

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

**National Construction Safety Team  
Advisory Committee Meeting**

**Project 6 – Standard Fire Tests of  
WTC Tower Typical Floor Construction**

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# Purpose of the Standard Fire Tests\*

- ❑ To establish the baseline performance of the floor system of the WTC towers as they were originally built,
- ❑ To differentiate the factors that most influenced the collapse of the WTC towers as they may relate to normal building and fire safety considerations and those unique to the terrorist attacks of September 11, 2001, and
- ❑ To study the procedures and practices used to accept an innovative structural and fireproofing system.

\* ASTM E 119 - Standard Test Methods for Fire Tests of Building Construction and Materials

# Factors Studied

- ❑ Fireproofing thickness
  - 1/2 in. “as specified”
  - 3/4 in. “as applied”
- ❑ Scale of the test
  - Full-scale (35 ft span)
  - Reduced-scale (17 ft span)
- ❑ Test restraint conditions
  - Restrained
  - Unrestrained

# Test Conditions

| <b>Test</b> | <b>Span</b> | <b>Thermal Restraint</b> | <b>SFRM Thickness</b> |
|-------------|-------------|--------------------------|-----------------------|
| 1           | 35 ft       | Restrained               | 0.75 in.              |
| 2           | 35 ft       | Unrestrained             | 0.75 in.              |
| 3           | 17 ft       | Restrained               | 0.75 in.              |
| 4           | 17 ft       | Restrained               | 0.5 in.               |

# SFRM Thickness

## Thicknesses of SFRM – original construction:

### ❑ “As Specified” = 0.5 in.

- Letter dated October 30, 1969 from Robert J. Linn (Manager, Project Planning, The World Trade Center) to Mr. Louis DiBono (Mario & DiBono)

### ❑ “As applied” = 0.75 in.

- Determined from thickness measurements of the existing fireproofing on floors 23 and 24 of WTC 1 - performed by the Port Authority in 1994

## Thickness of SFRM - “upgraded” (since 1995)

### ❑ “As specified” = 1.5 in.

- PANYNJ white paper titled “Fireproofing Requirements for World Trade Center Tenant Floor Joist Construction that Requires Installation Due to Asbestos Removal or Local Removal to Facilitate Construction,” August 1995.

### ❑ “As applied” = 2.5 in.

- Determined from thickness measurements – PANYNJ Construction Audit Reports for floors affected by fire

# SFRM Application

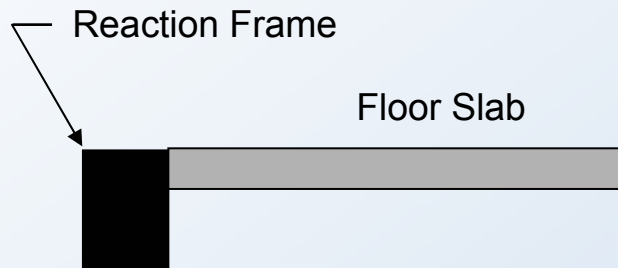
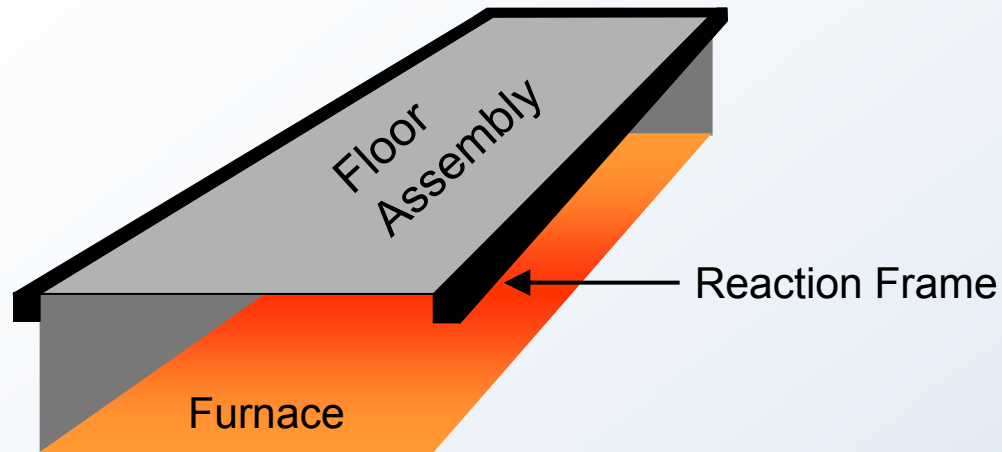
SFRM was applied as follows:

- ❑ “As applied” = 0.75 in. (Tests 1 to 3)
  - Applied to main trusses
  - Applied to bridging trusses at one half thickness
  - Not applied to metal deck but overspray allowed
- ❑ “As specified” = 0.5 in. (Test 4)
  - Applied to main trusses
  - Not applied to bridging trusses
  - Not applied to metal deck

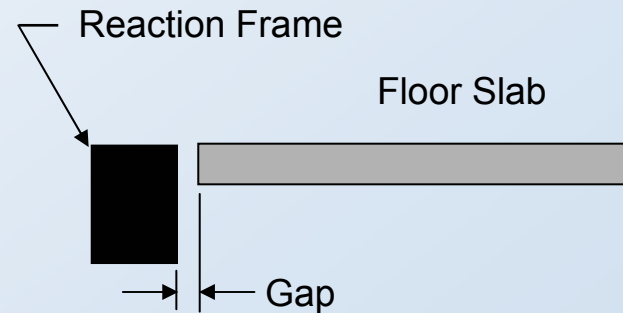
# WTC Tower Floor Truss Fireproofing



# Effect of Restraint Against Thermal Expansion



Restrained Test Condition



Unrestrained Test Condition

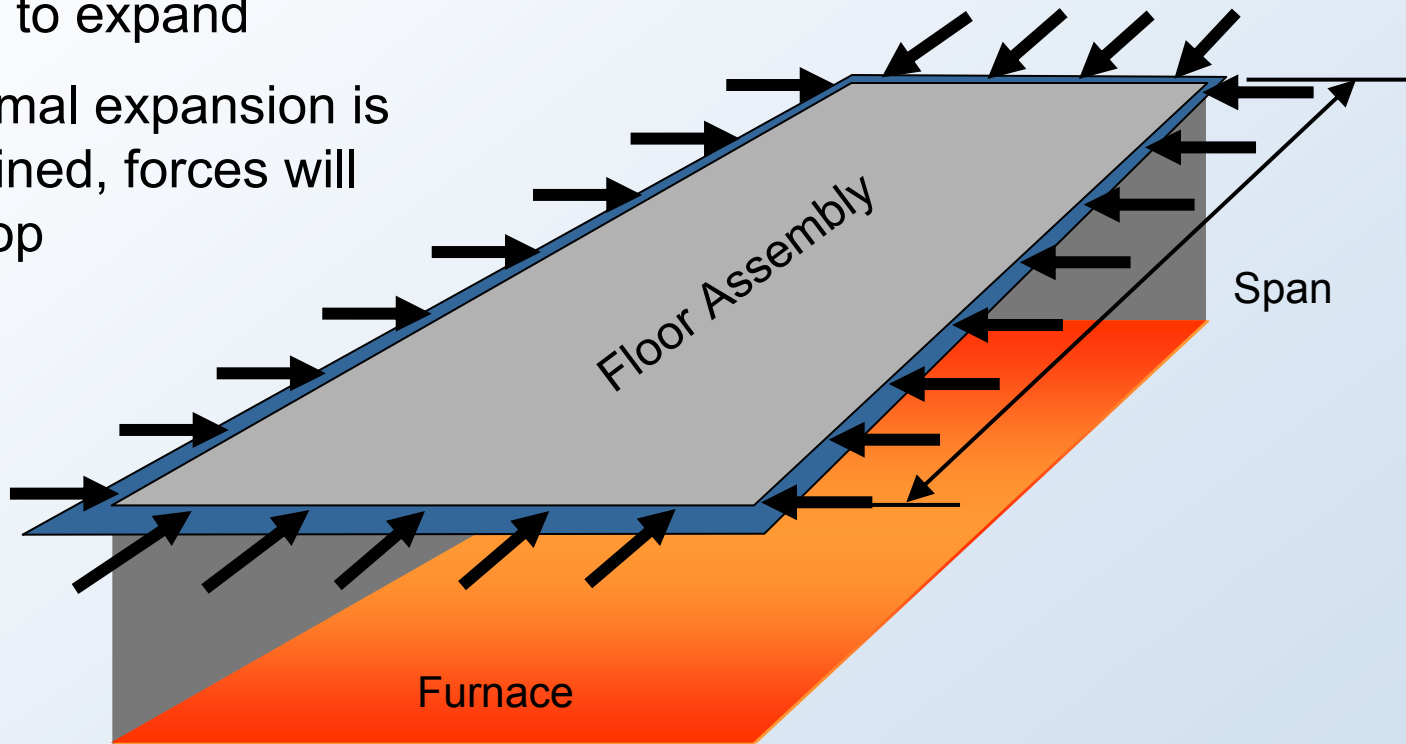


# Effect of Restraint Against Thermal Expansion

Floor assembly is subjected to fire conditions

Heated floor assembly wants to expand

If thermal expansion is restrained, forces will develop



# Standard Methods of Fire Tests of Building Construction and Materials

## ASTM Designation: E 119-61

- The ASTM E 119 - 61 conditions of acceptance address the following:
  - Resistance to passage of flame
  - Resistance to the transmission of heat through the floor
  - Structural soundness of the construction

# Standard Methods of Fire Tests of Building Construction and Materials

## ASTM Designation: E 119-00

### Conditions of Acceptance - Restrained Assembly Test

- ❑ In obtaining a restrained assembly classification, the following conditions shall be met:
  - The specimen shall have sustained the applied load during the classification period without developing unexposed surface conditions which will ignite cotton waste.
  - Transmission of heat through the specimen during the classification period shall not have been such as to raise the average temperature on its unexposed surface more than 250 °F (139 °C) above its initial temperature.

# Standard Methods of Fire Tests of Building Construction and Materials

## ASTM Designation: E 119-00

### Conditions of Acceptance – Restrained Assembly Test

- ❑ In obtaining an unrestrained assembly classification, the following conditions shall be met:
  - For specimens employing steel structural members (beams, open-web steel joists, etc.) spaced more than 4 ft on centers, the temperature of the steel shall not have exceeded 1300°F (704°C) at any location during the classification period
  - nor shall the average temperature recorded by four thermocouples at any section have exceeded 1100°F (593°C) during the classification period.

# Standard Methods of Fire Tests of Building Construction and Materials

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# Design of Reduced-Scale Tests

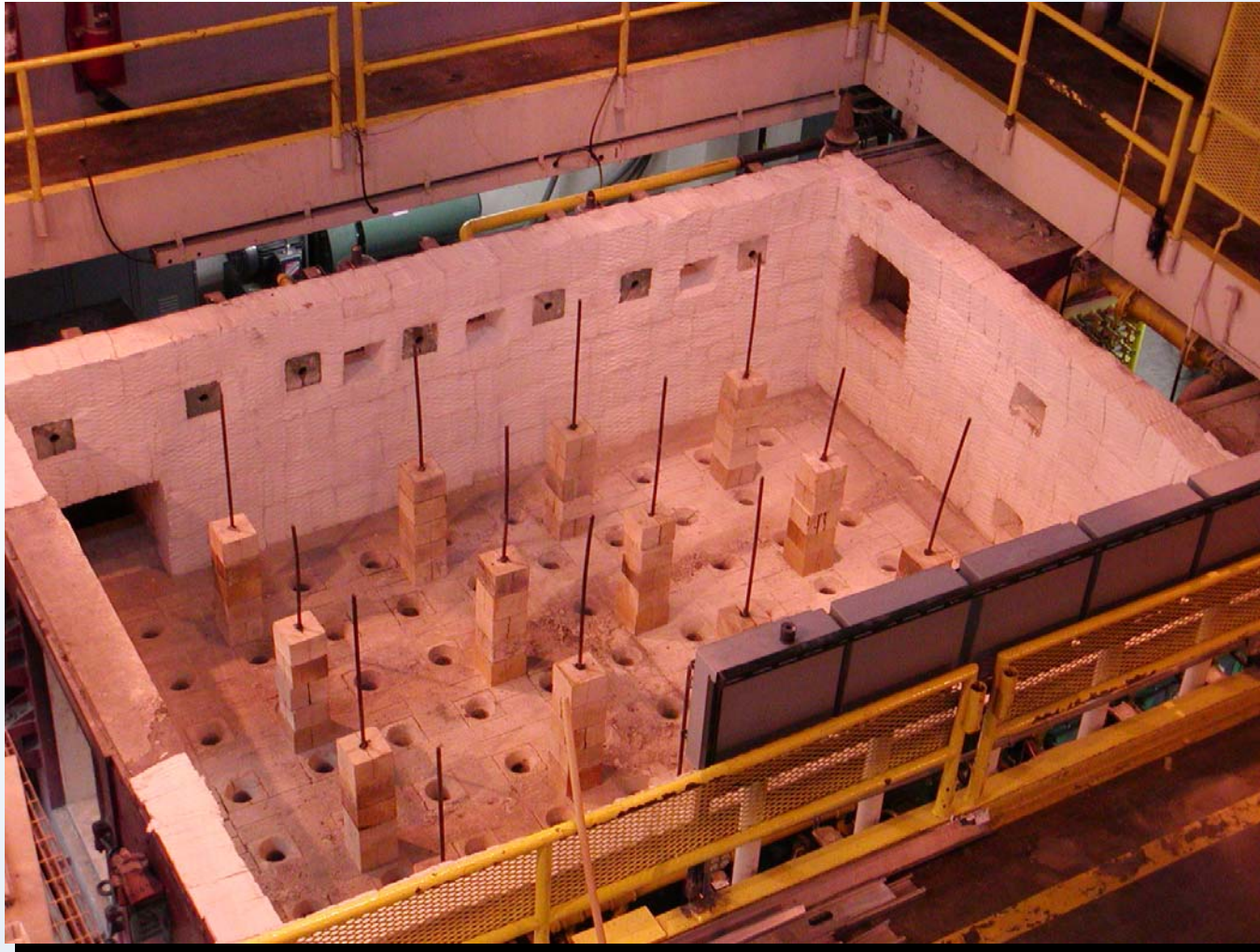
## Test conditions of acceptance

- ❑ Temperature on unexposed surface of assembly
  - Thermal properties of concrete
  - Thickness of concrete
- ❑ Temperature of the steel (unrestrained rating)
  - Thermal properties of steel and fireproofing
  - Size of steel sections, thickness of fireproofing
- ❑ Sustain applied load
  - Mechanical properties of steel and concrete
  - Size of steel sections and thickness of concrete
  - Geometry of assembly
  - Loading

# Preparation of Test Assemblies



# UL (Northbrook) Furnace





# UL (Northbrook) Furnace with Test Specimen



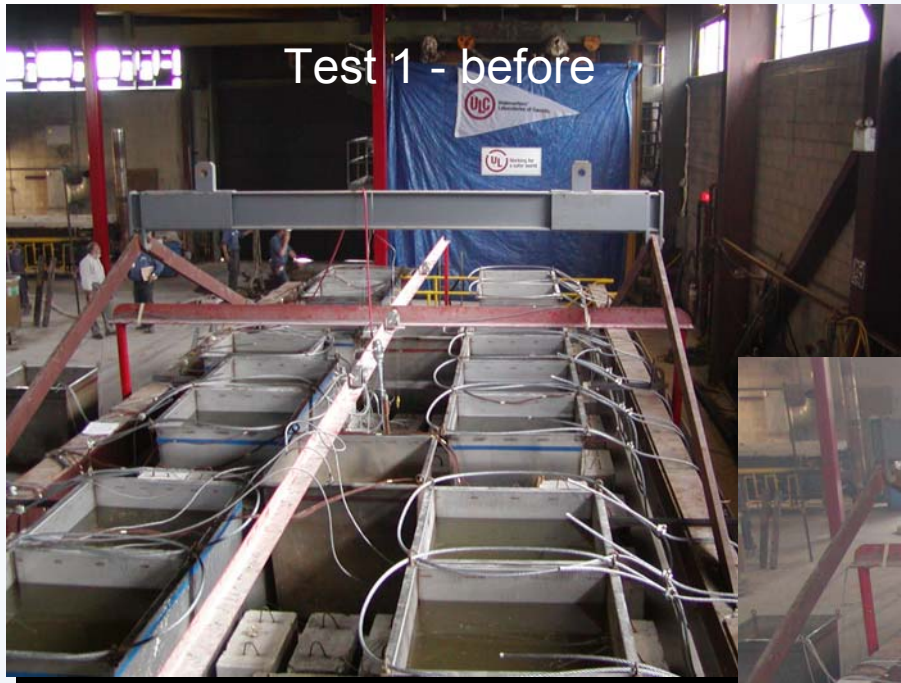
# Loading of the UL Tests - Northbrook



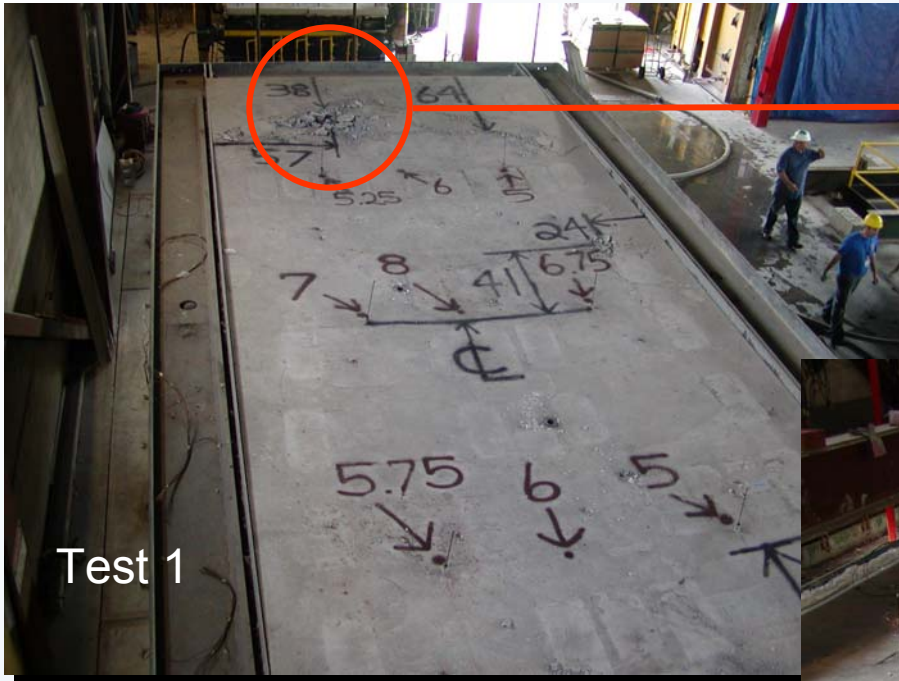
# Loading of the UL Tests - Toronto



# Post Test Observations - Slab Deflections



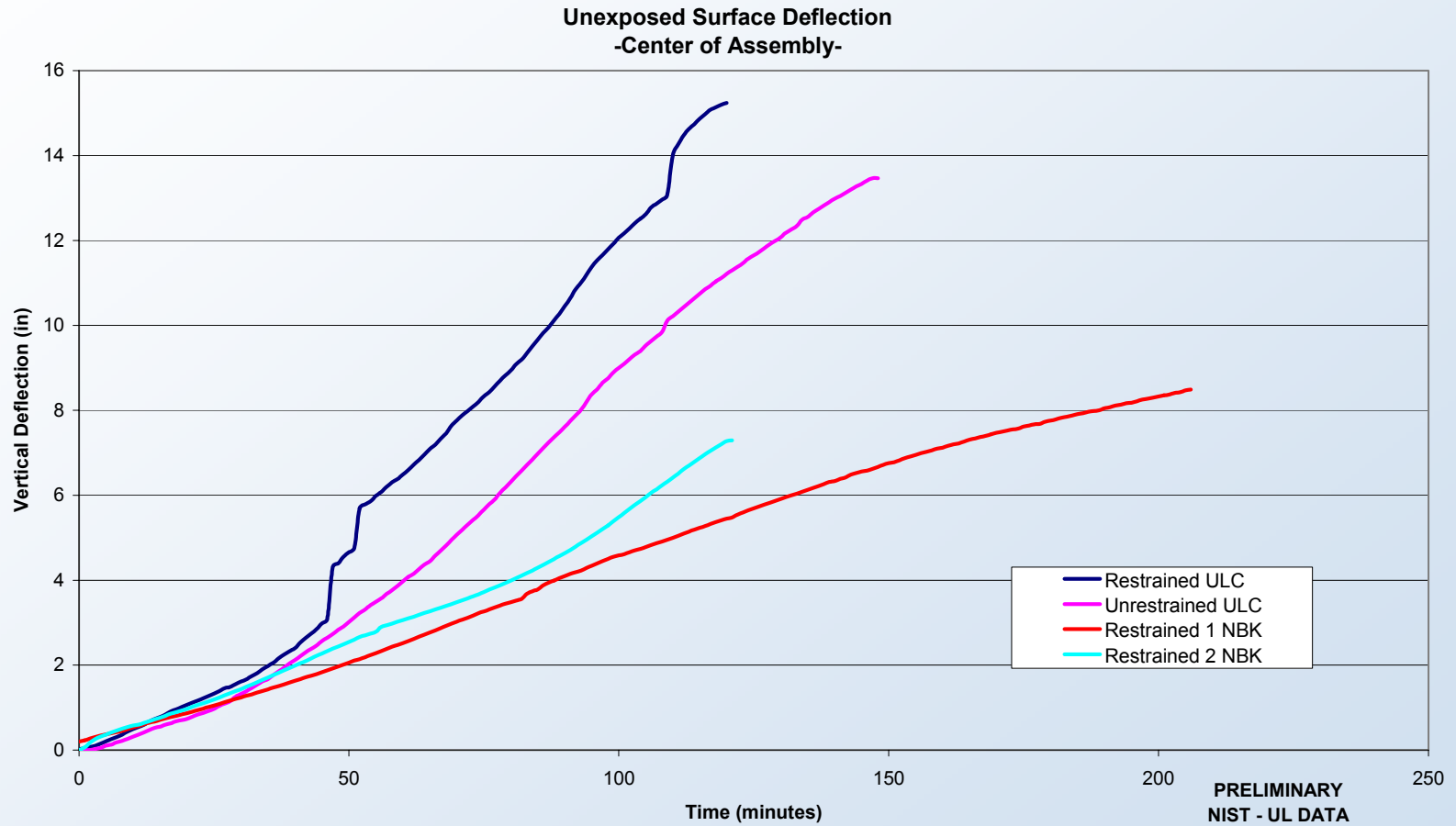
# Post Test Observations - Restrained vs. Unrestrained Test Assembly



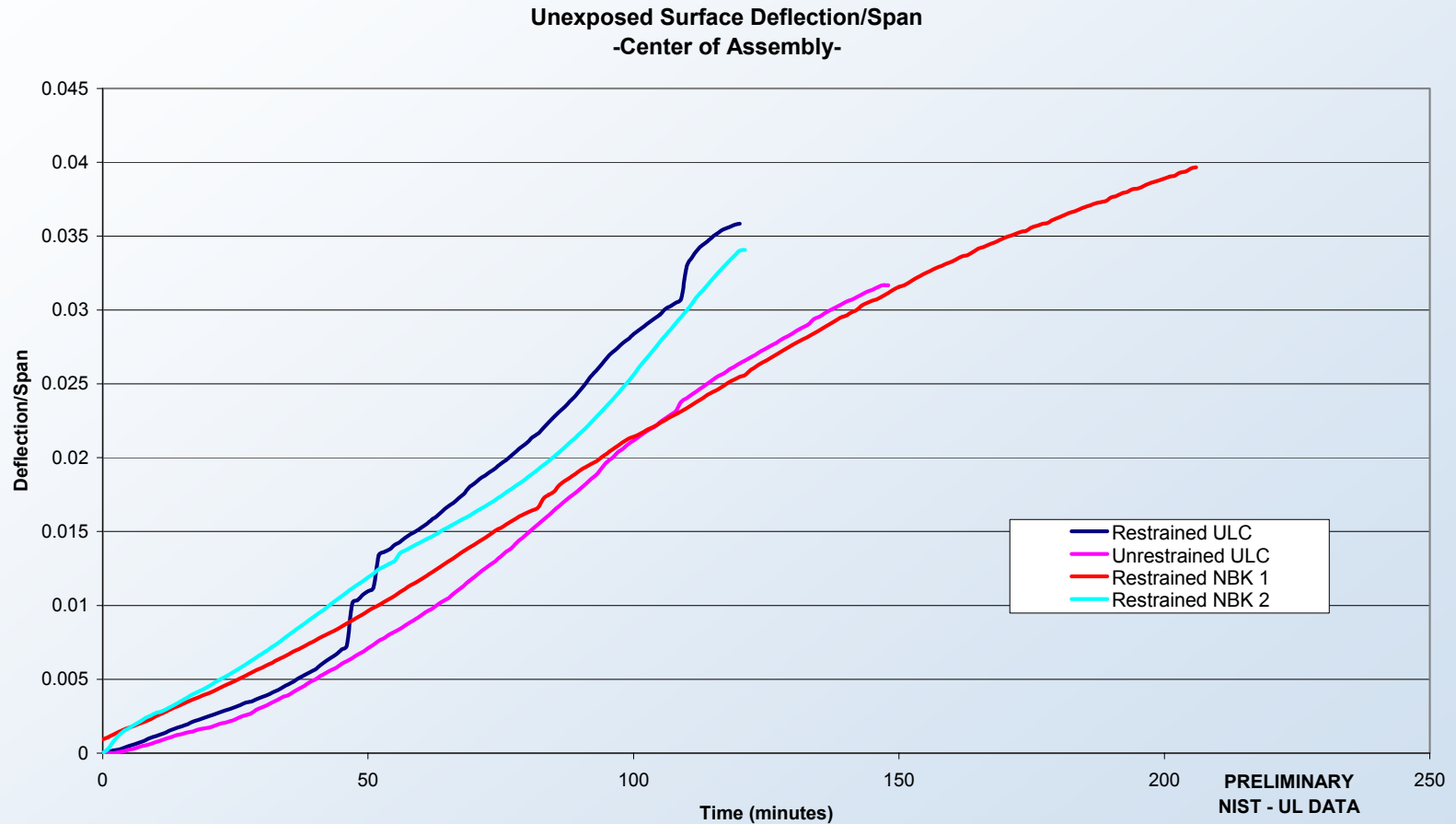
# Post-Test Observations – Steel Truss Behavior



# Post-Test Observations – Slab Deflections



# Post-Test Observations – Slab Deflections





# Results From Standard Fire Tests at UL

| Test | Description                             | Times to Reach End-Point Criteria (min) |                          |                    |                  |                         | Test Terminated (min) | Standard Fire Test Rating |                        |                          |
|------|---|---|--------------------------|--------------------|------------------|-------------------------|-----------------------|---------------------------|------------------------|--------------------------|
|      |   | Temperature on Unexposed Surface        |                          | Steel Temperatures |                  | Failure to Support Load |                       | ASTM E 119-61             | ASTM E 119-00          |                          |
|      |   | Average (Ambient +250°F)                | Maximum (Ambient +325°F) | Average (1100°F)   | Maximum (1300°F) |                         |                       | Rating (hr)               | Restrained Rating (hr) | Unrestrained Rating (hr) |
| 1    | 35 ft, restrained, ¾ in. fireproofing   | ---                                     | 111                      | 66                 | 62               | (3)                     | 116 <sup>(1)</sup>    | 1½                        | 1½                     | 1                        |
| 2    | 35 ft, unrestrained, ¾ in. fireproofing | ---                                     | ---                      | 76                 | 62               | (3)                     | 146 <sup>(2)</sup>    | 2                         | ---                    | 2                        |
| 3    | 17 ft, restrained, ¾ in. fireproofing   | 180                                     | 157                      | 86                 | 76               | (3)                     | 210 <sup>(2)</sup>    | 2                         | 2                      | 1                        |
| 4    | 17 ft, restrained, ½ in. fireproofing   | ---                                     | 58                       | 66                 | 58               | (3)                     | 120 <sup>(1)</sup>    | ¾                         | ¾                      | ¾                        |

(1) Imminent collapse

(2) Vertical displacement exceeded capability to measure accurately

(3) Did not occur

Note: Colors of the numbers indicate the correlation between the end-point criteria and the standard fire test rating.

# Observations

- ❑ The test assemblies were able to withstand standard fire conditions for between three quarter hour and two hours.
- ❑ The restrained WTC floor system obtained a fire resistance rating of 1½ hr while the unrestrained floor system achieved a 2 hr rating. Past experience with the ASTM E119 test method would lead investigators to expect that the unrestrained floor assembly would not perform as well as the restrained assembly, and therefore, it would receive a lower fire rating.
- ❑ A restrained fire rating of 2 hr was determined from the full-scale test with the “as-applied” (¾ in. or 19 mm) fireproofing thickness while a restrained fire rating of 1½ hr was determined from the reduced-scale test with the same fireproofing thickness.

## Observations (Cont'd)

- ❑ The result described above raises the question of whether or not a fire rating based on the ASTM E 119 performance of a 17 ft (5 m) span floor assembly is “scalable” to a larger floor system such as found in the WTC towers where spans ranged from 35 ft (11m) to 60 ft (18 m).
- ❑ A fire rating of  $\frac{3}{4}$  hr was determined from the reduced-scale test with the “as-specified” ( $\frac{1}{2}$  in. or 13 mm) fireproofing thickness. This rating would not have satisfied 1968 New York City building code rating requirement for floor systems in Construction Class IB buildings—the designation assigned to the WTC towers when they were built.

## Observations (Cont'd)

- ❑ An average thickness of fireproofing of  $\frac{3}{4}$  in. (13 mm) with a variability as determined from measurements reported by the Port Authority (cov=0.4) is approximately equivalent, on a performance basis, to 0.6 in. uniform thickness.
- ❑ Data from two floors in WTC 1 are not necessarily representative of all fireproofing conditions, and the average thickness may indeed be less than  $\frac{3}{4}$  in.

# Issues

Adequacy of the ASTM E 119 Standard to provide guidance on:

- ❑ Criteria for determining structural limit states, including failure, and means to measure them,
- ❑ Scale of test assembly versus prototype application,
- ❑ Effect of end restraint conditions (restrained and unrestrained) on test results, including the influence of stiffness,
- ❑ Structural connections,
- ❑ Combination of loading and exposure (temperature profile) adequately represent expected conditions,

## Issues (cont'd)

Adequacy of the ASTM E 119 Standard to provide guidance on:

- ❑ Procedures to analyze and evaluate data from fire resistance tests of other building components and assemblies to qualify an untested building element,
- ❑ Repeatability and reproducibility of test results (single test currently defines rating for system),
- ❑ Relationships between prescriptive ratings and actual performance of the construction in realistic building fires.

***Thank you***

<http://wtc.nist.gov>