Awarded Contracts for External Experts to Support the NIST World Trade Center (WTC) Disaster Investigation

Contract No.	Awarded to	Date Awarded
SB1341-06-W-0459	Applied Research Associates	3/31/2006

WTC 7 STRUCTURAL ANALYSIS AND COLLAPSE HYPOTHESES

Under solicitation number SB1341-06-Q-0186, a fixed price purchase order has been awarded to APPLIED RESEARCH ASSOCIATES, INC. (ARA) of Albuquerque, New Mexico:

ARA is an engineering firm founded in 1979 that performs research and design studies for complex defense, security, environmental, transportation, and readiness problems. This study will be managed from the Silicon Valley Office of ARA that specializes in finite element analysis and nonlinear structural dynamics under blast and impact loading, impact and penetration mechanics, failure analysis, and blast effects and the analysis of progressive collapse in buildings. Specific examples of the team's past work include:

- Analysis of the aircraft impact on the WTC towers using explicit finite element analysis to model the dynamic impact loads and resulting progression of damage and component failures in the towers.
- Vulnerability and progressive collapse analyses of buildings for General Services Administration (GSA), including courthouses, embassies, and typical office buildings. ARA engineering services for GSA included development of the "Progressive Collapse Analysis & Design Guidelines for New Federal Office Buildings and Major Modernization Projects."
- Studies of progressive collapse and the effects of blast on buildings for the United States Department of Defense (DoD). ARA services included development of the "Unified Facilities Criteria (UFC) – Design of Buildings to Resist Progressive Collapse" for the DoD.
- Studies on both static and dynamic buckling and collapse of structures. Scope included development of explicit nonlinear finite element methodologies for prediction of buckling loads.
- Studies on the degradation and failure of structures subjected to localized thermal loading. Evaluation of combined effects of material degradation and geometric changes resulting from dynamic temperature profiles.

ARA will conduct analyses, in collaboration with NIST, to determine the location and cause of the initiating event (i.e., the first component or group of components that failed) that led to global collapse of WTC 7. The analyses will determine the series of component and subsystem failures subsequent to the initiating event that led to global collapse that are consistent with observations from video and photographic records and other evidence. NIST will conduct all fire analysis of the building and analysis of the structural response to fires in-house and supply ARA initiating event data based on the in-house analyses.

ARA will conduct nonlinear dynamic collapse analyses using LS-DYNA that include analyses of detailed full floor models and global models. The detailed floor analyses will determine likely modes of failure for Floors 8 to 46 due to failure of one or more supporting columns (at one or more locations), and aid the development of a more coarse model for use in the global analyses that captures essential behaviors and failure mechanisms. Two types of global analyses will be conducted. Sensitivity studies will be conducted to determine the response of WTC 7 to various scenarios of initiating events. Final analyses will support

the determination of the location and cause of the initiating event, by incorporating data from NIST for simulating the initiating event, as well as the location and cause of subsequent failures that led to global collapse. The specific tasks that ARA will perform include:

1. Conduct detailed analyses of floor components and subsystems with appropriate steel and concrete constitutive models.
2. Determine the floor response to gravity loads for up to twenty initiating event scenarios
3. Develop an equivalent representation of the tenant floors for the global model.
4. Conduct global analysis under service gravity loads to determine the structural response of WTC 7 to different initiating events, including characterization of the load redistribution within the structural system for two states of damage from debris impact.
5. Conduct a sensitivity study to determine the global structural response to gravity loads for up to twenty initiating event scenarios
6. Conduct final global analyses that simulate up to five initiating events and the subsequent failure sequences up to the point of global instability.

The team from ARA has expertise and experience in failure analysis, nonlinear structural analysis, damage of steel and concrete structures, progressive collapse analyses, nonlinear constitutive and damage modeling, analysis of structures subjected to thermal loads, and blast effects on structures. The team will be led Dr. Steven W. Kirkpatrick. Select experience of key project personnel is summarized below:

- Dr. Steven W. Kirkpatrick is the program manager for this project. Dr. Kirkpatrick is a Principal Engineer with 21 years of experience in structural dynamics, failure analysis, finite element analysis, impact and penetration mechanics, and vehicle crashworthiness. He has more than 40 publications in these areas. His research experience includes a wide range of government and commercial projects for rail, highway, civil, military, and aerospace applications. He has been a program leader for many studies requiring close collaboration between experimental and computational efforts with emphasis on model validation. Dr. Kirkpatrick was previously the PI for the ARA participation in the NIST WTC investigation in performing the aircraft impact analyses. Dr. Kirkpatrick has a doctorate in mechanical engineering from Stanford University.
- Dr. Robert Bocchieri, Principal Engineer, will provide expertise in nonlinear dynamic finite element analysis, solid mechanics, materials constitutive modeling, rate-dependent material behavior, fracture mechanics and failure analysis, mechanics of composite materials, and structural dynamics. Dr. Bocchieri has a doctorate in aerospace engineering from the University of Texas at Austin.
- Mr. James Brokaw, Senior Security Engineer and Director of the Security Engineering Group, will provide expertise in the analysis of progressive collapse in buildings. He has served as the lead consultant for numerous projects of national significance subject to terrorist threats and assisted in the development of GSA's progressive collapse analysis and design guidelines. Mr. Brokaw has a Master's Degree in civil engineering from West Virginia University.
- Mr. Robert MacNeill, Senior Engineer, will provide expertise in finite element analysis (FEA) and thermal analysis. Mr. MacNeill is an experienced user of LS-DYNA, having implemented many advanced features of the code and is skilled at constructing complex parametric finite element models designed to easily interface with simulation based design (SBD) systems and design databases. Mr. MacNeill has a Master's Degree in mechanical engineering from the Rochester Institute of Technology.
- Mr. Brian Peterson, Senior Engineer, will provide expertise in nonlinear dynamic finite element analysis, impact and penetration mechanics, solid mechanics, materials constitutive modeling, fracture mechanics, and failure analysis. Mr. Peterson has experience in testing of materials and structures and has extensive experience with advanced features of LS-DYNA. Mr. Peterson has a Master's Degree in mechanical engineering from Stanford University.