Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Project #3: Analysis of Structural Steel

Update

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Project 3 Tasks

- Task 1 - Collect and catalog physical evidence
- Task 2 - Document failure mechanisms and damage
- Task 3 - Determine metallurgical and mechanical properties (RT, high temp., high strain rate)
- Task 4 - Correlate specified properties with measured properties
- Task 5 - Characterize thermal excursions of steel
- Task 6 - Prepare final report

Addressed Today:

1. Task 4 - Correlate specified properties with measured properties
2. Task 5 - Characterize thermal excursions of steel
3. Findings
4. Investigation issues associated with Project 3

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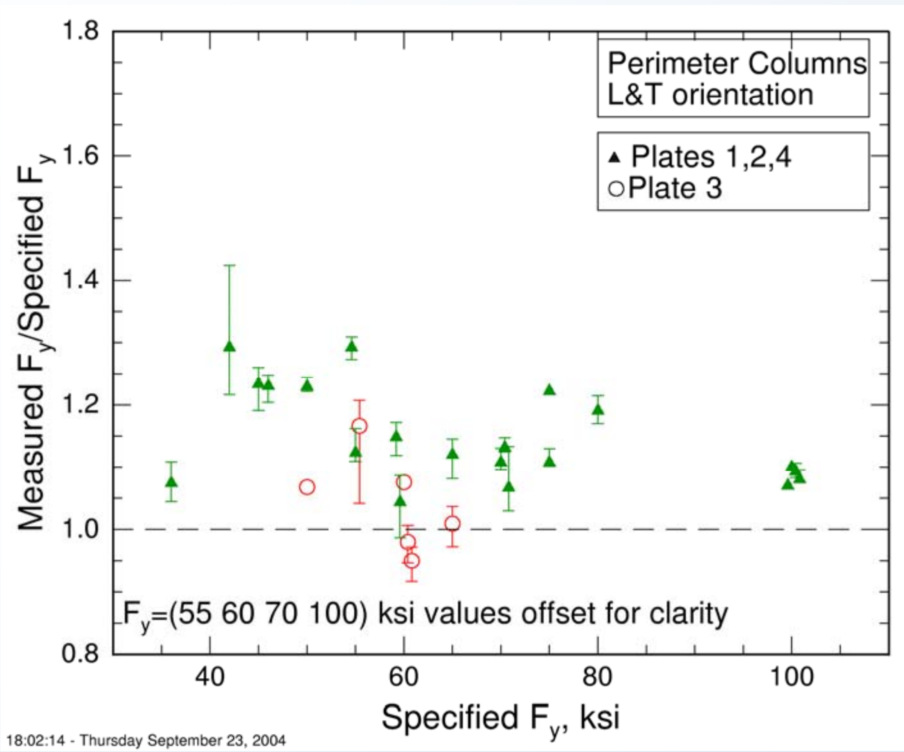
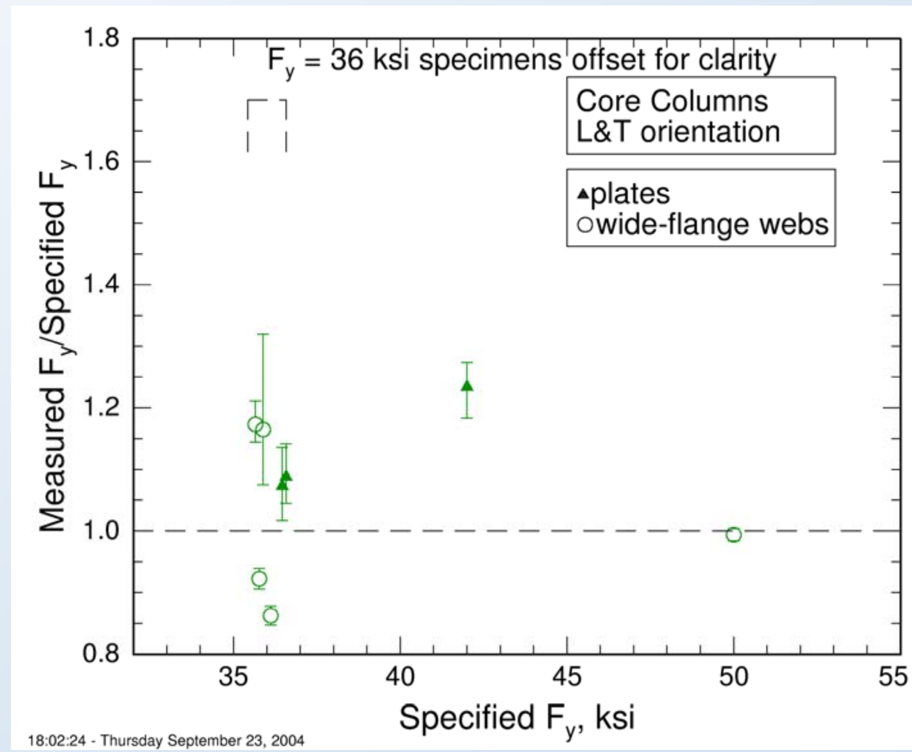
Task 4 - Correlate specified properties with measured properties

Perimeter Columns

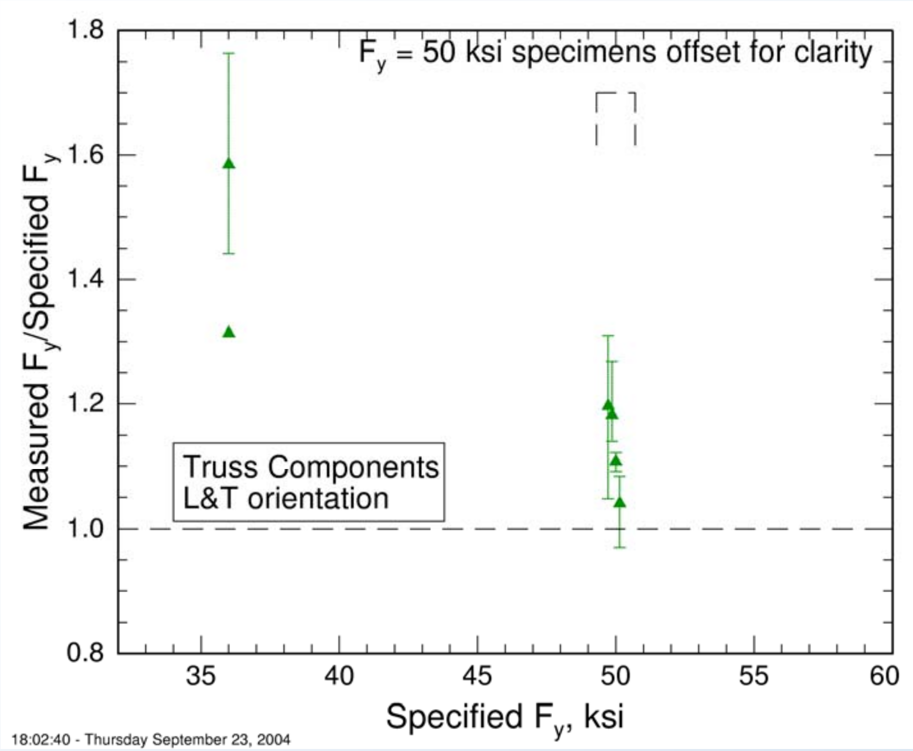


Core Columns

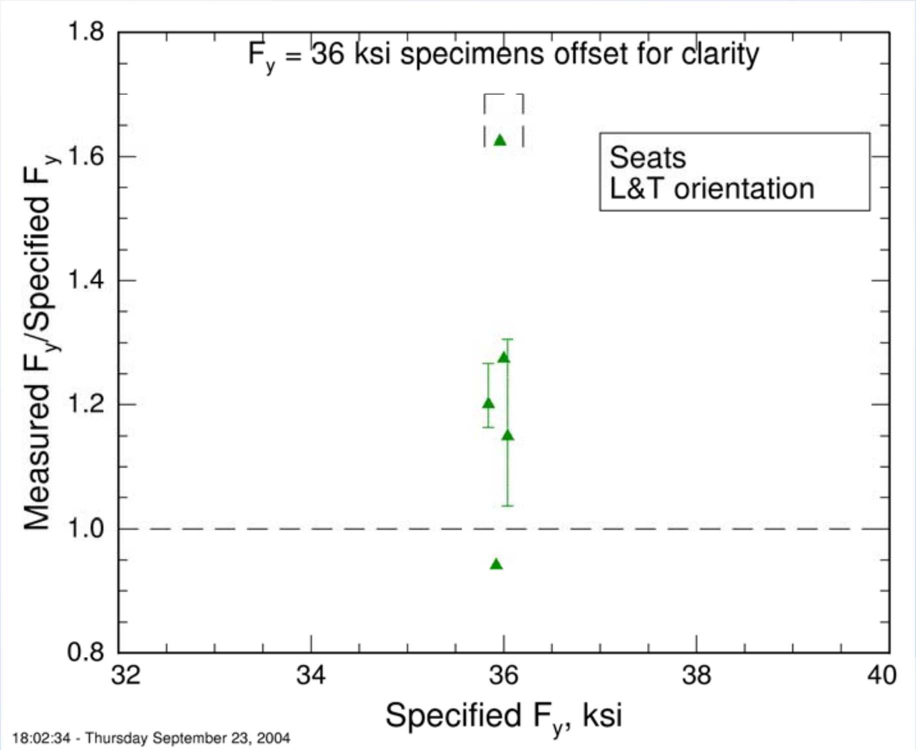


Task 4 - Correlate specified properties with measured properties

Floor Truss Components



Truss Seats



Task 4 - Correlate specified properties with measured properties

Conclusions – Room Temperature Strength

- **~87% of tests exceed required minimum yield strength ~13% of test results on the damaged steel did not meet the required minimum yield strength. This distribution not unexpected, considering:**
  - Change in test procedure from mill tests could account for 2-3 ksi
  - Loss of yield point due to damage to steel accounts for 2-4 ksi in several cases
- **Wide flange core column property distribution lower than expected from historical data; other component distributions consistent with historical data**
- **Observed distributions are accounted for in typical design factor of safety for allowable stress design.**

Task 5 - Characterize thermal excursions of steel

June 2004 presentation:

Photographic study

- Recovered panels mapped for pre-collapse exposure to fire

Paint study

- Paint condition used to map upper limits to temperature exposure on 21 perimeter panels

➔ Most perimeter panels (157 of 160 locations mapped) saw no temperature T > 250 °C, *despite pre-collapse exposure to fire on 13 panels*

Today:

- Conventional metallographic study of coarsening of carbide phases
- Correlation with fire model results

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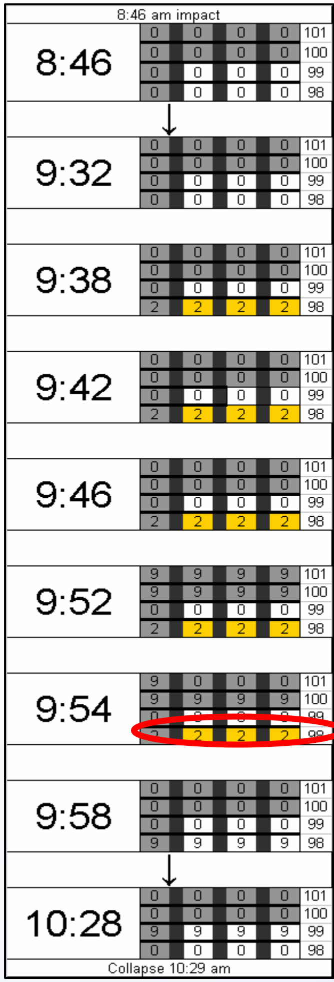
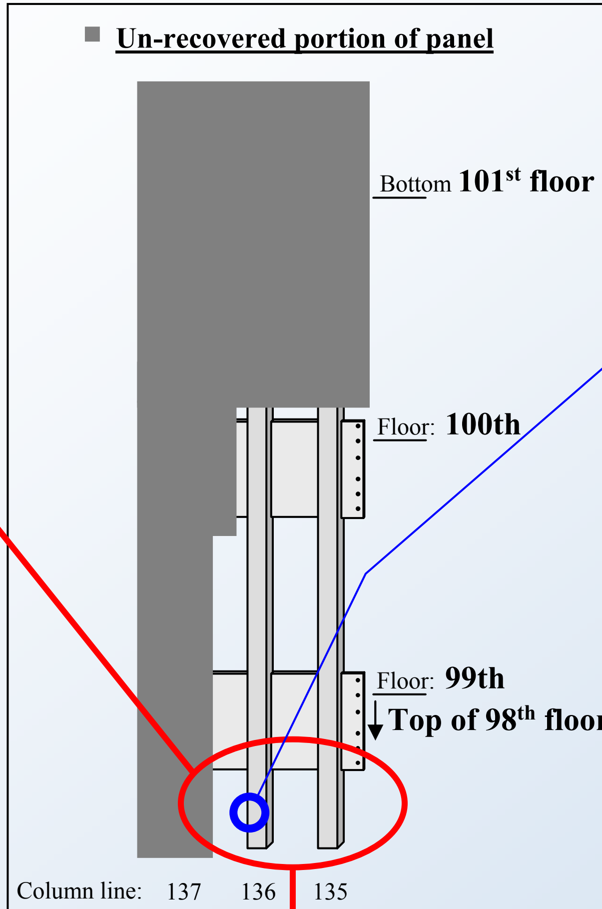


External flaming	3
Fire inside	2
Spot fire	1
No fire evident	0
No determination	9
Unrecovered portion of panel	#

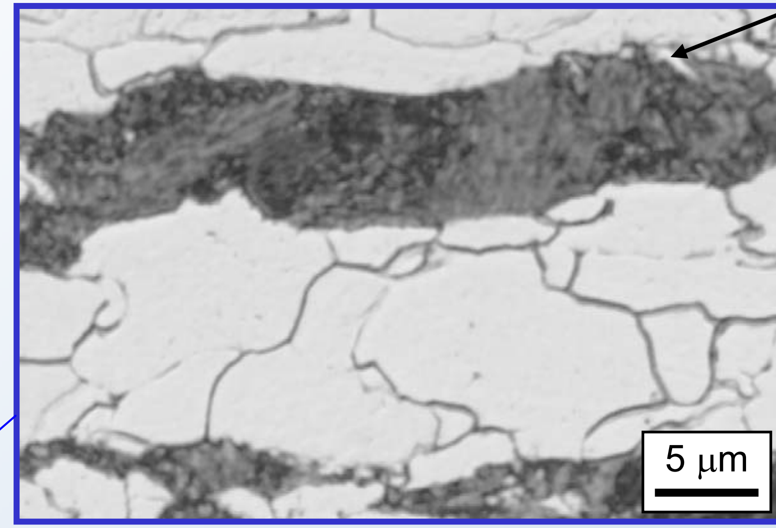
NIST Name: C-40
Panel ID: A136: 98-101
Panel location: WTC 1, north face
Window lines: 34-37



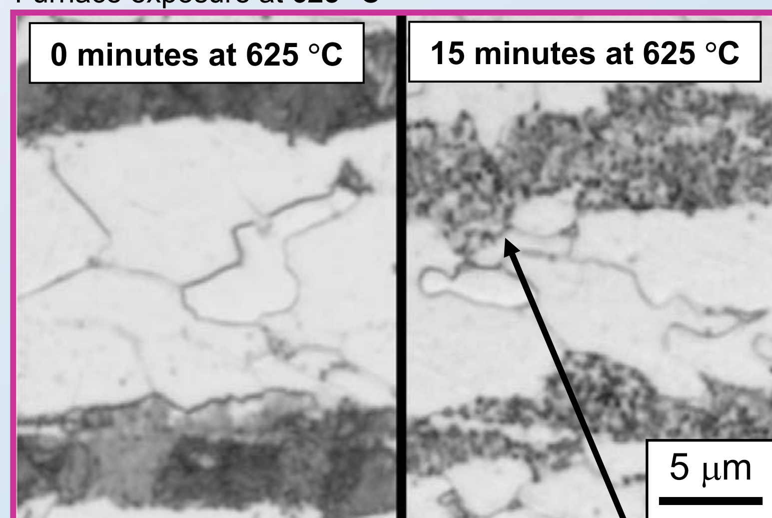
fire exposure:
16 minutes minimum

Sample location: WTC1, column 136, 98th floor
-Column with Fy = 60 ksi
-No mud cracking of paint

Cementite as *plates*



Laboratory exposed sample: WTC1, column 126, 97th floor
- Similar column with Fy = 60 ksi, no mud cracking
- Furnace exposure at **625 °C**



Cementite has begun to *spheroidize* after 15 min exposure

Task 5 - Characterize thermal excursions of steel

Summary of metallographic analysis – Perimeter Columns

- For all perimeter column flanges, outer webs, and spandrels with Fy = 55, 60, and 65 ksi
  - 136 distinct samples (many from the fire floors) evaluated with no spheroidization observed, and thus no significant steel temperatures over 625 °C.

Conclusions

Paint and metallographic analysis →

Exposure to fire does not necessarily lead to high temperatures in insulated steels

Fire model

- Detailed comparison with paint results underway
- Model predicts temperature in Plate 3 (inner web) to be maximum of 200-350 °C when fire proofing (1 3/16”) intact; Spandrels, with 0.5” fire proofing, maximum 450 °C

Task 5 - Characterize thermal excursions of steel

Summary of metallographic analysis – Core Columns

- Two core columns in impact area with sufficient paint
- Columns 603 (floors 92-93) and 605 (floors 98-99)
- Paint analyses indicate both columns < 250 °C

Consistent with:

Impact model results

- Col 603 (fl 92-93) and 605 (fl 98-99) - Fire proofing intact

Fire and thermal/structural models

- Col 603, floors 92 and 93
  - no significant fires near
  - peak temperature of approximately 100 °C
- Col 605 on floor 98
  - some surrounding fire
  - peak temperature less than 200 °C

Findings – Steel inventory

- 236 recovered pieces have been cataloged
  - pieces from the impact and fire region
  - perimeter columns
  - core columns
  - trusses
  - other pieces such as truss seats and wind dampers.
- 14 grades (i.e., strengths) of steel were specified in the structural engineering plans, but only 12 grades of steel were actually used in construction due to an upgrade of two grades
- Ten different steel companies fabricated structural elements for the towers, using steel supplied from at least eight different suppliers. Four fabricators supplied the major structural elements of the 9th to 107th floors
- The original, as-built location for many of the pieces was identified.

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Findings – Steel inventory

- NIST has examples of:
  - the many grades of perimeter columns and spandrels,
  - the 2 grades of wide-flange and built-up box core columns (representing 99% of the core columns),
  - the two grades of steel in the floor trusses, and
  - examples of core and perimeter truss seats.
- The collection of steel is considered adequate for the needs of the investigation

Findings – Forensic assessment

- Of the more than 170 areas examined on the exterior panels, only three locations had a positive result indicating that the steel may have reached temperatures in excess of 250 ºC.
- Severing of perimeter columns tended to occur at internal stiffener or diaphragm plate (associated with the spandrel connection).
- The perimeter columns impacted by the airplane experienced a higher frequency of base plate fracture near welds as opposed to those outside of the impact zone.
- Perimeter columns exposed to fire had a great tendency for local buckling of the inner web.
- Welds on perimeter columns appeared to perform as intended. Analysis of base plate fracture near welds indicate that the type of joining method, materials, welding procedures were appropriate.
- All recovered WTC 1 perimeter truss seats below the 96 floor were deformed downwards; above this floor deformation was random.

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Findings – Mechanical Properties

The steel used in the construction of the World Trade Center towers met the expectations of the designers and the specifications called for in the steel contracts. Material substitutions of higher strength steels were common in the perimeter columns and floor trusses.

Furthermore, most mechanical test results were consistent with values expected based on the historical literature. Exceptions include:

- Yield strengths of undamaged steels in rolled wide-flange core columns were lower than historical literature indicates as typical.
- The recovered bolts were stronger than contemporaneous literature indicates.
- *Design factors of safety in typical design are able to account for such variations*

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Investigation issue associated with Project 3

Under *Structures and Materials – Materials*

- **Evaluation of presently available fire-resistant steels**
- **Comparison of fire-resistant steels with conventional steels, and**
- **Test protocols and acceptance criteria for fire-resistant steel**

The issue of the use of fire-resistant steel was inspired by the use of performance-based standards for fire protection in Japan and Europe.

Thank you

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