

World Organization Of Building Officials

Tokyo, Japan
April 21, 2004

Traw Associates
Consulting



WILLDAN
Serving Public Agencies



**“Structural Lessons Learned from the Collapse of the
World Trade Center Towers, New York, USA”**

**By: Imad Eldurubi, WOBO Governor
Deputy Building Official, WILLDAN**

Credits:

**Traw and Associates, Mr. Jon Traw, Former President,
International Conference of Building Officials**

Willdan, Ms. Terri Pomroy, Administrative Supervisor

Key Buildings

- WTC 1 and 2 (110 Stories)
- WTC 3 (110 Stories)
- WTC 4, 5 and 6 (9, 9 and 8 Stories)
- WTC 7 (47 Stories)
- Bankers Trust (40 Stories)

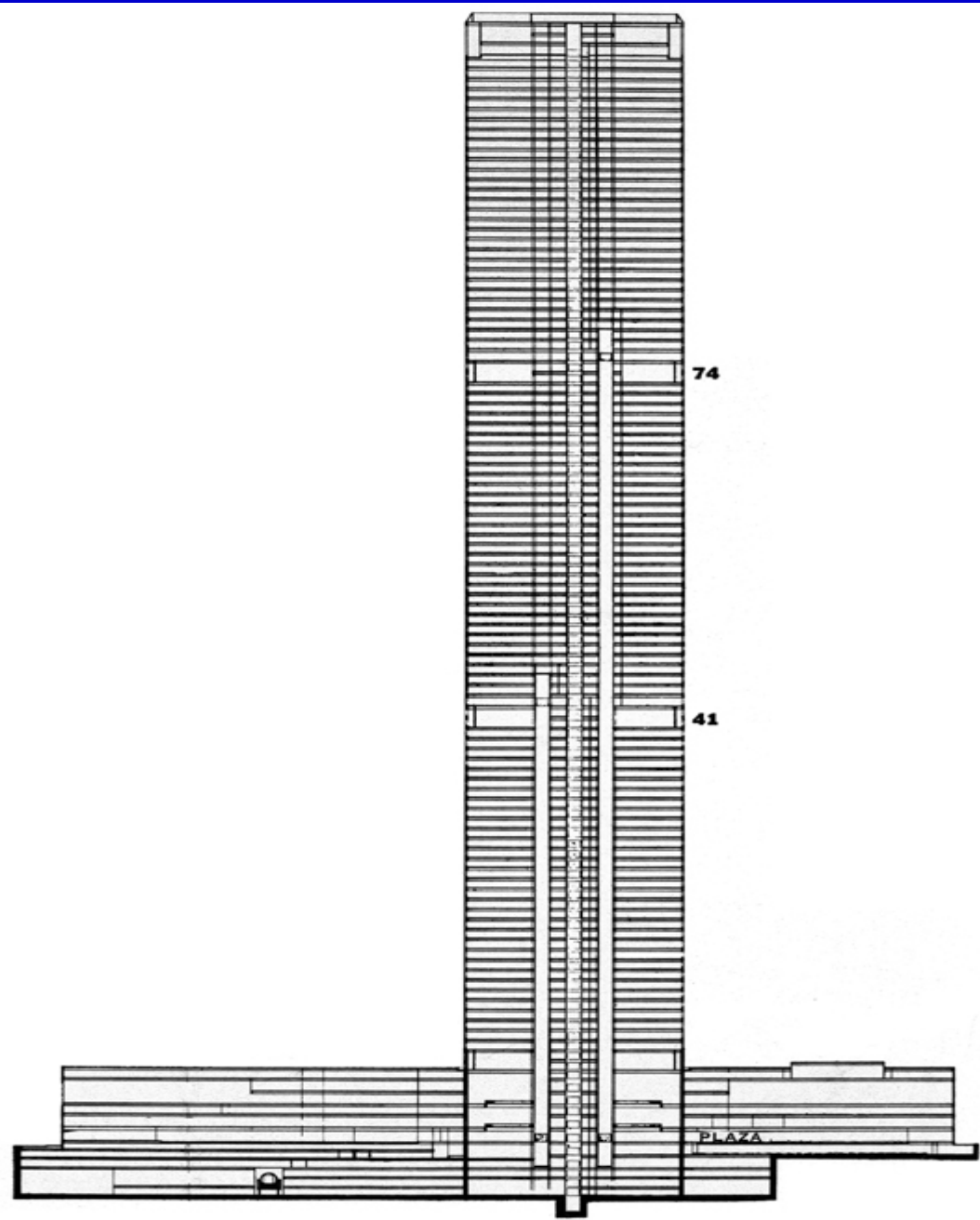


- G** No Damage – 384 total buildings inspected
- Y** Moderate Damage – 18 total
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- R** Partial Collapse – 4 total

WTC Emergency Building Ratings SEAoNY

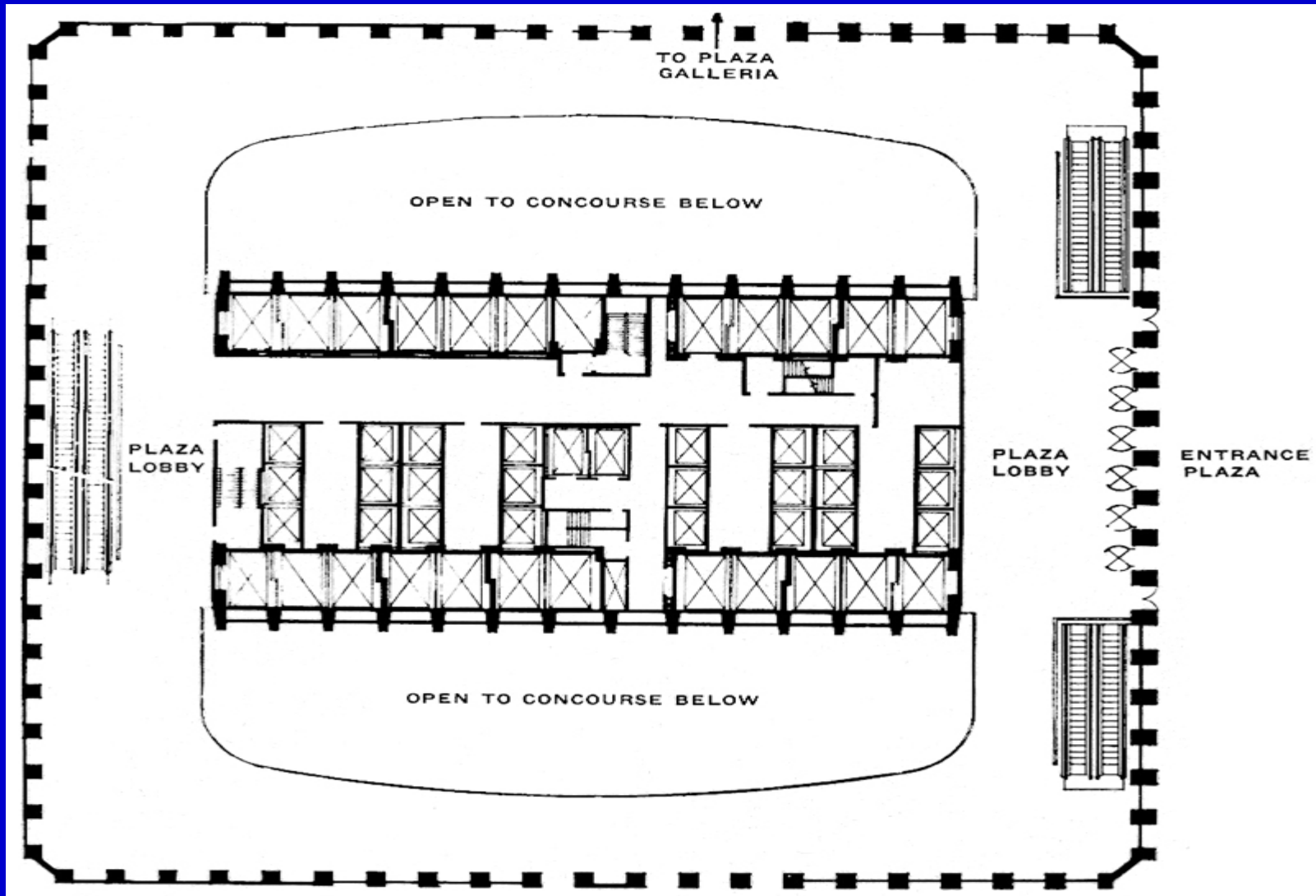


NYC DDC/DoB
Cooperative Building
Damage Assessment
22 September 2001

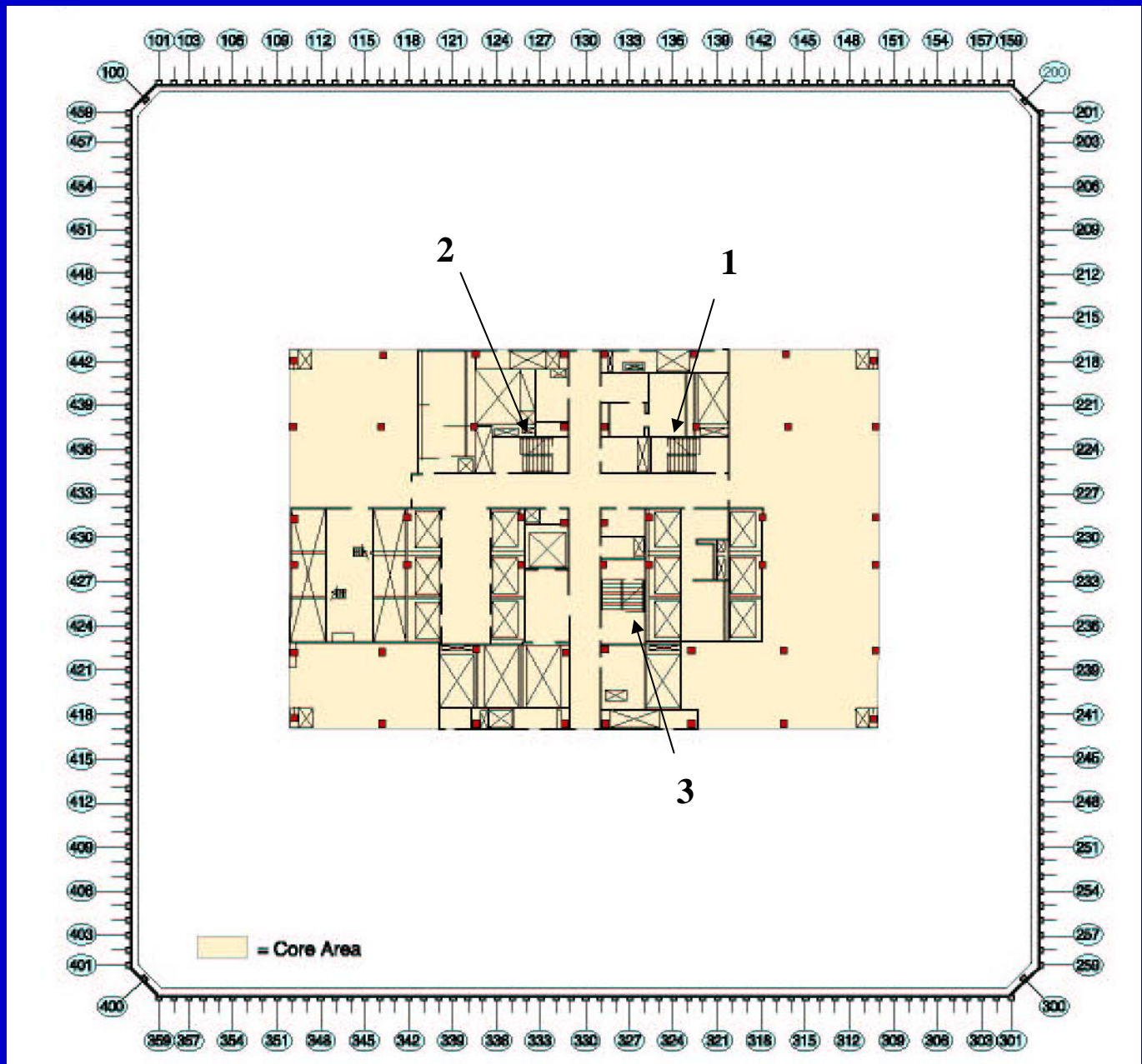


Elevation

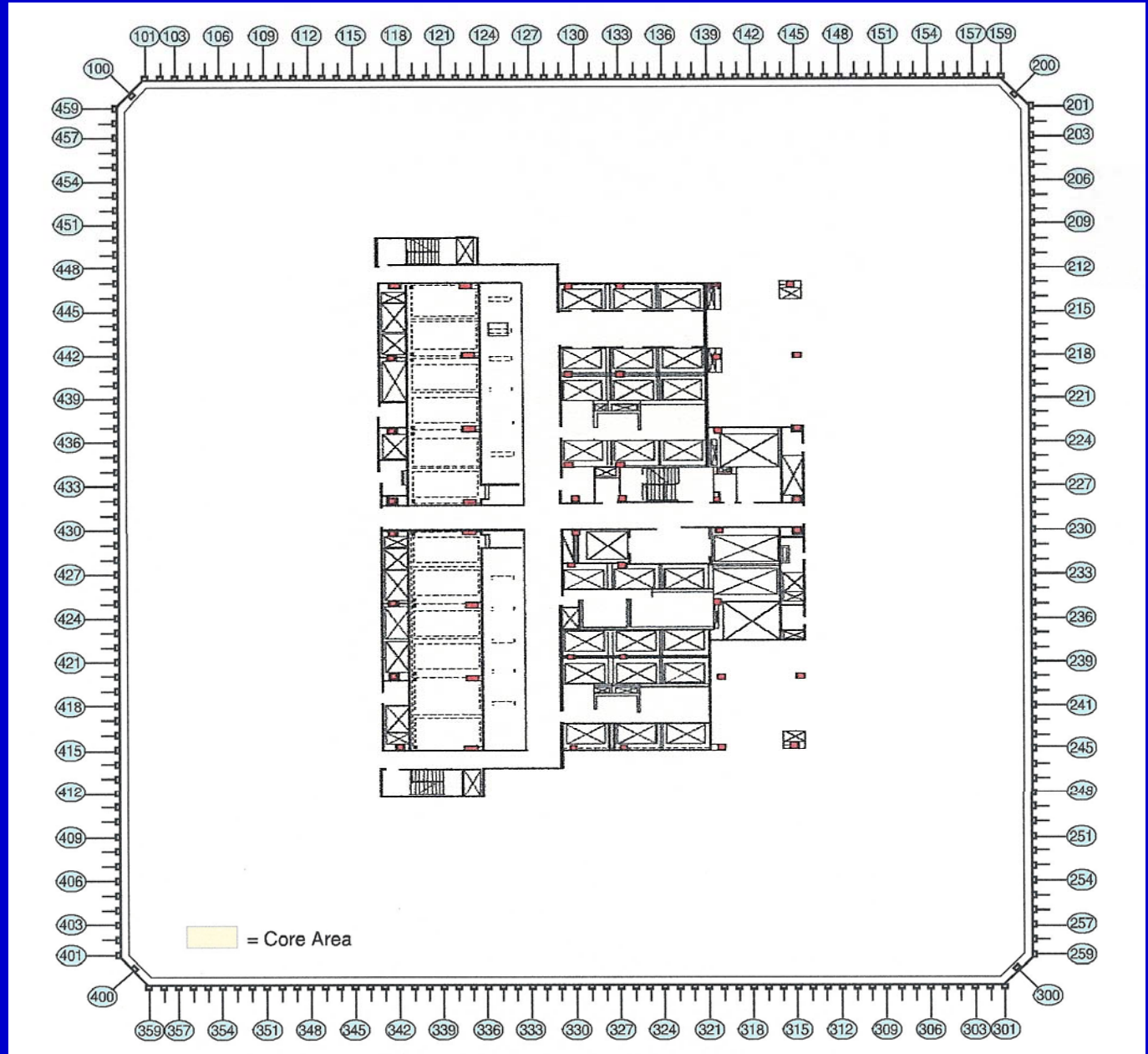
Plaza Level



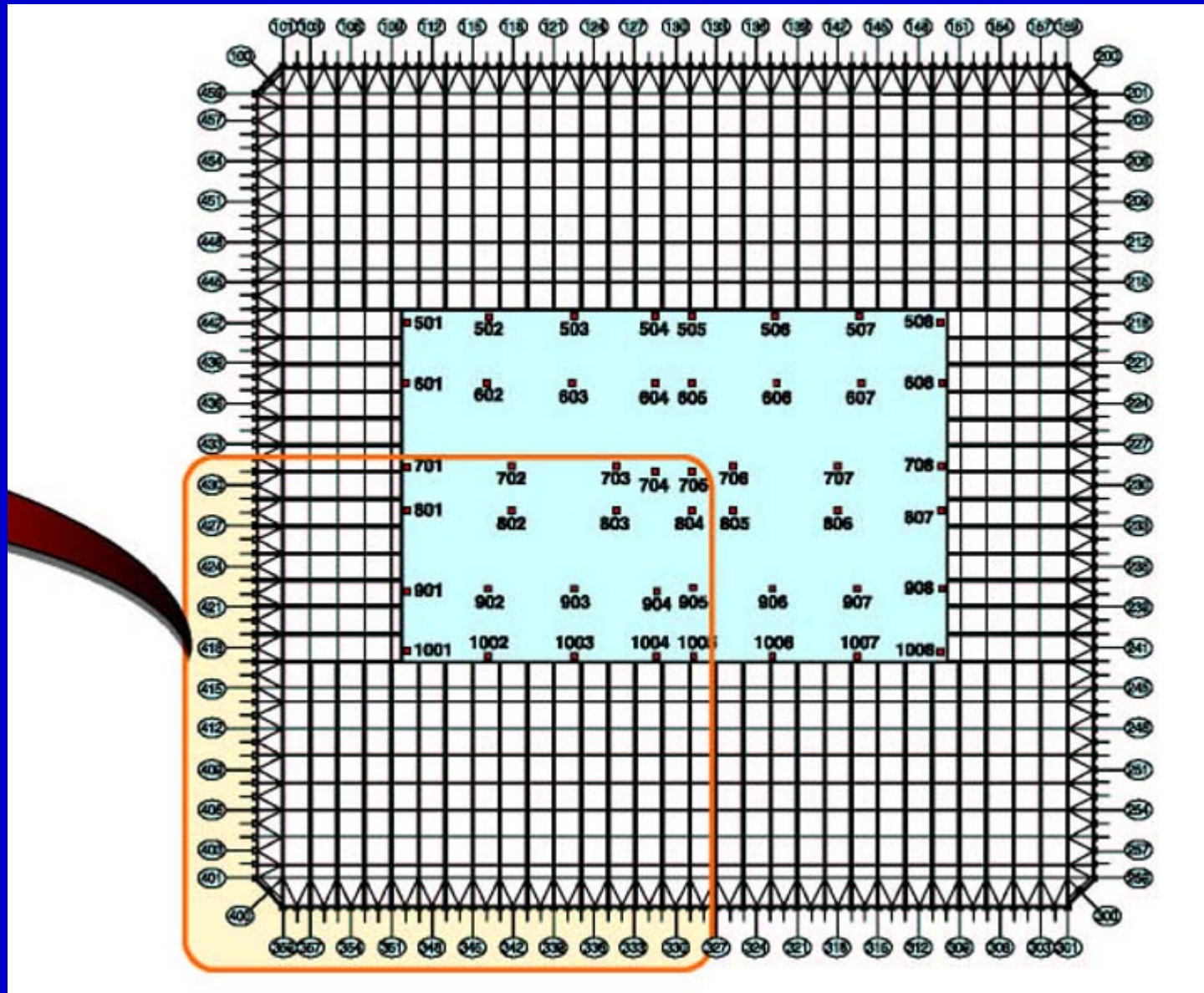
Typical Floor Plan WTC 1 North Tower



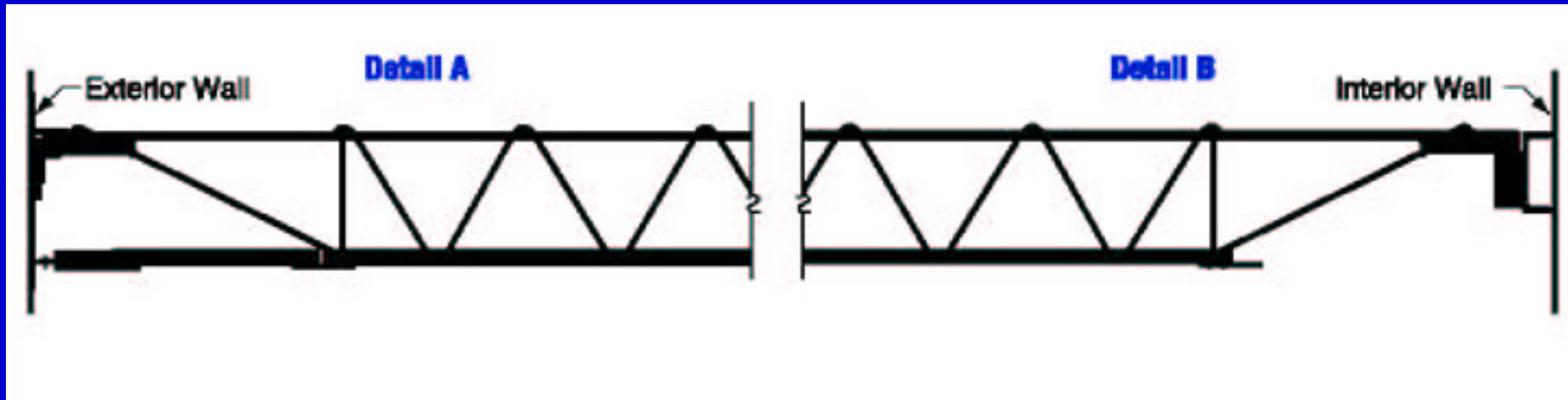
Typical Floor Plan WTC 2 South Tower



Trusses

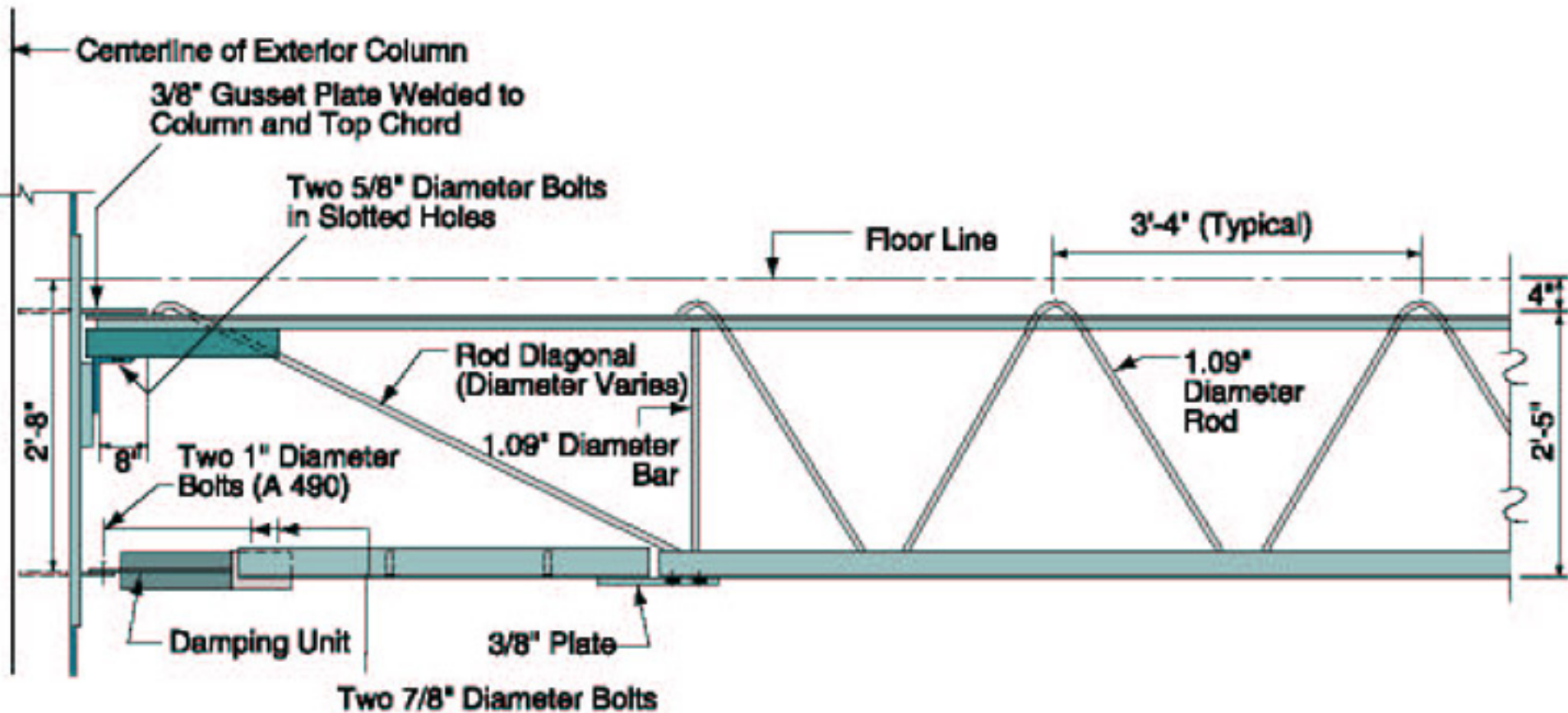


Trusses



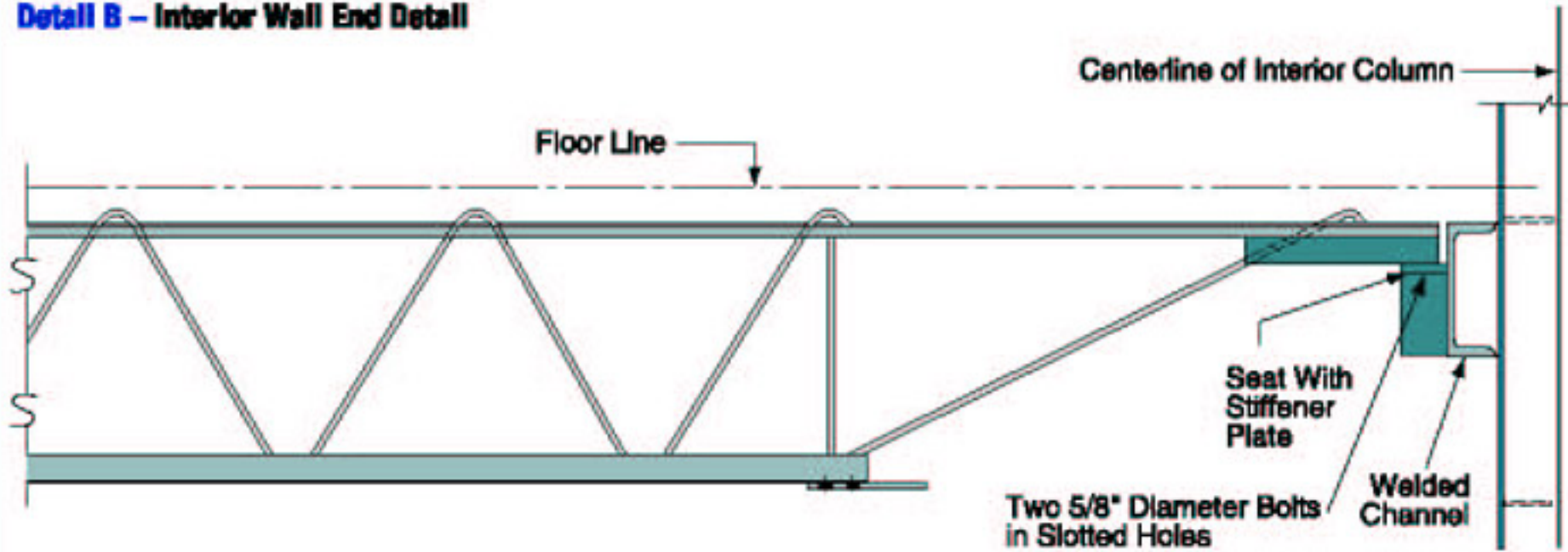
Trusses - Exterior Wall End Detail

Detail A - Exterior Wall End Detail

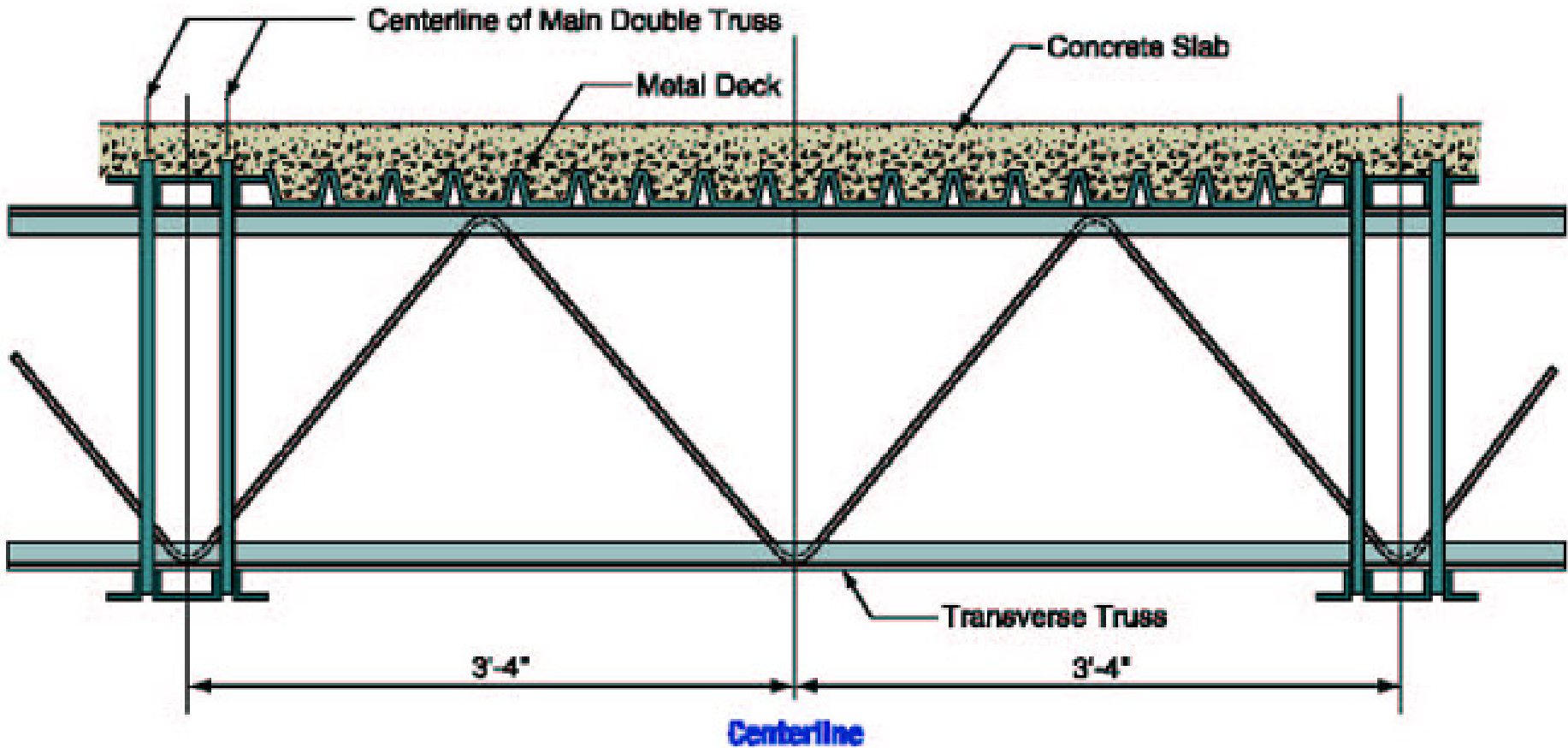


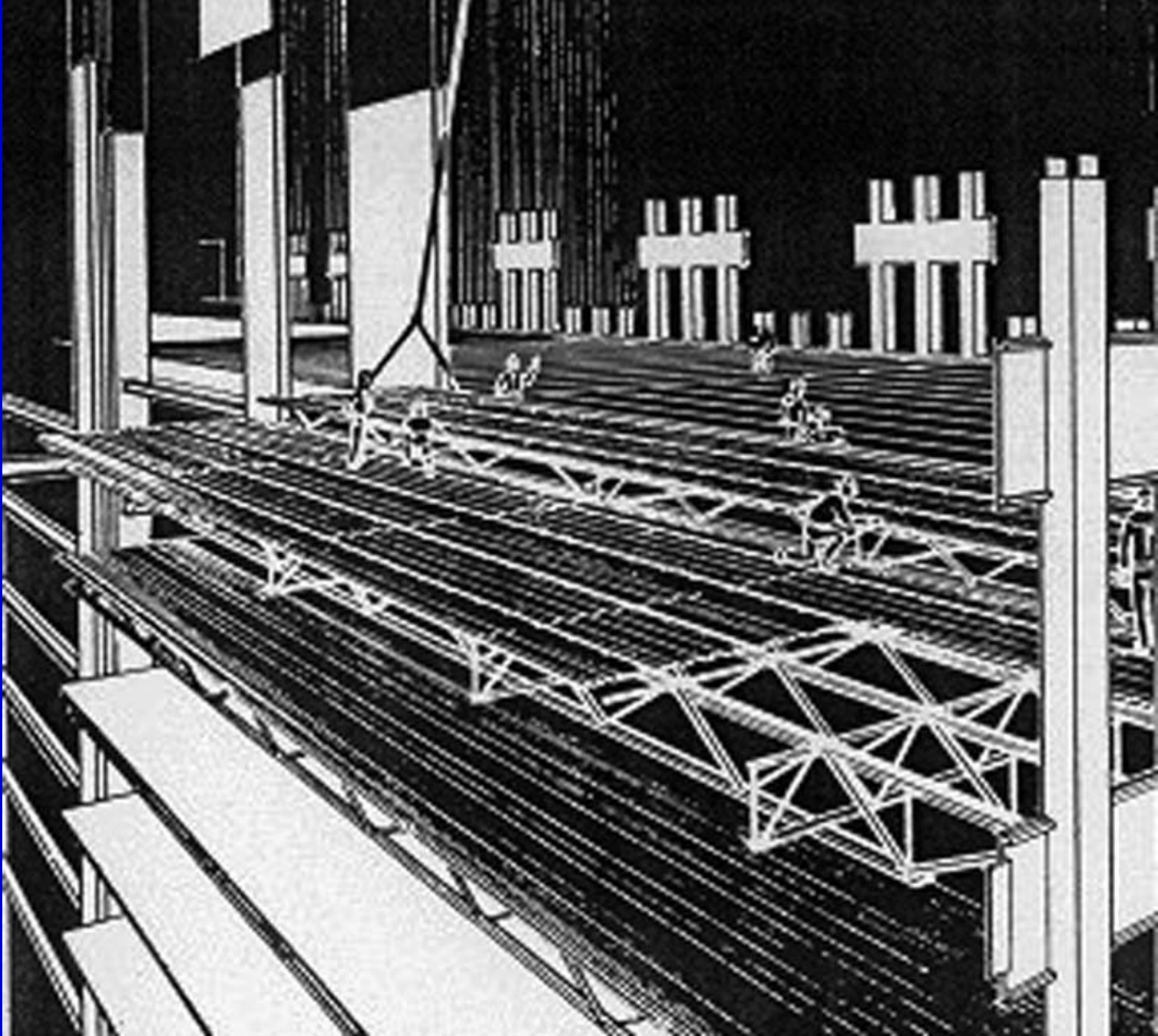
Trusses - Interior Wall End Detail

Detail B - Interior Wall End Detail

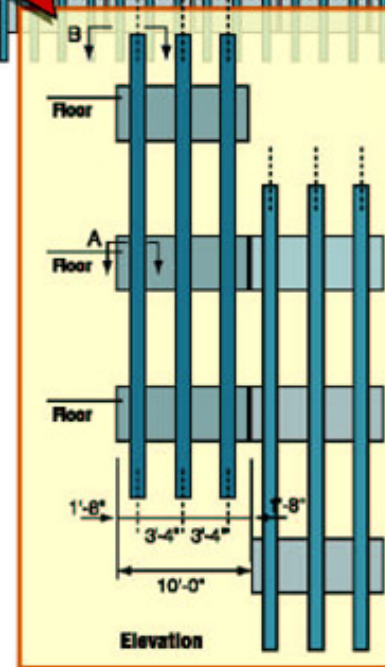
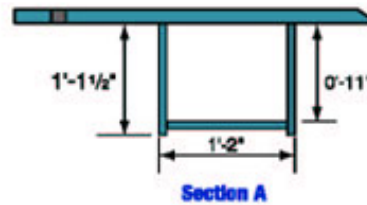
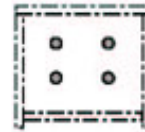
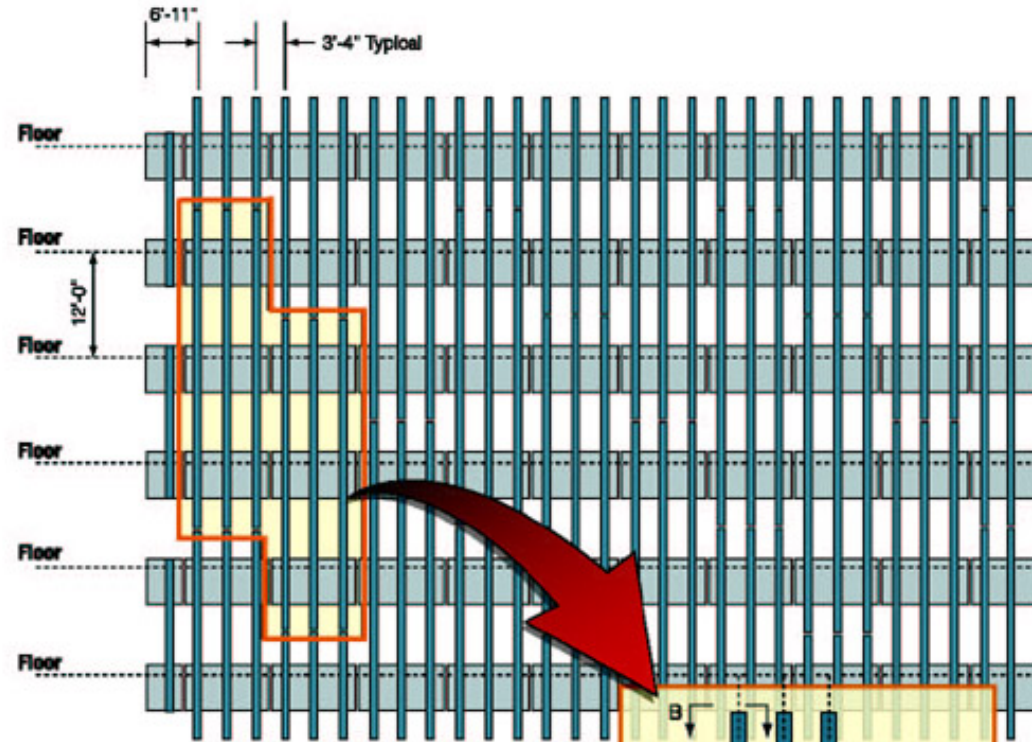


Transverse Truss





Exterior Wall Framing



During Construction





Fireball erupts on north face of the WTC2 as UA175 strikes building



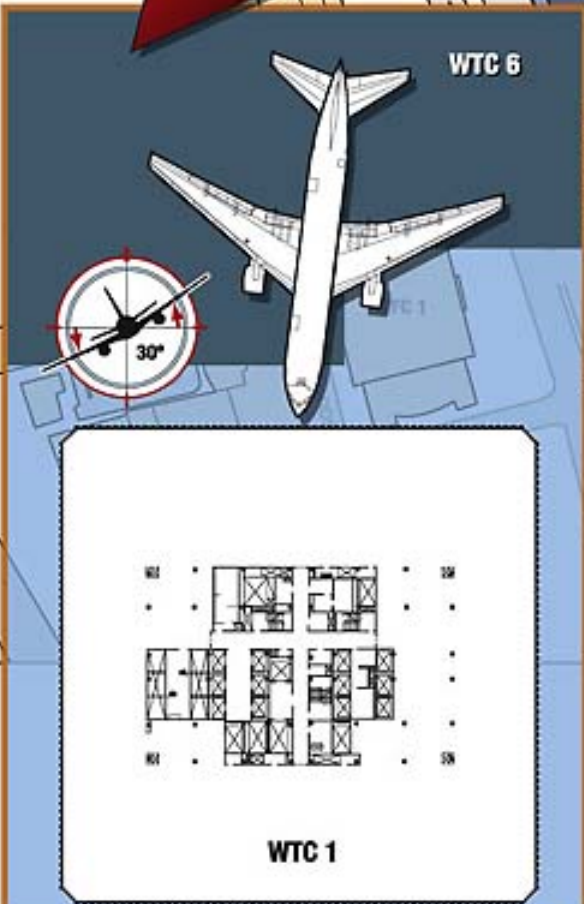
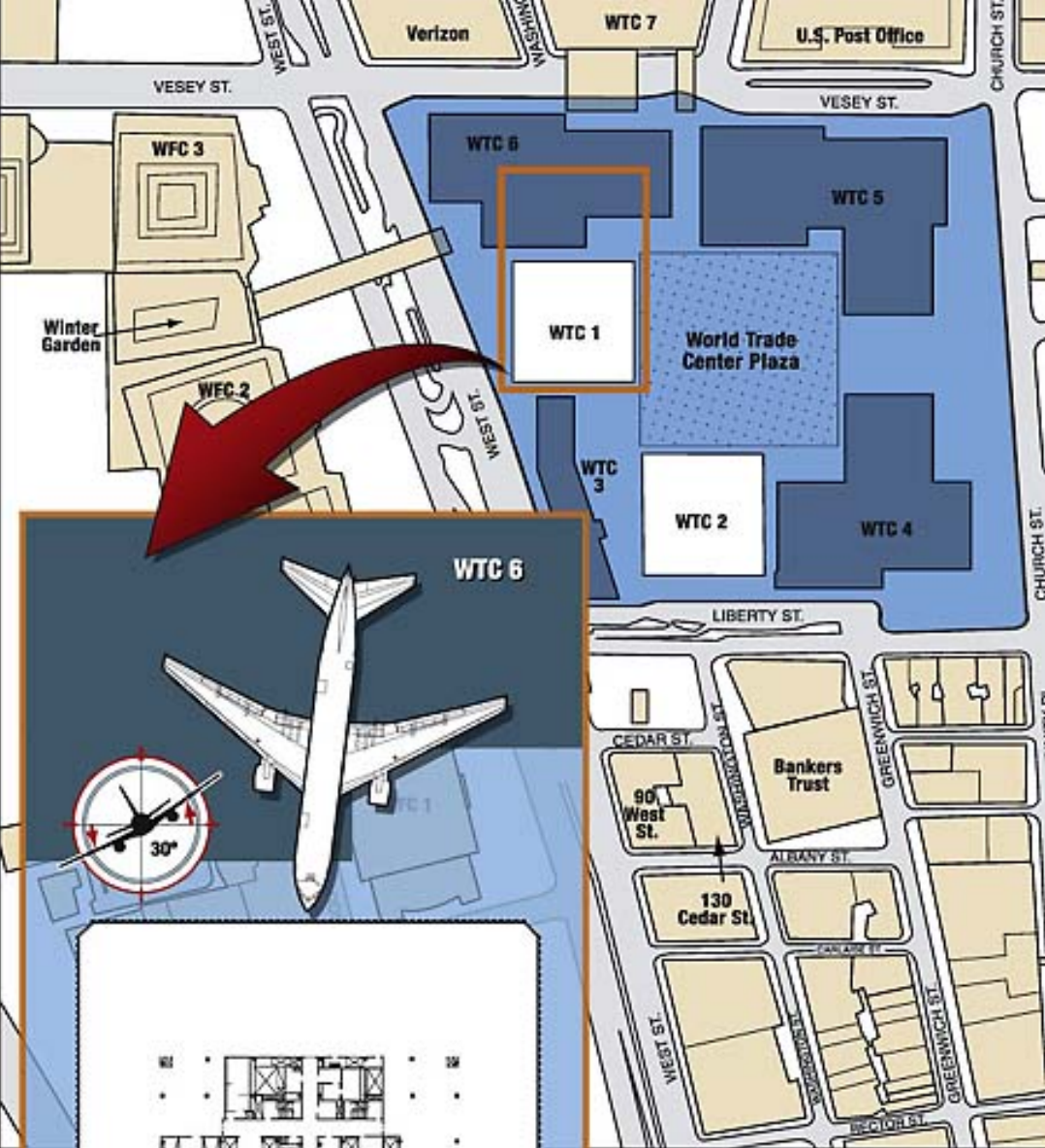




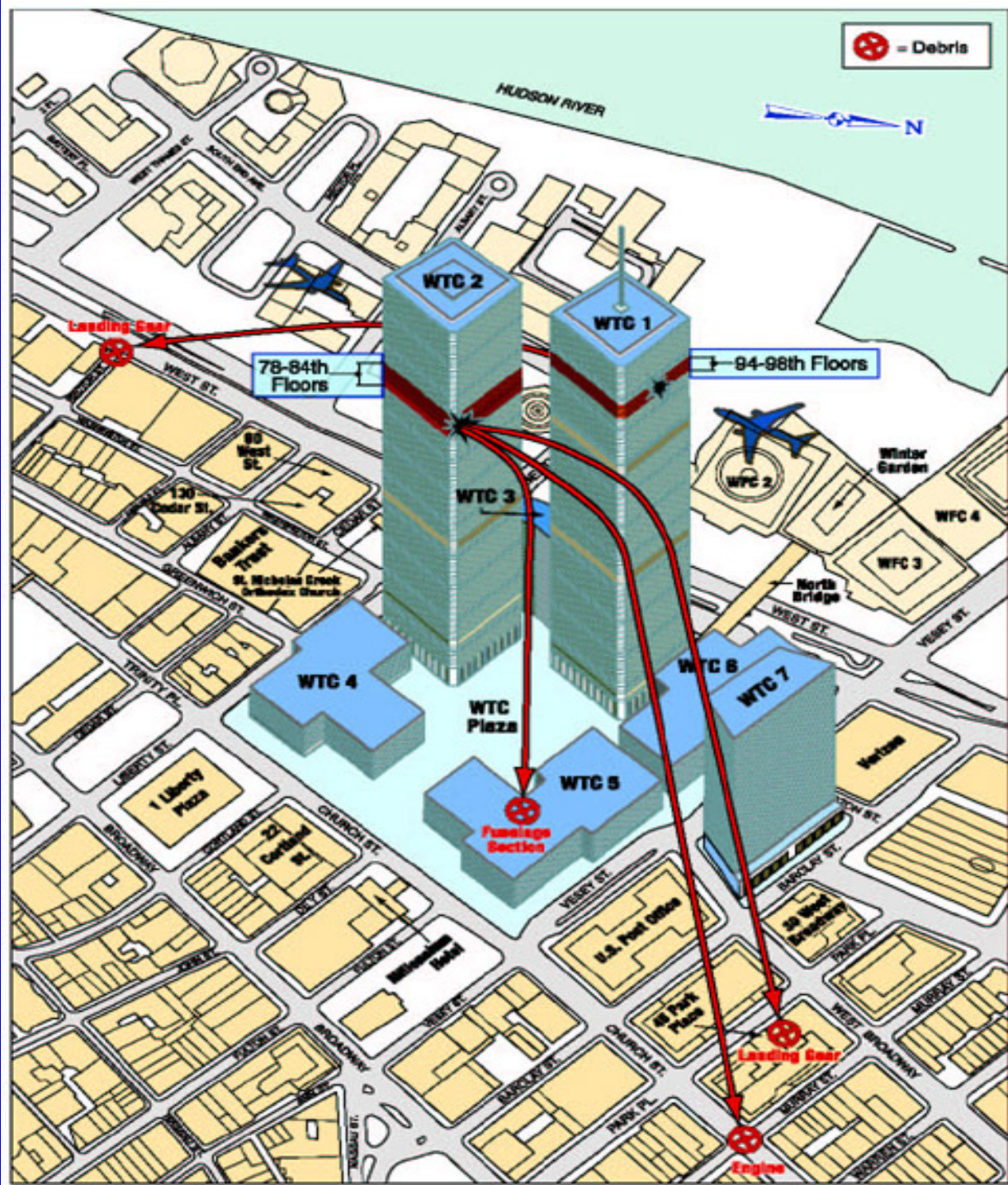


9.25.01





Areas of Debris Impact



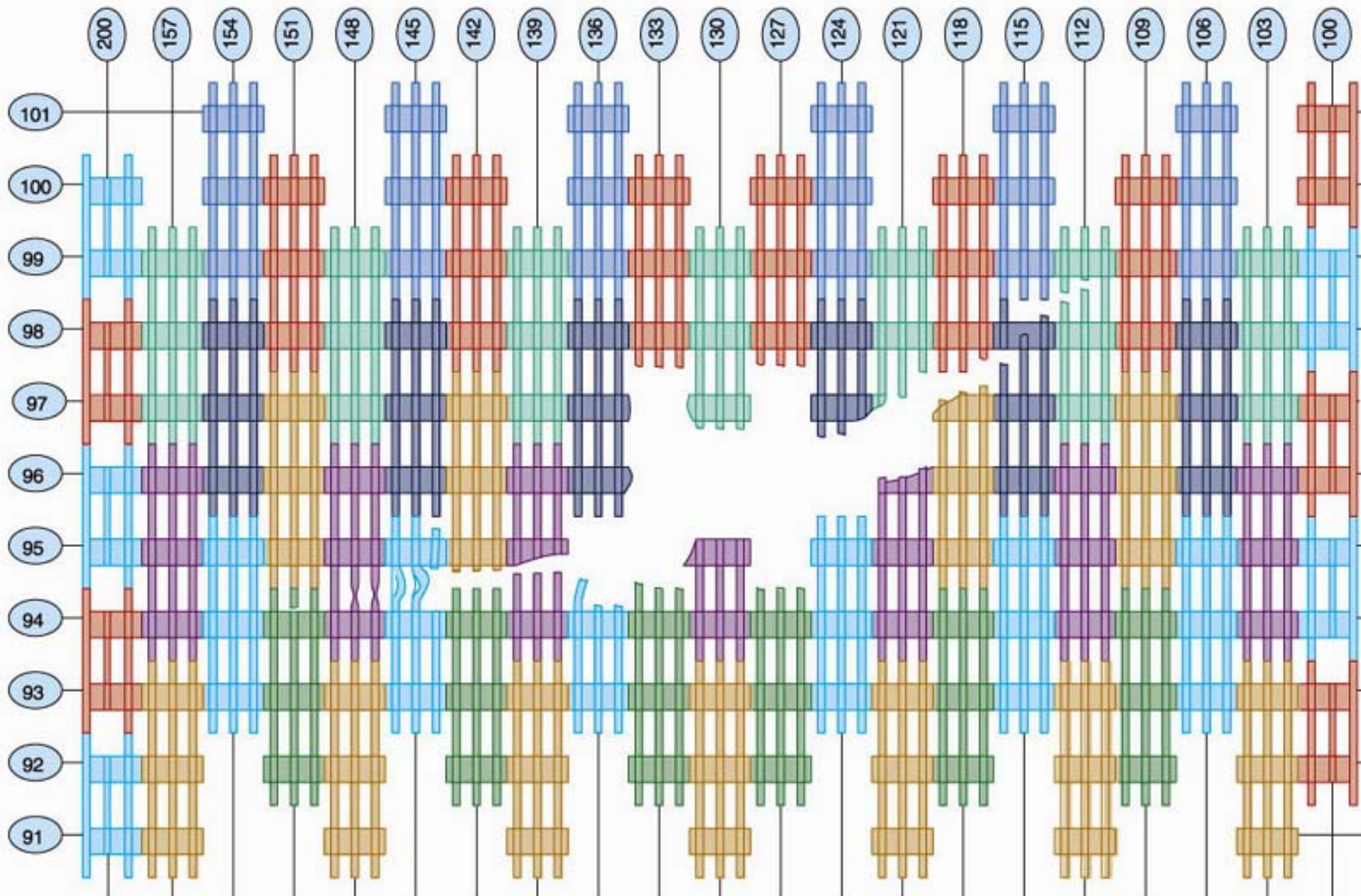


**North
Face
Entry
View**



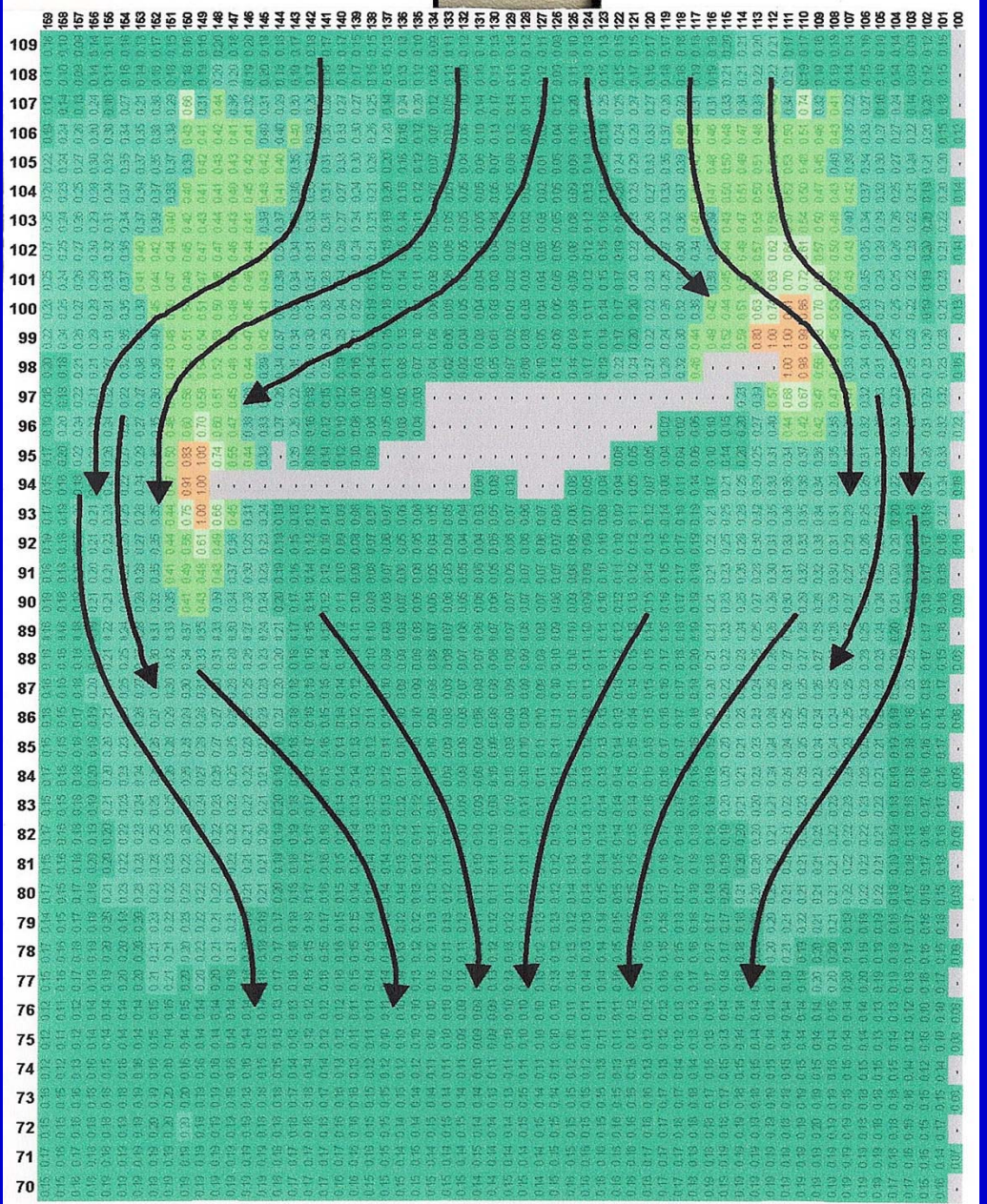


WTC-1 North Facade

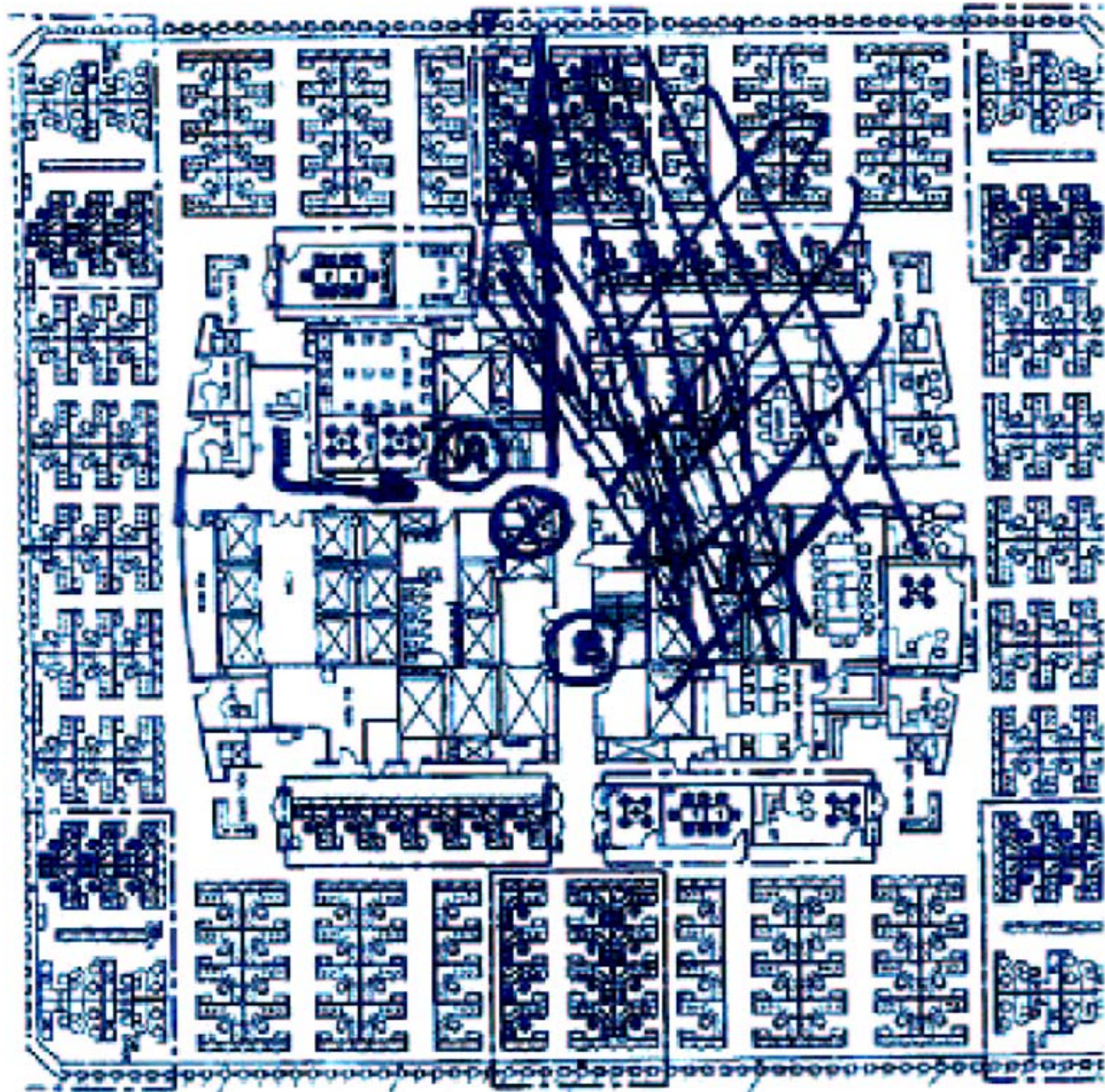


GENERAL NOTES: 1) Column damage captured from photographs and enhanced videos. 2) Damage to column lines 120, 121, and 122 at level 96 is estimated.

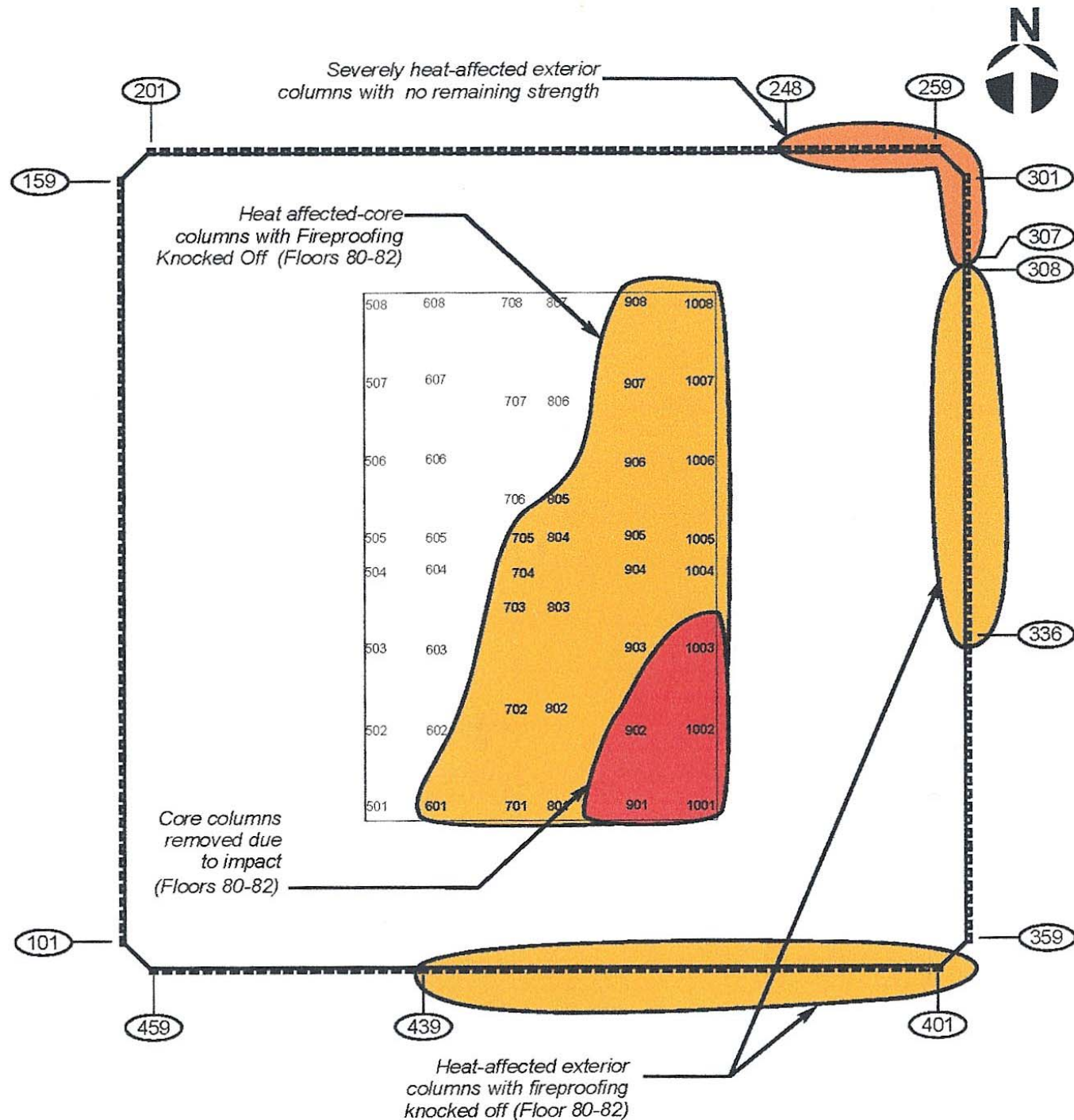
Load Distribution Pattern



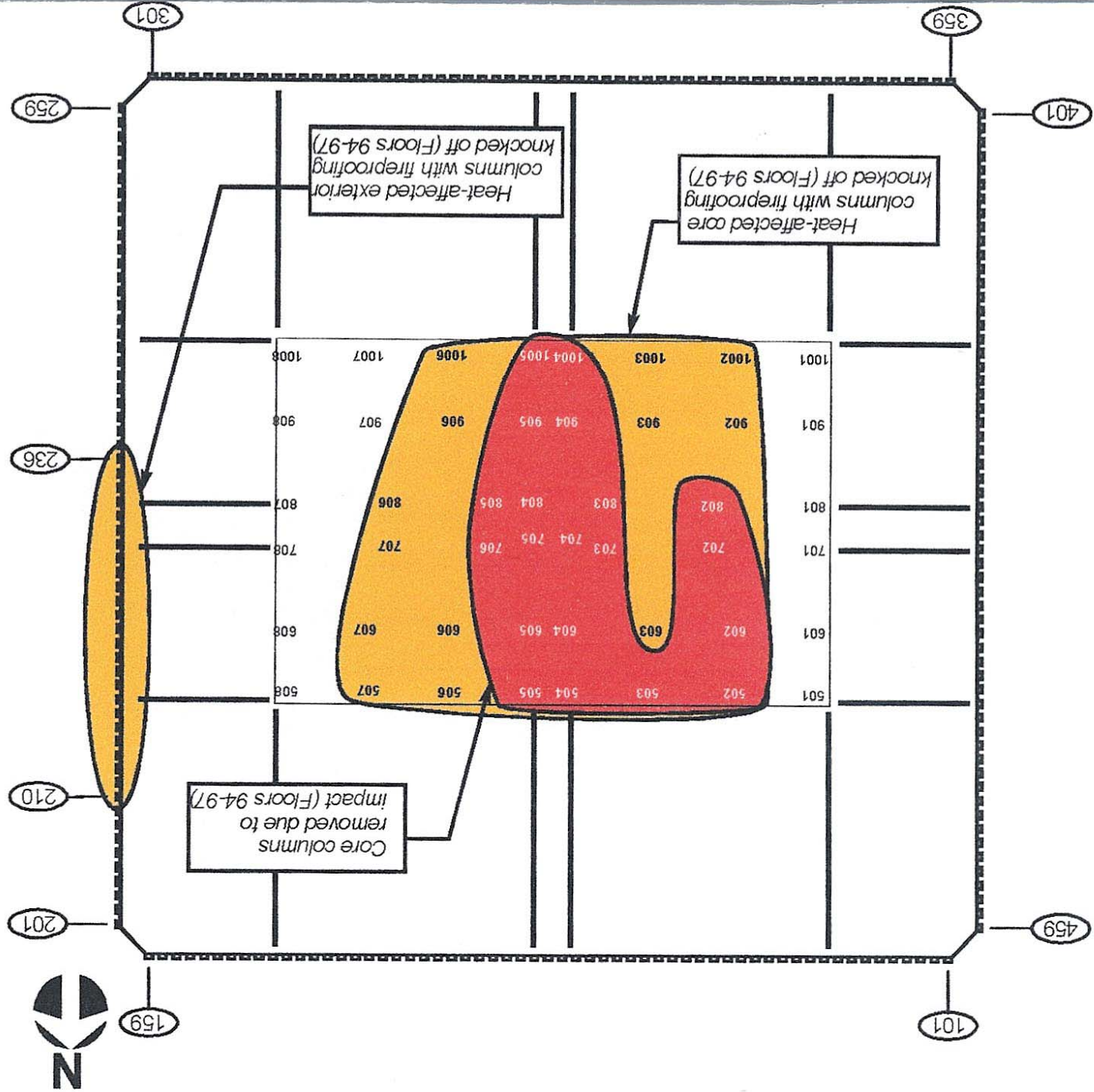
COLUMN D/C RATIO RANGES					
< 0.2	0.2 - 0.4	0.4 - 0.6	0.6 - 0.8	0.8 - 1.0	> 1.0



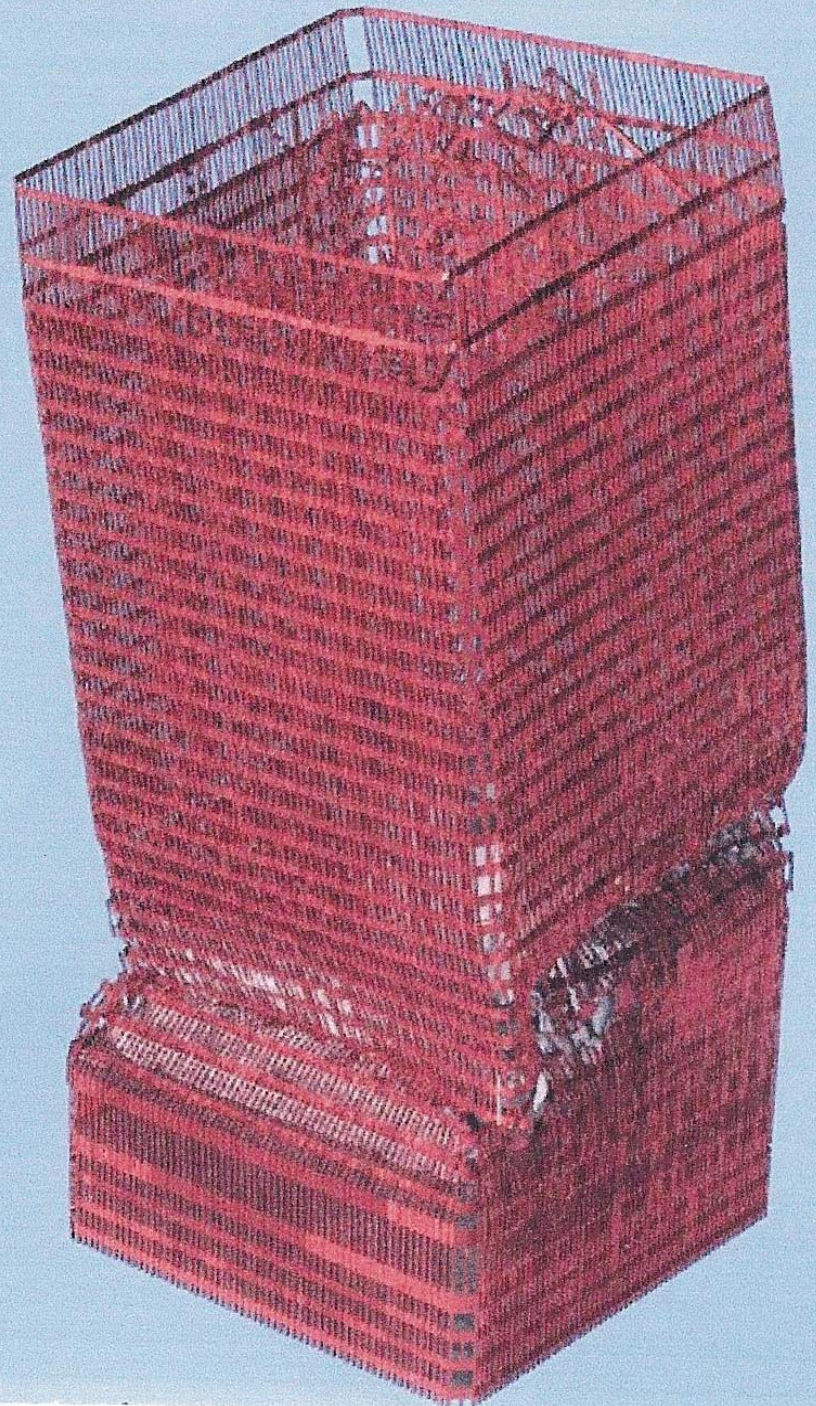
Tower 2 Core Damage Estimate



Tower 1 Core Damage Estimate



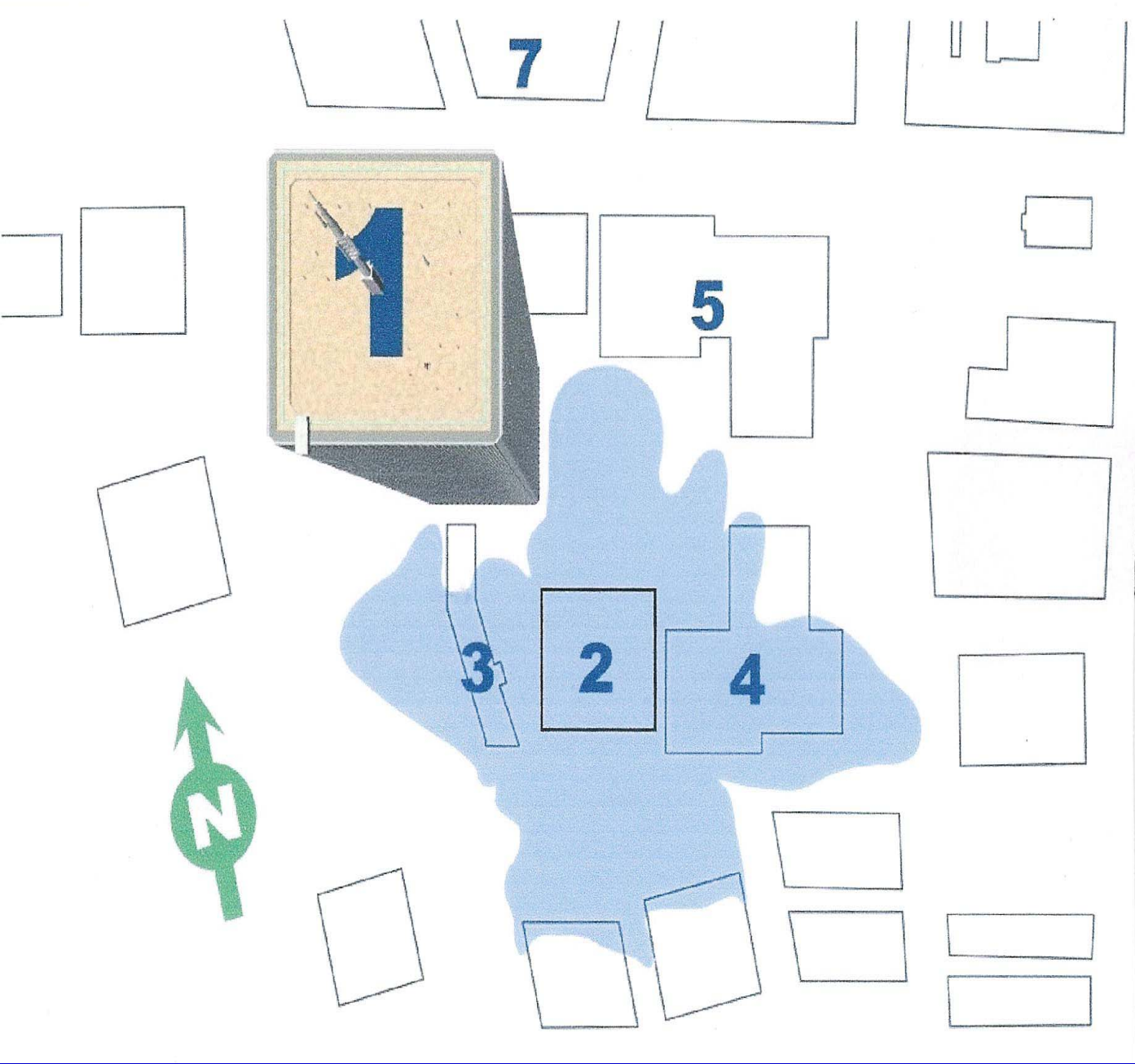
Tower 2 Collapse Simulation







Tower 2 Debris Pattern



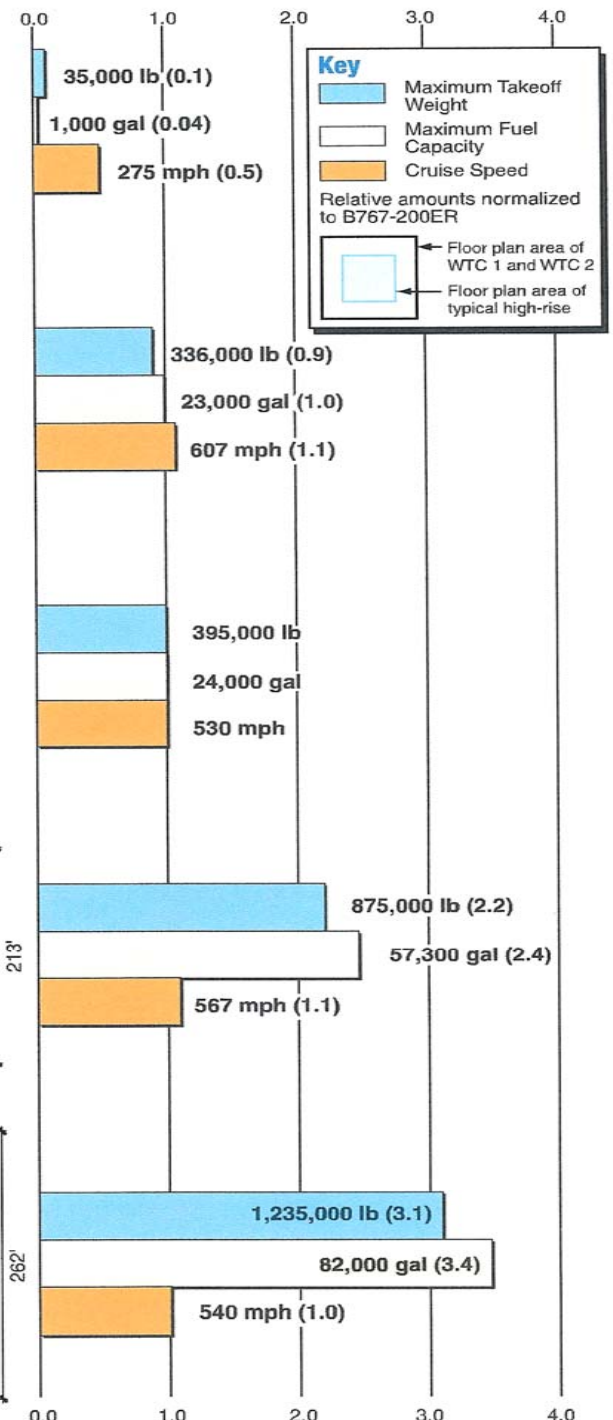
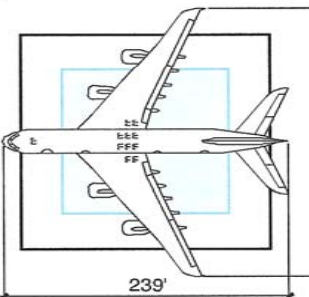
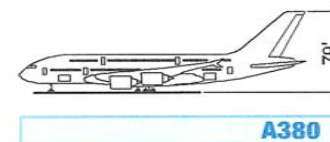
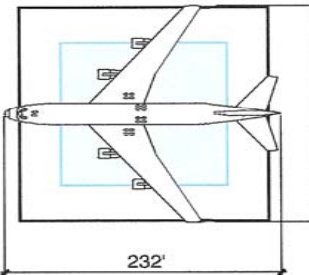
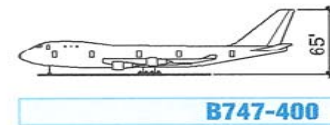
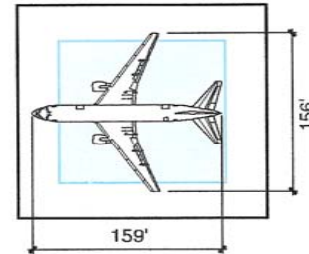
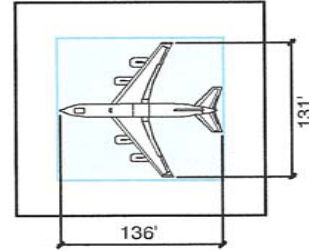
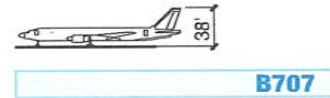
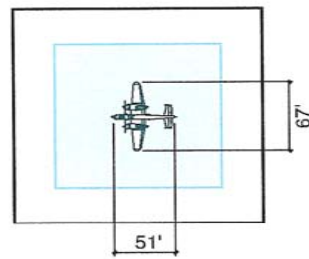




S
A
Y
A
90

92-10-1

Plane Facts





G No Damage – 384 total buildings inspected

Y Moderate Damage – 18 total

B Major Damage – 9 total

R Partial Collapse – 4 total

WTC Emergency Building Ratings SEAoNY

NYC DDC/DoB
Cooperative Building
Damage Assessment

22 September 2001



Bankers Trust Damage



Bankers Trust Floor Damage





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**WTC 7 with
Both
Mechanical
Penthouses
Intact**



WTC 7 Penthouse Collapse



Location of "Kink" or Fault

WTC 7 Kink in Building



WTC 7 Collapse



7 World Trade Center ~ September 11th, 2001



WTC 7





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WTC Emergency Building Ratings SEAoNY



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WTC 3



WTC 4, 5 and 6



Roof

9th Floor

8th Floor

7th Floor

6th Floor

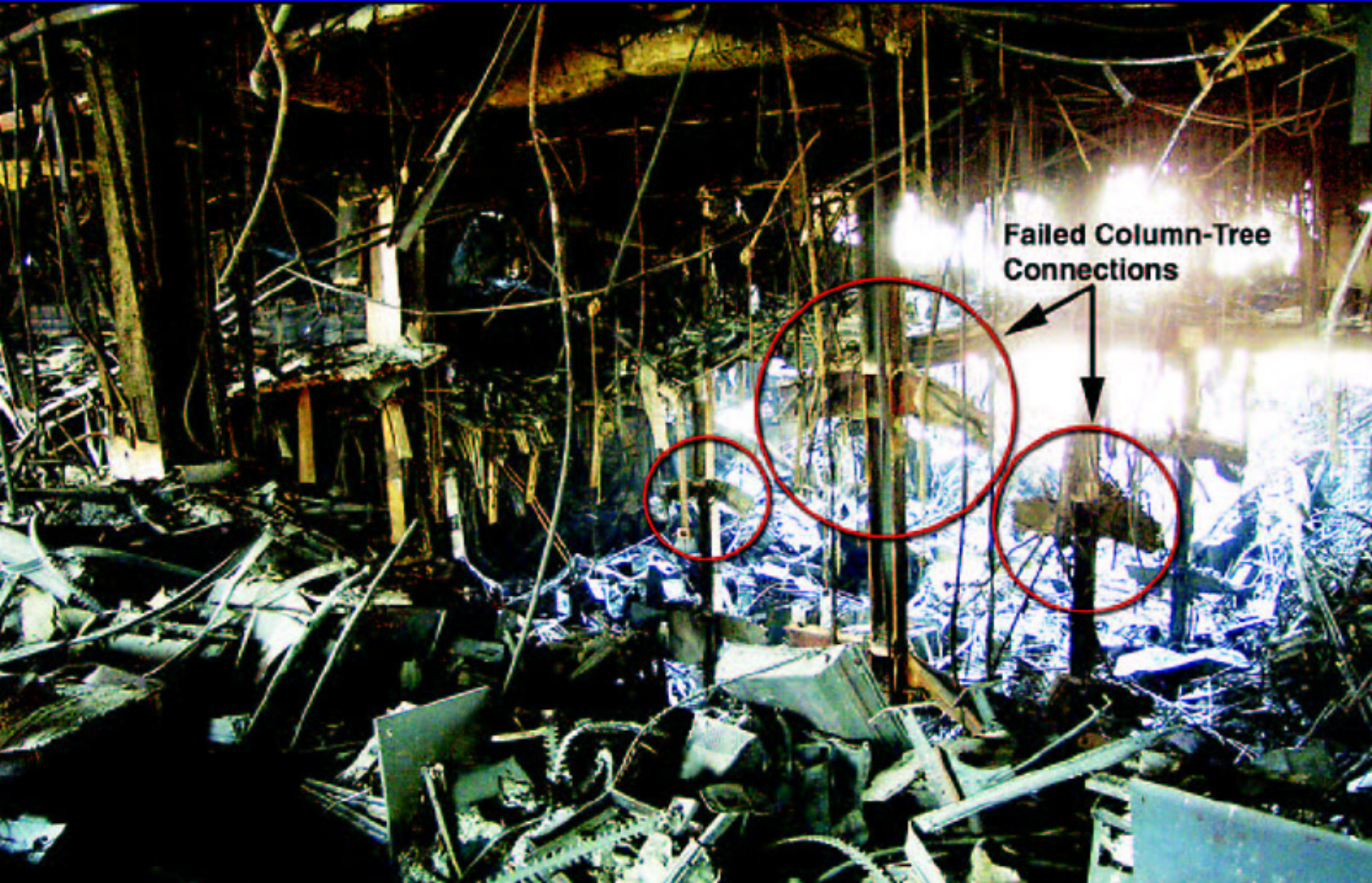
5th Floor

4th Floor

3rd Floor

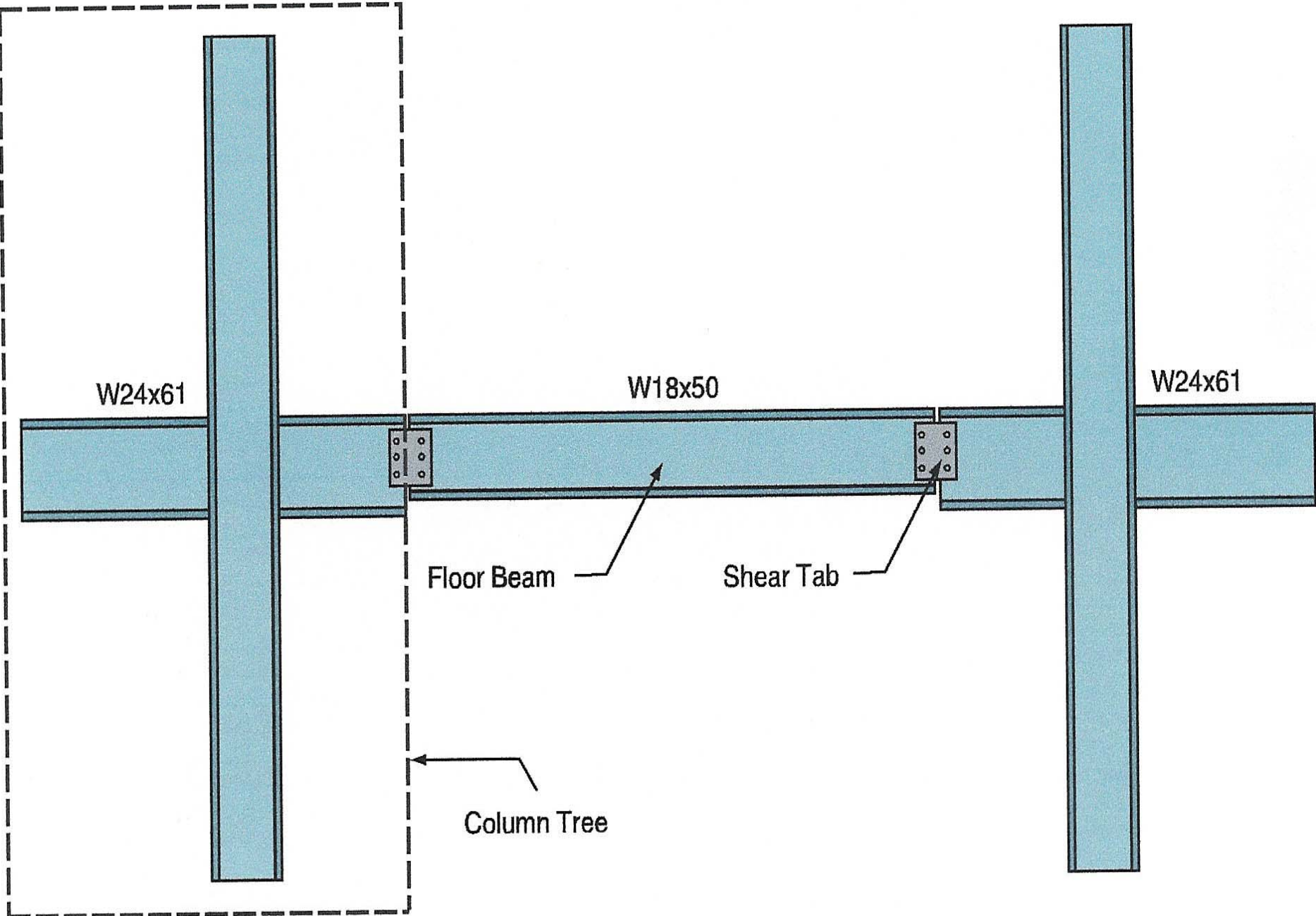


WTC 5 Collapsed Area



WTC 5 Collapsed Area





W24x61

W18x50

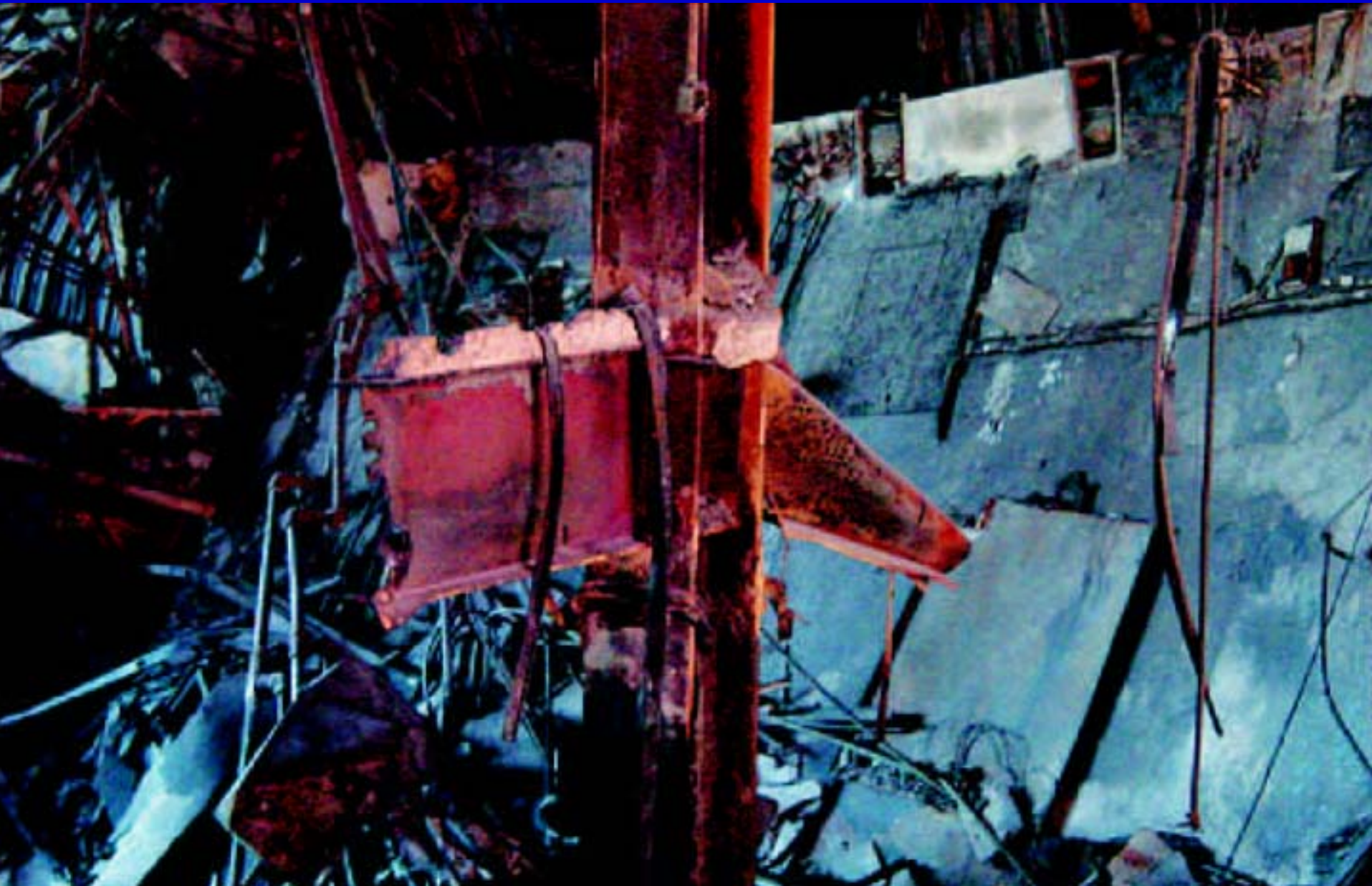
W24x61

Floor Beam

Shear Tab

Column Tree

WTC 5 Collapsed Area







3rd Floor

2nd Floor

WTC Collapse Sequence

- **Impact not Sufficient**
- **Required Second Large Event**
- **Fire Was Second Event**

Why Survival Time?

- **Multiple columns**
- **Transfer of load**
- **Overcapacity**

Structural Lessons Learned

- Need redundancy
- Need robustness
- Consider fire resistance related to importance of member

Fireproofing Lessons Learned

- Stick under impact
- Stick under deformations
- Effective after attack

Fire Protection Lessons Learned

- Sprinkler water supply needs
 - Reliable
 - Redundant
- Loss of supply means loss of protection

Exiting Lessons Learned

- Need redundancy
- Need robustness
- Need separation
- Need impact resistance

Connections Lessons Learned

- **For All Buildings**
 - Need fire rating
 - Need test data
 - Need analysis

Summary

- **Towers survived impact**
- **Fire brought down towers**
- **Redundancy and robustness worked**
- **Transfer trusses need special consideration**
- **Fire resistance of connections important**
- **Relate fireproofing to fire load**
- **Exit stairs with impact needs review**

World Trade Center Building Performance Study:

*Data Collection, Preliminary
Observations, and
Recommendations*



Federal Emergency Management Agency
Federal Insurance and Mitigation Administration,
Washington, DC

FEMA Region II,
New York, New York

World Trade Center Building Performance Study

“The World Trade Center should, because of its importance, become a representation of man’s belief in humanity, his need for individual dignity, his beliefs in the cooperation of men, and through cooperation, his ability to find greatness.”

Minoru Yamasaki, Chief Architect
of the World Trade Center