# Damage to Buildings at Ground Zero Area and Ancillary Benefits of Earthquake-Resistant Design with Regard to Human-Made Disasters

George Lee, Michel Bruneau
Multidisciplinary Center for Earthquake Engineering Research
Red Jacket Quadrangle, University at Buffalo, Buffalo, NY 14261

Andrei Reinhorn, Andrew Whittaker, Jeff Berman, Gordon Warn
Department of Civil Engineering, University at Buffalo, Buffalo, NY, 14261

## 1.0 Research Objectives

This research project conducted by the Multidiscplinary Center for Earthquake Engineering Research focuses on the collection of the perishable data that can be studied to gain a better understanding how resilience is achieved in both physical, engineered systems and in organizational systems.

This project is therefore divided into two major components respectively focusing on the impact of this disaster on engineering and organizational systems:

(a) Organizational and Community Resilience in the World Trade Center Disaster (research conducted by Kathleen J. Tierney, Benigno Aguirre, James Kendra, Tricia Wachtendorf of the Disaster Research Center at the University of Deleware, and not reported here)

(b) Damage to Buildings at Ground Zero Area. The objective of this effort is to collect preliminary information on the various types of damage suffered by buildings at Ground Zero, including most importantly those that suffered moderate damage from impacting large debris but that remained otherwise standing, and to investigate whether the analytical methods used in earthquake engineering can be used to explain the observed structural behavior. This important work can lead to a better understanding of how to economically enhance the resilience of buildings against terrorist attacks.

## 2.0 Research Plan and Techniques

A subset of the Research Team has conducted two visits to scope the extent of structural damage to buildings in the vicinity of the World Trade Center towers. Extensive damage to buildings surrounding the WTC 1 and 2 towers has resulted from impact of large falling debris. This team identified a few buildings that appear worthy of further possible study and interfaced with MCEER's industry partners to obtain relevant engineering information. Additional visits by members of the team are foreseen to be conducted at a later time, when major reconstruction and repair activities get underway for two buildings identified to be of key interest.

Research activities to date have consisted primarily of field observation with a special emphasis on the collection of perishable data, and preliminary analyses to explain why the observed damage has not triggered more massive incremental collapses in some of the adjacent buildings that suffered major collateral damage. Traditional engineering analyses are considered as well as more advanced design approaches commonly used in earthquake engineering. Alternative damage scenarios are also contemplated to establish the limits of these buildings' blast-resilience.

## 3.0 Progress, Findings, and Benefits of the Research

The mission of MCEER is to help make communities, organizations, and other social units more resilient in the face of earthquakes and other disasters, including those caused by human action. The current research activities contributes to MCEER's mission by attemp ting to use earthquake engineering tools to assess the resilience of buildings to terrorist-induced blasts as well as to impacts from collapsing buildings. This research provides an unprecedented opportunity to develop a deeper understanding of the blast-resilience of structural systems, which can in turn lead to the development of effective measures to significantly enhance this resilience nationwide.

The data collected from the above efforts could also have long term positive impact on research activities on the protection of critical buildings with respect to (1) understanding dynamic loading conditions (including shockwave and temperature) on buildings, (2) collapse (including the changes of material properties due to fire) mechanisms, (3) post-event debris hazards and removal, and (4) development of retrofit strategies for buildings with multiple objectives (earthquake and blast loadings plus fire).

Much activity is currently underway using the collected data. An overview of these preliminary findings will be presented during this FEMA/John Jay Urban Hazards Forum.

Additional information about MCEER is available at http://mceer.buffalo.edu

## Biography of Presenting Author

Michel Bruneau, Ph.D., P.Eng.
Professor, Department of Civil, Structural and Environmental Engineering
Deputy Director, Multidisciplinary Center for Earthquake Engineering Research
State University of New York (SUNY) at Buffalo

| | | |
|---|---|---|
| B. Sc. | Civil Engineering, *Université Laval*, Québec, | 1983 |
| M.S. | Structural Engineering, *University of California, Berkeley, USA*, | 1984 |
| Ph.D. | Structural Engineering, *University of California, Berkeley, USA*, | 1987 |

With specialization in Earthquake Resistant Design.

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 Others Strutures.

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