinary way of thinking about infrastructure. Since its creation in 1998, the Institute has sponsored or co-sponsored dozens of workshops and forums with other academic institutions, non-profit organizations, government and industry, and since 9/11 ICIS' director has promoted collaborations and directed various events for scholars and first line responders. For more information about ICIS see *www.nyu.edu/icis*.

Acknowledgements and Disclaimer: This work is supported in part by the Institute for Civil Infrastructure Systems (ICIS) at New York University (in partnership with Cornell University, Polytechnic University of New York, and the University of Southern California) supported by the National Science Foundation under Cooperative Agreement No. CMS-9728805 and CMS-0204660 "Urban Infrastructure Services in a Time of Crisis: Lessons from September 11th," a Small Grant for Exploratory Research (SGER). Any opinions, findings, and conclusions or recommendations expressed in this document are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

World Trade Center Disaster: Response and Recovery Issues from the Private Sector Perspective

Brent H. Woodworth
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The cooperation and partnership demonstrated in NYC between government officials and private sector firms in responding to the tragic events of 9-11 provided multiple lessons for responding to future events.

The City of New York began an active partnership with the private sector during their preparation activities for Y2K. The unique skills and depth of knowledge of the private sector was viewed as a positive addition to the NYC Emergency Operations Center (EOC) team. This partnership in the development of the Y2K plan came to light as the basis for critical system recovery during 9-11.

IBM was one of several private sector firms to work inside the Pier 92 EOC on the 9-11 recovery effort. Based on experience in responding to multiple complex international disasters, the IBM team focused on identifying and resolving challenges that could be addressed through the linkage of proven technology and crisis management services.

Key observations included the following:

- Existing disaster management systems required rapid modifications to meet complex and changing field operation requirements.
- Information gathering and reporting between government agencies required a high level focus to foster timely information sharing while eliminating potential "stove-pipe" functions.
- A robust and secure communication system was required to meet mobile "real-time" information access needs by authorized decision makers.

IBM and their business partners provided the city with multiple rapidly deployed solutions including the implementation of a secure wireless "blackberry" network, building management database, logistics management, and family relief center applications.

The partnership between the public and private sector helped to accelerate recovery efforts, reduce cost, eliminate redundancy, and improve efficiency. Many of the lessons learned can be summarized in an approach for preparedness by local, state, and federal agencies.

Emerging government approach to preparedness:

- Conduct a detailed risk, vulnerability, & continuity assessment in advance
- Identify required crisis event decision making variables
- Design and implement targeted "real time" decision support systems
- Utilize proven disaster resistant technology solutions with linkage to legacy systems.
- Design for a "high stress," degraded infrastructure environment
- Utilize flexible, scalable and easily modified systems
- Anticipate social, economic, environmental and political needs.

Cooperation, combined with a desire to develop and embrace common disaster management principles and systems (even if they are developed outside of your agency) are among the keys to success in the implementation of national disaster preparedness strategy.

Disruptions in Interdependent Infrastructures: A Network Flows Approach

William A. Wallace, J. Mitchell, E. Lee and D. Mendonca
Rensselaer Polytechnic Institute

Extreme events, like the September 11th attacks, can introduce unforeseen disruptions in infrastructure systems due to the dependent and interdependent nature of these systems. Critical infrastructure interdependencies arise when two or more infrastructures must act in concert to provide a service. An example is the need for both electric power and subway infrastructures for the provision of mass transportation service. The two infrastructures are interdependent with respect to this service in that if one is subjected to a disruption, the service in question cannot be provided. Consequences of the recent attack on the World Trade Center in New York City are still taxing local, state and national capabilities to restore services via a vast infrastructure network. Response and recovery activities themselves were affected by infrastructure interdependencies. The New York Times reported many interdependencies between various infrastructures and associated issues involving protecting infrastructure capabilities. For example, numerous geographic areas below Canal Street were experiencing failures in multiple services in the first few days following the attack. A report released on September 12th to the U.S. Congress by the U.S. General Accounting Office (2001), documented the importance of identifying and managing critical infrastructure interdependencies.

The proposed research seeks to provide to those responsible for assessing the vulnerability of our infrastructures and those who have duties and responsibilities as emergency managers with a decision aid that is mathematically sound, comprehensive and can be used via a GIS display. The result of our work will include a clear and unambiguous set of definitions of critical infrastructure interdependencies; a mathematical representation of the infrastructure systems that incorporate dependencies and interdependencies among and between systems; algorithms that can be used to run the model for vulnerability assessment and emergency response; and an integrated GIS display for user interaction with the model.

MCEER Research to Integrate Multidisciplinary Aspects of Resilience

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Agencies and other groups engaged in disaster mitigation have placed much emphasis in recent years on the objective of achieving disaster-resilient communities. Because of their potential for producing high losses and extensive community disruption, earthquakes have been given high priority in efforts to enhance community disaster resistance. The implementation of voluntary practices or mandatory policies aimed at reducing the consequences of an earthquake, along with training and preparedness measures to optimize the efficiency of emergency response immediately after a seismic event, all contribute to abating the seismic risk and the potential for future losses. While these activities are important, justified, and clearly related to resilience enhancement, there is no explicit set of procedures in the existing literature that suggest how to quantify resilience in the context of earthquake hazards, how to compare communities with one another in terms of their resilience, or how to determine whether individual communities are moving in the direction of becoming more resilient in the face of earthquake hazards.

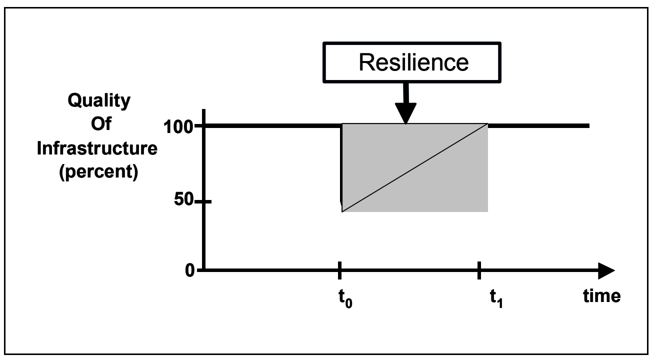
MCEER has developed a comprehensive framework to define seismic resilience and quantitative measures of resilience that can be useful for a coordinated research effort focusing on enhancing this resilience (this framework developed in collaboration with Stephanie E. Chang (University of Washington), Ronald Eguchi (ImageCat Inc.), Ralph Keeney (University of Southern California), George Lee (MCEER), Thomas O'Rourke (Cornell University), Andrei Reinhorn (University at Buffalo), Masanobu Shinozuka (University of California Irvine), Kathleen Tierney (University of Delaware), William A. Wallace (Rensselaer Polytechnic Institute), and Detlof von Winterfeldt (University of Southern California)).

For purposes of the analyses being undertaken by MCEER, community earthquake resilience is defined as the ability of social units (e.g. organizations, communities) to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize social disruption and mitigate the effects of future earthquakes. The objectives of enhancing earthquake resilience are to minimize loss of life, injuries, and other economic losses, in short, to minimize any reduction in quality of life due to earthquakes. Earthquake resilience can be achieved by enhancing the ability of a community's infrastructure (e.g. lifelines, structures) to perform during and after an earthquake, as well as through emergency response and strategies that effectively cope with and contain losses and recovery strategies that enable communities to return to levels of pre-disaster functioning as rapidly as possible.

MCEER has elected to carry out its mission of enhancing the seismic resiliency of communities, through a focus on improving the resilience of facilities and organizations whose functions are essential for community well-being in the aftermath of earthquake disasters. These critical facilities include water and power lifelines, acute-care hospitals, and organizations that have the responsibility for emergency management at the local community level.

This leads to a broader conceptualization of resilience. More specifically, a resilient system is one that shows:

1. Reduced failure probabilities,
2. Reduced consequences from failures, in terms of lives lost, damage, and negative economic and social consequences,
3. Reduced time to recovery (restoration of the system to its "normal" level of performance)



A broad measure of resilience that captures these key features can be expressed, in general terms, by the concepts illustrated in the figure above. Refinements are required to further develop this concept into a workable framework that can be used for the management of a large-scale coordinated research program, and to expand the concept to integrated definitions of resilience. This will be discussed in more details at the workshop.

The presentation made during the MCEER WTC Workshop will focus, as a case study, on how to implement the proposed framework to assess and enhance the seismic resilience of acute care facilities

Understanding and Overcoming Obstacles to Hazard Mitigation

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William J. Petak, School of Policy Planning and Development, University of Southern California, Los Angeles, 90089

The basis of this paper is research being conducted by Professors Petak and Alesch under the auspices of the Multidisciplinary Center for Earthquake Engineering Research.[1] The purpose of the research is to identify obstacles to implementing hazard mitigation and to propose means for overcoming those obstacles.

The project includes an extensive literature review and the development of propositions based on that literature. The propositions identify barriers to successful implementation and are grouped in terms of a simple descriptive model.[2] Additionally, the project includes the development of a case study on State of California legislation mandating seismic retrofit of pre-1973 acute care hospitals in that state. The case study provides a basis for field evaluation of the propositions. To the extent possible, the results will be integrated into models for evaluating the efficacy of alternative mitigation strategies.

This presentation focuses on implementing resiliency. Except in relatively small terrorist attacks, natural hazard events, or accidents, returning to the *status quo ex ante* is not an option. For catastrophes, implementing resiliency begins with designing for system survival. System survival means protecting core elements of the system and, following the event, moving on to a new system state that is viable in the new environmental context.

Successfully implementing resiliency requires being entirely clear about what it is one is trying to protect and what it is one is trying to protect it from. The advocate must explicate all the consequences of implementation, including side effects. It is critically important to specify who will be charged with implementing the mitigation. Advocates of resilient design must

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[1] This research is supported primarily by the Earthquake Engineering Research Centers Program of the National Science Foundation under award number EEC-9701471.

[2] Alesch, Daniel J. and William J. Petak, *Overcoming Obstacles to Implementing Earthquake Hazard Mitigation Policies: Stage 1 Report*. Buffalo: Multidisciplinary Center for Earthquake Engineering Research. Technical Report MCEER-01-0004. December 17, 2001.

understand that implementation is primarily a political, not a technical, problem. Fifth, program designers must take into account both the complexity and the dynamic characteristics of the systems for which they plan interventions. Sixth, resilient design advocates can increase the probability of buy-in by others by using collaborative design practices, including other critical actors in the system. Finally, advocates must keep in mind the principle of incompleteness of design; systems must adapt to meet the challenge of complex environments, so it is important to design hazard mitigations that facilitate that adaptation.

Implementation of an Innovative Design Solution for Blast-Effects Mitigation through Aggressive Multi-Lateral Dissemination

David L. Houghton, S.E. and Jesse E. Karns, S.E.
Myers, Houghton & Partners, Inc. – Structural Engineers

This research report highlights a generational breakthrough in steel frame connection geometry, known in the industry as SidePlate™ connection technology, which, because of its wholly new connection geometry and recognized robustness, is intuitively able and ready to combat post 9-11 realities, using only one structural system to economically satisfy Antiterrorism/Force Protection (ATFP) building performance standards. In light of the recent attacks on America, implicit to gaining the necessary confidence in the performance of a steel frame building to survive the threat of progressive floor collapse, direct bomb blast pressures, vehicular or debris impact and/or thermal attack is the national awareness of the availability of a girder-to-column-to-girder connection geometry that intuitively exhibits discrete structural continuity across a violently torn-loose column; inherently provides torsional strengthening and blast hardening of girder and column ends at the girder-to-column joint; and demonstrates proven reserve capacity, robustness, and joint ductility.

Specific practical design applications using SidePlate™ connection technology in the construction of U.S. Federal Government buildings and specialty structures completed prior to and since September 11th, 2001 are presented that clearly exhibit these essential attributes, using a single structural system for multi-hazard mitigation, and without adding cost to the global steel frame. The simplicity and symmetry of SidePlate™ connection geometry inherently accommodate a broad set of diverse framing and design applications, that are integrated with a common geometry, including both moment frame and braced 'Dual' frame systems, uniaxial and biaxial dual strong axis connection configurations, and *hollow* columns; all with no design limitations on girder and column member sizes, depths and shapes. Hollow tube or box columns can be filled with concrete for reserve capacity, and for blast and impact hardening, or can be used as interior "wet columns," or as chimney flues for natural venting, to mitigate thermal attack.

Conversely, using high-fidelity physics-based non-linear continuum modeling, this research report demonstrates that 'traditional' connection geometry, which includes the pre-Northridge connection and its post-Northridge derivatives (e.g., RBS 'dog bone' and others), is fundamentally not able to satisfy the performance expectations for credible mitigation of blast effects. The essential girder-to-girder structural linkage across a blast-failed column, required to mitigate progressive collapse of the building, simply does not exist. This pivotal finding corroborates similar conclusions reached by other blast researchers, making multi-hazard mitigation using a single structural system clearly unachievable with 'traditional' connection geometry.

This report concludes with a candid review of certain outlooks and biases that have been encountered with the implementation of the SidePlate™ design solution for blast-effects mitigation, which include technical, educational, security, political and industry hurdles. Excerpts from Senate Bill 1398 are explored concerning a recent directive from Congress to Federal Government property owners and managers, which formally holds them accountable to Congress to identify structural technologies, including connection technologies, that are capable of resisting blast effects. Senate Bill 1398 is considered to be a start in the right direction, by a directive from the top down, to achieve aggressive multi-lateral dissemination and implementation of essential technologies. Finally, the first sign of a breakthrough is flagged by showcasing excerpts from Appendix AP2 of the the new Department of Defense (DOD) Antiterrorism Measures for New and Existing Buildings, dated January 25, 2002 which makes this specific recommendation (<u>underlining</u> added for emphasis): *"Unexpected terrorist acts can result in local collapse of building components. To limit the extent of collapse of adjacent components, utilize <u>highly redundant structural systems</u> such as <u>moment resisting frames</u>, detail <u>connections to provide continuity across joints</u> equal to the full structural capacity of connected members, and detail members to accommodate large displacements without complete loss of strength. This recommendation is consistent with AP1.2.1 (Standards 7) for preventing progressive collapse, but <u>recommends selection of certain structural systems</u> and <u>greater attention to structural details</u>."*

Additional information about blast-effects mitigation research and design applications by Myers, Houghton & Partners – Structural Engineers is available at *www.mhpse.com*.

Strengthening Resilience through Remote Sensing Data Fusion: The World Trade Center Example

Charles Huyck
ImageCat, Inc.

A combination of factors culminated in a breakthrough for remote sensing technology in emergency management, following the events of September 11th. First, the World Trade Center attack is an event unparalleled in history. The devastation was beyond the imaginative capabilities of emergency management professionals - there was simply no appropriate script for such an event. The demand for information proved to be immense. Second, Manhattan is unique in the United States because of the density of high-rise buildings and the value of real estate. Because of this, and the logistical needs that follow, the City of New York had already undertaken intense mapping efforts, resulting in the production of highly accurate vector and raster databases. Third, even though this was a very large disaster, the scale of events in New York was highly localized, with primary impacts concentrated in a small geographic area. The need to coordinate the response for an event of this magnitude in a dense, yet relatively small area, made the combination of imagery and data maps particularly useful.

The following are some examples of how remote sensing was used:

- CAD drawings were overlaid with aerial images to identify the locations of stair-wells where bodies were later found.
- Images from helicopters were used extensively within the first few days to assess damage, accessibility, and the dangers of hanging debris.
- Thermal images were used to assess various fire fighting techniques
- The locations of hazardous materials within the debris, mapped on top of aerial images provided a focus for fire fighting efforts, possibly preventing explosions.
- LIDAR data registered persistent and significant changes in elevation due to subsidence
- Using hyperspectral AVRISS, the EPA and USGS were able to quantify the amount of asbestos in the air

Although highly valued and of widespread use following September 11th, it is important to recognize that with better planning and preparedness, remote sensing and GIS could have played an even greater role in increasing resilience. Lessons learned are considered with respect to data acquisition, processing and logistical aspects of integrating remote sensing and GIS into emergency operations. Working with post-event imagery, new methods of data visualization are also presented, which may have proved useful for response and recovery teams. These findings establish the basis for a series of recommendations for future applications of remote sensing in disaster management. Interviews undertaken with key emergency management and GIS personnel constitute the main source of information for this document. Coupled with our knowledge of remote sensing and emergency response, these accounts underpin an evaluation of the role played by advanced spatial technologies following September 11th.

Issues Related to the Adoption of New Design Approaches to Produce More Disaster Resilient Structures

James O. Malley
Degenkolb Engineers

Much has been learned and undoubtedly much more will be learned in the future regarding the resilience of structures as a result of the terrorist attacks on September 11th. A number of issues will be encountered in adopting this new information into engineering practice. Lessons that have been learned over the 50 years of code adoption related to seismic design will be useful in understanding these issues and the challenges that they present.

Model building codes in the United States generally are intended to address the great majority of building designs and demands. But, it recognized that unique structures and "non-credible" demands are outside their scope, either due to a lack of information, and/or a lack of societal pressure. In all but the most extreme demands, such as a major earthquake, building code provisions attempt to result in little or no damage or loss of function to the structure and its' contents. For extreme events, the goal of building codes is to protect life safety, but not necessarily limit property damage.

Codes in the United States are adopted through a consensus procedure that involves a large number of participants from various stakeholder groups. Many of these participants are experts in a small portion of the code. Competing stakeholder groups constantly apply tension to preserve their portion of the construction market, in order to keep the so-called "level playing field." Model codes are adopted by local jursidictions that can apply local amendments, resulting in the potential for varying design requirements. Building codes also generally only deal with hazards on an individual basis. Sequential demands from blast followed by fire create multiple scenarios that will create extensive challenges for code writing bodies.

As with the hazard created by earthquakes, the threat posed to the existing building stock by terrorist attack is far more challenging, both from an engineering as well as a societal perspective. The huge stock of existing buildings creates a wide array of possible targets. The cost of retrofitting existing construction to make it more resistant to these demands is very large due to the physical constraints posed by the building. Such constraints can be much more easily avoided in new construction.

There is a wide body of blast resistance information and technology that have been developed by the DOD and other agencies that could be incorporated into building codes. Any such implementation will take time to be accepted and extensive training of engineers, building officials, owners and other stakeholders. As with most new technology, peer review will likely be necessary for early and complex applications.

Building codes are legal documents enacted by local jursidications that mandate design procedures. Guidelines provide recommendations for good practice that may be better suited for special applications or small portions of the building inventory. Codification of good design practices often leads to unintended consequences that could result in less resistant designs. Resistance to progressive collapse will be difficult to define due to the man-made nature of the hazard, and the fact that large structural deformations will likely be required. It must be recognized that all structures have a failure limit, and that defining how much resistance is "enough" will entail cost tradeoff decisions. While engineers have traditionally taken the lead role in determining the level of safety in our codes, society has reacted to events when they occur. Ultimately, society will determine how resources will be allocated, based on their understanding of the credibility of the threat, weighed against the cost needed to provide the resistance.

Biographical Sketches

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Dr. Alesch focuses his research on decision-making associated with low probability-high consequence risks, the effects of disasters caused by willful acts and natural hazard events on complex community and organizational systems, and on hazard mitigation strategies.

Prior to joining the University, Alesch served as Senior Social Scientist and Project Manager for RAND, the California-based think tank. Prior to that, he served in the University of Southern California School of Public Administration and in the Executive Chamber of New York State government. He has consulted across the United States and in Asia. His many publications include *The Politics and Economics of Earthquake Hazard Mitigation* (1986) and *Overcoming Obstacles to Implementing Earthquake Hazard Mitigation Policies: Stage 1 Report* (2001) with William Petak, and *Organizations at Risk: What Happens When Small businesses and Not-for-Profits Encounter Natural Disasters* (2001) with James Holly.

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Mr. Bachman is a licensed Civil and Structural Engineer in the states of California and Washington. He is a graduate of U.C. Berkeley with a B.S. Degree in Civil Engineering in 1967 and a M.S. Degree in Structural Engineering in 1968. He has over 34 years of engineering experience on a variety of domestic and foreign projects.

After working for Earth Sciences, A Teledyne Company from 1968-1969 and Holmes and Narver from 1969-1975, he joined Fluor Engineers and Constructors in 1975. As department manager of the Fluor Daniel Civil/Structural Department in Irvine and Aliso Viejo, California from 1989 through April 2000, Mr. Bachman reviewed and directed the Civil/Structural engineering of all projects executed by the Civil/Structural Department. Mr. Bachman was actively involved in establishing the structural design criteria for all projects and was particularly involved in the seismic criteria.

Mr. Bachman served as earthquake engineering consultant to the other Fluor Daniel and Duke Fluor Daniel offices when requested. His area of technical focus was the seismic design and evaluation of non-building structures and non-structural components, and the seismic design of base isolated structures. Mr. Bachman has authored or co-authored over 30 technical papers on earthquake design related subjects.

During his professional career, Mr. Bachman has been involved in the design and/or analysis of a variety of mission critical facilities. These include:

- Nuclear Power Plants (Indian Point No. 2 pressure piping and the reactor of the Gulf General Atomic High Temperature Gas Cool Reactor)
- Underground Nuclear Containment Structures (Nevada Test Site)
- Department of Energy Nuclear Facilities (High Performance Fuel Laboratory and Canister Waste Storage Facility completed in 2000 at Hanford)
- Liquefied Natural Gas Receiving Terminals in California (L.A., Oxnard and Pt. Conception)
- Seismically Isolated Emergency Command and Control Facilities (Los Angeles County, San Diego County, City of Long Beach)
- Blast Resistant Control Buildings for numerous petrochemical facilities

Mr. Bachman has had significant involvement in professional society seismic code development activities. He is past chair of the SEAOC State Seismology Committee which had the responsibility for development of the seismic provisions of the Uniform Building Code. He currently serves as chair of the Seismology Committee's Performance Based Seismic Engineering Ad-Hoc Committee. He is also a member of the NEHRP Provisions Update Committee of the Building Seismic Safety Council which has the responsibility for the development of the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (FEMA 368 and 369) and past chair of its Technical Subcommittee for Architectural, Mechanical and Electrical Components. The NEHRP Provisions serve as the primary basis of the seismic provisions of the International Building Code and the Tri-Services Manual. He also currently chairs the ASCE 7 – Task Committee for Seismic Loads.

Since electing to take early retirement from Fluor Daniel in April of 2000, Mr. Bachman has served as a Peer reviewer or Consultant for several notable clients. He currently chairs the Technical Peer Review Panel for the base isolated XBR Antenna Foundation for the National Missile Defense System and is a member of the Peer Review Panel for the base isolated LA/USC Hospital Replacement Project.

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Dr. Bruneau is conducting research on the seismic evaluation and retrofit of existing steel bridges, steel buildings, and masonry buildings. Dr. Bruneau has directed many large-scale research experiments investigating the ultimate behavior of such structures subjected to large destructive forces up to collapse. He has published over 150 technical publications as a result of this research, and has co-authored the book *Ductile Design of Steel Structures* published in 1997 by McGraw Hill. He has also received many awards for his research and publications.

Dr. Bruneau has conducted numerous reconnaissance visits to earthquake stricken areas (including the Chi-Chi Taiwan earthquake, the Marmara Turkey earthquake, the Hyogoken Nanbu (Kobe) earthquake, the Northridge earthquake, the Loma Prieta earthquake, and the 1985 Mexico earthquake), and is a member of numerous technical committees, including the Canadian CSA-S16 Steel Design Standard, and the Seismic Committee of the Canadian Highway Bridge Design Code (which contains the first North American ductile detailing seismic provisions for steel bridges), the NCHRP Project 12-49 for the development of *Comprehensive Specifications for the Seismic Design of Bridges*, and BSSC TS6 Subcommittee on Steel Structures for the 2003 Edition of the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*.

Dr. Bruneau is also Project Director for the new $20 million versatile earthquake engineering experimental facility being constructed at the University at Buffalo, as part of the George E. Brown Jr. Network for Earthquake Engineering Simulation (described in more details at *http://civil.eng.buffalo.edu/seesl/*).

More information on the presenting author is available at *http://www.civil.buffalo.edu/ Faculty/bruneau.html*.

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Michael C. Constantinou is Professor and Chair, Department of Civil, Structural and Environmental Engineering, and co-director of the Structural Engineering and Earthquake Simulation Laboratory at the University at Buffalo, State University of New York. His current research interests include seismic isolation and damping systems, and performance-based design, areas in which he authored or co-authored about 160 papers, books and book chapters and reports. He received a Presidential Investigator Award in 1988 and a Best Paper Award from ACI in 1991 for his research, and is the co-recipient of three professional practice awards: the 1994 General Services Administration Design Award for the structural strengthening of the US Court of Appeals Building in San Francisco, the 2002 Diamond Award of the New York Association of Consulting Engineering Companies and the 2002 Grand Award of the American Council of Engineering Companies, both for design of the Ataturk International Airport in Turkey.

Dr. Constantinou served as member of the teams that developed the 1997 *FEMA Guidelines for Seismic Rehabilitation of Buildings*, the 1999 *AASHTO Guide Specifications for Seismic Isolation Design* and the 1997 and 2000 *NEHRP Recommended Provisions for Seismic Regulations*. He is Chair of BSSC TS 12, charged with the development of the New Technologies section of the 2003 *NEHRP Recommended Provisions for Seismic Regulations*. He has consulted extensively on the analysis and design of structures with seismic isolation and seismic energy dissipation systems.

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W. Gene Corley, is currently Senior Vice President, Construction Technology Laboratories, Inc., Skokie, Illinois. He received his B.S. '58, M.S. '60, and Ph.D. '61 from the University of Illinois in Urbana. Dr. Corley is a member of the National Academy of Engineering, and an honorary Member of ASCE. He is Past President of the National Council of Structural Engineers Associations, Past Vice Chairman of the Building Seismic Safety Council, and Past Chairman of the ACI Building Code Committee (ACI- 318). He has authored over a 160 articles and books dealing with the subject of structural design and behavior. Dr. Corley has received more than a dozen national awards for his work.

For more than four decades, Dr. Corley has served as a designer, researcher, and consultant for building and bridge construction. His expertise includes material behavior, structural behavior, fatigue of structural concrete, earthquake effects and blast effects on buildings and bridges. Dr. Corley has served on a joint ACI-PCA Earthquake Damage Investigation team that has done investigations of earthquake damage in Central America, South America, Japan, and California. He is a Licensed Structural Engineer in Illinois, holds Professional Engineer licenses in 19 states, and is a Chartered Structural Engineer in the U.K.

Following the bombing of the Murrah Building in Oklahoma City, Dr. Corley was Principal Investigator on the ASCE team of forensic engineers that did an independent Building Performance Assessment for the Federal Emergency Management Agency (FEMA). In September of 2001, he was asked to lead the ASCE/SEI team to do a Building Performance Assessment of the World Trade Center for FEMA. The team's report on the WTC Building Performance was presented by Dr. Corley at the House Science Committee Hearing on May 1, 2002.

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Education: M.S., Structural Engineering and Structural Mechanics, University of California at Berkeley, 1967

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1992-Present: Principal engineer, Karagozian & Case, Glendale, CA
1987-1992: Senior Scientist, TRW Defense Systems Group, Redondo Beach, CA
1981-1987: Engineering Specialist, The Aerospace Corporation, El Segundo, CA
1967-1981: Research Structural Engineer, Naval Civil Engineering Laboratory, Port Hueneme, CA

Mr. Crawford has been designing and assessing the effects of blast and shock for over 30 years. He has visited embassies and other Government buildings subjected to blast and impact loads to provide designs for reducing their risks to terrorist bombs, performed peer reviews of other A&E's blast effects related design, given support in legal matters related to blast and shock effects, and generated software tools for design and analysis related to blast and shock. He has performed assessments for a broad range of structures subjected to both conventional and nuclear explosives; has extensive experience with the behavior and response of structural materials, like reinforced concrete and steel structures, subjected to blast and impact loads; and is experienced with the response of conventional buildings and building components subjected to blast loads, and personnel hazards related thereto. He also has extensive experience with predicting the response of equipment, piping and vehicles and their contents to blast and impact loads, and developing shock isolation systems and other means to protect them from these loads. He has presented his work at numerous conferences and published many reports and papers on the subject of blast effects mitigation.

Mr. Crawford has developed a number of unique design concepts to protect buildings, windows, and occupants from the effects of blasts and fragments. He has spearheaded the use of composites and other new materials (e.g., polymers) as essential elements in developing effective and esthetic blast-resistant design. He originated the use of analytic human injury modeling to evaluate the effectiveness of blast resistant designs in terms of their impact on lethality and casualty estimates. He has developed and evaluated a variety of airblast barriers including the use of water walls to reduce the effects of airblast.

Mr. Crawford is one of the pioneers in developing nonlinear 3-D finite element analysis techniques for predicting the actual behaviors of a broad range of structures, specializing in blast and impact effects on structures and prediction of structure failure. He has extensive experienced with a number of engineering tools, especially single degree-of-freedom models and interpolation algorithms, like P-I curves for determining the response of structures to blast. He has performed numerous studies evaluating the effectiveness of these design tools and developed a variety of new engineering tools to assess/design structures subjected to the effects of blast. He is familiar with the physics associated with and generation of airblast and ground shock.

Mr. Crawford has written over 350 reports and papers primarily involving assessing and mitigating the effects of blast and shock on structures and mechanical systems, and people.

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Gary F. Dargush is presently a Professor in the Department of Civil, Structural and Environmental Engineering at the University at Buffalo, State University of New York. Dr. Dargush has research interests in computational mechanics, earthquake engineering and structural control. His research has led to the development of boundary element methods for a wide range of physical problems, including those associated with wave propagation, fracture mechanics, thermomechanics and fluid-structure interaction. Many of these formulations are now employed in commercial software.

In recent years, he has also concentrated on collaborative research involving the application of computational mechanics and physical experiments to gain a better understanding of complex engineering systems and processes. He has helped to develop a mechanics-based approach to problems of structural control. This latter effort led to the publication of the first book on passive energy dissipation systems, co-authored with Professor T.T. Soong. His current work in this area is directed toward the development of an automated approach for computational aseismic design and retrofit of passively-damped structures, based upon a complex adaptive systems approach.

Altogether, Dr. Dargush has published over forty papers in archival journals, a half dozen book chapters and numerous conference papers. He received his doctoral degree from the University at Buffalo in 1987. Prior to that he worked as a research engineer and finite element analyst at Ford Motor Company and General Motors Corporation.

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Mr. Donovan is responsible for directing and overseeing an 11.2 million square foot portfolio of real estate within the Greater Washington DC metropolitan area. In this role, he works with various in-house and outside groups to review and establish policy for this portfolio as well as to establish and maintain relationships with various governmental groups. Mr. Donovan is supported by property and facility team's within this forty-two (42) building portfolio.

Mr. Donovan is a "key crisis employee" within CarrAmerica and has worked to establish the operating protocols for his firm and other tenant organizations. He represents the local group of owners in initially negotiating with Secret Service to regain access to buildings around the White House as well as to develop a business plan that can be used should this group need to seize properties in the future. Mr. Donovan continues to work with the various governmental groups to maintain ongoing information flow to assure that all parties/concerns are listened to as situations develop.

Mr. Donovan represented the building industry groups in a round table discussion with GSA relating to the potential effects of changes that could be requested by GSA of private industry. Mr. Donovan interfaces with FEMA on assessing and developing a program for commercial the industry to establish and then mitigate potential hazards from earthquake events (Prof. Fred Krimgold – Seattle School Study).

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Theodore J. Fisch, Regional Director, New York State Emergency Management Office (SEMO), Region 1 NYC/LI, has spent five (5) years in the Emergency Management field.

Prior to joining NYSEMO, Ted Fisch served in Corporate Security and Asset Protection. In his last capacity, he served as a Regional Executive in Federated Department Stores in their Special Investigations Unit. This unit dealt with internal fraud, safety, operations, and inventory management for all southern Connecticut and lower Hudson Valley stores.

Ted Fisch joined the New York State Emergency Management Office as the Regional Coordinator for Region 2, Poughkeepsie, in 1997. In this role, he served as the forward point of contact for county emergency managers in the lower Hudson Valley. In 1999, he relocated to SEMO Region 1, which is responsible for the City of New York and the Long Island region.

Ted has participated in various State disasters since joining SEMO, such as the Ice Storm, West Nile Virus, Tropical Storm Floyd and, most recently, the World Trade Center Attack.

Ted arrived in New York City on the morning of September 11, 2001, following the collapse of the North Tower, to provide assistance to NYC OEM. He served in various areas of the response, spanning from the logistics section to State operations officer with FEMA. Ted remained with the formal operation until the Emergency Operation Center ended in January of this year.

Following the World Trade Center Event, Ted was promoted to Regional Director of SEMO Region 1.

Mr. Theodore J. Fisch is a graduate of Norwich University Military College of Vermont and has a Bachelor of Arts degree in Psychology and History.

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David Hadden is a practicing chartered civil engineer at Arup, a multidisciplinary design consultancy which plans, designs and delivers projects across the whole range of the built environment around the globe.

After completing his initial degree in Engineering at Cambridge University, David Hadden worked for contractors on the site engineering and management of a variety of civil engineering and building projects in the UK and elsewhere. He then undertook a second degree in Concrete Structures at Imperial College London following which he joined Arup.

At Arup, Mr. Hadden was, for a number of years, part of a multidisciplinary building engineering group from which he carried out structural design and appraisals for projects throughout the UK as well as in Spain, Hong Kong and the Caribbean.

In the aftermath of the terrorist bomb attacks on the City of London in the early 1990s, Mr Hadden undertook appraisals of several affected buildings and their subsequent reinstatement. Out of this experience, during which he was able to witness at first hand the effects of large vehicle bombs on building fabric and structures, he developed his interest in blast effects and mitigation measures.

He is currently an Associate Director of Arup Security Consulting, a specialist group within the firm, where he leads the blast engineering team. The work of this group includes threat and risk assessments, resilience studies, advice on and the design of blast resistant structures and façade systems for clients in the commercial, public and Government sectors.

Mr Hadden has served on the Security Committee of the British Council for Offices (BCO) and the BCO Risk Management Working Party as well as the Steering Committee for the Concrete Structures MSc course at Imperial College.

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Mr. Hamburger is an internationally recognized expert in earthquake-resistant design and structural performance evaluation, with over 28 years of experience in civil and structural engineering. Having formerly served as Chief Structural Engineer for the EQE Structural Engineers Division of ABS Consulting, Mr. Hamburger recently joined Simpson, Gumpertz & Heger as a Principal in the firm's San Francisco office.

He is widely recognized in the structural engineering community for his leadership in performance-based engineering. He is a past President of the Structural Engineers Association of California, past- Vice President of the Earthquake Engineering Research Institute and incoming President-elect of the National Council of Structural Engineering Associations. He has participated in many committees engaged in the development of codes, structural design standards and guidelines for the American Society of Civil Engineers, the Applied Technology Council, the American Institute of Steel Construction, the American Welding Society, the Building Seismic Safety Council, the International Code Council, National Fire Protection Association, SEAOC and currently serves as chair of the Building Seismic Safety Council's Provisions Update Committee. He has also been responsible for the design, evaluation and upgrade of several hundred structures around the world.

Mr. Hamburger has investigated damage from seven major earthquakes, and lectured on their effects with the Earthquake Engineering Research Institute. He has been a guest lecturer at the University of California at Berkeley and Los Angeles, Stanford University, California Polytechnic Institute, the University of Illinois, the University of Washington and University of Alaska. He has authored and presented more than 70 publications on earthquake resistant design and performed research for the National Science Foundation, Federal Emergency Management Agency and California Division of Mines and Geology. ENR magazine named him one of the top engineering newsmakers in the year 2000, for his leadership in the FEMA/SAC program for resolution of problems created by the adverse performance of steel moment frames in the 1994 Northridge earthquake. He recently served as lead author of the FEMA/ASCE Building Performance Assessment Team study of the collapse of New York's twin World Trade Center towers, on September 11, 2001.

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Mr. Houghton received both his Bachelor of Science and Master of Science Degrees from the University of Southern California. A registered Structural Engineer in California, as well as a Professional Engineer in the states of Georgia and Kentucky, Mr. Houghton has over 30 years of experience in seismic design of notable buildings and specialty structures, specializing in diverse structural steel framing systems with multi-hazard applications.

Following the 1994 Northridge earthquake, Mr. Houghton was one of several authors of FEMA 267, Interim Guidelines: Evaluation, Repair, Modification and Design of Steel Moment Frames. He is the Inventor-of-Record of SidePlate™ connection technology (U.S. Patents 5,660,017 & 6,138,427) used by engineers in the design of steel frame buildings throughout the country for earthquake, extreme winds and terrorist attack mitigation. He was awarded McGraw Hill's Engineering News Record (ENR) Top 25 Newsmakers special recognition for significant construction industry achievement in 1995 for having "...devised a joint that resists the kind of cracking in steel moment resisting frames (SMRFs) triggered by the 1994 Northridge earthquake." The author of over twenty technical papers, Mr. Houghton has been a guest speaker in numerous national and international forums.

Mr. Houghton has distinguished himself as a researcher, innovator and leader in helping to shape and enhance national Antiterrorism/Force Protection design standards, including the mitigation of progressive collapse and the localized effects of direct blast, debris and vehicular impact and thermal attack. His innovative and cost-effective blast-resistant steel frame designs have been implemented in multiple and diverse buildings and specialty structures which include the U.S. Navy's Pacific Command Headquarters in Oahu, Hawaii, GSA's U.S. Courthouse in Laredo, Texas, FAA's Sea-Tac International Airport Air Traffic Control Tower and Terminal Radar Approach Control Facility in Seattle, Washington, and the U.S. Army Command General Staff College at Fort Leavenworth, Kansas.

More information on the presenting author and his career accomplishments is available at *www.mhpse.com* and *www.sideplate.com*.

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Mr. Huyck is a geographer specializing in the integration of advanced technologies into emergency response and loss estimation. He has worked in various capacities for the insurance industry in addition to federal, state, and local governments to produce a wide array of GIS-based models that analyze the possible effects of earthquakes, floods, fires, and terrorist events on persons, property, the built environment, and the lifeline infrastructure. He founded the GIS and Remote Sensing unit for EQE/ABS, where he served as an advisor to executive personnel on the integration of GIS into several prominent loss estimation programs. At the California Governor's Office of Emergency Services (OES), he was responsible for geographic and statistical analysis, database development and mapping disaster information under intense time constraints. At OES, he responded to the Northridge Earthquake, the California Winter Storms, and the California Fire Storms. Under contract to ESRI, Mr. Huyck worked with urban and regional planners to develop a GIS which analyzed demographic data, transit systems, land uses, and pedestrian facilities to determine the potential for stimulating pedestrian activity. Mr. Huyck has developed numerous GIS and database applications with an assortment of languages and tools. He is a member of URISA and ASPRS.

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Professor George C. Lee is Director of the Multidisciplinary Center for Earthquake Engineering Research (MCEER). He is also Samuel P. Capen Professor of Engineering at the State University of New York at Buffalo (UB), and Senior University Advisor for Technology. Previously, he has served as Chair of UB's Department of Civil Engineering and Dean of the School of Engineering and Applied Sciences.

Dr. Lee's research emphases are on several aspects of structural mechanics and engineering. He has published over 150 papers and co-authored four books on mechanics, analysis and stability of civil engineering structures including performance and design of structures in cold regions and in regions of strong earthquake ground motion. He is also a frequent contributor to literature on biomechanics.

Since September 2001, he has been working on a new research project to compare building responses due to blast and earthquake loading conditions. A progress report of this research is presented at this MCEER workshop.

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Richard G. Little is Director of the Board on Infrastructure and the Constructed Environment of the National Research Council (NRC) where he develops and directs a program of studies in building and infrastructure research and maintains outreach and liaison with federal agencies, the legislative branch, and affiliated organizations. He has directed NRC study activities, participated in workshops and panels, and written several papers dealing with blast-effects mitigation and critical infrastructure protection. He served as the Study Director for the 1995 NRC report, *Protecting Buildings from Bomb Damage* and the 2001 report, *Protecting People and Buildings from Terrorism: Technology Transfer for Blast-effects Mitigation*. Mr. Little has over thirty years experience in planning, management, and policy development relating to public facilities. He has been certified by examination by the American Institute of Certified Planners and is a member of the Federal Planning Division of the American Planning Association. Mr. Little holds a B.S. in Geology and an M.S. in Urban-Environmental Studies, both from Rensselaer Polytechnic Institute.

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James O. Malley is a Senior Principal with Degenkolb Engineers of San Francisco, California. He received both his Bachelors and Masters Degrees from the University of California at Berkeley. A registered Structural Engineer in California, Mr. Malley has over 19 years of experience in the seismic design, evaluation and rehabilitation of building structures. He has specialized in the seismic design of steel frame structures, especially for health care facilities.

Mr. Malley served as the Project Director for Topical Investigations for the SAC Steel Program. In that position, he was responsible for directing data collection and interpretation of steel frame buildings damaged by the Northridge Earthquake and all of the analytical and testing investigations performed as part of the SAC Steel Project. In 2000, this work was recognized by AISC in presenting Mr. Malley its' Special Achievement Award.

Mr. Malley is a member of the AISC Specifications Committee and the Chair of the AISC Seismic Subcommittee that is responsible for developing the AISC Seismic Provisions that are the basis of the 2000 IBC. Mr. Malley is a member of the ASCE Committee on Steel Buildings and the ASCE Seismic Effects Committee. He was a member of the steel subcommittee of the ATC 33 project that developed FEMA 273/274, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, and is the chair of the Building Seismic Safety Council TS 6 on Structural Steel Construction. Jim has served as a member of the SEAONC and SEAOC Board of Directors, and recently completed a year as President of SEAONC. Mr. Malley is also a member of the AWS D1.l Subcommittee on Seismic Welding Issues. He has made numerous presentations on the effects of the Northridge Earthquake on Steel Frame Buildings, as well as the seismic design of steel structures. The author of over forty technical papers, Mr. Malley was the Co-Recipient (with the late Egor Popov) of the 1986 ASCE Raymond C. Resse Research Prize ASCE for the paper "Shear Links in Eccentrically Braced Frames."

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Dr. Meacham joined Arup in 2000 after five years as Technical Director and Research Director of the Society of Fire Protection Engineers, where he led the effort to develop risk-informed performance-based building codes and fire engineering guides in the United States. He is widely respected as a leading authority on these topics, having undertaken research in these areas for the SFPE with support from the National Science Foundation and the National Institute of Standards and Technology. His current work is in the area of building response to multi-hazard events.

Dr. Meacham has played a key role in the development of the draft of the first performance building code for the United States, the *ICC Performance Code for Buildings and Facilities*, serving as a member of the code development committee and undertaking research in support of the effort. He was also a member of the NFPA 101 Committee that drafted the performance option to the 2000 *Life Safety Code*®. In 2001, he was appointed to the National Research Council Committee on Developing a Performance-based Approach for Security-related Design of Federal Facilities (BICE-J-00-02-A) for his expertise in performance-based fire safety design and regulation.

Dr. Meacham is also member of several international committees on risk assessment, performance-based design, regulation and fire issues, including the SFPE Engineering Task Group on Fire Risk Analysis; NFPA 551, Fire Risk Assessment; CIB W14, Fire; CIB TG37, Performance Based Building Regulatory Systems; and CIB TG50, Tall Buildings. He serves on the International Scientific Committee for the 2003 CIB Conference, *Strategies for Performance in the Aftermath of the World Trade Center* (more information available at *http://www.cibklutm.com/*).

Details regarding Arup Risk Consulting can be found at *www.arup.com/risk*. Additional biographical details about the author can be found at *http://www.aruprisk.net/contact/resume/ArupRiskResume_BJM.pdf*.

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Dr. Reed L. Mosher is responsible for planning, directing, managing, and executing complex theoretical and applied research and development programs. These programs are associated with the science and engineering development for advanced survivability and protective technologies to enhance the protection of U.S. forces from the foxhole to fixed facilities against weapons threats ranging from small arms to terrorist weapons through advanced conventional weapons. He serves as the U.S. Army Engineer Research and Development Center's (ERDC) senior Technical Advisor for the survivability and protective structures research program. Dr. Mosher has taken a leadership role in ERDC's Terrorist Threat Protection research area under the Army's Survivability and Protective Structures research program. He was involved in the assessment of bombing attacks at Oklahoma City, Khobar Towers, and the U.S. Embassy in West Africa.

Dr. Mosher joined the U.S. Army Engineer Waterways Experiment Station (WES) (presently named ERDC) in 1978 as a civil engineer in the Computer-Aided Design Group, Automated Data Processing Center. Dr. Mosher became Chief of the Structural Mechanics Division for the Structures Laboratory, WES, in May 1994. He directed research and development related to the dynamic response of structures to blast and shock from conventional and nuclear weapons, seismic effects from earthquakes, and hydraulic loads from fluid flow. In 1999, Dr. Mosher was promoted to one of the Army's new Senior Scientific Technical Manager (SSTM) positions under the Science and Technology Laboratory Demonstration Project. This position is one of only sixteen in the Army, and is the only one within the Corps of Engineers.

Dr. Mosher earned his bachelor's degree in Civil Engineering from Worcester Polytechnic Institute, Worcester, Massachusetts, in 1977. He earned his master's degree in Civil Engineering from Mississippi State University at the WES Graduate Center in 1982. Dr. Mosher graduated with a Doctor of Philosophy degree in Civil Engineering from Virginia Polytechnic Institute and State University, Blacksburg, VA, in 1992. He is currently an adjunct professor at Mississippi State University, University of Puerto Rico, Virginia Polytechnic Institute and State University, and Louisiana State University.

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Randy Nason is a corporate Vice President as well as Manager of the Security Consulting Group with C.H. Guernsey and Company in Oklahoma City, Oklahoma. His experience includes a broad spectrum of the security profession including threat assessment, vulnerability analysis and site surveys through complete system design and construction management. Randy's current clients include the New York City of Environmental Protection, Hoover Dam, Avaya Communication, Frito Lay, the US Army, and the 2002 Olympics. Randy is also serving on a National Academy of Sciences committee to review current security standards for federal facilities.

Randy is widely published on topics affecting security system analysis, design and operation. Recent articles have appeared in *Architectural Record*, *Security Technology and Design* and *The Construction Specifier*. He is a member of American Society for Industrial Security (ASIS) and is a past member of the Board of Directors of the Oklahoma City Chapter of the Building Owner's and Manager's Association (BOMA). He is a past chairman of the ASIS Standing Committee on Security Architecture and Engineering. He has spoken at numerous conferences sponsored by ASIS, as well as the Energy Security Council, the International Association for Healthcare Security and Safety, the Construction Specifications Institute and the Building Owners and Managers Association and Facility Forum.

Randy has Bachelor's and Master's degrees in Nuclear Engineering from Kansas State University. He spent five years at Sandia National Laboratories in Albuquerque, New Mexico as a project leader responsible for identification and resolution of security related issues at Department of Energy nuclear facilities. Randy is a registered professional engineer the State of Oklahoma.

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As the Acting Regional Director of the Federal Emergency Management Agency's Region II Office in New York City, Joseph F. Picciano is responsible to the Regional Director for the day-to-day direction, management and monitoring of all FEMA programs within the Region.

Mr. Picciano has been with FEMA since the Agency's inception in 1979, assigned to the New York Regional Office. He has served as the Hazardous Materials Coordinator, the Chairman of the Regional Advisory Committee (RAC) for Radiological Emergency Preparedness, the Deputy Director of the Emergency Management and National Preparedness Division, Emergency Analyst, Director of the Natural and Technological Hazards Division, and Director of the Mitigation Division.

Mr. Picciano has served in Presidentially-declared Major Disasters and Emergency operations, including flooding disasters in Texas, California, New York and New Jersey; hurricanes in Puerto Rico and the U.S. Virgin Islands; and Hurricane Andrew. He was the recipient of a Meritorious Service Award for his service during the Virgin Islands Hurricane Hugo recovery operation. He has been appointed Federal Coordinating Officer for a number of disaster operations, responsible for the coordination of all Federal assets deployed for response and recovery.

Prior to his service with FEMA, Mr. Picciano worked with engineering consultants in the fields of floodplain management, environmental planning and engineering. Mr. Picciano graduated from Newark College of Engineering in 1971 with a BS in Civil Engineering, and received a Masters Degree in Environmental Engineering from the New Jersey Institute of Technology in 1976.

During the September 11 tragedy Mr. Picciano actively supported the overall response of FEMA providing key staff and facilities and working directly with the Federal Coordinating Officer appointed by the President. Since 9/11 Mr. Picciano has played a lead role in the long-term federal recovery effort has worked to develop impacted residences and mitigation projects protecting against future acts.

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In the 1960's, James H. Redyke began his blasting career under Controlled Demolition, Inc., Baltimore, MD. While in their employ, he participated in the explosive felling of hundreds of structures, shooting thousands of cubic yards of reinforced concrete in a variety of applications throughout the United States. His responsibilities included sales (dealing with contractors, City, State and Federal Officials), advance planning and supervision of structural preparation and engineering layout and placement of explosives (including power plants, refineries, bridge piers and a massive reinforced wall at Metro Station in Washington, D.C.).

Since starting up his own company in 1975, he has become well known in the explosive demolition field using his expertise worldwide. Dykon's experience includes felling of hundreds of buildings, bridges, smokestacks, and industrial structures. His experience includes blasting of thousands of yards of heavily reinforced concrete in various types of exposures (primarily plants, bridges and refineries). Dykon also provides rock drilling and blasting services for construction (utility trenches, mass excavation, and road cuts).

As President of DYKON, Jim's duties are to oversee the overall performances of blasting operations including participation in the design of blasting plans and actual loading of explosives for thousands of structures. Jim is active in many demolition organizations including the Society of Explosive Engineers (National and International), the Ozark Chapter of S.E.E. (Past President), the National Association of Demolition Contractors (having served on the Board of Directors) and many others. He is licensed in all states requiring licenses and many foreign countries. He has worked in Mexico, South Africa, Puerto Rico, Korea, Canada, Saudi Arabia, United Arabic Emirates, England and Aruba.

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Dr. Andrei Reinhorn is conducting research on the seismic evaluation and retrofit of existing structural systems, including building bridges and special structures using conventional and innovative structural control. Dr. Reinhorn has directed many research experiments investigating the behavior of structures under dynamic loads near collapse. Dr. Reinhorn carried pioneering experiments of actively controlled structures and developed design procedures for controlled systems with active or passive damping components. He developed numerous analytical methods for evaluation and analysis of structures in damage state without and with control systems. He has published over 300 technical publications as a result of this research. He has also received many awards for his research and publications.

Dr. Reinhorn has conducted numerous reconnaissance visits to earthquake stricken areas (including, the Northridge earthquake 1994, the Loma Prieta earthquake 1989, the Whittier earthquake 1987 and the 1985 Mexico earthquake), and is a member of numerous technical committees, the ASCE Dynamic Loads Committee and Associate Editor of JSE, the NCHRP Project 12-49 for the development of Comprehensive Specifications for the Seismic Design of Bridges, and corresponding member of BSSC TS2 Subcommittee on Seismic Loads 2003 Edition of the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Others Structures*.

Dr. Reinhorn is the senior Co-Project Investigator for the new $20 million versatile earthquake engineering experimental facility being constructed at the University at Buffalo, as part of the George E. Brown Jr. Network for Earthquake Engineering Simulation (described in more details at *http://nees.buffalo.edu/*).

More information on the presenting author is available at *http://www.civil.buffalo.edu/ Faculty/reinhorn.html*.

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Cruz Russell has directed the Port Authority's Office of Policy and Planning since 1995. In this capacity, he has led the Port Authority's long-range planning process; developed some of the agency's major regional transportation initiatives, environmental and energy policies; and provided the agency and the region with the regional demographic and economic analysis. He has worked extensively on community outreach effort to ensure that Port Authority transportation improvements create benefits for neighboring communicates, with a minimum of negative impacts. He currently serves on the boards of a number of community organizations, including the Business Outreach Center Network of NY, and the Greater Jamaica Development Corporation, and as a member of the North Jersey Transportation Planning Authority, Inc.

Previously, Mr. Russell served as Secretary of the Port Authority, as Assistant Secretary for State Relations, as Manager of Labor Force and Business Development, and as manager of various economic development programs. He received his undergraduate education at Dartmouth College, and his graduate education in urban planning at New York University.

Paul E. Senseny, Ph.D.
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Dr. Senseny manages and conducts experimental and computational research related to natural hazards, fires, explosions and to the thermal and mechanical performance of boilers, pressure vessels, piping and machines.

Dr. Senseny has worked extensively in the area of nonlinear, time-dependent structural and material behavior for over thirty years. He has developed a variety of experimental methods, and has received a US patent for one of these developments. He has made significant contributions in developing constitutive models based on both experimental data and the underlying micromechanics.

Dr. Senseny was Program Manager for the Hard Target Defeat Program at the Defense Threat Reduction Agency and was responsible for developing technologies related to the interaction of munitions with buried structures. Additionally, he served there as the Deputy Chief of the Structural Dynamics Division. He was also Manager of the Materials Laboratory at RE/SPEC, Inc. where he developed a laboratory that measured material behavior at high temperature and high pressure.

Dr. Senseny has authored or coauthored nearly 100 peer-reviewed journal articles, symposia papers, and technical reports. He is a Fellow of the American Society of Mechanical Engineers, former Chairman of a technical committee for the American Society for Testing and Materials, and a member of the American Academy of Mechanics, American Geophysical Union, American Society of Civil Engineers, International Society of Rock Mechanics, Society for Engineering Science, Society for Experimental Mechanics, Earthquake Engineering Research Institute and the Advisory Board for the *International Journal for Numerical and Analytical Methods in Geomechanics*.

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Dr. Smilowitz has over twenty-five years' experience in mathematical modeling and dynamic elastic and inelastic response calculations for ship, satellite, hardened silo, and conventional structures subjected to dynamic shock and vibration loading applied through linear and nonlinear media. He participated in design and analysis of Hardened-silo and conventional structures to resist dynamic shock loading, including advanced aircraft shelter facilities, NATO command center, and candidate basing modes for the MX missile. Dr. Smilowitz analyzed the World Trade Center underground parking garage slabs (B2 & B1) in response to the 1993 bombing and Khobar Towers to terrorist vehicle bomb attack and was a member of the ASCE/FEMA Building Performance Assessment Team to document the course of events and responses of the World Trade Center and surrounding buildings on 11 September. Dr. Smilowitz participated in the protective design and vulnerability study of numerous Federal Courthouses, Federal Office Buildings, Embassy Structures, airline terminals and commercial properties. Dr. Smilowitz provided technical support and advice for explosive testing of full-scale curtain wall mock-ups and full-scale 4 story structures at White Sands Missile Range (WSMR). Dr. Smilowitz participated in the development of a curtainwall response analysis code for protecting structures from terrorist threat and is also the principal developer of the Ship Response to Underwater Explosion (SRUE) and SRUE-BEAM software. Dr Smilowitz is a Registered Engineer in the states of New York and California.

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Mr. Joseph L. Smith is a nationally known security and blast consultant with 21 years of experience in the areas of security engineering and explosion effects from conventional, nuclear and improvised (terrorist) explosions. He holds a BS in Civil Engineering from the United States Air Force Academy and an MS in Civil Engineering from Columbia University in New York City.

Mr. Smith has played a significant role in the U.S. response to the threat of terrorism. Most recently, he has assisted in the development of the GSA Security Criteria, the Interagency Security Criteria and the FAA Security Order 1600.69. In addition, he has led development teams in the creation of new technology and programs such as WINGARD for the GSA and WINLAC for the State Dept. These computer programs are recognized national standards for determining hazards from windows in explosions. Mr. Smith has also led teams in the development of new national progressive collapse guidelines, and has performed large scale explosive testing on numerous products and specimens.

Mr. Smith has directed 42 airport blast analyses and assessments since 9/21/2001. He performed airport blast assessments for some of the major airports in the US since 1995. He has assisted the FAA in the assessment of blast hazards for the National Air-Space System including Air Route Traffic Control Centers, major towers, and the National Network Control Centers. Mr. Smith is currently leading teams in the blast and security risk management assessments of numerous facilities for the GSA and IRS. His current design projects include the new US Mission to the UN in New York City. Mr. Smith has also participated in the assessment and design of nearly 50 U.S. embassies to resist terrorist car bombings. He is the patent holder of the Hardened Baggage Container, developed in response to the downing of Pan Am 103.

Mr. Smith is a well-known speaker. He has presented at: the American Society of Industrial Security (ASIS) National Seminars in 1997, 1998, 1999, 2000 and 2001; the ASIS PacRim Conferences in 1998 and 2001; the GlassWeek 2000 National Conference; the S2K Security Conference; Protective Glazing Council Seminar and Exhibits; the International Symposium on the Interaction of the Effects of Munitions with Structures; and numerous other presentations. Mr. Smith is the author of over 300 technical papers and published works. He is a member of the American Society of Civil Engineers and the Society of American Military Engineers. He serves on the board of directors for the Protective Glazing Council and acts as a technical advisor to the Protecting People First Foundation.

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Mr. Sprague is a Project Manager and Structural Engineer specializing in the areas of Antiterrorist / Force Protection, and seismic engineering. His duties at Black & Veatch include the structural design of critical facilities, assessment of existing facilities, and the repair and rehabilitation of existing structures. Mr. Sprague is a leader in the development of Performance Based Design for structural engineering. He has been responsible for the design of critical industrial facilities, office buildings, schools, and telecommunication facilities. Mr. Sprague's experience includes structural system selection, design and analysis, seismic construction, forensics, repair and rehabilitation of existing structures, and corrosion-resistant construction. He has designed major structures in concrete, steel, wood, aluminum, and composite plastics.

Mr. Sprague has several years of experience in terrorist resistant design, explosion resistant design, force protection, and chemical / biologic weapons of mass destruction. Mr. Sprague has developed projected terrorist threats, and analyzed structures to assess vulnerability. He has participated in several workshops and has lectured extensively on the topic. He is active in the area of explosion resistant design, and serves on the American Institute of Steel Construction "Committee for the Design of Blast Resistant Structures." Mr. Sprague has lectured extensively in the area of terrorist threat and terrorist resistant design.

Mr. Sprague is active in seismic code development. He serves on the Building Seismic Safety Council Provisions Update Committee. He formed and chaired the Technical Subcommittee 13 (TS13) – Nonbuilding Structures. He served as chairman of TS13 from 1975 to 2001. He is currently developing the applications manual for the 2000 Edition, *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*. He has authored articles on seismic design, and he has conducted several seminars for practitioners and graduate university students to develop a better understanding of seismic behavior and seismic design. He also serves on the American Society of Civil Engineers (ASCE) 7 Seismic Task Committee.

Mr. Sprague developed the standards and design criteria for the seismic performance of the nonstructural components for the National Missile Defense project in Alaska. He also assessed numerous facilities in Heidelberg, Germany for the U.S. Army to determine their vulnerability to a terrorist attack.

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Kathleen Tierney is Professor of Sociology and Director of the Disaster Research Center at the University of Delaware. With funding from MCEER and the National Science Foundation, she has been conducting research on the organizational and community response in New York following the attack on the World Trade Center. With over two decades of experience in the disaster field, she has been involved in research on many different disaster events, including earthquakes in California and Japan, floods in the Midwest, and Hurricanes Hugo and Andrew. Her current and recent research projects include studies on public perceptions of the earthquake threat in the Northern California Bay Area, the implementation of FEMA's Project Impact in communities around the US, real-time warning systems for earthquakes, and the business impacts of disasters. Tierney is the author of dozens of articles, book chapters, and technical reports on the social aspects of hazards, disasters, and risk, including articles in *The International Journal of Mass Emergencies and Disasters*, *The Journal of Contingencies and Crisis Management*, *Sociological Spectrum*, *Sociological Forum*, *Natural Hazards Review*, and *Prehospital and Disaster Medicine*. Her publications also include *Disasters, Collective Behavior, and Social Organization* (1994), co-edited with Russell Dynes, and *Facing the Unexpected: Disaster Preparedness and Response in the United States* (2001), co-authored with Michael K. Lindell and Ronald W. Perry. Her recent professional activities include service on a FEMA-sponsored National Institute of Building Sciences panel charged with developing a methodology for assessing the cost-effectiveness of hazard mitigation activities across the U. S., and co-authorship of the US Geological Survey's newly-formulated plan for coordinating post-earthquake investigations. More information on the Disaster Research Center can be found on the DRC web site at *http://www.udel.edu/DRC*.

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Richard L. Tomasetti's 30 years of experience as a structural engineer includes numerous major projects from the design of the World Financial Center in New York to Plaza 66 in Shanghai, the tallest concrete building in China. Currently his firm is Structural Engineer for Boston Properties' Times Square Tower and 5 Times Square, and the world's tallest buildings, the Petronas Twin Towers in Kuala Lumpur, Malaysia.

With more than 500 people in offices in ten states, London, Hong Kong and Shanghai, his firm's three divisions, Thornton-Tomasetti Engineers, LZA Technology and LZA Associates provide multi-disciplinary engineering design and building investigative services throughout the world, including vulnerability analysis and protective design.

Mr. Tomasetti received his B.C.E. degree and an Honorary Doctorate from Manhattan College, and his M.S. degree from New York University and has completed additional postgraduate studies at the University of Connecticut and Polytechnic Institute of New York. Currently he is a member of advisory boards to Manhattan College, Columbia University and New York University.

His numerous honors and awards include the 1999 Concrete Industry Board Leader of Industry Award, Engineering News Records citation "Those Who Made Marks" for developing the "stressed-skin" tube structure for high-rise buildings, and the 2001 Founders Award from the Salvadori Center. He is an active author, lecturer and recognized investigator of structures in distress and has co-authored the book, "Exposed Structures in Building Design."

Active in the development of industry professional standards, Mr. Tomasetti is a Director and Past Vice Chairman of the New York Building Congress, and has been Chairman of the ASCE Committee on Tall Buildings, a member of New York City's Seismic Code Advisory Board, co-author of the ASCE Manual, *Quality in the Constructed Project*, and Vice President of the New York Association of Consulting Engineers, which recently presented him with their 2002 Engineer of the Year Award.

On September 11th, Mr. Tomasetti and his firm were commissioned by the New York City Department of Design and Construction to lead the engineering efforts required for building assessments and search, rescue and demolition operations at the World Trade Center Disaster Site. Mr. Tomasetti is also a member of the recently formed WTC Task Force Structures Working Group to consider appropriate revisions to the NYC Building Code.

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Major Tyboroski manages the Structural Dynamics Branch's specialized assessments program. These assessments are conducted to evaluate the risk to high value installations from potential terrorist threats. Retrofit criteria are developed using computational fluid dynamic codes to define blast loads and assess structural and personnel hazards.

Major Tyboroski has conducted numerous vulnerability assessments in the National Capitol Region and at key U.S. facilities throughout the world. Most recently he completed a comprehensive assessment of the Capitol Hill area including plans for the proposed Capitol Hill Visitors Center. Future projects include an assessment of Port Authority facilities in New York Harbor for the United States Coast Guard.

Major Tyboroski is a registered Professional Engineer in Colorado and holds Master's degrees in Civil (Structural) Engineering from Cal Poly and Civil (Environmental) Engineering from Virginia Tech. He is currently completing work on his Ph.D. at Virginia Tech in the area of risk assessment.

William Wallace
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William (Al) Wallace holds his primary appointment at Rensselaer Polytechnic Institute as professor of decision sciences and engineering systems, and joint appointments in cognitive sciences and civil and environmental engineering; and is research director of Rensselaer's Center for Infrastructure and Transportation Studies. As a researcher and a consultant in Management Science and Information Systems, Professor Wallace has over 25 years experience in and research on the development of decision support systems for industry and government. Professor Wallace has, since 1990, authored and edited 6 books and over 80 articles and papers - out of a total of over 200 archival publications He has held academic positions at Carnegie-Mellon University and the State University of New York at Albany; was Consultant, Board on Infrastructure and the Constructed Environment, National Research Council and Expert, Civil and Mechanical Systems Division, National Science Foundation; was a research scientist at the International Institute of Environment and Society, Science Center, Berlin, Germany and a project engineer at Illinois Institute of Technology Research Institute; was Visiting Professor, at Polyproject: Risk and Safety of Technical Systems, Swiss Federal Institute of Technology, Zurich, and at Systems Engineering and Policy Analysis, Delft University of Technology, Netherlands; and is a Navy veteran. He was selected as a Visiting U.S. Faculty, Management Information Systems, and Decision Support Systems, National Center for Industrial Science and Technology Management Development, Dalian, People's Republic of China. National and international media including Associated Press, Christian Science Monitor and Business Week has reported on his research. His awards include the Institute of Electrical and Electronic Engineers, Fellow and Institute of Electrical and Electronic Engineers, Third Millennium Medal. His educational background includes a B.Ch.E. from Illinois Institute of Technology and a Master of Science and Doctorate in Management Science from Rensselaer Polytechnic Institute.

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Mr. Woodworth is the worldwide manager of IBM's Crisis Response Team and specializes in providing disaster preparedness, mitigation, response, and recovery services in over 100 countries. Brent and his team deliver services to commercial accounts, government agencies, and international humanitarian relief organizations. They have proven their skills in multiple disaster situations worldwide including: floods, earthquakes, tornadoes, hurricanes, fires, ice storms, volcanic eruptions, civil unrest, and acts of terrorism.

Mr. Woodworth is a regularly featured speaker on radio and television broadcasts along with corporate meetings and industry conferences. Brent has written several articles on disaster management and has been a guest lecturer on the subject of disaster preparedness and recovery at colleges, government seminars, and corporate meetings. Brent was appointed to the U.S. Congressional subcommittee for the development of the national pre-disaster mitigation plan, and serves as chairman of the NIBS Multi-hazard Mitigation Council in Washington DC. Brent have worked in partnership with multiple international relief agencies including USAID, UNICEF, UNHCR, UNDP, WHO, WFP, the International Red Cross and many others in responding to over 70 major global disaster events since 1993.

Mr. Woodworth has worked closely with elected officials and heads of state throughout the world in the development and delivery of improved risk identification, disaster management, and global humanitarian relief services. Brent has personally led IBM's on-site efforts in response to disasters in Colombia, Japan, Turkey, Greece, Taiwan, India, El Salvador, Taiwan, South Africa, Kosovo, Rwanda, Venezuela, Ecuador, Peru, and the United States. Brent and his team have received international recognition for their efforts and are considered among the leaders in public / private sector global disaster preparedness partnerships. Brent was named to the Contingency Planning & Management "Hall of Fame" and is a Computerworld Honors "Laureate".

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Rae Zimmerman is Professor of Planning and Public Administration at New York University's Robert F. Wagner Graduate School of Public Service and directs the NSF-funded Institute for Civil Infrastructure Systems (ICIS) and directed the Urban Planning Program. She was President of the Society for Risk Analysis in 1997, an over 2,400 member international, interdisciplinary professional society of scientists, engineers, and social scientists, and prior to that she was President-Elect and Council Member. She is a Fellow of the American Association for the Advancement of Science and the Society for Risk Analysis. Areas of graduate teaching and research include epidemiology, risk assessment and risk management, environmental planning and management, environmental impact assessment and urban infrastructure. The numerous multidisciplinary research grants in those areas she has directed encompass applications to extreme events for environmental and hazardous waste management, industrial and transportation accidents, global climate change, flood plain management, fate and transport of chemicals, and infrastructure such as coal gas sites, transportation and environmental infrastructure. Recent research includes collaborations through ICIS on two dozen 9/11 events, NSF-funded infrastructure vulnerability and performance studies in the context of users and communities, and U.S. EPA funded projects on farmers' attitudes on water quality, social and economic dimensions of inactive hazardous waste sites, and environmental studies for the South Bronx, NY. She has worked professionally on large infrastructure facilities for water treatment, transportation, and waste disposal. Current appointments include: the NAS Army Chemical Stockpile Disposal Program Committee and the U.S. EPA Board of Scientific Counselors and National Drinking Water Advisory Committee's Research Working Group. Selected former positions are: U.S. EPA Science Advisory Board Subcommittee on Residual Risk, National Research Council Board on Infrastructure and the Constructed Environment, and the NYS Comparative Risk Committee, NYS Air Toxics Workgroup, the Risk Science Institute meta-analysis group, and the U.S. Congress Office of Technology Assessment Advisory Panel for "Research on Risk Assessment Methodology for Chemical Carcinogens" study (1992-1993). She authored *Governmental Management of Chemical Risk* (1990). Recent publications are on the performance of urban infrastructure services especially during extreme events (*Journal of Urban Technology*, 2001); global warming impacts on infrastructure (Columbia Earth Institute 2001, NY Academy of Sciences, 1996), and risk methodology (co-author, risks of extreme events in *Risk Analysis*, 1999); risk attitudes associated with agricultural pesticides (*Water Resources Research*, 1999; *Risk Analysis*, 1999; *Agriculture, Ecosystems and Environment*, 1999), meta-analysis for health effects of benzene, dioxins, and formaldehyde (*Policy Studies J.,* 1995) and environmental epidemiology guidelines (*Regulatory Toxicology and Pharmacology*, co-author, 1995); impacts of the 1993 Mississippi Floods (*The Sciences*, 1994); environmental equity

(*Fordham Urban Law J.,*1994; *Risk Analysis,* 1993; chapters in *Fundamentals of Risk Analysis and Risk Management*, 1997 and *Better Environmental Decisions*, 1999); Earlier publications include chapters in books such as *Dimensions of Hazardous Waste Politics and Policy* (Greenwood, 1988), *Public Health and the Environment* (Guilford, 1987), *Risk Evaluation and Management* (Plenum, 1986), *Risk Analysis in the Private Sector* (Plenum, 1985), and *Low Probability/High Consequence Risk Analysis* (Plenum, 1984). Much of this work results from government-funded research. She has been a consultant to U.S. Environmental Protection Agency's Superfund program (Region II) on environmental equity around hazardous waste sites. Prior to that, she was with EPA in water resources management and environmental impact assessment until 1977. Education: A.B., Chemistry, U. of California (Berkeley); Master of City Planning, U. of Pennsylvania; Ph.D., Planning, Columbia University.

Appendix A

Workshop Information

Agenda

Participants

Agenda

Monday, June 24

08:30 - 09:00	Registration - Concourse Lobby
09:00 - 09:15	Welcome/Introduction, Presentation of Workshop Objectives, and General Comments - Co-chairs of Workshop
09:15 - 10:45	How Did 9/11 Help NYC Cope with the Next Disaster?
	Management of Complex Emergencies Perspective Cruz Russell (New York-New Jersey Port Authority)
	Engineering Preparedness Perspective Gene Corley (CTL Group)
	Engineering Response Perspective Daniel Cuoco (LZA Technologies / Thornton Tomasetti Group)
	Break - Concourse Lobby
11:00 - 12:00 noon	<u>Workshop Discussion Session #1</u> Achieving Resilience in the Face of Complex Civil Emergencies Moderator: Kathleen Tierney (MCEER/Disaster Research Center, University of Delaware)
	Overview of Issues Richard Little (National Research Council)
	Local Government Issues; NYS Perspective Edward F. Jacoby, Jr. (New York State Emergency Management Office)
	Local Government Issues; A FEMA Perspective Joseph Picciano (Federal Emergency Management Agency - Region II)
	Owners' Perspective (large management complex) Joseph Donovan (Carr America)
12:00 - 13:00	***Lunch***

A sandwich buffet is provided for those who have pre-registered for the conference. However, the conference venue is conveniently located near 5th Avenue and 34th Street and several fast food options are nearby.

13:00 - 14:15	Session 1 (Continued)
	Security in the Post 9/11 Environment Randy Nason (C.H. Guernsey & Company)
	The Trade-offs of Handling Risk and Resilience David Hadden (ARUP)
	How NYC Adopted Earthquake-resistant Design Codes Richard Tomasetti (Thornton Tomasetti Group)
	Discussion and Resolution of Issues from Session #1
14:15 - 17:00	Workshop Discussion Session #2 The Tools to Achieve Resilience - State-of-the-Art Moderator: Michel Bruneau (MCEER/University at Buffalo)
	Overview of Issues Robert Smilowitz (Weidlinger Associates)
	Strategies and Tools in Blast Engineering Joseph Smith (ARA)
	Strategies and Tools in Earthquake Engineering Andrew Whittaker (University at Buffalo)
	Easiest and Most Difficult Buildings to Implode James Redyke (Dykon Blasting)
	Break
	Anti-terrorism / Force Protection Harold Sprague (B&V Special Projects)
	Advanced Technologies to Achieve Seismic Resilience Michael Constantinou (University at Buffalo)
	Fire-related Issues Paul Senseny (Factory Mutual Global)
	Discussion and Resolution of Issues from Session #2
17:00	Day 1 Adjournment

Tuesday, June 25

08:30 - 08:45	Registration, Coffee - Concourse Lobby
08:45 -12:00	<u>Workshop Discussion Session #3</u> The Tools to Achieve Resilience - The Future Moderator: Thomas O'Rourke (MCEER/Cornell University) Overview of Issues John Crawford (Kazagozian and Case) Performance Based Design for Fire Brian Meacham (ARUP) Performance Based Design in Earthquake Engineering Ronald Hamburger (EQE) Blast-mitigation Program at DOD Frank Tyboroski (DOD) Structural Control Andrei Reinhorn (University at Buffalo) Design of Mission-critical Facilities Robert Bachman (Consultant) ***Break - Concourse Lobby*** Retrofit for Blast Mitigation Effects Reed Mosher (USACE/ERDC) Resilient Design using a Complex Adaptive Systems Approach Gary Dargush (University at Buffalo) Comparison of Building Responses under Blast and Earthquake Loadings; A Case Study George Lee (MCEER/University at Buffalo) Discussion and Resolution of Issues from Session #3
12:00 - 13:00	***Lunch***

The conference venue is conveniently located near 5th Avenue and 34th Street with several nearby fast food options. Lunch will be provided to those who have pre-registered for the conference.

13:00 - 16:30	Workshop Discussion Session #4 The Political, Economic, and Engineering Fusion of Resilience-Enhancing Design Moderator: Richard Little
	Overview of Issues Kathleen Tierney
	Enhancing Resilience of Integrated Civil Infrastructure Systems Rae Zimmerman (New York University, Institute for Civil Infrastructure Systems)
	Response and Recovery Issues Brent Woodworth (IBM)
	How to Prepare for Anything but a Repeat of the Past William Wallace (RPI)
	MCEER Research to Integrate Multidisciplinary Aspects of Resilience Michel Bruneau
	Break
	Implementation of Resilience Daniel Alesch (University of Wisconsin)
	Implementation of an Innovative Design Solution for Blast-effects Mitigation Through Aggressive Multi-lateral Dissemination David Houghton (Myers Houghton & Partners)
	TBD Richard Rotanz (Fire Department of New York City)
	Strengthening Resilience through Remote Sensing Data Fusion: The World Trade Center Example Charles Huyck (ImageCat, Inc.)
	Issues Related to the Adoption of New Design Approaches to Produce More Disaster-resilient Structures James Malley (Degenkolb Engineers)
	Discussion and Resolution of Issues from Session #4
16:30 - 17:00	Closure: Summary of Outcomes Co-chairs of the Workshop

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