

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

Session VI - Structural Fire Response and Collapse Analysis

Fire Protection of Structural Steel

September 15, 2005

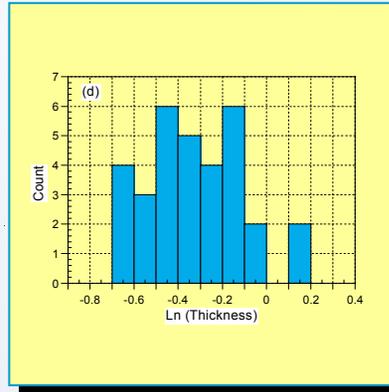
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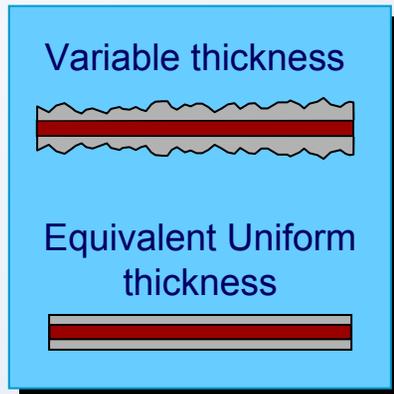
Fire Protection of Structural Steel



Specified and “actual” thickness of fireproofing



Thickness measurements and variability



Equivalent uniform thickness

“Specified” Thickness of Fireproofing (SFRM)

In October 1969, ... , the Port Authority stated, in a letter to the fireproofing contractor, that

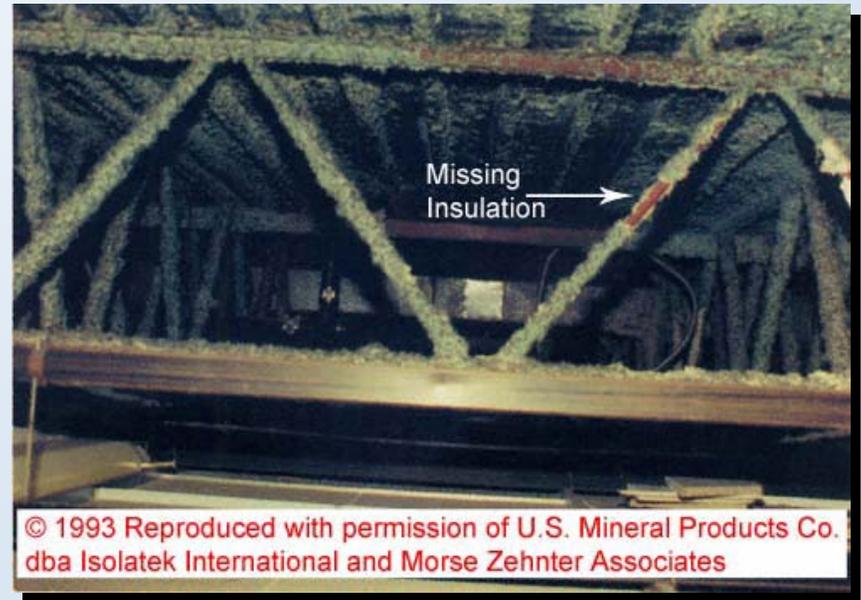
- “All Tower beams, spandrels, and bar joists requiring spray-on fireproofing are to have a ½” covering of Cafco.
- The above requirements must be adhered to in order to maintain the Class 1-A Fire Rating of the New York City Building Code.”[1]

[1] Letter dated October 30, 1969 from Robert J. Linn (Manager, Project Planning, The World Trade Center) to Mr. Louis DiBono (Mario & DiBono Plastering Co., Inc.).

Original Fireproofing



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Upgraded Fireproofing



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Qualitative Data on Condition of Fireproofing

- ❑ Sample Area Data Sheets from 1990 contained comments on the state of the in-place SFRM.
- ❑ As an example, the data sheet for floor 29 of WTC 1 states the following for the South West quadrant of the floor:

“Fluffy spray-on fireproofing coating the support beams, joists, and deck above the ceiling. The thickness of the material on the beams and joists **was consistently about 1/2”**. Regarding the deck it ranged from very sparse [*sic*] in areas to 1/4” in other areas. The areas we sampled were coated with a light green encapsulant.”

- ❑ And, on the 23rd floor,

“truss members located adjacent to the outside walls (within 3 ft.) are devoid of fireproofing material”.

Fireproofing Thickness Measurements*

Averages of six measurements (\bar{x})

- Average thickness = 0.75
- Standard deviation of averages = 0.16
- Standard deviation of individual measurement = ?

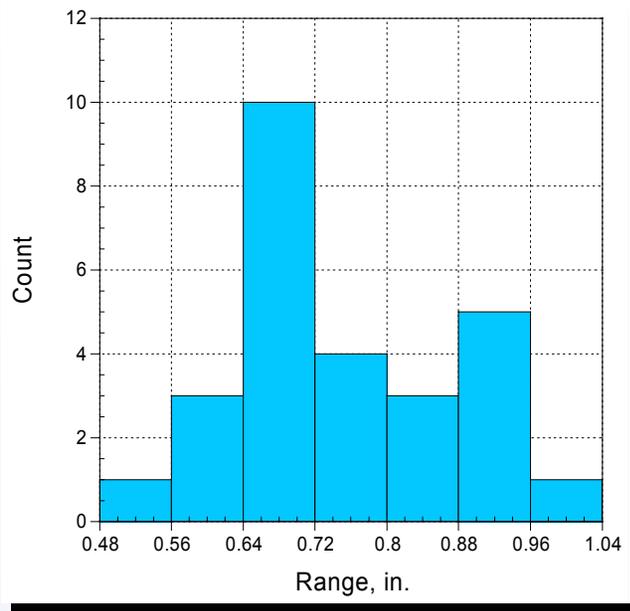
* ASTM E 605 - Standard Test Methods for Thickness and Density of SFRM Applied to Structural Members

Floor 23	Floor 24
0.60	0.76
0.53	0.60
0.70	0.90
0.76	0.72
0.88	0.64
0.89	0.80
0.83	0.68
1.17	0.65
0.88	0.67
0.71	0.77
0.82	0.96
0.52	0.66
0.69	0.65
0.52	1.11
0.64	0.95
0.52	0.56

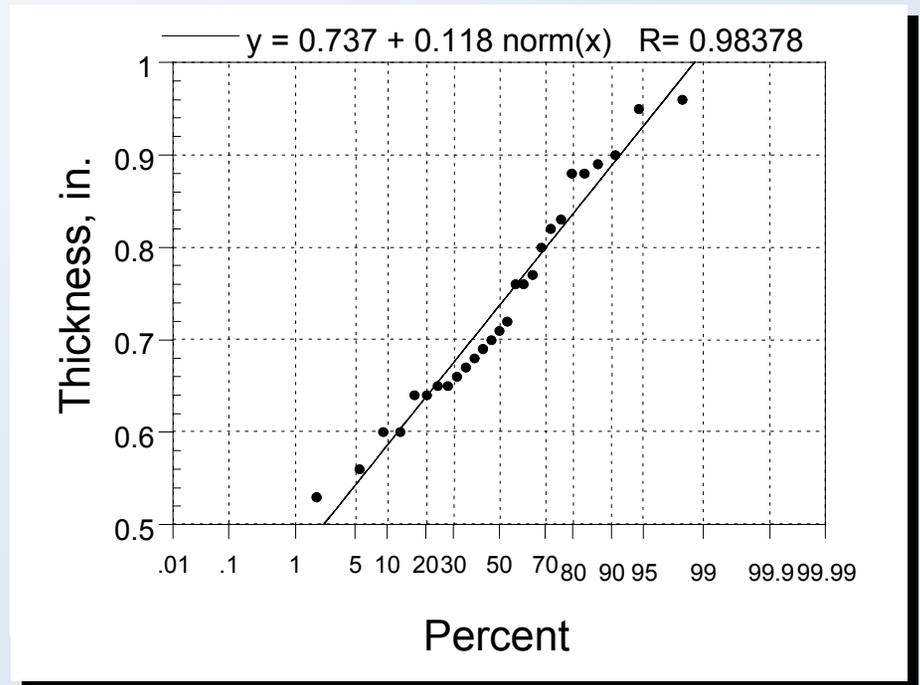
Source: Port Authority of New York and New Jersey.

Distribution of Measurements - Original

Distribution



Normal Probability Plot



$$S_{\bar{X}} = 0.12 \text{ in.}$$

$$S = 0.12\sqrt{6} = 0.29 \text{ in.} \approx 0.30 \text{ in.}$$

Photograph Analysis



- Webs of main trusses
- Webs of bridging trusses
- Diagonal strut at the exterior wall

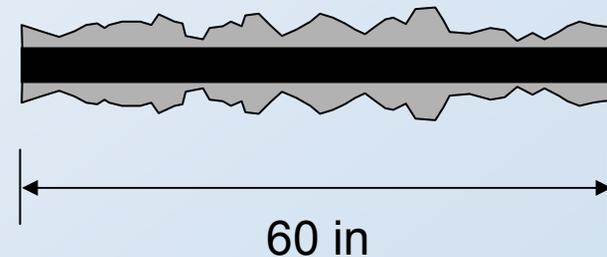
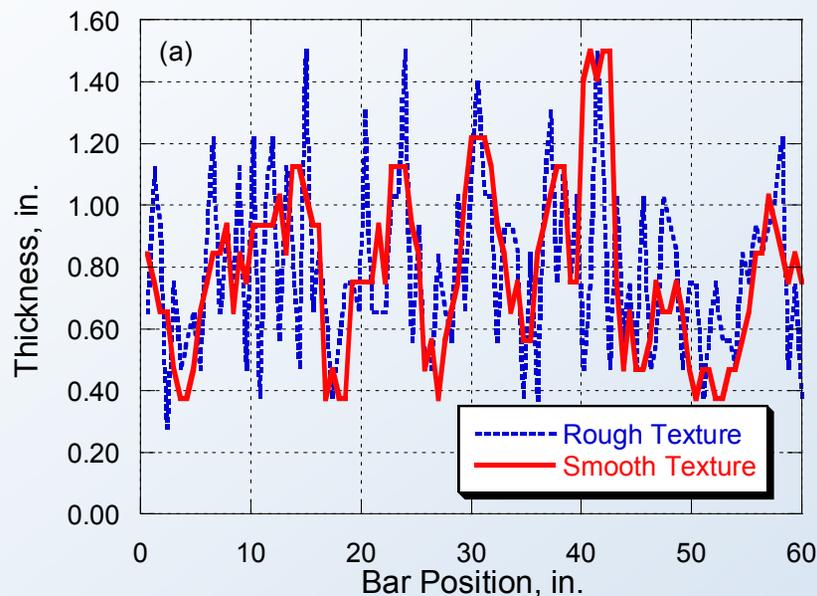
Statistics for Photograph Analyses

- ❑ Main trusses - original (85 measurements):
 - Average thickness = 0.6 in.
 - Standard deviation = 0.3 in.
- ❑ Bridging trusses - original (52 measurements):
 - Average thickness = 0.4 in.
 - standard deviation = 0.25 in.
- ❑ Diagonal struts - original (26 measurements):
 - Average thickness = 0.4 in.
 - Standard deviation = 0.2 in.
- ❑ Main trusses - upgrade (52 measurements):
 - Average thickness = 1.7 in.
 - Standard deviation = 0.4 in.

Equivalent Thickness

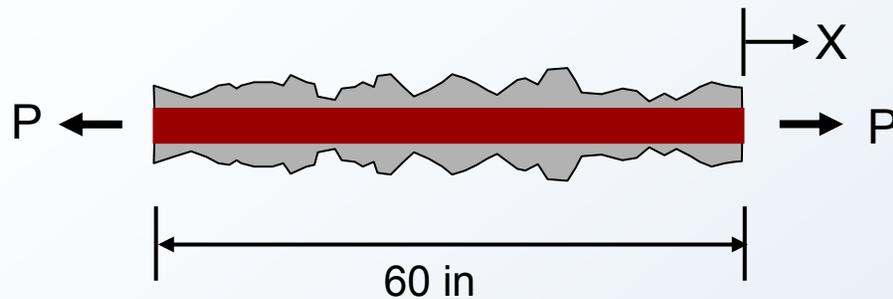
- Pseudo random number generator was used to select values from a lognormal distribution with central value and dispersion consistent with average of 0.75 and standard deviation of 0.3

Generated thickness profile

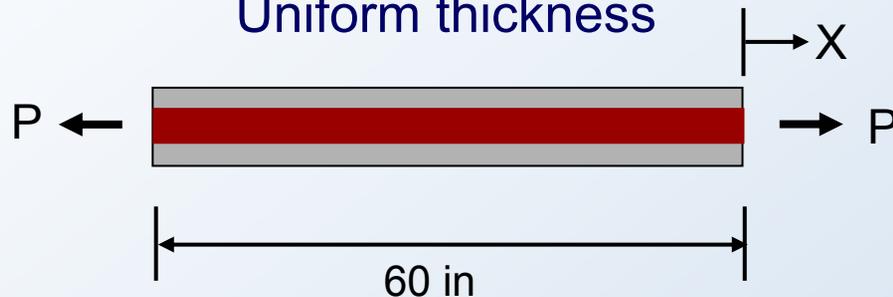


Equivalent Thickness

Variable thickness



Uniform thickness

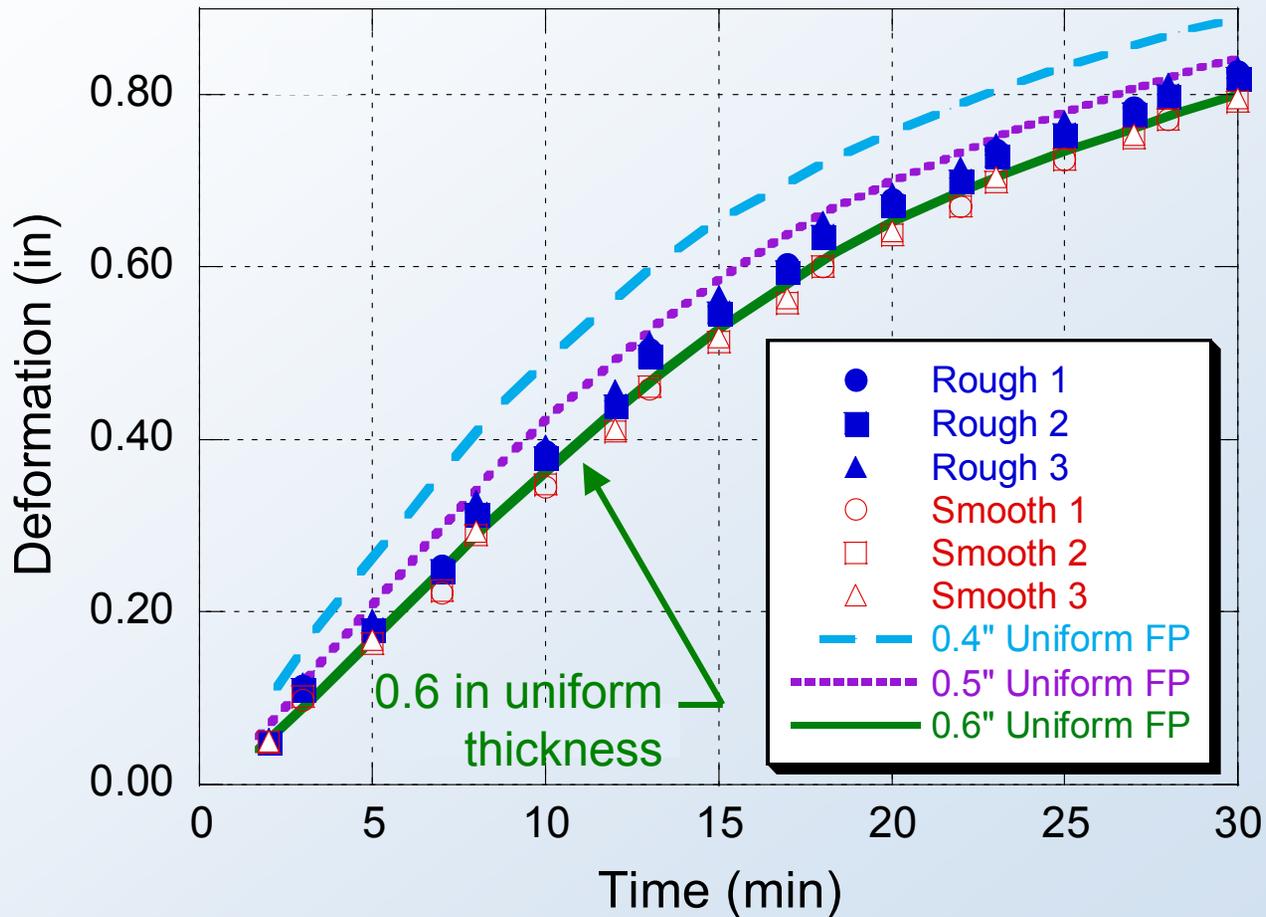


- 3 data sets each
 - Rough
 - Smooth
- average thickness = 0.75 in.
- standard deviation = 0.3 in
- distribution = lognormal

- thickness = 0.4, 0.5, 0.6 in

- $P = 9800$ lb (12,500 psi)
- Applied heat flux from a 1100 °C fire

Equivalent Thickness



Types and Locations of SFRM – Floor System

Building Component	Material	Thickness		
		Specified	Installed	Used in Analysis
Floor System				
Original				
Main trusses and diagonal struts	BLAZE-SHIELD DC/F	0.5	0.75	0.6
Bridging trusses – one-way zone	BLAZE-SHIELD DC/F	0.5	0.38	0.3
Bridging trusses – two-way zone	BLAZE-SHIELD DC/F	0.5	0.38	0.6
Upgraded				
Main trusses and diagonal struts	BLAZE-SHIELD II	1.5	2.5	2.2
Bridging trusses – one-way zone	BLAZE-SHIELD II	1.5	2.5	2.2
Bridging trusses – two-way zone	BLAZE-SHIELD II	1.5	2.5	2.2

Types and Locations of SFRM – Exterior Wall

Building Component	Material	Thickness		
		Specified	Installed	Used in Analysis
Exterior Wall System				
Box Columns				
Exterior Face	BLAZE-SHIELD DC/F	1 3/16	N/A	1.2
Interior Face	Vermiculite Plaster	7/8	N/A	0.8
Spandrels				
Exterior Face	BLAZE-SHIELD II	1/2	N/A	0.5
Interior Face	Vermiculite Plaster	1/2	N/A	0.5

Types and Locations of SFRM – Core

Building Component	Material	Thickness		
		Specified	Installed	Used in Analysis
Core Columns				
Wide Flange Columns				
Light	BLAZE-SHIELD DC/F	2 3/16	N/A	2.2
Heavy	BLAZE-SHIELD DC/F	1 3/16	N/A	1.2
Box Columns				
Light	BLAZE-SHIELD DC/F	N/S	N/A	2.2
Heavy	BLAZE-SHIELD DC/F	N/S	N/A	1.2
Core Beams	BLAZE-SHIELD DC/F	1/2	N/A	0.5