Minutes of October 28, 2003, Workshop to Review Reference Structural Models of the WTC Towers Developed by LERA - Gaithersburg, Maryland

On October 28, 2003, a workshop for NIST investigators and contractors was conducted to review the reference structural analysis models of the WTC towers developed by the firm of Leslie E. Robertson and Associates, Inc. (LERA); the firm responsible for the structural engineering of the WTC towers. The workshop attendees included:

- Mr. William J. Faschan and Mr. Richard B. Garlock of LERA
- Mr. William F. Baker and Mr. Robert C. Sinn of Skidmore, Owings & Merrill (SOM), retained by NIST as the third-party reviewer for the deliverables from the LERA contract
- Dr. Shankar Nair of Teng & Associates, retained by NIST as an outside expert on probable structural collapse
- Professor Kasper Willam of the University of Colorado at Boulder, retained by NIST as an outside expert on thermal-structural analysis
- Professor David M. Parks of MIT, retained by NIST as an outside expert on computational mechanics for aircraft impact analysis
- Dr. Steven Kirkpatrick and Mr. Brian Peterson of Applied Research Associates (ARA), retained by NIST as a contractor on analysis of aircraft impact into the WTC towers
- Key NIST investigators

In addition, members of the National Construction Safety Team Advisory Committee were all invited to the workshop.

Dr. Fahim Sadek, Leader of Project 2 on Baseline Structural Performance and Aircraft Impact Damage Analysis, started the workshop by welcoming and introducing all the attendees to the meeting. Dr. Sadek then provided a brief overview of the status of the LERA contract that includes the development of the structural databases and reference structural models and finally the baseline analysis. He also outlined the review process of the reference models that includes an in-house review by NIST and the independent third-party review by SOM. Finally, he explained that these models will be used as a reference for more detailed models to be developed for Projects 2 (aircraft impact and analysis) and 6 (thermal-structural response and collapse initiation analysis).

Dr. Sadek then turned the floor over to Dr. S. Shyam Sunder, Lead Technical Investigator, of NIST for his remarks. Dr. Sunder emphasized the importance of this workshop, which he described as a key meeting for ensuring that the models that are being developed are accurate, free of any biases, and capture the intended behavior of the WTC towers.

After Dr. Sunder's remarks, Mr. William J. Faschan and Mr. Richard B. Garlock of LERA provided a series of presentations on the development of the reference structural models of the WTC towers. Each presentation was followed by a question and answer period. The following is a summary of each presentation:

First Presentation

The first presentation was an overview of the structural system of the towers as well as the structural design documents including the large-size drawing sheets and the drawing books. The presentation covered the major structural systems in the truss-framed and beam-framed floors along with the global system of the towers, including exterior walls, core columns, bracing, and hat trusses. The presentation also provided a quick summary of the structural databases that were developed as the first task of this project. The following summarizes the discussion afterwards:

NIST: What was the thought behind the hat truss? If it was not for the antenna, would the hat trusses have been built? At which stage in the design process was the hat truss introduced?
LERA*: The hat truss was conceived originally as a form of safety net. That is, under the unlikely circumstance that the as-measured stiffness characteristics of the towers proved to be significantly different from the stiffness characteristics determined by analysis, the hat truss was to be constructed. This was a matter of a verbal understanding between Malcolm P. Levy (of PANYNJ) and Leslie E. Robertson.

Accordingly, the hat truss was not included in the original construction documents. Instead, throughout the period of the construction, the natural frequencies of oscillation were measured so as to determine, experimentally, the stiffness characteristics of the structural systems. These experimental determinations matched well the theoretical values. It followed that, until the arrival of the need for the antenna mast, there was no plan to incorporate the hat trusses. With the realization that the antenna mast was to be a part of the work, the hat trusses were then incorporated into the design. At the time of the decision to incorporate the hat trusses, structural steel work had progressed significantly, thus complicating the design.

The hat truss for the North Tower was designed to support one central antenna mast. The hat truss for the South Tower was designed to support either: (1) a single antenna mast more or less identical to that to be incorporated into the North Tower; or (2) four antenna masts, each smaller than the single antenna mast of the North Tower, but the foursome creating an overturning moment and a base shear, both smaller than the overturning moment and the base shear for the single antenna mast of the North Tower.

As an aside, circa 1965, we incorporated a hat truss in the corporate headquarters building for the United States Steel (USS) Corporation. That hat truss for USS is of the same scale as that incorporated into WTC.

NIST: For the column reinforcing at floors 98 to 106 of both towers, why was that modification done? When was the strengthening done, before or after tower occupation?
LERA*: Core column reinforcing was performed on Columns 508 and 1008 for Tower B from Floors 45-98. This work was performed for a tenant renovation which requested a bank vault on the 98 Floor. The core column reinforcing for Floors 98-106 was issued 1 December 1971 and subsequently installed in both towers. The columns were 501, 508, 703, 803, 904, 1002, 1007, and 1006. We are continuing to research this question and will send additional information as it becomes available.

NIST: Was the inclination of the end diagonals for floor trusses dictated by the length of the viscoelastic damper?

* Answer was provided after the meeting.

LERA*: At the exterior wall, the inclination of the end diagonals of floor trusses was our judgment call associated with our best estimate of possible future requirements for mechanical, electrical, and plumbing (MEP). The length of the viscoelastic damper was only one factor in the parameters leading to a decision.

NIST: How were two adjacent floor truss panel connected?
LERA*: Book 7 provides the contract document information for the truss floor panels, truss elevations, and details. The notes and elevations provide a combination of detailed connections and undetailed connection requirements (i.e., connections forces). Details provided in Book 7 indicate a combination of field welded and field bolted connections for the trusses and bridging crossing the panel joints. We find that the Laclede shop drawings for the floor panels (e.g., FP A1C, FP BR1C, etc.) indicate connections between panels (e.g., details 7C, 2C, etc., found in the CD2XX drawings) which are consistent with the contract document notes and information provided in Book 7 Detail 7-AB-16.

NIST: When did the structural renovation book stop?
LERA*: The structural renovation book was an in-house document where tenant renovations requiring structural work performed by us were noted. This document does not include tenant work performed by others and is not exhaustive for our own work. It was one of several tools that one could review to understand the history of a given floor. We find that the most recent annotation to the book was June 2001.

Second Presentation

The second presentation included the development of the floor models using SAP2000 software. The presentation provided details on the selection process of a typical truss-framed floor and a typical beam-framed floor in the expanded impact and fire zones of the towers by reviewing and identifying structural similarities among the various floors. Floor 96 of WTC 1, selected as a typical truss-framed floor, was then presented. The major components of the model were discussed, including primary trusses, bridging trusses, concrete slab, and strap anchors. Next, Floor 75 of WTC 2, selected as a typical beam-framed floor, was presented. The major components of the model were described, including composite beams, beam reinforcement, concrete slab, and horizontal trusses. Finally, 1/4 floor models for the extended impact zone floor models (floors 89-193 of WTC 1 and 74-88 of WTC 2) were presented. The presentation also described the initial verification of floor models. The following summarizes the discussion afterwards:

SOM: How accurate is the assumption that the concrete slab and the upper chord of the truss are modeled at the same plane?
LERA: The approach that was taken is to model the floor slab and the upper chord at the level of the neutral axis of the combined slab and upper chord. A rigid link was used to connect the upper chord to the slab at the location of the knuckle. We believe that this is a reasonable assumption.
NIST: We will compare the response of this model to the floor model of the floor trusses developed in Project 6.

SOM: The fact that the concrete slab between the knuckles is not connected to the upper chord means that there is no transfer of bending moment to the upper chord.
LERA: That is correct.

NIST: How was the decision made to use dampers in the towers?
LERA: It started with the need to eliminate core partitions (use gypsum partitions instead of typical blocks). That created a need for increasing damping in the towers, and hence the decision to use dampers.

Third Presentation

The third presentation dealt with parametric studies to support the development of the towers' global models. These included typical exterior wall panels, typical corner panels, and flexible floor diaphragm modeling. In all these models, simplified (less detailed) models were obtained from detailed models by tuning the parameters of the simplified models to match the behavior of the detailed models. The following summarizes the discussion afterwards:

SOM: The analysis for the exterior wall panel considers only lateral loading. We should also look at the behavior of the panel under vertical loading because the frame element modeling may result in a softer representation of the vertical stiffness of the panel.
LERA: Agree.

NIST: Why did you straighten the model of the corner panel?
LERA: That was done to simplify the analysis and isolate the behavior of interest under lateral loading.

Fourth Presentation

The last presentation provided details on the global models of WTC 1 and 2. The models include the following parts: core columns, exterior wall (foundation to floor 7), exterior wall trees (floors 7 to 9), exterior wall (floors 9 to 106), exterior wall (floors 107 to 110), hat trusses, and rigid and flexible diaphragms representing the floor systems. The presentation included modeling assumptions and initial verification of the models. The following summarizes the discussion afterwards:

NIST: The estimated natural periods seem to be longer than expected, indicating the model is more flexible than it should be.
LERA: These estimates are preliminary. The structural mass was estimated using loads obtained from the original structural drawings and distributed equally along the height of the tower. The eigenvalue modal analysis will be repeated once we have realistic estimates of the gravity loads as part of the baseline analysis.

NIST: Did you look at the stiffness of the corner panels and its effect on the response of the towers under wind loading?
LERA: That will be considered in the baseline analysis.

NIST: How accurate is the rigid floor diaphragm modeling?

LERA: We believe it provides for accurate representation of the behavior of the floors away from the levels with bracings or hat trusses.
SOM and Teng: That is typically done in practice. We feel comfortable with this assumption.

Summary

Dr. Sunder asked the experts and contractors to comment on the models that were developed by LERA. All participants indicated that they are pleased with the effort and feel that the models, in general, are a faithful representation of the towers' behavior and are suitable for the purpose of the baseline analysis. Examples of these responses include:

Teng & Associates: I feel comfortable with the modeling effort that was presented today. For the global models, that is similar to what we do for design purposes. The floor models and parametric studies are beyond what we typically do in practice.
SOM: We are comfortable with what LERA has done. LERA needs to look into the axial stiffness of the exterior wall panels in the global models and also compare the floor truss model with the detailed model that has been developed by NIST.

At the end, Dr. Sadek thanked all the participants and outlined the next steps for the project, which include completion of the SOM third-party and in-house NIST reviews that would include the feedback from this workshop. The results of the review will be reported to LERA for modifying the models. After implementation of the review comments, the models will be approved by NIST, and the NIST-approved reference models will be used for the baseline analysis of the towers, as the final phase of this project.