11-4403-cv

United States Court of Appeals

for the

Second Circuit

AEGIS INSURANCE SERVICES, INC., LIBERTY INSURANCE UNDERWRITERS, INC., NATIONAL UNION INSURANCE COMPANY OF PITTSBURGH, NUCLEAR ELECTRIC INSURANCE LIMITED, CERTAIN UNDERWRITERS AT LLOYDS, (Syndicates 1225 and 1511), as subrogor of Consolidated Edison Company of New York, Inc., and CONSOLIDATED EDISON COMPANY OF NEW YORK, INC.

Plaintiffs-Appellants,

(For Continuation of Caption See Inside Cover)

ON APPEAL FROM THE UNITED STATES DISTRICT COURT FOR THE SOUTHERN DISTRICT OF NEW YORK

JOINT APPENDIX
Volume 13 of 16 (Pages JA-3321 to JA-3616)

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(For Continuation of Appearances See Inside Cover)

v.

7 WORLD TRADE COMPANY, L.P.,

Defendant-Cross-Defendant-Cross-Claimant-Third-Party Plaintiff-Appellee,

CITIGROUP INC., CITIGROUP GLOBAL MARKETS HOLDINGS INC., SALOMON SMITH BARNEY HOLDINGS, INC., SALOMON INC., SILVERSTEIN DEVELOPMENT CORP., SILVERSTEIN PROPERTIES, INC.,

Defendants-Cross-Defendants-Cross-Claimants-Appellees,

TISHMAN CONSTRUCTION CORPORATION,

Defendant-Cross-Defendant-Appellee,

OFFICE OF IRWIN G. CANTOR, P.C., FLACK & KURTZ, INC.,

Defendants-Cross-Defendants-Third-Party Defendants-Appellees,

SWANKE HAYDEN CONNELL ARCHITECTS, SYSKA & HENNESSY GROUP, INC., AKA SYSKA & HENNESSY ENGINEERS,

Defendants-Cross-Defendants-Cross-Claimants-Third-Party Plaintiffs,

H.O. PENN MACHINERY CO., INC., ALL FIRE SYSTEMS, INC.,

Defendants-Cross-Defendants-Cross-Claimants,

GRACE CONSTRUCTION PRODUCTS, EMERY ROTH & SON, P.C., SECURITAS AB, SECURITY SERVICES, INC., CENTIFUGAL ASSOCIATES, INC., SYSKA & HENNESSY, INC.,

Defendants-Cross-Defendants,

AMBASSADOR CONSTRUCTION CO., INC., COSENTINI ASSOCIATES INC., CANTOR SEINUK GROUP, P.C., SKIDMORE OWINGS AND MERRILL, L.L.P., AMBASSADOR CONSTRUCTION CO., INC., AMEC CONSTRUCTION MANAGEMENT, INC., FKA MORSE DIESEL INTERNATIONAL, INC.,

Defendants-Cross-Defendants-Third-Party Defendants,

DIC/UNDERHILL, a joint venture, KABACK ENTERPRISES, PREFERRED UTILITIES MANUFACTURING CORP., ELECTRIC POWER SYSTEMS, INC., G.C. ENGINEERING & ASSOCIATES, P.C., FIRECOM INC., FIBERLOCK TECHNOLOGIES, INC., ROSEBWACH TANK CO., INC., ABCO PEERLESS SPRINKLER CORPORATION, AMR CORPORATION, AMERICAN AIRLINES, INCORPORATED, UAL CORPORATION, UNITED AIRLINES INCORPORATED, COLGAN AIR, INCORPORATED, US AIRWAYS GROUP, INCORPORATED, US AIRWAYS, INCORPORATED, HUNTLEIGH USA CORPORATION, ICTS INTERNATIONAL NV, GLOBE

AVIATION SERVICES CORPORATION, BURNS INTERNATIONAL SECURITY SERVICES CORPORATION, PINKERTON'S INCORPORATED, BOEING COMPANY, AMEC, PLC, KABACK ENTERPRISES,

Defendants,

THE WTC PLAINTIFFS,

Plaintiff-Intervenor.

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UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF NEW YORK

In re: September 11 Property Damage and Business Loss Litigation

Consolidated Edison Company of New York, Inc., et al., Plaintiffs

against

7 World Trade Center Company, LP, et al., Defendants

Civil Action No.
21 MC 101 (AKH)/04 CV 7272 (AKH)

Expert report
by

Frederick W. Mowrer, Ph.D.
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February 15, 2010

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1. INTRODUCTION

This expert report has been prepared at the request of counsel for Consolidated Edison (Con Ed) in this matter, which relates to the fire-induced collapse of the World Trade Center 7 building (WTC7) that occurred in New York City on September 11, 2001. This report is intended to serve as a disclosure of my expert opinions and the bases for these opinions in this matter. This expert report may be amended or supplemented if additional information becomes available that affects the opinions expressed herein.

In developing my opinions in this matter, I have relied on my knowledge of Fire Protection Engineering and Fire Science, including my personal experience as an Assistant Professor and Associate Professor of Fire Protection Engineering, as a Researcher in Fire Science and as a Consultant specializing in Fire Protection Engineering and Fire Science. Additional information on my education, experience, qualifications and publications is provided in my curriculum vita in Exhibit A.1. Documents that I have considered and/or relied upon in developing my opinions are listed in Exhibit A.2. My fee schedule for services provided on this matter is provided in Exhibit A.3. A schedule of the cases in which I have provided expert testimony during the past four years is provided in Exhibit A.4.

2. SUMMARY

WTC7 was a 47-story steel-framed fire-resistive building located in downtown Manhattan, just north of the main World Trade Center (WTC) plaza, as shown in Figure 1. The building, designed and constructed in the mid-1980s, was bounded by Vesey Street on the south, Washington Street on the west, Barclay Street on the north and West Broadway on the east. WTC7 had a trapezoidal floor plan that paralleled the surrounding streets. Part of the WTC7 building was constructed above an existing Con Ed electric substation. Part of the WTC7 building was also constructed over a truck ramp serving the main WTC plaza.

The trapezoidal shape of the WTC7 building and its construction over the Con Ed substation and WTC truck ramp resulted in an unusual structural design that included the use of transfer trusses, long-span steel beams and girders, and asymmetric framing configurations between beams and girders, and between girders and columns. At the time of the design and construction of WTC7, this structural design was largely untested with respect to its reaction to fire.

The Port Authority of New York and New Jersey (PA) had jurisdiction over the construction of the WTC7 building. It was the policy of the PA to comply with the Building Code of the City of New York (NYCBC) for buildings under PA jurisdiction and located within New York City. At the time of design and construction of WTC7, the 1968 edition of the NYCBC was in force along with a number of local laws that amended the requirements of the 1968 NYCBC. These codes and standards were used to regulate the design and construction of the WTC7 building.

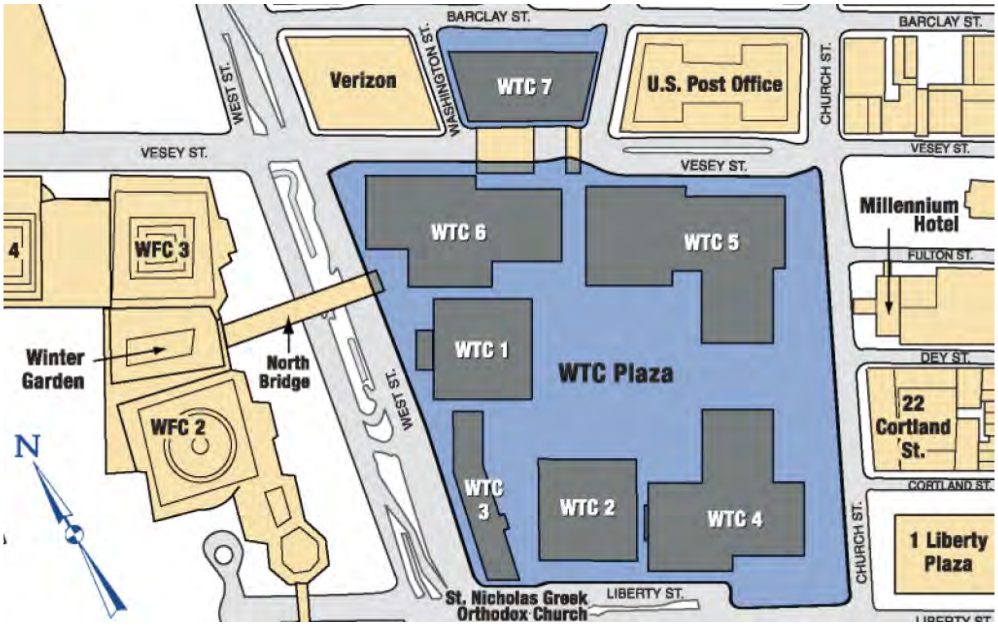

Figure 1. WTC site plan, showing location of WTC7 to north of main WTC site. (Extracted from Figure 1-1 of FEMA 403 report)

WTC7 was occupied primarily as an office building, but also contained spaces used for other purposes, including electric power generation. One of the unusual features of the WTC7 building was the installation of a large number of standby generators within the building. Unlike the two 900 kW emergency generators that were installed on the 5th floor to provide emergency power for the life safety systems within the building, these standby generators were installed within the building by some of the tenants to serve their own business interests. For example, Salomon Brothers (SB) installed nine 1750 kW standby generators on the 5th floor along with a pressurized fuel oil system to support the operation of the generators.

The WTC7 building was classified as Occupancy Group E, with an associated Fire Index of 2, based on its primary use as an office building. Occupancy Group D-1 was the appropriate occupancy classification for the spaces where the SB electric power generators were located on the 5th floor of WTC7. Occupancy Group D-1 has an associated Fire Index of 3. With a Fire Index of 3, the generator spaces should have been separated from adjoining spaces by construction with at least a 3-hour fire resistance rating. The spaces occupied by the SB standby generators on the 5th floor of the WTC7 building also should have been sprinklered, or protected by an alternative fire suppression system, based on any one of a number of building code requirements.

The WTC7 building was designated as construction Class I-B under the NYCBC. This construction class includes buildings and spaces in which the bearing walls and other major structural elements are generally of 3-hour fire-resistance rating. The major structural elements requiring a 3-hour fire-resistance rating include columns, girders, trusses and framing supporting more than one floor; floor construction, including beams, requires a 2-hour fire resistance rating in buildings of Class I-B construction.

In an effort to provide the specified fire resistance ratings for structural elements throughout the WTC7 building, the structural steel and metal floor decks were coated with an insulating material known as a spray-applied fire-resistive material (SFRM). The product selected for this application was a cementitious material, Monokote MK-5. This material is applied to structural elements and floor assemblies in different thicknesses to achieve different fire resistance ratings based on fire test results and listing requirements published by Underwriters Laboratories, Inc. (UL).

The WTC7 architect specified fire resistance ratings consistent with Class I-B construction, but also specified that “All steel framing shall be considered as being of the restrained type.” This statement in the specifications regarding steel framing being considered as restrained refers to the dual-classification system used in the United States for fire resistance ratings of steel-framed floor-ceiling assemblies, roof-ceiling assemblies and beams since the early 1970s. Under this dual-classification system, steel-framed floor-ceiling assemblies, roof-ceiling assemblies and beams are classified with two different fire resistance ratings based on two conditions of support: restrained and unrestrained. Engineering judgment is needed to evaluate whether an assembly or beam should be considered as restrained or unrestrained.

In general, lesser thicknesses of fireproofing are required for restrained assemblies and beams to achieve a specified level of fire resistance than for unrestrained assemblies and beams to achieve the same level of fire resistance. Consequently, designers should ensure that steel framing will behave in a restrained manner before specifying that steel framing shall be considered as being of the restrained type. Otherwise, the specified level of fireproofing will not provide the required level of fire resistance.

As noted in Appendix C of the UL 263 fire test standard, “For the purpose of this Guide, restraint in buildings is defined as follows: Floor and roof assemblies and individual beams in buildings shall be considered restrained when the surrounding or supporting structure is capable of resisting substantial thermal expansion throughout the range of anticipated elevated temperatures. Constructions not complying with this definition are assumed to be free to rotate and expand and shall therefore be considered as unrestrained.” The WTC7 architect specified that all steel framing would be considered as restrained without considering whether the surrounding or supporting structure was capable of resisting substantial thermal expansion throughout the range of anticipated elevated temperatures.

The floor assembly designated as UL Design No. D739 was used as the basis for the fire resistance rating of the WTC7 floor assemblies. The UL Design No. D739 achieved the 2-hour fire resistance rating required of floor assemblies in buildings of Class I-B construction under the NYCBC only as a restrained assembly. For unrestrained assemblies, the UL Design No. D739 only achieved a fire resistance rating of 1 hour, which would not have qualified it for use in a building of Class I-B construction. Consequently, to the extent that the floor assemblies in the

WTC7 building behaved as unrestrained assemblies, the level of fire resistance specified and provided for the floor assemblies did not meet the NYCBC requirements for a building of Class I-B construction.

The Design Information Section in the 1983 and 1985 editions of the UL Fire Resistance Directory required that "Cavities, if any, between the upper beam flange and floor or roof units shall be filled with the fire protection material applied to the beam, unless stated otherwise on an individual design." The listing for UL Design No. D739 did not state otherwise, so this provision would have applied to the WTC7 floor assemblies. This provision requiring cavities to be filled is still included in the current version of the UL Fire Resistance Directory.

Figure 2, a photograph from the Steel Design Guide 19[1] published by the American Institute of Steel Construction (AISC), shows an example of filled cavities between the upper beam flange and a fluted metal deck. In order for flutes to be properly filled, they must be filled completely, as shown on Figure 2. In contrast, Figure 3, a photograph of a floor assembly on one of the floors in the WTC 7 building, shows an example of unfilled cavities. This photograph is representative of other photographs in the WTC7 building that show similarly unfilled cavities between the upper beam flanges and the fluted metal decks.

Figure 2. Photograph from AISC Steel Design Guide 19, showing proper filling of cavities between steel beam and fluted metal deck.

[1] Ruddy, J.L., Marlo, J.P., Ioannides, S.A., and Alfawakhiri, F., *Fire Resistance of Structural Steel Framing*, Steel Design Guide 19, American Institute of Steel Construction, 2003.

Figure 3. Photograph showing condition of fireproofing in WTC7.[2]
(Bernstein Photo 5-93 View: 5th floor NE→NW (BERNSTEIN0000029.01.pdf))

In summary, the WTC7 building had a number of deficiencies with respect to its fire protection. These deficiencies included:

- Improper specification of the steel framing in the building as restrained;
- An inadequate fire resistance rating of 1-hour for the floor assemblies based on an unrestrained assembly classification;
- Failure to fill the cavities between the upper beam flanges and the fluted metal decks with fireproofing material in accordance with UL requirements for floor assemblies, further reducing the actual level of fire resistance provided for the floor assemblies;
- Failure to provide a 3-hour fire separation between the standby generator spaces (Occupancy Group D-1) and adjacent spaces (generally Group E);
- Incomplete sprinkler protection, including the lack of sprinkler protection or alternative fire suppression in the SB standby generator spaces on the 5th floor.

As a result of these deficiencies, WTC7 did not meet the standards for fire protection of a Class I-B structure and consequently was more vulnerable to fire than it should have been.

[2] BATES NUMBER BERNSTEIN0000029.01)

WTC7 is the only modern fire-resistive high-rise building in the United States that has ever suffered global collapse as a direct result of fire. Other modern fire-resistive high-rise office buildings, notably the First Interstate Bank (FIB) in Los Angeles and the One Meridian Plaza (OMP) in Philadelphia, have suffered uncontrolled fires on multiple floors, but these buildings did not collapse as a result of the fires. On the contrary, these buildings, particularly the FIB, exhibited the type of performance expected of fire-resistive buildings when subjected to uncontrolled fires by maintaining their structural integrity.

Following 9/11, Beitel and Iwankiw[3] conducted a survey of historical information on fires in multi-story (defined as four or more stories in their survey) buildings that resulted in full or partial structural collapse. Their survey included buildings of all types of construction, including concrete, steel-framed, brick and wood frame. WTC7 is the only steel-framed high-rise building identified by Beitel and Iwankiw as having suffered a total collapse as a result of fire.[4] This exemplary performance record for fire-resistive steel-framed buildings highlights the fact that the WTC7 building was deficient in its ability to withstand the impact of fire.

3. BACKGROUND INFORMATION

3.1 Construction Classifications

For most of the past century, building codes in the United States have classified buildings into a small number of construction classifications based on the combustibility and fire resistance of construction elements and assemblies. For example, the first edition of the Uniform Building Code (UBC), published in 1927, recognized five different types of construction[5]:

- Type I – FIRE-RESISTIVE Construction
- Type II – HEAVY-TIMBER Construction
- Type III – ORDINARY MASONRY Construction
- Type IV – METAL FRAME Construction
- Type V – WOOD FRAME Construction

Under the 1927 UBC, the structural frame of a Type I building was required to be of concrete or of fireproofed structural steel or iron. Structural steel or iron members were required to be "thoroughly fireproofed with not less than four-hour fire-resistive protection for columns, beams and girders and three-hour fire-resistive protection for floors, for all buildings more than eight (8) stories or eighty-five (85) feet in height; and with three-hour fire-resistive protection

[3] Beitel, J., and Iwankiw, N., *Analysis of Needs and Existing Capabilities for Full-Scale Fire Resistance Testing*, NIST GCR 02-843-1 (Revision), National Institute of Standards and Technology, October 2008 (Replaces NIST GCR 02-843, December 2002)
[4] Ibid., Table 2.1.
[5] *Uniform Building Code*, 1st edition, Sec. 1702, 1927, p. 56.

for columns, beams and girders and two-hour fire-resistive protection for floors for all buildings which are eight (8) stories or eighty-five (85) feet or less in height."[6]

The technical bases for construction classifications under the building codes were described in 1942 in Report BMS92[7], entitled "Fire-Resistance Classifications of Building Constructions," published by the National Bureau of Standards (predecessor to the National Institute of Standards and Technology). Report BMS92 concluded that by considering only the basic properties having a bearing on fire hazard and fire resistance, four types of building construction classifications were sufficient to cover the whole range of building construction. Within each type, two or more classes are defined based on the fire resistance required for their structural members. The types of construction identified in BMS92 include:

- Type I. Fireproof construction (now called "fire resistive")
- Type II. Incombustible construction (now called "noncombustible")
- Type III. Exterior-Protected construction
- Type IV. Wood construction

In BMS92, Type I – Fireproof Construction is defined as "That type of construction in which the structural elements are of incombustible materials with fire-resistance ratings sufficient to withstand the fire severity resulting from complete combustion of the contents and finish involved in the intended occupancy but not less than the rating specified in table 1 (of BMS92) …". Table 1 of BMS92 laid out the minimum fire-resistance ratings of structural elements for Type I construction. Six different subtypes were established, based on the expected fire load, expressed in terms of the weight of combustibles per unit floor area, lb/ft^2. In this way, BMS92 recognized that buildings of "Fireproof Construction" could be provided with different levels of fire resistance based on different levels of anticipated fire severity.

The construction types identified in BMS92 are very similar to the construction types recognized in current model building codes, although the current codes recognize different subcategories under each construction type and have different designations for some of the construction types. The 1968 NYCBC is similar to other building codes, but uses different terminology to represent different construction types. The NYCBC includes only two broad construction groups, I-Noncombustible and II-Combustible, with five classes under each group. The classes under construction group I-Noncombustible include:

- I-A— (4-hr. protected)
- I-B— (3-hr. protected)
- I-C— (2-hr. protected)
- I-D— (1-hr. protected)
- I-E— (unprotected)

[6] Ibid., Sec. 1809, p. 58
[7] Report BMS92, *Fire-Resistance Classifications of Building Constructions*, National Bureau of Standards, 1942.

As noted in Section 27-276 of the NYCBC, Class I-B construction includes buildings and spaces in which the bearing walls and other major structural elements are generally of three-hour fire-resistance rating. For the other construction classes, the fire resistance rating of major structural elements is the hourly rating indicated in the parentheses for each construction class noted above. The fire resistance ratings of all construction elements in Construction Group I-Noncombustible buildings are identified in Table 3-4 of the NYCBC.

3.2 Fire Resistance Ratings

The fire resistance ratings of construction elements referenced in the NYCBC, as well as in other building codes, are based on the test procedures and criteria described in the ASTM E119 Standard Method of Fire Tests of Building Construction and Materials. As noted in the Introduction section of the ASTM E119 standard, "The performance of walls, columns, floors, and other building members under fire exposure conditions is an item of major importance in securing constructions that are safe, and that are not a menace to neighboring structures nor to the public."[8]

The basic features of the fire test method described in the ASTM E119 standard have remained virtually the same since this standard was first introduced in 1918. In this fire test method, specimens that are supposed to be "truly representative of the construction for which classification is desired"[9] are installed in a fire test furnace and subjected to relatively severe fire exposure conditions represented by a standard time-temperature curve. The standard time-temperature curve used to define the exposure conditions in the ASTM E119 standard is represented in terms of the following temperatures at the respective times:

1000°F (538°C) at 5 min
1300°F (704°C) at 10 min
1550°F (843°C) at 30 min
1700°F (927°C) at 1 h
1850°F (1010°C) at 2 h
2000°F (1093°C) at 4 h
2300°F (1260°C) at 8 h or over

Based on the fire test results and acceptance criteria described in the ASTM E119 standard, construction elements and assemblies are assigned fire resistance ratings that are typically expressed in terms of hourly ratings, e.g., 1-hour, 2-hour, etc.

For floor assemblies, the area of the test specimen exposed to the fire conditions must be at least 180 ft^2 (16 m^2), with neither dimension less than 12 ft (3.7 m). A test specimen that is 12 ft (3.7 m) long and 15 ft (4.8 m) wide meets these requirements. Throughout a test, a load is superimposed on the floor assembly to simulate a maximum load condition. The question arises

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[8] ASTM E 119 – 00a, *Standard Test Methods for Fire Tests of Building Construction and Materials*, 2000.
[9] Ibid., Section 9.1.

as to whether the results of this test can be extrapolated to actual floor constructions with spans that are more than 4 times longer than the test assembly, as they were in the northeast corner of WTC7. As noted in Section 4.2 of the ASTM E119 standard, "…Variation from the test conditions or specimen construction, such as size, materials, method of assembly, also affects the fire-test-response. For these reasons, evaluation of the variation is required for application to construction in the field." To illustrate this point, Figure 4 shows the approximate area of a floor test assembly superimposed as a red rectangle on a typical WTC7 floor plan.

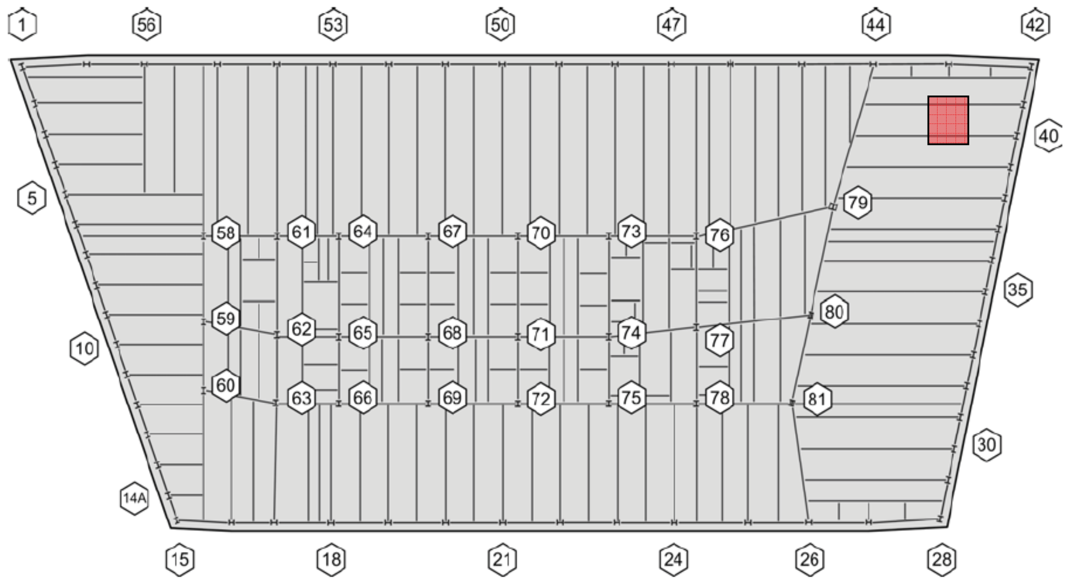

Figure 4. Floor plan of WTC7 with approximate area of ASTM E119 test specimen superimposed (red rectangle).

The conditions of acceptance specified in the ASTM E119 standard for floor assemblies include:

- The specimen must sustain the applied load during the classification period without developing unexposed surface conditions which will ignite cotton waste;
- The transmission of heat through the specimen during the classification period must not raise the average temperature on its unexposed surface more than 250°F (139°C) above its initial temperature;
- For unrestrained assemblies employing steel structural members (beams, open-web steel joists, etc.), spaced more than 4 ft (1.2 m) on centers, the temperature of the steel must not exceed 1300°F (704°C) at any location during the classification period and the average temperature recorded by four thermocouples at any section must not exceed 1100°F (593°C) during the classification period. For restrained assemblies, these temperature criteria apply for a period of one half the classification period of the assembly or 1 hr, whichever is greater.

The purpose of these conditions of acceptance is to evaluate the potential for flame penetration or heat transmission through the floor assembly as well as the structural integrity of the floor assembly.

Since the early 1970s, a dual-classification system has been used in the United States for fire resistance ratings of steel-framed floor-ceiling assemblies, roof-ceiling assemblies and beams. Under this dual-classification system, steel-framed floor-ceiling assemblies, roof-ceiling assemblies and beams are classified with two different fire resistance ratings based on two conditions of support: restrained and unrestrained. Engineering judgment is needed to evaluate whether an assembly or beam should be considered as restrained or unrestrained.

In general, lesser thicknesses of fireproofing are required for restrained assemblies and beams to achieve a specified level of fire resistance than for unrestrained assemblies and beams to achieve the same fire resistance rating. Consequently, designers should ensure that steel framing will behave in a restrained manner before specifying that steel framing shall be considered as being of the restrained type. This concept is demonstrated in Section 4302(b) of the 1985 Uniform Building Code, which includes the following provision:

"Fire-resistive assemblies tested under U.B.C. Standard No. 43-1 shall not be considered to be restrained unless evidence satisfactory to the building official is furnished by the person responsible for the structural design showing that the construction qualifies for a restrained classification in accordance with U.B.C. Standard No. 43-1. Restrained construction shall be identified on the plans."

U.B.C. Standard No. 43-1 is functionally equivalent to the ASTM E119 and UL 263 fire resistance test standards. This same requirement appeared in the 1979 Uniform Building Code and still appears in the International Building Code that has succeeded the Uniform Building Code as well as the NYCBC.

The Design Information Section of the UL Fire Resistance Directory, including the 1983 and 1985 editions, provides guidance for determining conditions of restraint for floor and roof assemblies and for individual beams; the Design Information Section includes excerpts from Appendix C of the UL 263 Standard for Fire Tests of Building Construction and Materials to provide this guidance:

"C1. The revisions adopted in 1970 have introduced, for the first time in the history of the Standard (UL 263), the concept of fire endurance classifications based on two conditions of support: restrained and unrestrained. As a result, most specimens will be fire tested in such manner as to derive these two classifications.

C2. A restrained condition in fire tests, as used in this Standard, is one in which expansion at the supports of a load-carrying element resulting from the effects of the fire is resisted by forces external to the element. An unrestrained condition is one in which the load-carrying element is free to expand and rotate at its supports.

C3. Some difficulty is recognized in determining the condition of restraint that may be anticipated at elevated temperatures in actual structures. Until a more satisfactory method is developed, this Guide recommends that all constructions be temporarily classified as either restrained or unrestrained. The classification will enable the architect, engineer, or building official to correlate the fire endurance classification, based on conditions of restraint, with the construction type under consideration.

C4. For the purpose of this Guide, restraint in buildings is defined as follows:
Floor and roof assemblies and individual beams in buildings shall be considered restrained when the surrounding or supporting structure is capable of resisting substantial thermal expansion throughout the range of anticipated elevated temperatures. Constructions not complying with this definition are assumed to be free to rotate and expand and shall therefore be considered as unrestrained.

C5. This definition requires the exercise of engineering judgement (sic) to determine what constitutes restraint to "substantial thermal expansion." Restraint may be provided by the lateral stiffness of supports for floor and roof assemblies and intermediate beams forming part of the assembly. In order to develop restraint, connections must adequately transfer thermal thrusts to such supports. The rigidity of adjoining panels or structures should be considered in assessing the capability of a structure to resist thermal expansion. Continuity, such as that occurring in beams acting continuously over more than two supports, will induce rotational restraint which will usually add to the fire resistance of structural members. In the following table, only the common types of constructions are listed. Having these examples in mind, as well as the philosophy expressed in the preamble, the user should be able to rationalize the less common types of construction."

The table referenced in Section C5 of Appendix C to the UL 263 standard is Table C1 – Considerations of Restraint for Common Construction. This table provides guidance for some common construction assemblies, but does not apply for the long spans and asymmetrical framing details that made the structural design of WTC7 non-standard.

An individual unrestrained beam classification is developed for beams from tests as part of a floor assembly. The classification so derived applies to beams when used with a floor or roof construction which has a comparable or greater capacity for heat dissipation from the beam than the floor or roof with which it was tested. The fire endurance classification developed by this procedure does not apply to beams smaller than those tested. The conditions of acceptance for an unrestrained beam classification derived in this way include:

- The specimen must sustain the applied load during the classification period;
- For steel beams the temperature of the steel cannot exceed 1300°F (704°C) at any location during the classification period and the average temperature recorded by four thermocouples at any section cannot exceed 1100°F (593°C) during this period.

The ASTM E119 standard also includes an alternative test of protection for solid structural steel beams and girders. This alternative test procedure is allowed for use in evaluating the protection of steel beams and girders without application of design load, provided that the protection is not required by design to function structurally in resisting applied loads. The conditions of acceptance include an average steel temperature at any one of the four measurement sections of not more than 1000°F (538°C) and a maximum temperature of 1200°F (649°C) at any one of the measurement points. According to the heading of this section of the ASTM E119 standard, this alternative rating method only applies for solid structural beams and girders and thus would not apply to castellated members or to members with extensive web penetrations.

Fire tests conducted in accordance with the ASTM E119 standard are generally performed at commercial laboratories, such as UL. These laboratories publish directories with the fire resistance ratings for the different construction elements and assemblies that have been tested and listed by the test laboratory. The UL directory is known as the Fire Resistance Directory; it includes a Design Information Section at the beginning of the directory that includes general information that applies to the listed assemblies included in the directory. Building designers generally select assemblies from this directory to meet the fire resistance rating requirements for the construction elements and assemblies used in their projects. In doing so, designers need to consider the uses and limitations associated with the fire resistance listings, particularly when designing buildings with unusual structural framing details, such as the WTC7 building.

3.3 Design for Burnout

A basic tenet of structural fire protection embodied in BMS92 and the building codes over most of the past century is that buildings of fire-resistive construction should maintain their structural integrity through complete burnout of their contents. This tenet is reiterated by Buchanan in his 2001 book *Structural Design for Fire Safety*, where he notes that "The fundamental step in designing structures for fire safety is to verify that the fire resistance of the structure (or each part of the structure) is greater than the severity of the fire to which the structure is exposed. This verification requires that the following design equation be satisfied:

$$\text{Fire resistance} \geq \text{fire severity}$$

where fire resistance is a measure of the ability of the structure to resist collapse, fire spread or other failure during exposure to a fire of specified severity, and fire severity is a measure of the destructive impact of a fire, or a measure of the forces or temperatures which could cause collapse or other failure as a result of the fire. …"[10]

Buchanan identifies one of the objectives for providing fire resistance: "To prevent structural collapse, structural elements must be provided with sufficient fire resistance to maintain stability for the fire design time. Prevention of collapse is essential for load-bearing structural

[10] Buchanan, A., Structural Design for Fire Safety, John Wiley & Sons Ltd., 2001., p. 91.

members and for load-bearing barriers which also provide containment. Structural fire resistance must be provided to the main load-bearing structural elements, and to secondary elements which support or provide stability to barriers or main members."[11]

Buchanan notes that "The term fire design time is not precisely defined. Depending on the importance of the building, the requirements of the owner, and the consequences of a structural collapse or spread of fire, the fire design time will be selected by the designer as one of the following:

(1) the time required for occupants to escape from the building,
(2) the time for fire-fighters to carry out rescue activities,
(3) the time for fire-fighters to surround and contain the fire,
(4) the duration of a burnout of the fire compartment with no intervention."

Buchanan goes on to note that "Codes in various countries use these times in different ways for different occupancies. Many small single-storey buildings may be designed to protect escape routes and to remain standing only long enough for the occupants to escape (time (1)) after which the fire will destroy the building. Alternatively, **all very tall buildings, or buildings where people cannot escape, should be designed to prevent major spread of fire and structural collapse for a complete burnout of one or more fire compartments (time (4))**. (Emphasis added) Times (2) and (3) are intermediate times which may be applied to medium sized buildings, to provide life safety or property protection, respectively."[12]

On the issue of trade-offs, Buchanan notes that "It can be difficult to justify trade-offs, especially reductions of fire resistance if automatic sprinkler systems are installed. It is generally accepted that if an automatic suppression system could be relied on to control a fire with total certainty, no fire resistance or passive fire protection would be necessary. However, no system is 100% effective, so the question is how much fire resistance should be provided for the remote probability that the suppression system fails to operate or fails to control the fire. As an example, it could be argued that if the suppression system fails when street water supplies are destroyed by an earthquake, the resulting fire will have the same severity as if there had been no suppression system at all, so there should be no trade-off for sprinklers."[13]

Very tall buildings, such as the WTC7 building, are generally required to be of fire resistive (called Type I in BMS92 and in some building codes) construction, one of several construction types recognized by the Building Code of the City of New York, as well as by the model building codes that have existed in the United States for much of the past century. As noted by Ingberg[14] in an article that appeared in 1929, the fire-resistive type of construction "… comprises buildings that can withstand a complete burning-out of combustible contents and

[11] Ibid., p. 17.
[12] Ibid., p. 19.
[13] Ibid., pp. 19-20.
[14] Ingberg, S.H., "Fire-Resistance Requirements in Building Codes," Quarterly of the National Fire Protection Association, Vol. 23, No. 1, July 1929.

trim without collapse of major structural members." This article also notes that "Buildings of this type are permitted to greater heights and with less restriction as to location and occupancy than buildings of non-fire resistive construction. In return, they are supposed to supply certain elements of safety under fire conditions … . In order that they may function as such, it is apparent that no general or local collapse of building or important building members must occur in a fire consuming combustible contents and trim, otherwise the hazard to surrounding buildings, occupants and fire fighting would not differ greatly from that for the non-fire resistive type. …"

As noted above, in Section 3.1, the Report BMS92 defined Type I construction is "that type of construction in which the structural elements are of incombustible materials with fire-resistance ratings sufficient to withstand the fire severity resulting from complete combustion of the contents and finish involved in the intended occupancy …". Assuming the fires which caused the initial and global collapse of WTC7 were contents fires, the building was not able to withstand the fire severity resulting from complete combustion of its contents without collapsing, thereby violating this principle.

This concept that fire resistance should exceed fire severity in fire resistive buildings is reiterated in an article that appeared in the Quarterly of the National Fire Protection Association in 1950.[15] Quoting from the NFPA Handbook of Fire Protection at the time, this article notes that "As ordinarily used the term 'fire-resistive building' refers to a building with structural members constructed of noncombustible materials of such quality and so protected that they will resist the maximum severity of fire expected within the structure without collapse." This article goes on to say that "if a fire-resistive structure *does* possess the proper degree of fire-resistance, it *will* resist a fire without collapse …". Since the WTC7 building did collapse, it clearly did not possess the proper degree of fire-resistance to resist the maximum severity of fire expected within the structure.

One reason the maximum severity of fire must be anticipated, particularly in tall buildings, is the reasonable expectation that firefighters will not engage in, or be effective in, offensive firefighting in such buildings. Consequently, there is also a reasonable expectation that fires in high-rise building will not be suppressed before burning out the available fire load. Firefighters could not be expected to enter high-rise buildings to attempt to fight fires if the structural stability of these buildings was questionable. This is one of the reasons why high-rise buildings are required to be of fire-resistive construction.

There have been a number of serious fires in high-rise building where firefighters have been unable to suppress the fire on multiple floors of the building, yet these buildings did not collapse. Two of these fires include the First Interstate Bank fire in Los Angeles in 1988 and the One Meridian Plaza fire in Philadelphia in 1991. In both of these fires, as well as in fires in other high-rise buildings, complete combustion of the contents occurred on one or more fire-affected floors, but did not result in total collapse of the buildings. The recent survey of building

[15] "Fires in 'Fireproof' Buildings," Quarterly of the National Fire Protection Association, Vol. 44, No. 1, July 1950.

collapse incidents compiled by Beitel and Iwankiw did not identify any steel-frame high-rise buildings, other than WTC7, that have completely collapsed primarily as a result of fire.

Because a high-rise building of fire resistive construction should be able to withstand complete combustion of its fuel load without collapsing and with no intervention by manual firefighting or automatic sprinkler protection, WTC7 should not have collapsed despite the lack of manual firefighting and the inoperative automatic sprinkler protection in the building on September 11, 2001. This concept is reiterated by Beitel and Iwankiw, who note that "Given that there can be no guarantee that a fire will not occur in a given building, or that it will be successfully contained and suppressed, the fire resistance of the building structure must be duly assessed in its design in order to avoid local and progressive collapses."[16]

4. Assessment of WTC7 Fire Protection and Vulnerability of Building to Fire

4.1 Occupancy Classifications

WTC7 was occupied primarily as an office building, but also contained spaces used for other purposes, including electric power generation. One of the unusual features of the WTC7 building was the installation of a large number of standby generators within the building. Unlike the two 900-kW emergency generators that were installed on the 5th floor to provide emergency power for the life safety systems within the building, these standby generators were installed within the building by some of the tenants to serve their own business interests. For example, Salomon Brothers (SB) installed nine 1750 kW standby generators on the 5th floor along with a pressurized fuel oil system to support the operation of the generators.

Under Section 27-239 and Table 3-1 of the NYCBC, the building would have been classified as Occupancy Group E, with an associated Fire Index of 2, based on its primary use as an office building. Additionally, under Section 27-238 of the NYCBC, every room or space must also be classified in one of the occupancy groups listed in Table 3-1 according to the occupancy or use of the space or room. As noted in Section 27-241 of the NYCBC, Table 3-2 and reference standard RS 3-3 list representative occupancies to be used as a basis for classifying buildings and spaces by occupancy.

RS 3-3 includes "Electric power or steam generating plants" and "Generating plants – electric or steam" under Occupancy Group D-1. Section 27-250 indicates that Occupancy Group D-1 "Shall include buildings and spaces in which the fabrication, assembly, manufacturing, or processing represents a moderate fire hazard due to the extent and nature of such operations, or to the materials involved." Thus, Occupancy Group D-1 would have been the appropriate occupancy classification for the spaces where the SB electric power generators were located on the 5th

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[16] Beitel, J., and Iwankiw, N., *Analysis of Needs and Existing Capabilities for Full-Scale Fire Resistance Testing*, NIST GCR 02-843-1 (Revision), National Institute of Standards and Technology, October 2008 (Replaces NIST GCR 02-843, December 2002), p. 17.

floor of WTC7. According to Table 3-1 of the NYCBC, Occupancy Group D-1 has an associated Fire Index of 3.

Section 27-240 of the NYCBC addresses separation of occupancies, with Subsection 27-240(a) requiring that “Spaces classified in occupancy groups having a higher fire index, as listed in table 3-1, than the fire index of the occupancy group classification of the building, shall be separated from adjoining spaces by construction meeting the fire-resistance rating requirements for fire divisions under the provisions of subdivision (a) of section 27-339 of article five of subchapter five of this chapter. Such occupancies shall, for the purposes of this code, be classified and treated as separate buildings (hereinafter referred to as “building section”).” Consequently, with a Fire Index of 3, the generator spaces should have been separated from adjoining spaces with fire-rated construction in accordance with Subsection 27-339(a).

Subsection 27-339(a) of the NYCBC addresses the fire segregation of occupancies by fire divisions in terms of the following requirements: “When different occupancies are to be segregated by fire divisions under the provisions of section 27-240 of subchapter three of this chapter, the occupancies shall be separated from each other, vertically and horizontally, by fire divisions having at least the fire-resistance ratings listed in table 5-2 for the occupancy groups involved. Every building section shall be constructed of elements having at least the fire-resistance rating of a construction class required for the area and height of the building section as listed in tables 4-1 and 4-2.”

Table 5-2 of the NYCBC requires spaces with occupancy classification of D-1 to be separated from spaces with occupancy classification of E, as well as from other spaces, by construction with at least a 3-hour fire resistance rating. Consequently, the spaces occupied by the SB standby generators on the 5th floor should have been separated from other spaces by construction with at least a 3-hour fire resistance rating.

4.2 Automatic Sprinkler Protection

The WTC7 building was equipped with a partial sprinkler system. Most of the building was protected with a wet-pipe sprinkler system, with the notable exception of much of the 5th floor. On the 5th floor, the SB generator spaces were not sprinklered,[17] or protected by an alternative fire suppression system, despite repeated recommendations to provide such protection over the period from at least 1988 to 2001.[18]

Subsection 27-954(i) of the NYCBC required the installation of sprinklers in “Buildings classified in occupancy group E, one hundred feet or more in height having air-conditioning and/or mechanical ventilation systems that serve more than the floor in which the equipment is

[17] Deposition testimony of David Cooper, February 5, 2009, pp. 284-287.
[18] Bates Numbers CONED0071004, CONED0070683, CONED0070930, CONED0071013, CONED0071915, SPI 042093

located … .” This provision would have applied to WTC7 and would have required the installation of sprinklers throughout the building, including on the 5th floor.

Table 4-1 of the NYCBC addresses height and area limitations for unsprinklered buildings and spaces. For spaces of Occupancy Group D-1 in an unsprinklered building of Class I-B construction, Table 4-1 establishes an area limitation of 7,500 square feet and a height limitation of 75 feet. Table 4-2 addresses height and area limitations for sprinklered buildings and spaces. For spaces of Occupancy Group D-1 in a sprinklered building of Class I-B construction, Table 4-2 does not limit the height or area of the space. This requirement is reiterated in Subsection 27-954(h) of the NYCBC, which requires the installation of sprinklers in “Spaces classified in industrial occupancy group D-1 exceeding seventy-five hundred square feet, in floor area excluding heliports.”

Subsection 27-954(l) of the NYCBC required the installation of sprinklers on floors above grade that could not be naturally ventilated. “Regardless of occupancy group classification, any story above grade that cannot be ventilated by at least twenty square feet of free openable area … per ten thousand cubic feet of volume. Such ventilation shall be provided by operable windows or other natural ventilation sources complying with section 27-749 of article six of subchapter twelve of this chapter. … Sprinklers may be omitted in toilets, shower rooms, stairs, and mechanical and electrical equipment rooms.” This provision would have applied to the 5th floor of the WTC7 because it did not have openable or operable natural ventilation pathways.

The 5th floor of the WTC7 building, including the spaces occupied by the SB standby generators, should have been sprinklered based any one of the building code requirements referenced in the preceding paragraphs.

Reference Standard 17-2 to the NYCBC addressed automatic sprinkler systems and referenced the NFPA 13 Standard for the Installation of Sprinkler Systems. Section 4-1.1.1 of the 1985 edition of NFPA 13, the edition that would have been current at the time of WTC7 construction, addressed the basic requirements for the spacing, location and position of sprinklers as follows:

“4-1.1.1* The basic requirements for spacing, location and position of sprinklers are specified in this chapter and are based on the following principles:

(a) Sprinklers installed throughout the premises, ...

Exception No. 1: See 4-4.3 and 4-4.4 for locations from which sprinklers may be omitted.”

Section 4-4.3 of NFPA 13-1985 addresses spaces beneath ground floors and Section 4-4.4 addresses concealed spaces, so neither exception addresses generator spaces. Section 4-4.14 of NFPA 13-1985 standard addresses electrical equipment as follows:

"4-4.14 Electrical Equipment. When sprinkler protection is provided in generator and transformer rooms, hoods or shields installed to protect important electrical equipment from water shall be noncombustible."

These NFPA 13 provisions are consistent with the ongoing recommendations to provide sprinkler protection for the generator spaces on the 5th floor of the WTC7 building. They show that sprinklers should be installed throughout the premises, including in generator rooms.

The design of automatic sprinkler systems in the United States anticipates only a single fire source. As noted in the current NFPA Fire Protection Handbook, "A number of assumptions have been employed in the writing of NFPA 13 to achieve an acceptable level of life safety and property protection while maintaining costs. For instance, the standard anticipates a single fire source, that is, no multiple ignitions in the building while the sprinkler system is operating. …"[19] Modern automatic sprinkler systems are hydraulically calculated to deliver the designed quantity of water to the area of a single fire source. When multiple fires occur, water is diverted to these additional fires, thereby decreasing the amount of water flowing to each of the multiple fire sources and increasing the probability that the sprinkler system will not control the fires.

4.3 Construction Classification of Building

The WTC7 building was designated as Class I-B construction under the NYCBC. This designation was identified in the "7 World Trade Center Fire Protection Plan for Department of Buildings" dated April 30, 1986, from Avery[20]. In an undated document entitled "System Description for 7 World Trade Center," Syska and Hennessy[21] indicated that "The building has a fireproof classification of 1B (3 hours) and occupancy Group E." This is reiterated later in this same document, where it is noted that "The building is classified as fireproofed construction – 1B – 3 hours."[22] As noted in Section 27-276 of the NYCBC, construction Class I-B includes buildings and spaces in which the bearing walls and other major structural elements are generally of three-hour fire-resistance rating. As noted in Table 3-4 of the NYCBC, the major structural elements requiring a three-hour fire-resistance rating include columns, girders, trusses and framing supporting more than one floor; floor construction including beams requires a two-hour fire resistance rating in buildings of Class I-B construction.

4.4 Fireproofing

To provide the specified levels of fire resistance for structural elements throughout the WTC7 building, the structural steel and metal floor decks were coated with an insulating material known as a spray-applied fire-resistive material (SFRM). The product selected for this

[19] Huggins, R., "Automatic Sprinkler Systems," Section 16, Chapter 3, Fire Protection Handbook, 20th edition, National Fire Protection Association, 2008.
[20] BATES NUMBER PANYNJ 0089052
[21] BATES NUMBER SPI 043970
[22] BATES NUMBER SPI 043973

application was a cementitious material, Monokote MK-5. This material is applied to structural elements and floor assemblies in different thicknesses to achieve different fire resistance ratings based on fire test results and listing requirements published by Underwriters Laboratories, Inc. (UL) or another recognized fire test laboratory.

The WTC7 architect specified (Specification 9K.1.1.1)[23] application of a sprayed-on cementitious coating over the "steel decking (fluted) and all floor support structural steel – occurring throughout the entire project – 2 hour rating." The WTC 7 architect also specified (Specification 9K.1.1.2)[24] a fire resistance rating of 2 hours for columns, girders, trusses and all other steel framing supporting a single floor and a fire resistance rating of 3 hours for columns, girders, trusses and all other steel framing supporting two or more floors. The note associated with this specification also stipulated that "… Girders, trusses, diagonal bracing, and other steel framing supporting columns shall be fire proofed to achieve a fire rating equivalent to that of the columns. **All steel framing shall be considered as being of the restrained type**." (Emphasis added)

The WTC7 architect also specified (Specification 9K.4.1)[25] that "The 'Design Information Section' including 'Floor-Ceiling Assemblies,' 'Roof-Ceiling Assemblies,' 'Beams,' 'Columns,' 'Wall and Partitions,' of the Underwriters' Laboratories 'Fire Resistance Index' dated January, 1975, and any later revisions and the 'Guide for Determining Conditions of Restraint.....' including Appendix 'C' from standard U.L. 263 shall form the basis of all required work and shall be referred to for guidance by the Sub-Contractor."

The floor assembly designated as UL Design No. D739 was used as the basis for the fire resistance rating of the WTC7 floor assemblies. In the 1983 edition of the UL Fire Resistance Directory, Design No. D739 was listed for 1, 1-1/2 and 2 hour restrained assembly ratings and for 1 hour unrestrained assembly and beam ratings. To achieve these ratings, W8x28 beams required ½ in. thick coating with the MK5 SFRM, W6x12 beams required ¾ in. thick coating with the MK5 SFRM and the general floor area without trench headers or electrical inserts required 3/8 in. of the MK5 SFRM following the contour of the steel floor units. A SFRM coating thickness of ½ in. on beams and 3/8 in. on floor decks is consistent with the intended level of fireproofing indicated on WTC7 fireproofing inspection reports.

The UL Design No. D739 achieved the 2-hour fire resistance rating required of floor assemblies in buildings of Class I-B construction under the NYCBC only as a restrained assembly. For unrestrained assemblies, the UL Design No. D739 only achieved a fire resistance rating of 1 hour, which would not have qualified it for use in a building of Class I-B construction. Consequently, to the extent that the floor assemblies in the WTC7 building behaved as unrestrained assemblies, the level of fire resistance provided for the floor assemblies did not meet the NYCBC requirements for a building of Class I-B construction.

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[23] BATES NUMBER CONED0074697
[24] BATES NUMBER CONED0074697
[25] BATES NUMBER CONED0074701

The Design Information Section in the 1983 and 1985 editions of the UL Fire Resistance Directory, which would have been the revisions of this directory applicable at the time of construction of WTC 7, included the following statement: "Cavities, if any, between the upper beam flange and floor or roof units shall be filled with the fire protection material applied to the beam, unless stated otherwise on an individual design." This provision is still included in the current version of the UL Fire Resistance Directory.

The photograph shown in Figure 2, taken from the AISC Steel Design Guide 19 (Figure 1.1 in the guide), shows a beam protected with SFRM. The flutes above the beam are completely filled with SFRM, such that the top flange of the beam is barely evident. This is representative of proper filling of the cavities between the upper beam flange and a fluted metal floor deck.

In contrast, the photograph shown in Figure 3, as well as the photographs shown in Figures 5a through 5q, show examples of the condition of the fireproofing in the WTC7 building. Note the appearance of unfilled cavities, i.e., voids, above the clearly visible top flanges of the steel beams and girders in these photographs. In a number of the photographs, cables are visible running through the cavities, providing further evidence that the cavities were not filled with fireproofing material. These photographs indicate that the sprayed-on fireproofing material was not properly or adequately applied to the fluted steel decking and floor support structural steel beams and girders as required by the project specifications because the cavities between the upper beam flanges and the fluted steel deck were not filled with the fire protection material applied to the beam as required in the UL Fire Resistance Directory.

Based on my review of these and other photographs, the fireproofing condition shown in these photographs appears to be representative of conditions throughout large areas of the WTC7 building if not the entire building. I have not seen any photographs showing flute cavities in the WTC7 building were filled with the fire protection material as shown in Figure 2 and as required by the UL Fire Resistance Directory.

Failure to construct the WTC 7 with the flute cavities above the beams and girders filled with the fire protection material applied to the beams, as required by the UL Fire Resistance Directory listing for the selected floor assembly and the project specification, reduced the fire resistance of the beams, girders and floor assemblies below the level that would have been achieved if these cavities had been filled in compliance with the requirements of the NYCBC. Failure to fill the flute cavities with the fire protection material applied to the beams, as required, permitted the girders and beams to heat up more quickly than expected when exposed to fire conditions. This is discussed in more detail in Section 5.6 of this report and in the expert report prepared by Prof. Colin Bailey.

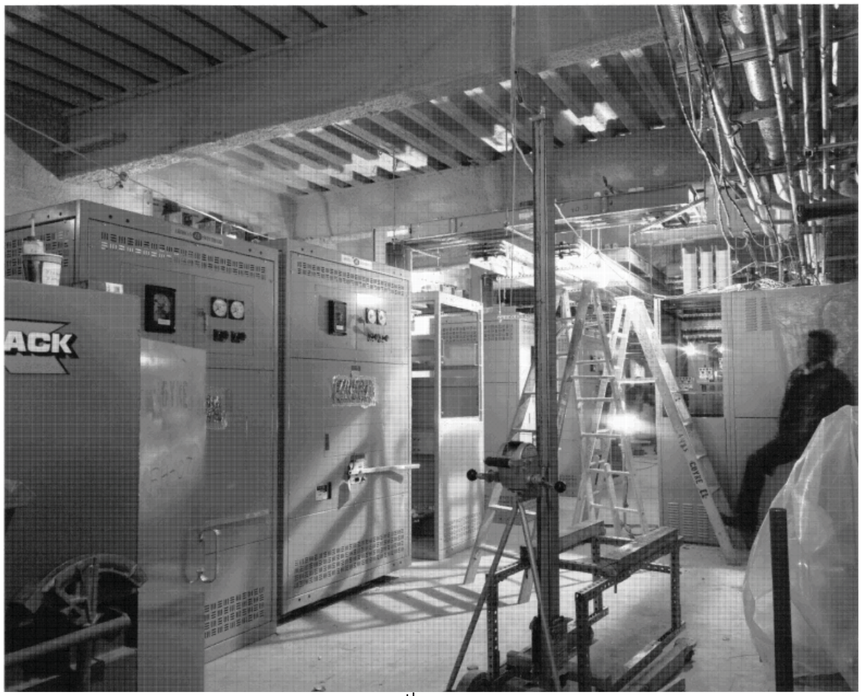

Figure 5a. Bernstein Photo 14-106 View: 5th FL. NE CORNER (BERNSTEIN0000093.01.pdf)

Figure 5b. Bernstein Photo 4-74 View: 5th floor NW→NE (BERNSTEIN0000021.01.pdf)

Figure 5c. Bernstein Photo 3-76 View: 5th floor NE→NW (BERNSTEIN0000016.01.pdf)

Figure 5d. Bernstein Photo 3-27 View: 41st FL. CORE MECH ROOM > NE (BERNSTEIN0000011.01.pdf)

Figure 5e. Bernstein Photo 8-93 View: 5th FL. NW CORNER (BERNSTEIN0000047.01.pdf)

Figure 5f. Bernstein Photo 7-83 View: 5th FL. NE→NW (BERNSTEIN0000043.01.pdf)

Figure 5g. Bernstein Photo 7-71 View: 31ST FL. NE→NW (BERNSTEIN0000040.01.pdf)

Figure 5h. Bernstein Photo 10-114 View: 5th FL. NE CORNER (BERNSTEIN0000065.01.pdf)

Figure 5i. Bernstein Photo 10-113 View: 5th FL. NE→NW (BERNSTEIN0000064.01.pdf)

Figure 5j. Bernstein Photo 9-110 View: 5th FL. NE CORNER (BERNSTEIN0000059.01.pdf)

Figure 5k. Bernstein Photo 9-106 View: 5th FL. NW CORNER (BERNSTEIN0000055.01.pdf)

Figure 5l. Bernstein Photo 9-68 View: 36th FL. NE→NW (BERNSTEIN0000053.01.pdf)

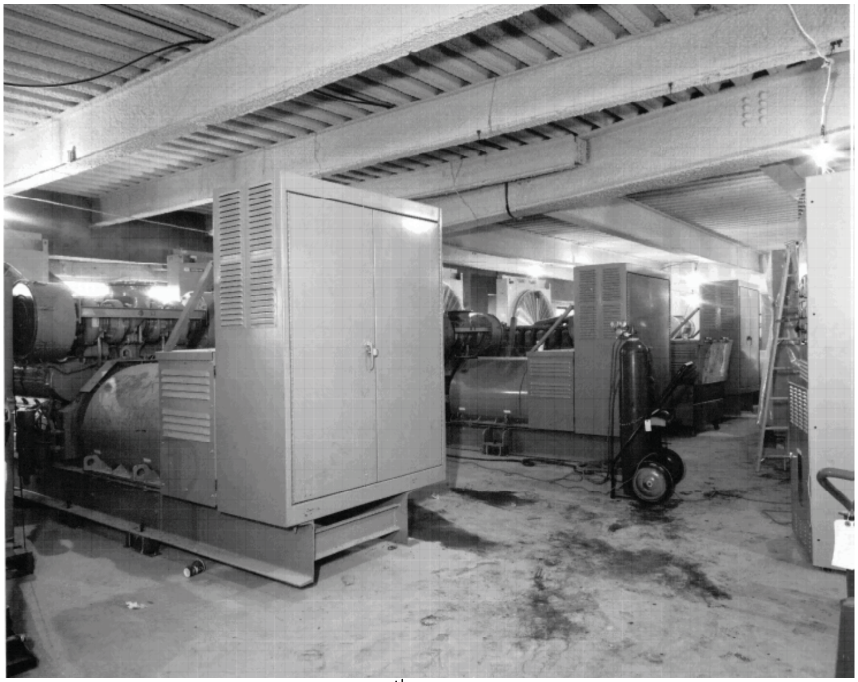

Figure 5m. Bernstein Photo 8-96 View: 5th FL. NE CORNER (BERNSTEIN0000050.01.pdf)

Figure 5n. Bernstein Photo 14-103 View: 5th FL. NW CORNER (BERNSTEIN0000090.01.pdf)

Figure 5o. Bernstein Photo 13-14 View: GV 5th FL. > NE (BERNSTEIN0000086.01.pdf)

Figure 5p. Bernstein Photo 11-104 View: 5th FL. NE>NW (BERNSTEIN0000072.01.pdf)

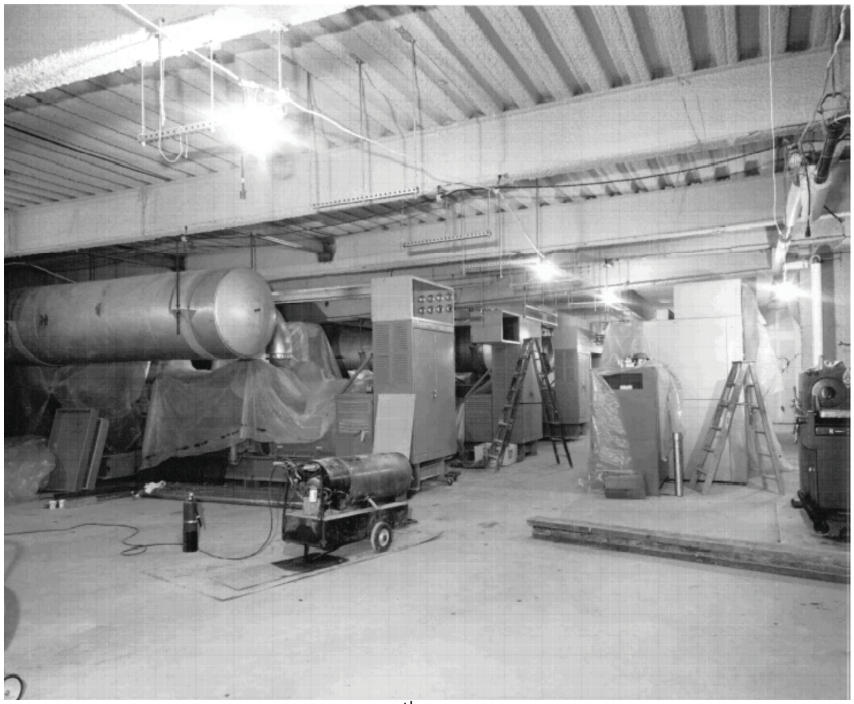

Figure 5q. Bernstein Photo 11-103 View: 5th FL. NE CORNER (BERNSTEIN0000071.01.pdf)

4.5 Long Span Beams and Web Penetrations

Many of the beams and girders used to support the floors in the WTC7 building had spans of more than 50 feet, particularly in the north and east areas of the building. As noted in Section 3.2 of this report, such spans are more than four times longer than the spans typically used in standard fire resistance tests.

As noted in Section 4.2 of the ASTM E119 standard, "The test exposes a specimen to a standard fire controlled to achieve specified temperatures throughout a specified time period. When required, the fire exposure is followed by the application of a specified standard fire hose stream. The test provides a relative measure of the fire-test-response of comparable assemblies under these fire exposure conditions. The exposure is not representative of all fire conditions because conditions vary with changes in the amount, nature and distribution of fire loading, ventilation, compartment size and configuration, and heat sink characteristics of the compartment. **Variation from the test conditions or specimen construction, such as size, materials, method of assembly, also affects the fire-test-response. For these reasons, evaluation of the variation is required for application to construction in the field.**" (Emphasis added)

The ASTM E119 standard also notes that "The test standard does not provide the following: … Full information as to performance of assemblies constructed with components or lengths other than those tested." In light of these admonitions within the ASTM E119 standard, the designer should have evaluated the potential effects of the long span beams and girders on the expected fire performance of the floor assemblies in the WTC7 building, particularly with respect to the issue of thermal restraint. There is no evidence to indicate that this was done; if it was, then the designer failed to appreciate the implications of these issues.

Based on a review of many photographs of the WTC7, it is apparent that the webs on many of the beams and girders in the structure were penetrated with extensive openings to provide pathways for building utilities such as ducts and electrical conduit. There is no evidence to indicate that the influence of these web penetrations on the fire performance of the floor assemblies was considered.

4.5 Fuel Tanks, Standby Generators and Pressurized Fuel Lines

One of the many unusual aspects of the WTC7 building was the presence of the large number of standby generators and associated fuel systems that were installed to serve the business interests of a number of tenants in the building. It is not unusual to have one or two electric generators present in high-rise buildings to provide emergency power for life safety systems in case the primary power fails. It is much less common to have the extensive number of standby generators and associated fuel tanks and systems in a high-rise office building that were installed in WTC7. Combined, these systems had a fuel oil storage capacity in excess of 42,000 gallons.

Two 900 kW generators and two 12,000 gallon capacity storage tanks were installed in 1987 as part of the base building system. The generators were located in a room on the 5th floor on the south side of the building near the southwest corner. A 275 gallon day tank was located in the 5th floor generator room to supply fuel to the two generators in the room. Section 27-829 of the NYCBC limited fuel supplies to a single 275 gallon maximum capacity storage tanks on any floor above the lowest floor.

Nine 1,750 kW generators were installed on the 5th floor and two 6,000 gallon fuel oil storage tanks were installed below the loading docks in 1990 as part of the SB project. Four of these generators were installed near the northeast corner of the 5th floor, two were located near the northwest corner of the 5th floor and three were located alongside the two base building generators in the existing generator room on the south side of the 5th floor.

The base building fuel oil system was modified a number of times. In 1994, this system was extended as part of the Ambassador Construction project to provide fuel oil to a 125 kW generator with a 50 gallon day tank located on the 9th floor. In 1994, the system was extended again as part of the American Express project to supply a 350 kW generator with a 275 gallon day tank located on the 8th floor. In 1999, the system was modified for the Mayor's Office of Emergency Management (OEM) project. This modification included the installation of a 6,000 gallon fuel tank on the 1st floor and three 500 kW generators and a 275 gallon day tank on the 7th floor.

The SB generators installed on the 5th floor could not be supplied from day tanks because a day tank was already present on the 5th floor for the base building generators and the NYCBC (27-829(b) only allowed one oil storage tank per story above the lowest floor. Consequently, the fuel system for these nine generators located on the 5th floor used a pressurized loop, rather than day tanks, as a means to circumvent the restriction on the number of tanks on the 5th floor.

The fuel oil supply (FOS) line serving the nine SB generators on the 5th floor fed each of the generators before terminating in a valve rig near the northeast corner of the 5th floor. The valve rig consisted of a backpressure regulator, gauges, a by-pass line and a liquid level switch. The liquid level switch controlled the pump set that supplied fuel oil supply to the FOS piping. The backpressure regulator was located just downstream of the liquid level switch and would relieve excess pressure into the fuel oil return (FOR) piping connected on the downstream side of the valve rig. The FOR piping routed fuel oil back to the storage tanks.

One failure scenario for the pressurized loop fuel oil system occurs if there is a break in the FOS piping between the pump set and the valve rig. This would cause a low level signal in the liquid level switch, which would activate the pump set. A broken FOS piping on the fifth floor would result in the pump set continuing to pump fuel oil from the tanks to the break until the storage tank(s) were emptied. Assuming the Salomon Brothers storage tanks were full at the start of such a scenario, the potential existed for the fuel oil stored in these two 6,000 gallons tanks to be pumped into the building through the break in the pipe. Assuming the tanks had 11,000 gallons of fuel oil in them, **t**his would be 40 times the capacity of a single 275 gallon day tank.

5. Fire Conditions on September 11, 2001

A number of fires were visible on different office floors in the WTC7 building throughout much of the day on September 11, 2001. However, the south façade of WTC7 remained shrouded in smoke and dust for most of the day, so additional fires may have been burning within the building that could not be observed or identified based on the available photographic and video evidence. Guy Nordenson and Associates (GNA) have prepared a 2-volume photographic analysis report that summarizes the photographic and videographic evidence of the fires that occurred in WTC7 on September 11, 2001. This GNA photographic analysis report is provided in Exhibit B of this report.

The photographic and video evidence of the fires in WTC7 on September 11, 2001, from the collapse of WTC 1 at approximately 10:30 AM until approximately 5:00 PM, shows that the most significant office floor fires in WTC7 during that period appear to have been traveling fires limited to a few office floors, including floors 7 through 9 and 11 through 13. Fires were observed on other office floors during this period, but these other fires were localized and did not persist. The photographic and video evidence of the fires on the office floors of WTC7 indicate that these fires were consistent with ordinary office contents fires; they were not extraordinary fires.

Office contents fires generally burn for approximately 20 to 30 minutes in any one location until the available fuel load is consumed and the fire moves on to the next area. That is why fires in large office spaces are sometimes called traveling fires. In tall buildings provided with an appropriate level of fire resistance, ordinary office contents fires will run out of fuel before heating and weakening structural steel to such an extent that it will fail.

The photographic and video evidence of the fires in WTC7 also shows that the character of the smoke emanating from the east side of the building changed at approximately 3:30 PM. After 3:30 PM, this evidence, along with testimony of several first responders[26], shows fires and smoke consistent with a petroleum-based diesel fuel fire emanating from the vicinity of the fifth/sixth floor louvers on the east side of WTC7. Examples of this are shown in Images 7.E.01 to 7.E.04 of the GNA photographic analysis report appended as Exhibit B to this report.

5.1 Office Workstation Fire Tests

The National Institute of Standards and Technology (NIST) has conducted a number of large-scale fire tests with office workstations. Madryzkowski[27] presented heat release rate data for single office workstations bounded on 2, 3, and 4 sides by workstation dividers, as shown in Figure 6. Madryzkowski and Walton[28] reported on the heat release rates measured during fire tests with single and multiple office workstations as part of their investigation of the Cook County Administration Building fire, as shown in Figures 7 and 8. McGrattan and Boudin[29] report on efforts to model office workstation fire tests with the FDS fire model developed at NIST, as shown in Figures 9 and 10. These office workstation fire tests verify the limited active burning duration of such furnishings.

[26] Deposition testimony of Daniel Delargy (June 17, 2009), Mark Giannini, (June 29, 2009), Peter Hayden (May 20, 2009), Joseph Meola (June 24, 2009) and Anthony Varriale (June 9, 2009).
[27] Madryzkowski, D., "Office Workstation Heat Release Rate Study: Full Scale vs. Bench Scale," *Interflam '96*, 1996, pp. 47-55
[28] Madryzkowski, D., and Walton, W.D., "Cook County Administration Building Fire, 69 West Washington, Chicago, Illinois, October 17, 2003: Heat Release Rate Experiments and FDS Simulations," *NIST Special Publication SP-1021*, July 2004.
[29] McGrattan, K., and Boudin, C., "Simulating the Fires in the World Trade Center," Interflam '04, pp. 999-1008 2004.

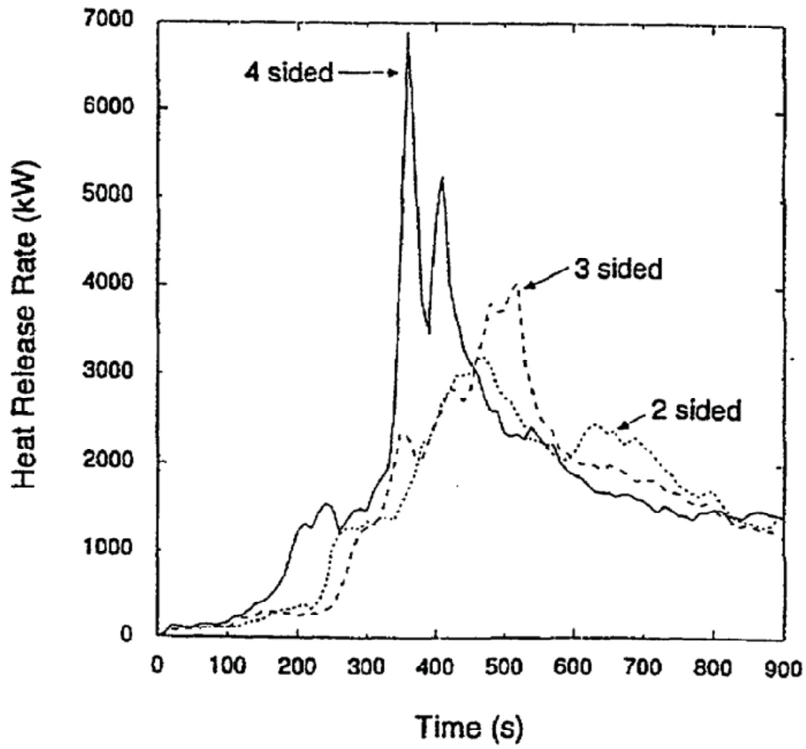

Figure 6. Measured heat release rates for 2-, 3-, and 4-sided office workstations. (27)

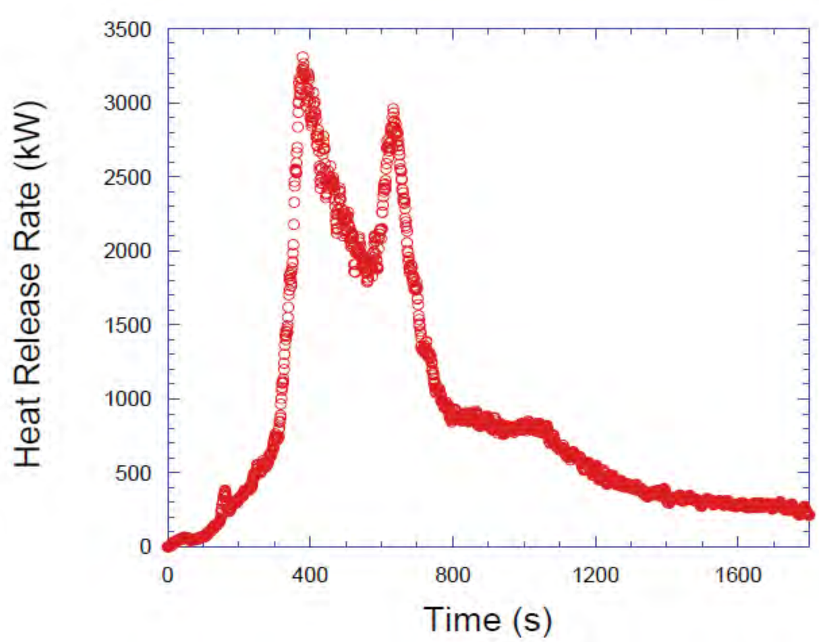

Figure 7. Measured heat release rate history for single workstation fire test. (28)

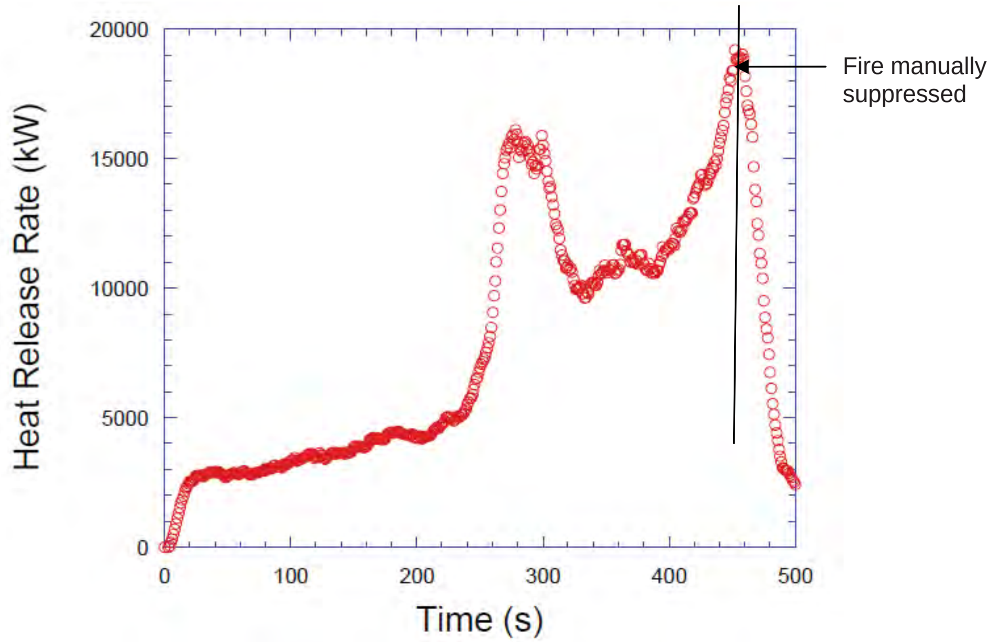

Figure 8. Measured heat release rate history for multiple (4) workstation fire test. (28)

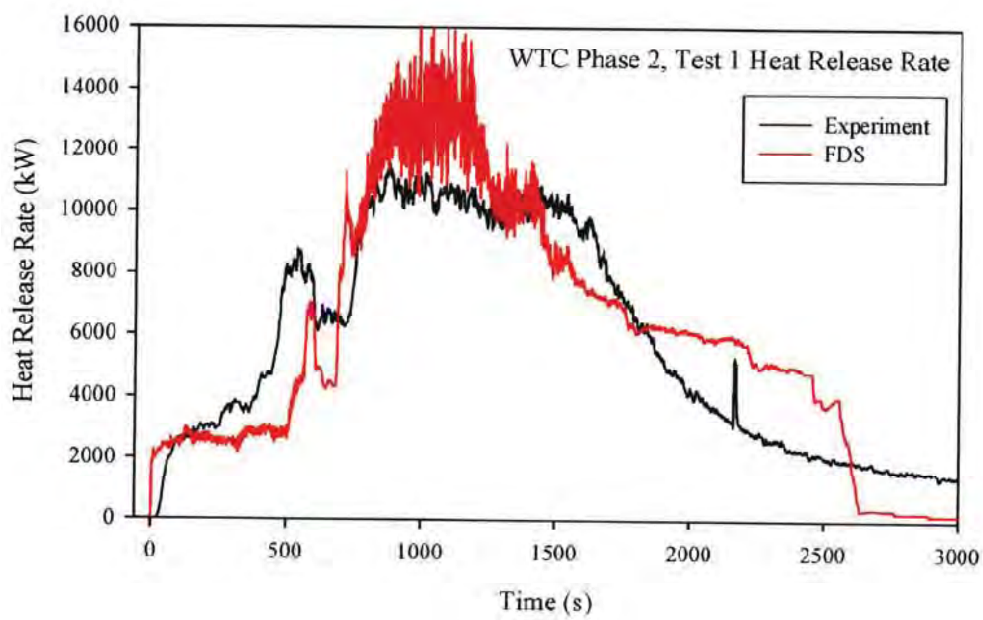

Figure 9. Measured and simulated heat release rates for multiple (3) workstation fire test. (29)

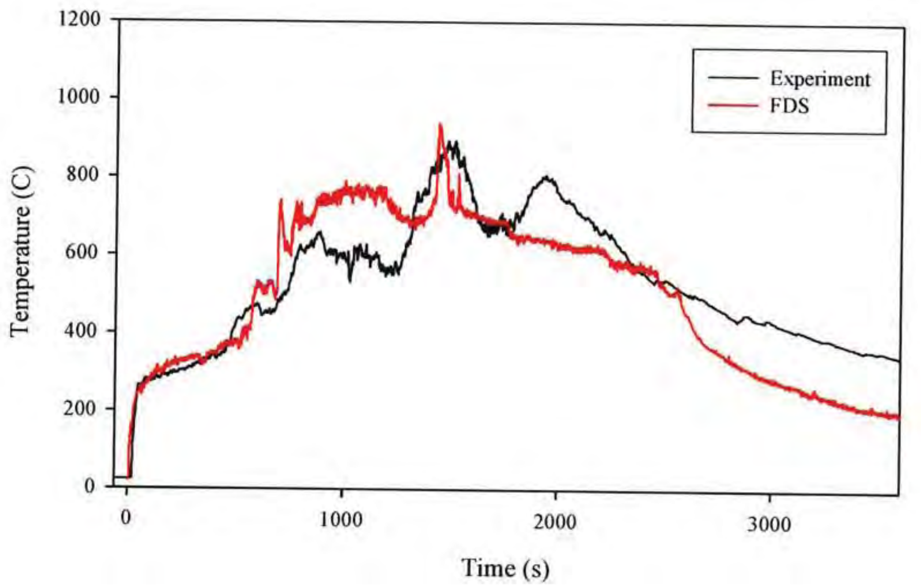

Figure 10. Measured and simulated temperatures for multiple (3) workstation fire test. (29)

5.2 Fire Spread on the 9th and 12th Floors

Figures 11 and 12 show the approximate floor plans of the 9th and 12th floors of WTC7, respectively. The 9th floor was occupied by the U.S. Secret Service; the 12th floor was occupied by the Securities and Exchange Commission. There is no evidence to suggest that the fuel loads on these floors were different from what would normally be expected in an office occupancy.

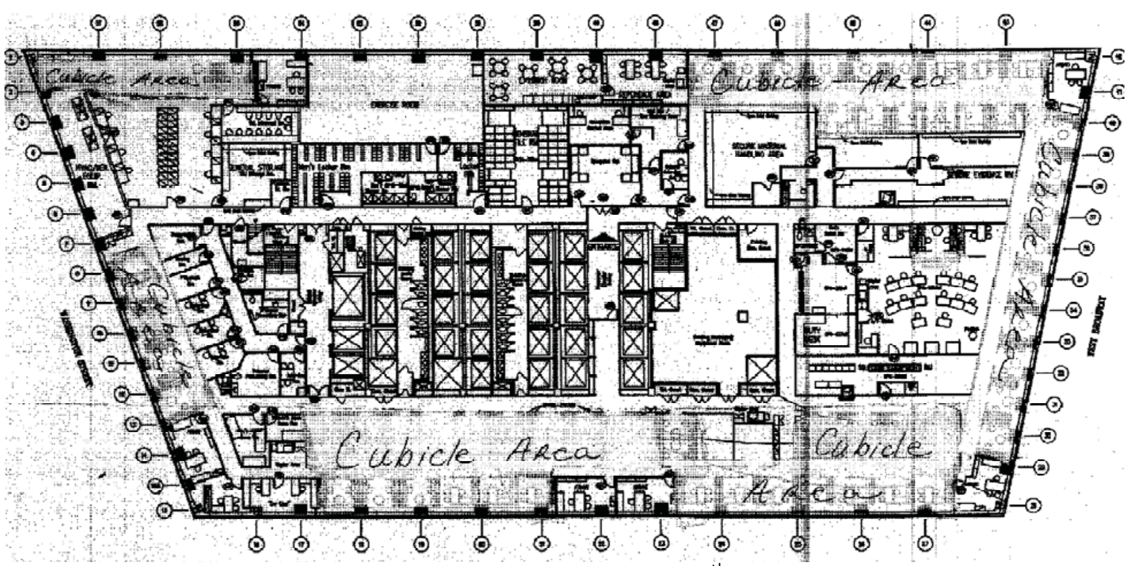

Figure 11. Approximate floor plan of the 9th floor of WTC7.

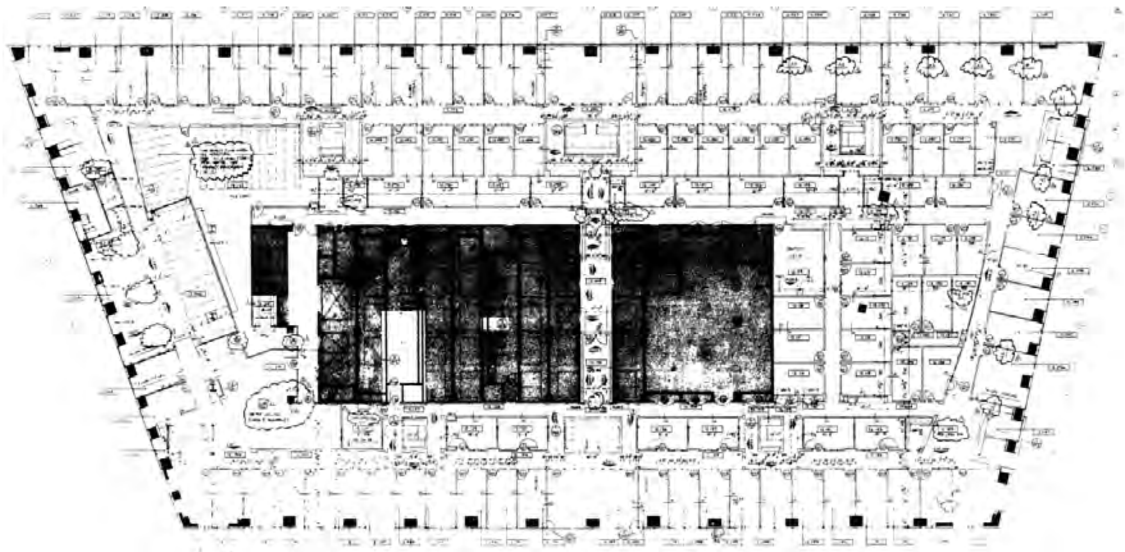

Figure 12. Approximate floor plan of the 12^{th} floor of WTC7.

For offices, the NFPA Handbook[30] indicates an average fuel load density of 420 MJ/m^2 of floor area with an 80% fractile of 511 MJ/m^2. Assuming a heat of combustion of 15 MJ/kg of wood, this 80% fractile value equates to a fire load of 34.1 kg/m^2 or 7.0 lb/ft^2. The NFPA Handbook[31] also indicates a mean total fire load of 7.3 lb/ft^2 for offices in government buildings based on a survey of 342 rooms and a mean total fire load of 7.7 lb/ft^2 for offices in private buildings based on a survey of 479 rooms. For the fire modeling described in the next subsection of this report, a fire load of 7.5 lb/ft^2 (36.6 kg/m^2) has been used. Using the concept of equivalent fire severity developed by NBS, this fire load equates to an equivalent fire severity of approximately 45 minutes in the ASTM E119 test.[32] Structural elements and assemblies with fire resistance ratings of 2- to 3-hours should be able to withstand such exposures without losing their structural integrity if they are properly designed and constructed.

Figures 13 and 14, prepared by GNA, summarize the photographic evidence of the fires on the 9^{th} and 12^{th} floors, respectively. The GNA analysis shows that fire on the 9^{th} floor progressed clockwise from west to east along the north façade. The first visual evidence of fire occurs at approximately 3:55 PM and the last visual evidence of burning fire occurs at approximately 4:38 PM on this floor. The fire on the 12^{th} floor progressed counter-clockwise, with the first visual evidence of fire on the east façade occurring at approximately 2:00 PM and the last visual evidence of burning occurring in the northwest corner of the building at about 5:00 PM. This photographic evidence generally shows the presence of active burning in any one location on Floors 9 and 12 for a period of less than 30 minutes, a period consistent with the durations demonstrated in the workstation fire tests referenced above.

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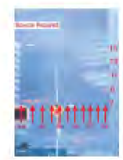
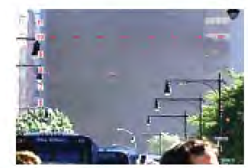
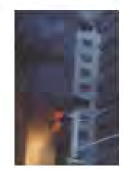
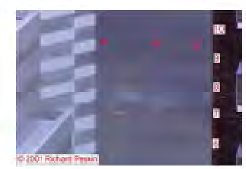
[30] Table 19.5.1, *Fire Protection Handbook*, 20^{th} edition, National Fire Protection Association, 2008.
[31] Table 18.1.2, *Fire Protection Handbook*, 20^{th} edition, National Fire Protection Association, 2008.
[32] Table 18.1.1, *Fire Protection Handbook*, 20^{th} edition, National Fire Protection Association, 2008.

	FIRST VISUAL EVIDENCE OF FIRE	LAST VISUAL EVIDENCE OF BURNING FIRE
A	Image 6.N.21 (near 3:55PM)	NA
B	Image 7.N.01 (4:10PM)	NA
C	Image 7.N.01 (4:10PM)	Image 7.N.03 (4:15PM-4:38PM)
D	Image 7.N.02 (likely 4:15PM)	Image 7.N.03 (4:15PM-4:38PM) & Image 7.N.04 (4:15PM-4:38PM)
E	Image 7.N.02 (likely 4:15PM)	Image 7.N.07 (likely 4:39PM)
F	Image 7.E.03 (4:15PM-4:38PM)	Image 7.E.04 (4:15PM-4:38PM)
G	Image 7.N.05 (4:38PM)	NA


Within Timeframe A (Image 6.N.21)


Within Timeframes B & C (Image 7.N.01)


Within Timeframe F (Image 7.E.04)


Within Timeframe G (Image 7.N.05)

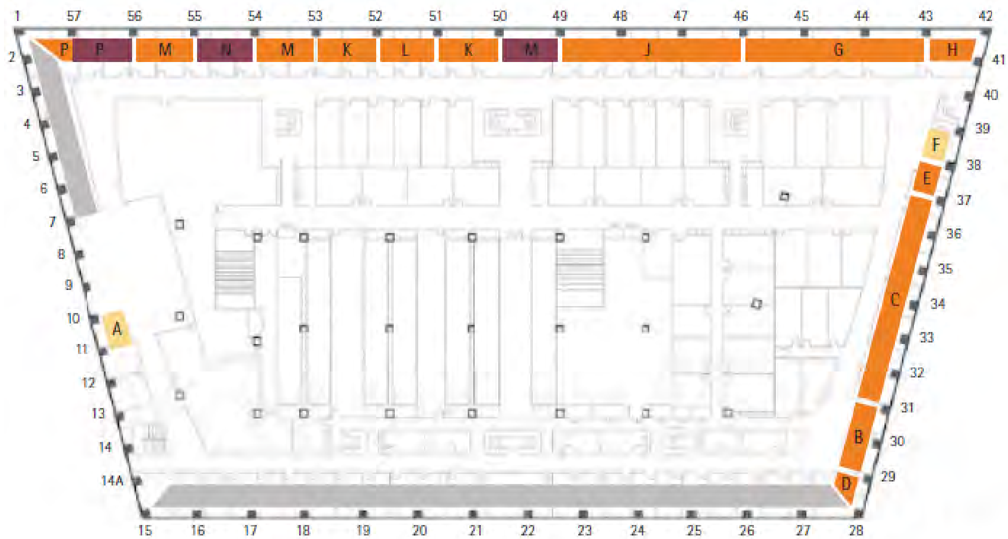
LEGEND

- Location of Burning Fire
- Location only shown with Smoke
- Location only shown as Burned-Out
- Location Not Visible

NOTES

1 Image times have been rounded to the nearest minute. See Appendix 1B for exact times.
2 Visual evidence of fire includes windows showing burning fire, smoke, or as burned-out. If a location is first seen with smoke or as burned-out but is later shown with burning fire it has still been designated as "Burning Fire". If a location is only ever visible with smoke or as burned-out it is designated accordingly.

Figure 13. Planometric diagram of fire progression for the 9th floor (source: GNA report – Exhibit B of this report).



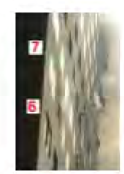
	FIRST VISUAL EVIDENCE OF FIRE	LAST VISUAL EVIDENCE OF BURNING FIRE
A	Image 4.W.10 (1:30PM-2:30PM)	NA
B	Image 5.E.02 (2:00PM-2:08PM) & Image 5.E.06 (2:00PM-2:08PM)	Image 5.E.53 (2:28PM)
C	Image 5.E.02 (2:00PM-2:08PM) & Image 5.E.08 (2:08PM)	Image 5.E.54 (2:28PM-3:10PM)
D	Image 5.E.21 (2:14PM)	Image 5.E.54 (2:28PM-3:10PM)
E	Image 5.E.27 (2:15PM-2:27PM)	Image 5.E.54 (2:28PM-3:10PM)
F	Image 5.E.54 (2:28PM-3:10PM)	NA
G	Image 5.N.01 (2:57PM) & Image 6.N.01 (3:05PM)	Image 6.N.04 (3:10PM) & Image 6.N.07 (3:10PM-3:13PM)
H	Image 6.N.02 (3:05PM-3:10PM) & Image 6.N.04 (3:10PM)	Image 6.N.05 (3:05PM-3:10PM)
J	Image 6.N.04 (3:10PM) & Image 6.N.06 (3:10PM) & Image 6.N.09 (3:12PM)	Image 6.N.10 (3:11PM-3:16PM)
K	Image 6.N.12 (3:41PM)	Image 6.N.16 (3:50PM) & Image 6.N.20 (3:54PM)
L	Image 6.N.12 (3:41PM)	Image 7.N.04 (4:15PM-4:38PM)
M	Image 6.N.12 (3:41PM) & Image 6.N.13 (3:42PM) & Image 6.N.15 (3:44PM)	NA
N	Image 6.N.21 (near 3:55PM)	NA
P	Image 8.N.01 (around 5:00PM)	NA

LEGEND

- Location of Burning Fire
- Location only shown with Smoke
- Location only shown as Burned-Out
- Location Not Visible

NOTES

1. Image times have been rounded to the nearest minute. See Appendix 1B for exact times.
2. Visual evidence of fire includes windows showing burning fire, smoke, or as burned-out. If a location is first seen with smoke or as burned-out but is later shown with burning fire it has still been designated as "Burning Fire". If a location is only ever visible with smoke or as burned-out it is designated accordingly.
3. Image 6.N.02 (3:05PM-3:10PM) shows an orange glow on the East facade possibly located near column 40. Because of the photo's ambiguity, this potential fire has not been included.



Within Timeframe A (Image 4.W.10)

Within Timeframe G (Image 6.N.01)

Figure 14. Planometric diagram of fire progression for the 12th floor (source: GNA report – Exhibit B of this report).

5.3 FDS Simulation of 12th Floor Fire Effects

Arup was commissioned to perform simulations of fire effects on the 12th floor. For these simulations, the Fire Dynamics Simulator (FDS v5.3.1) developed by NIST was used. Available photographic evidence and information regarding the layout of the 12th floor were used as bases for these FDS simulations. Details of the FDS simulations conducted by Arup are provided in Exhibit C of this report.

The FDS model was used to simulate a seven-hour long fire incident, starting at approximately 10:30 AM, corresponding to the time when the WTC1 tower collapsed, and ending at 5:30 PM, corresponding to the approximate time when the WTC7 building collapsed. An initiating fire was specified in the area of the southwest corner of the 12th floor. A fuel load of 7.5 lb/ft^2 was prescribed throughout the occupied areas of the 12th floor, with the fire spreading through the prescribed fuel load. A window breakage sequence was also prescribed in the FDS model based on the window breakage sequence observed in the photographic analysis of the 12th floor fire.

Figures 15 through 21 show comparisons of the visual evidence of fire along the east and north facades at the different times identified in the figures. These figures summarize the results of the GNA photographic analysis and the Arup FDS simulation. The figures show that the FDS simulations results are consistent with the photographic evidence in terms of the visual observations of fire in different windows at different times.

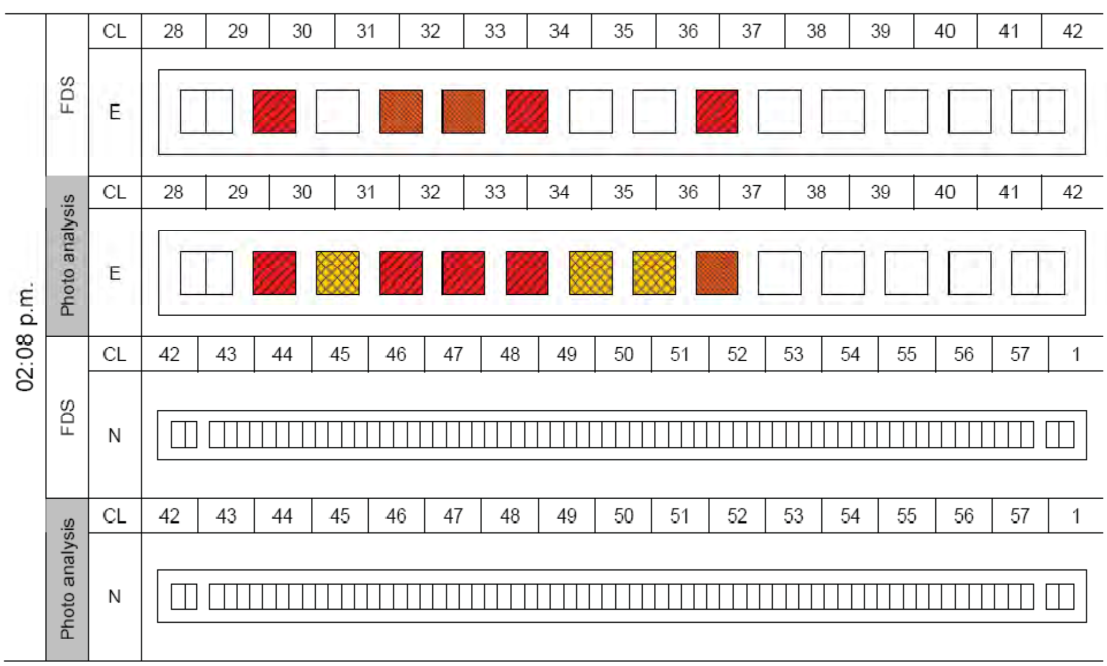


Figure 15. Comparison of visual evidence with FDS simulation at 2:08 PM.

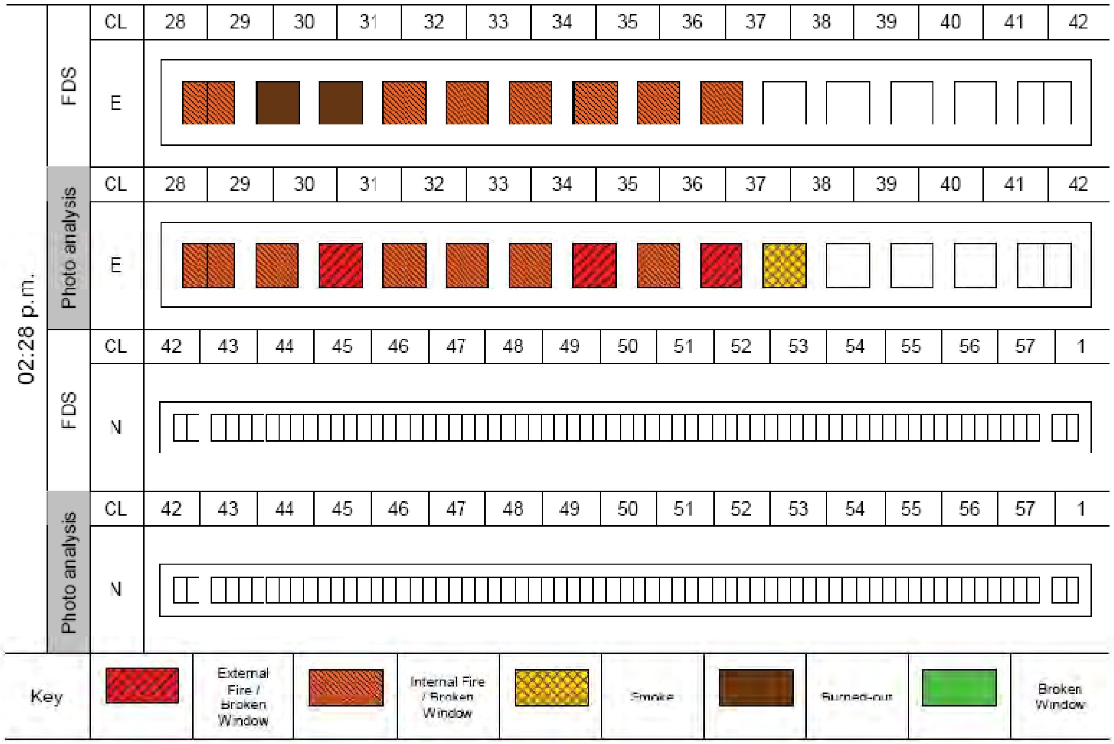


Figure 16. Comparison of visual evidence with FDS simulation at 2:28 PM.

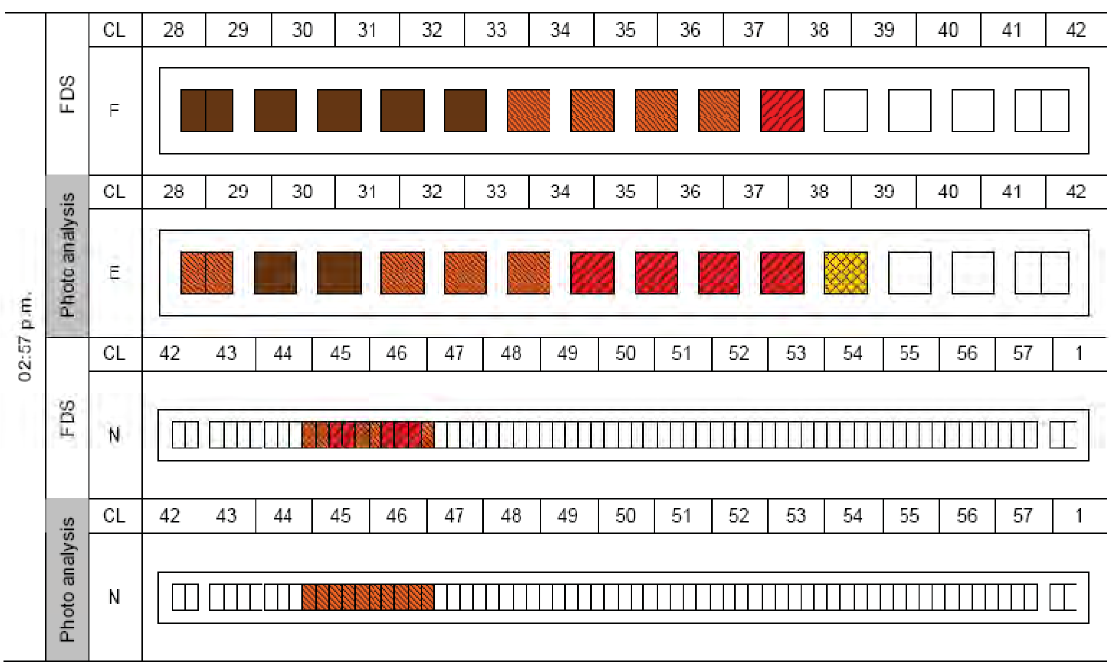


Figure 17. Comparison of visual evidence with FDS simulation at 2:57 PM.

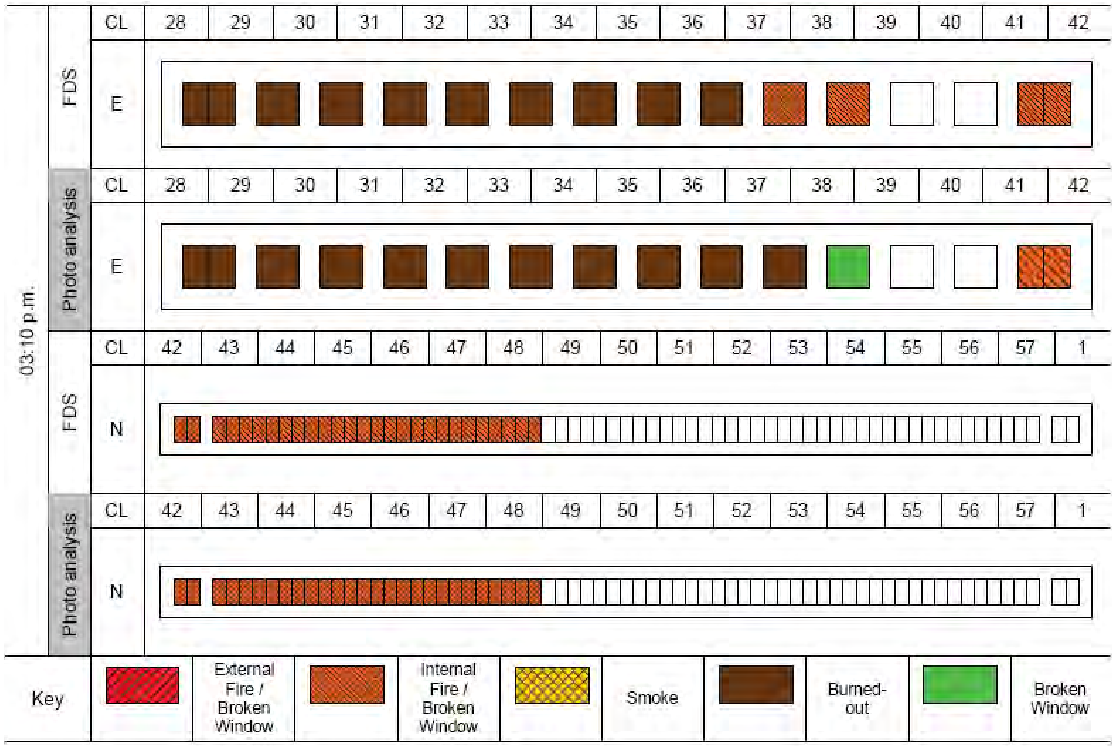


Figure 18. Comparison of visual evidence with FDS simulation at 3:10 PM.

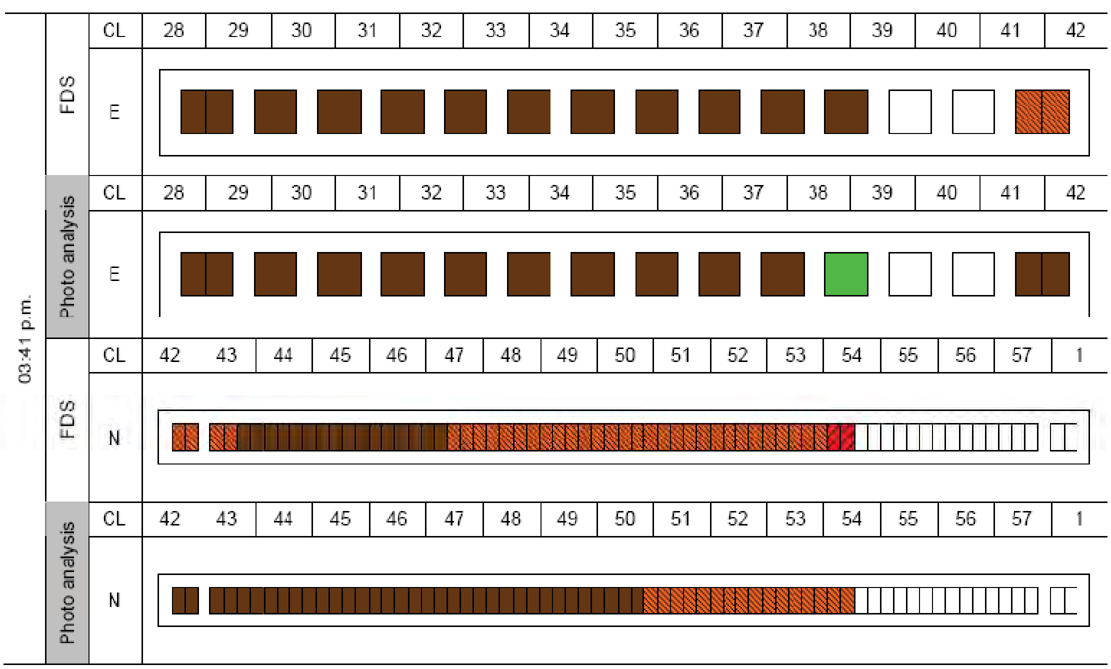


Figure 19. Comparison of visual evidence with FDS simulation at 3:41 PM.

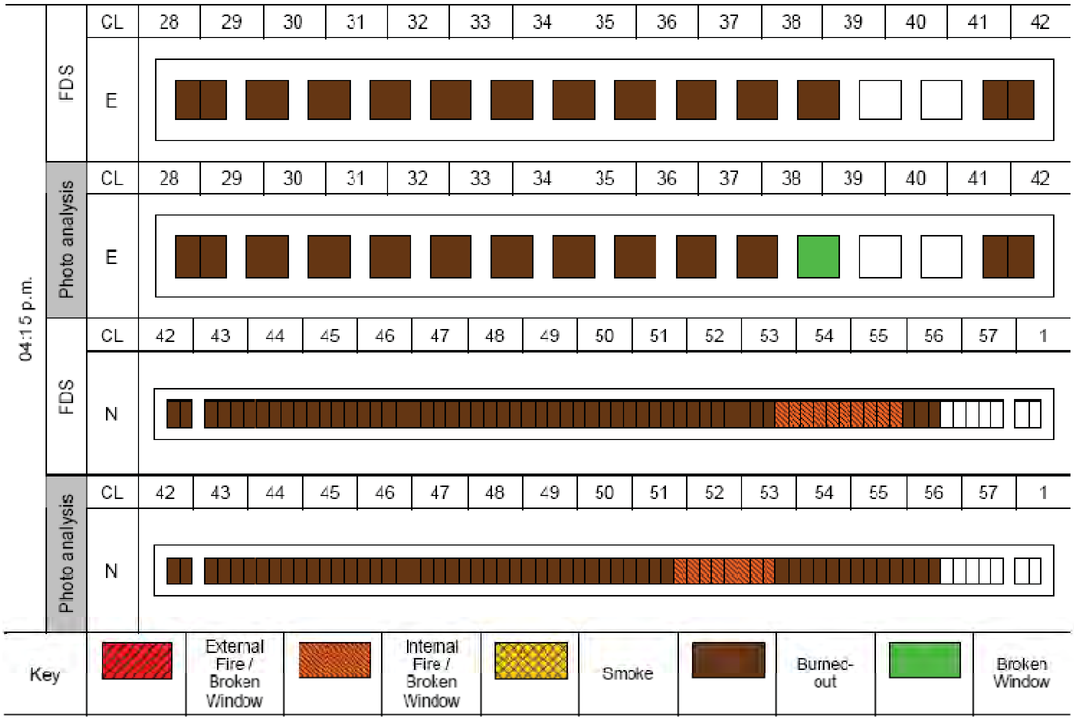


Figure 20. Comparison of visual evidence with FDS simulation at 4:15 PM.

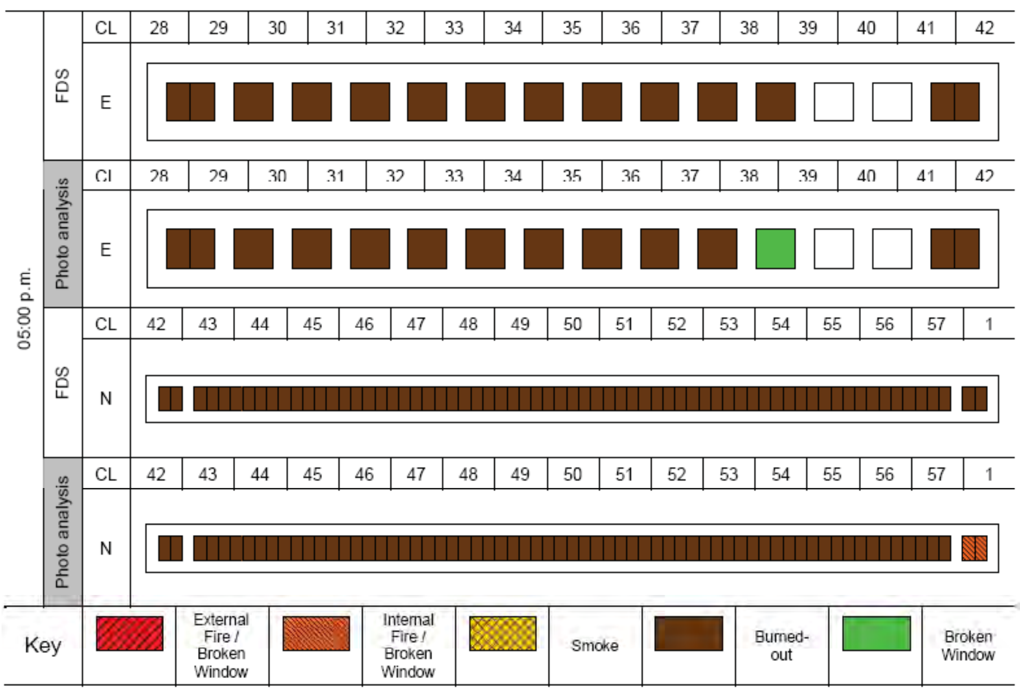


Figure 21. Comparison of visual evidence with FDS simulation at 5:00 PM.

Figure 22 shows the estimated heat release rate calculated in the FDS simulation of the 12th floor fire. The FDS simulation calculates a large increase in the estimated heat release rate starting just before 3:00 PM; this increase is associated with the large number of windows breaking along the north façade starting at 2:57 PM.

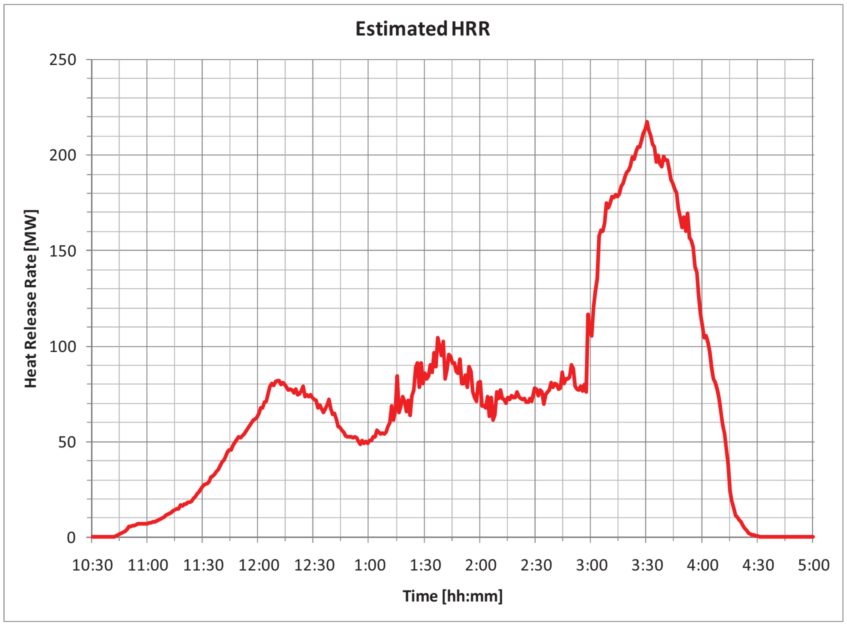


Figure 22. Estimated heat release rate history for the FDS simulation.

For the structural fire analyses conducted by Arup and discussed in the expert report of Prof. Colin Bailey, the eastern part of the structure was modeled. The approximate area of this part of the structure is highlighted in Figure 23. Figure 24 shows the peak 1-hour rolling average gas temperatures calculated at each elevation in the FDS simulation throughout this highlighted area. The average value of the peak 1-hour rolling average gas temperature was 537°C, with higher temperatures occurring closer to the ceiling and lower temperatures occurring closer to the floor. The temperatures at the highest two measurement elevations of 2.8 m and 3.2 m above the floor were within the range of 700 to 800°C, as shown in Figure 24. Since these elevations are in closest proximity to the floor assemblies above, gas temperatures of 700°C and 800°C for a period of 1 hour were selected to bracket the exposure conditions used for the structural fire analyses.

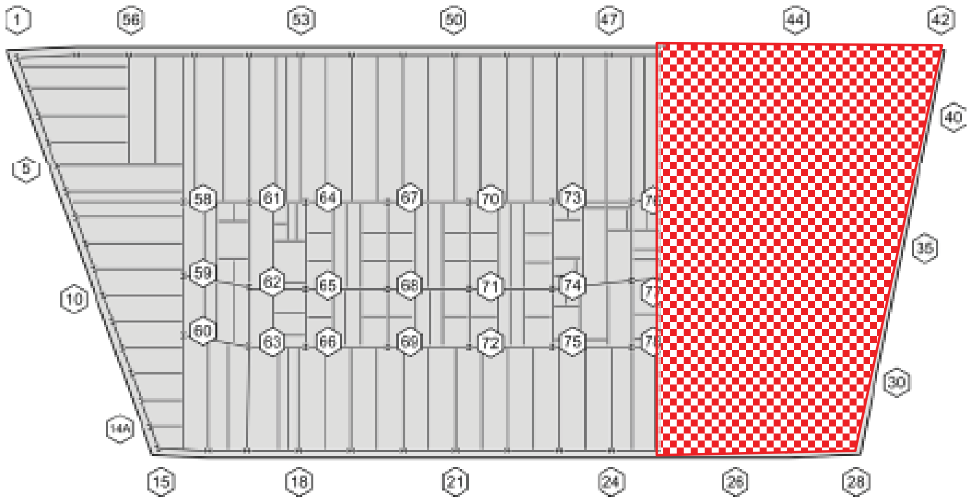


Figure 23. WTC7 floor plan with approximate structural fire analysis area highlighted in red.

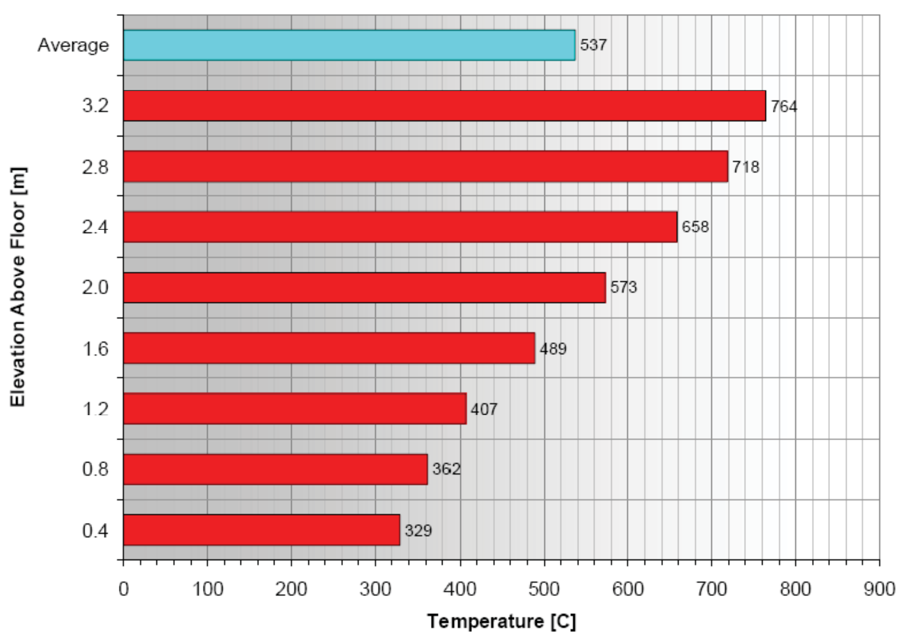


Figure 24. Peak 1-hour rolling average temperatures at each monitoring elevation within area highlighted in Figure 23.

5.4 Relationship between 9th and 12th Floor Fires

The FDS simulation of the 12th floor fire effects is based on the observed window breakage sequence for the 12th floor. As noted in Figures 13 and 14, the fire in the northeast quadrant on the 9th floor occurred later than the fire on the 12th floor in this area. The fire on the 9th floor also spread from west to east along the north façade of the building rather than from east to west as on the 12th floor. The fire loads and time frames for these traveling fires are similar to each other, so the fire conditions for these fires are expected to be similar to each other. Consequently, the parametric fire conditions used for the structural fire analyses described in the following section can be used to analyze the structural impact of the fire on the 9th floor as well as the fire on the 12th floor.

5.5 Parametric Fire Conditions Used for Structural Fire Analyses

Two temperature histories were selected to represent the gas phase boundary conditions for the structural fire analyses conducted as part of this investigation. These gas temperature histories were represented as a temperature of either 700°C or 800°C for a period of 1 hour, followed by a temperature of 20°C for another hour, as shown in Figure 25. The step change in gas temperature to 20°C after 1 hour is faster than would be expected, but the net effect of this is simply to accelerate the cooling that would be experienced by structural elements once a fire burns out.

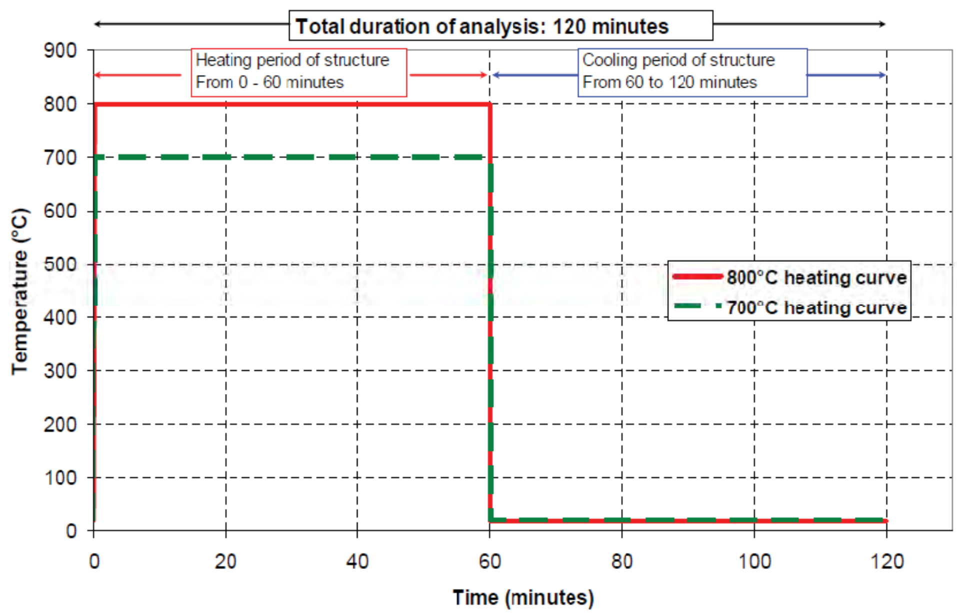
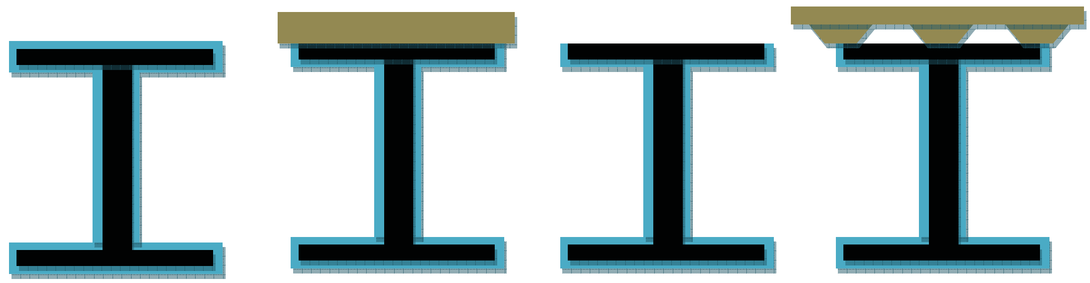


Figure 25. Gas temperature histories used for structural fire analyses.

5.6 Structural Element Temperatures Used for Structural Fire Analyses

The temperatures of structural elements were calculated in response to the gas phase temperatures, shown in Figure 25, based on the sizes of the different structural elements and the extent of SFRM applied to the elements. A number of different cases have been calculated to represent different heating conditions. These cases are illustrated in Figure 26.



(A) (B) (C) (D)

Figure 26. Illustration of cases used to represent structural element heating conditions.

Case A represents an element that is insulated with SFRM on all four sides and is exposed to fire conditions on all four sides. Case B represents an element that is insulated with SFRM on three sides and is exposed to fire conditions on three sides, with the fourth side assumed to be in contact with the floor slab being supported. This case is representative of filled cavities between beams and fluted metal decks. Case C represents an element that is insulated with SFRM on three sides and is exposed to fire conditions on all four sides. This case represents the extreme condition for Case D. Case D represents an element that is insulated with SFRM on three sides and is partially in contact with a fluted deck on the fourth side; this element is fully exposed to fire conditions on the three sides insulated with SFRM and partially exposed to fire conditions on the fourth side, not insulated with SFRM. This case is representative of unfilled cavities between beams and fluted metal decks. The Case D schematic diagram in Figure 26 shows the fluted decking in parallel with the beam axis for illustrative purposes only; the analysis is based on the decking being perpendicular to the beam axis.

Heat transfer analyses were conducted for these four cases at the University of Edinburgh, with results of these analyses provided in Exhibit D. These heat transfer analyses were performed to calculate the temperature histories of structural elements with different section sizes and insulation thicknesses in response to the two boundary conditions represented in Figure 24. A two-dimensional heat transfer model for Cases (A), (B) and (C) was developed for different section sizes using ABAQUS and thermal properties for the SFRM insulation material. A three-dimensional heat transfer model was developed for Case (D); this model covered approximately 40 contact areas between the beam and the trapezoidal metal deck to assure that the heat transfer effects of the deck could be defined accurately without any axial boundary condition effects.

A representative result for the Case D analysis is shown in Figure 27, which shows that the heat distributes fairly evenly in the upper flange and the main temperature gradient is in the vertical direction. From this, it was established that three average temperatures could be used to describe the temperature of a steel section for the Case D analyses. The three temperatures are labeled T_{top} for the upper flange temperature, T_{middle} for the middle web temperature and T_{bottom} for the lower flange temperature.

A one-dimensional lumped capacity analysis was also performed for Case (A); this lumped capacity analysis followed the step-by-step method outlined in Section 8.4.6 of Buchanan's book *Structural Design for Fire Safety*. The expression used for this lumped capacity analysis was of the form:

$$W C_s \frac{\Delta T_s}{\Delta t} + D\rho_i C_i d_i \frac{\left(\frac{T_s+T_g}{2}\right)}{\Delta t} = D\frac{k_i}{d_i}\left(T_g - T_s\right) \quad (1)$$

where d_i is the insulation thickness, T_g is the gas temperature, T_S is the steel temperature, W is the weight per unit length of the steel member and D is the heated perimeter of the member. Subscript "s" is for steel and subscript "i" is for insulation. The boundary condition is set as the gas temperature at the surface for the analytical expression, while for the ABAQUS analysis a total heat transfer coefficient of 45 W/m^2K is used.

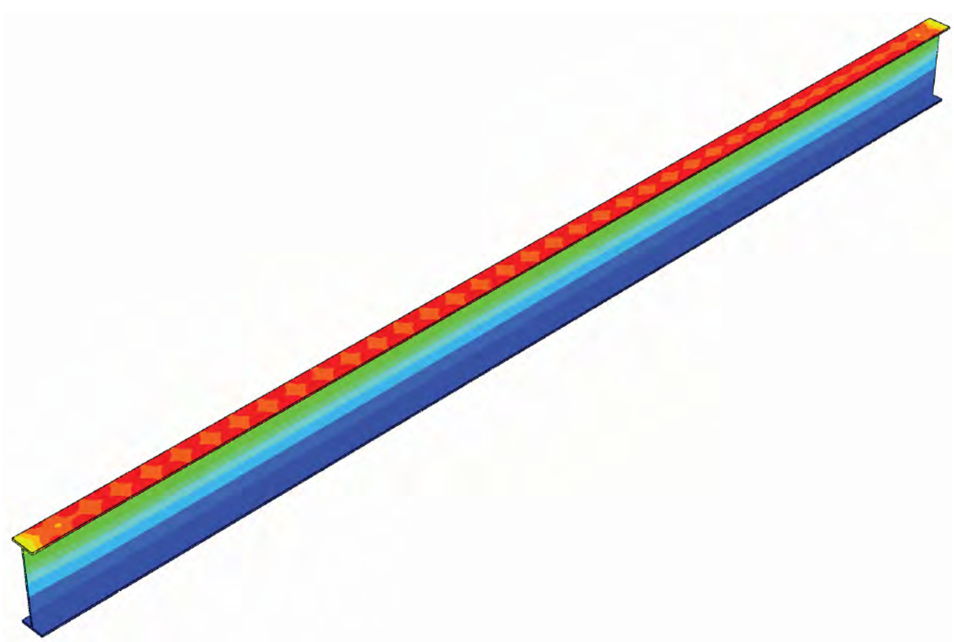


Figure 27. Representative calculated 3-D temperature distribution for a beam in Case D.

Figure 28 shows an example of the structural element temperatures specified in the structural fire analysis. This example shows the temperature history for the W33x130 girder between Columns 44 and 79 for the 800°C exposure condition. This figure shows that the top flange temperature is much higher for the unfilled flute case than for the filled flute case, which is assumed to have a uniform temperature through the steel section.

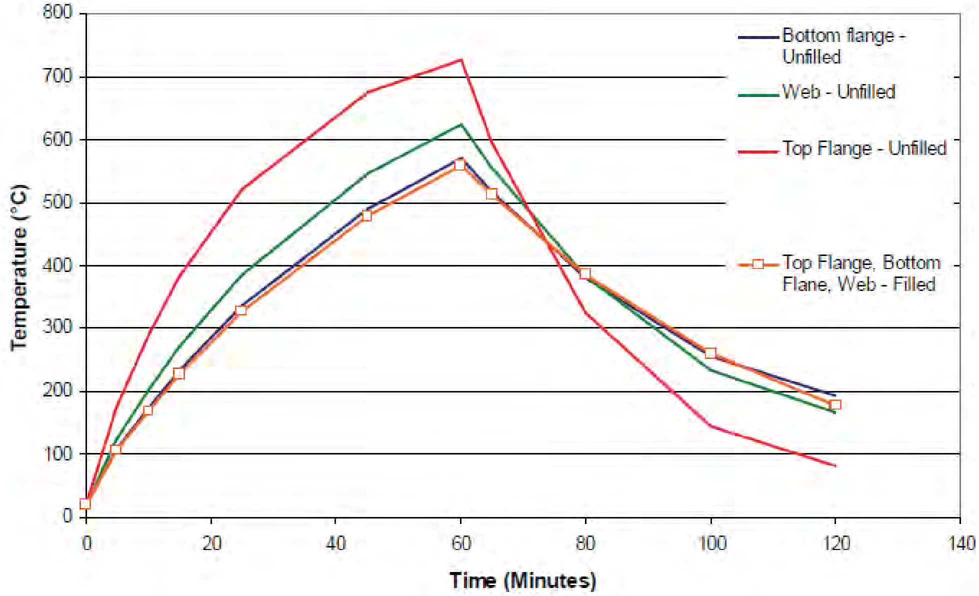


Figure 28. Representative girder temperatures under 800°C exposure condition for flute filled and unfilled cases.

Figure 29 shows another example of the structural element temperatures specified in the structural fire analysis, in this case for Column 79 insulated with 7/8 in. of SFRM material. As noted in this figure, the columns remain cool relative to the beam temperatures due to the large column section sizes, associated thermal mass and applied fireproofing.

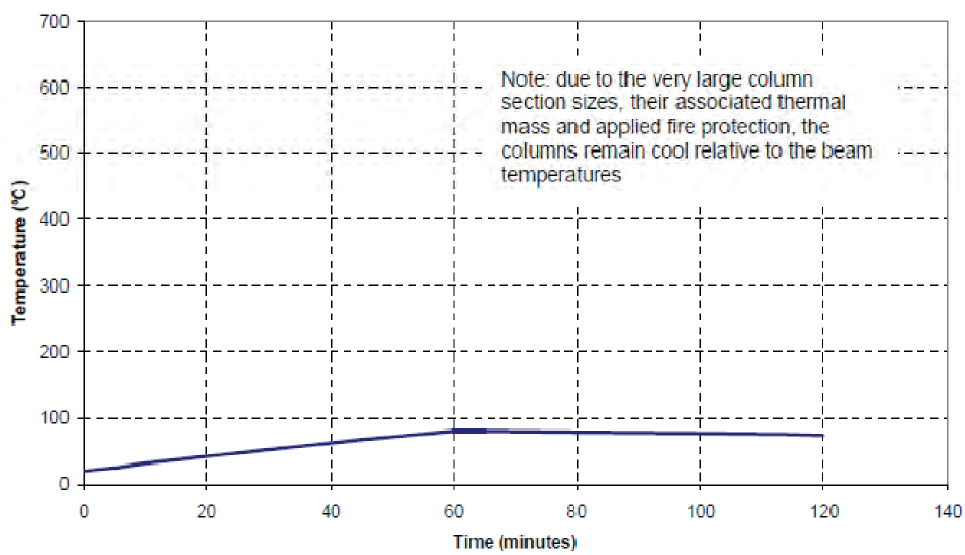


Figure 29. Representative column temperature under 800°C exposure condition.

Concrete temperature gradients were also calculated at the University of Edinburgh with the ABAQUS model for the two exposure conditions shown in Figure 25. For these calculations, an equivalent uniform slab thickness of 4 in. was assumed to represent the 2.5 in. concrete on the 3 in. deep fluted metal deck. The results are shown in Figure 30 for the 800°C exposure condition.

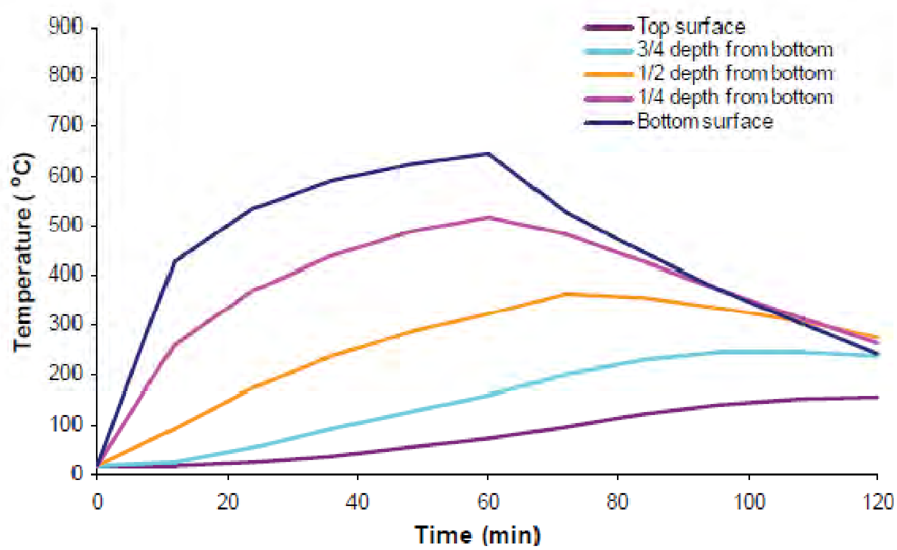


Figure 30. Calculated concrete slab temperatures for 800°C exposure condition.

The structural steel and concrete temperatures calculated in these heat transfer analyses were used in the structural fire analyses performed by Arup and described by Prof. Colin Bailey in his expert report.

5.7 Imposed Heat Load Analysis

An imposed heat load analysis was performed to compare the fire exposure conditions used for the parametric analyses with those associated with the ASTM E119 standard time-temperature curve. The basic premise of this imposed heat load analysis is that a building assembly or element with a specified fire resistance rating should be able to withstand, without loss of structural integrity, the imposed heat load associated with the ASTM E119 standard time-temperature curve for the period of its fire resistance rating. For comparison purposes, this imposed heat load is defined as the area under the blackbody emissivity curve associated with a specified time-temperature history. This is expressed mathematically as:

$$Q" = \int_0^t E(t)\,dt = \int_0^t \sigma T(t)^4\,dt \qquad (2)$$

where $Q"$ is the imposed heat load (MJ/m^2), E is the blackbody emissivity of the fire gases (kW/m^2), σ is the Stefan-Boltzmann constant (5.67 x 10^{-14} MW/m^2.K^4), and T(t) is the absolute temperature (K) of the fire gases as a function of time. This relationship assumes (1) that the imposed heat load is dominated by radiation, which is generally true at post-flashover fire temperatures, (2) that the fire gases emitting radiation to the building assembly are optically thick, such that their emissivity approaches unity, and (3) that the building assembly only "sees" these optically thick fire gases.

The imposed heat load calculated in accordance with Equation 2 for the ASTM E119 standard time-temperature curve is shown in Table 1 for a period of 4 hours and in Figure 31 for a period of 2 hours.

The two parametric time-temperature histories shown in Figure 25 were used to define the exposure boundary conditions for the structural fire analyses conducted by Arup. For Cases 1 (flutes unfilled) and 2 (flutes filled) of the Arup structural fire analyses, the gas temperature was specified to be constant at 700°C for a period of 1 hour, followed by 20°C for a period of 1 hour. For Cases 3 (flutes unfilled)and 4 (flutes filled) of the Arup structural fire analyses, the gas temperature was specified to be constant at 800°C for a period of 1 hour, followed by 20°C for a period of 1 hour. These alternative time-temperature curves and associated imposed heat loads are shown in Table 2 and Figure 32 for the 700°C exposure condition and in Table 3 and Figure 33 for the 800°C exposure condition.

Table 1. Imposed heat load for the ASTM E119 standard time-temperature curve

Time (min)	Temp rise (deg-C)		Time (s)	Temp (deg-C)	Blackbody emissivity (kW/m^2)	Cumulative imposed heat load (MJ/m^2)
0	0		0	20	0.42	0.00
5	556		300	576	29.48	4.48
10	659		600	679	46.60	15.90
15	718		900	738	59.27	31.78
30	821		1800	841	87.37	97.77
60	925		3600	945	124.85	288.76
90	986		5400	1006	151.80	537.75
120	1029		7200	1049	173.26	830.30
180	1090		10800	1110	207.52	1515.71
240	1133		14400	1153	234.55	2311.45

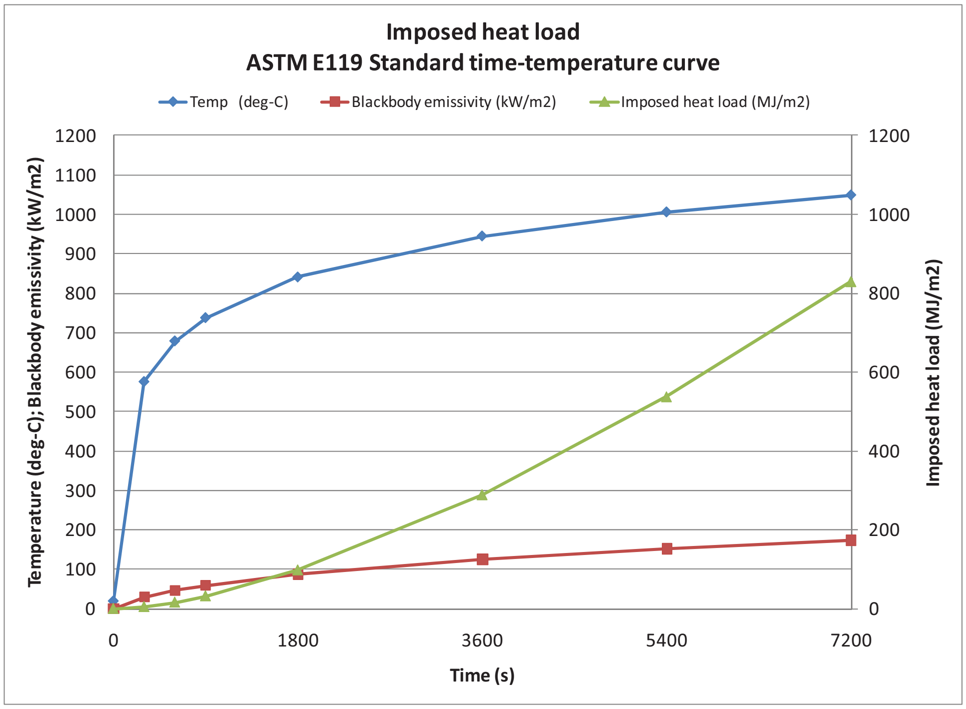


Figure 31. Imposed heat load for the ASTM E119 standard time-temperature curve.

Table 2. Alternative time-temperature curve – 700C for 1 hour

Time (s)	Temp (deg-C)	Blackbody emissivity (kW/m^2)	Imposed heat load (MJ/m^2)
0	700	50.85	0.00
300	700	50.85	15.26
600	700	50.85	30.51
900	700	50.85	45.77
1800	700	50.85	91.53
3600	700	50.85	183.06
3601	20	0.42	183.09
5400	20	0.42	183.84
7200	20	0.42	184.60

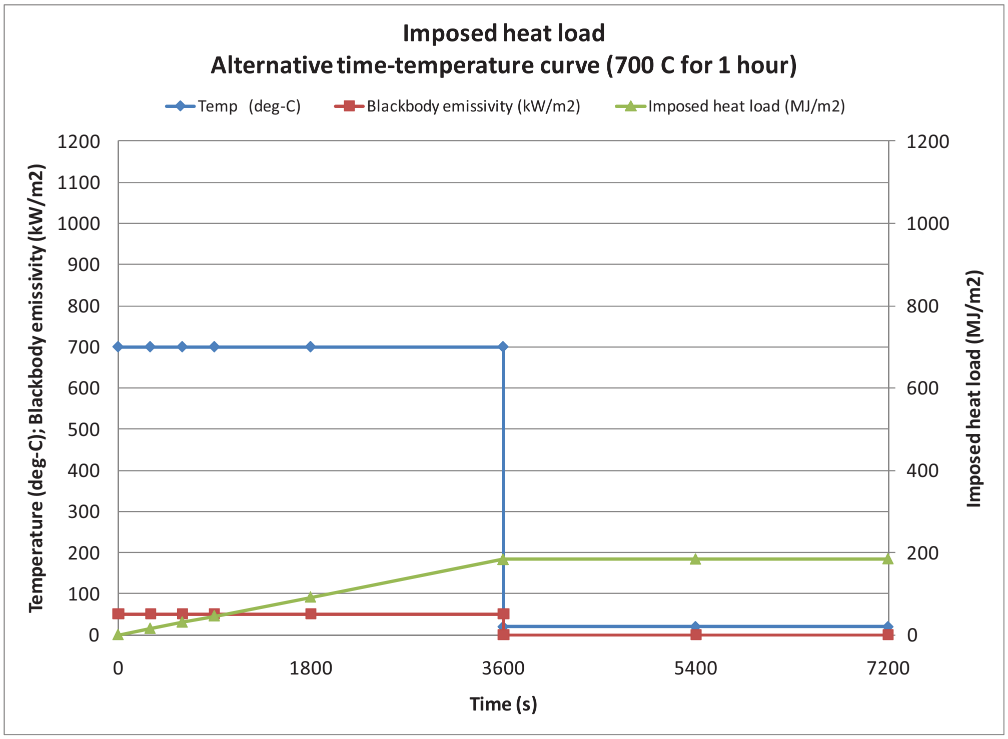


Figure 32. Imposed heat load associated with the 700°C time-temperature curve.

Table 3. Alternative time-temperature curve - 800 C for 1 hour

Time (s)	Temp (deg-C)	Blackbody emissivity (kW/m^2)	Imposed heat load (MJ/m^2)
0	800	75.20	0.00
300	800	75.20	22.56
600	800	75.20	45.12
900	800	75.20	67.68
1800	800	75.20	135.36
3600	800	75.20	270.72
3601	20	0.42	270.76
5400	20	0.42	271.52
7200	20	0.42	272.27

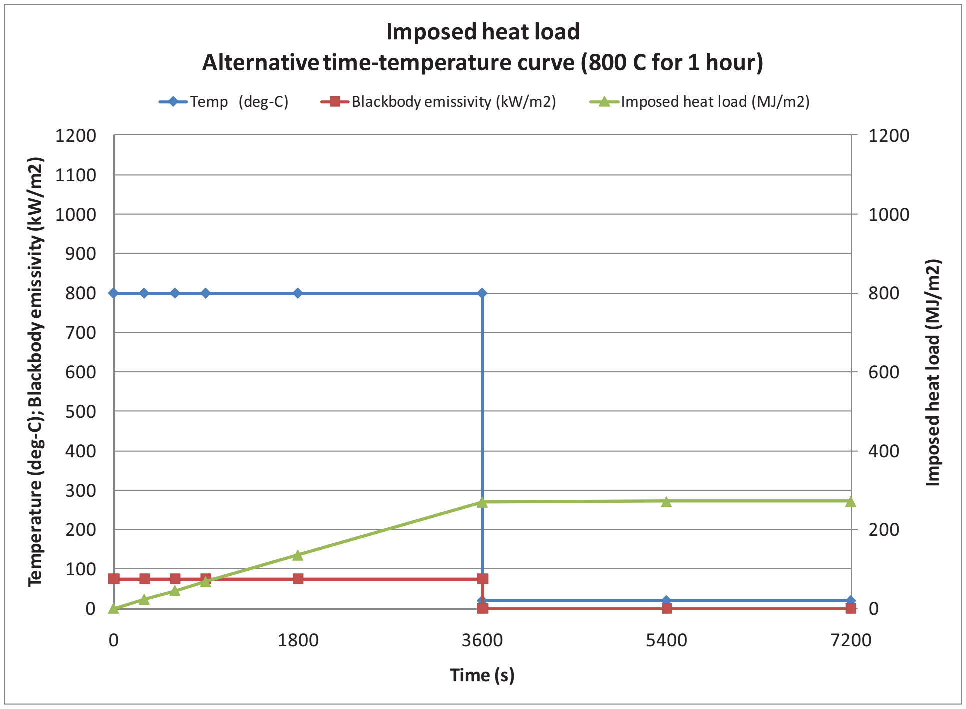


Figure 33. Imposed heat load associated with the 800°C time -temperature curve.

Figure 34 shows a comparison of the imposed heat loads for the standard and alternative boundary conditions. For the 700°C case, the imposed heat load at the end of the 1-hour exposure was approximately 180 MJ/m^2. For the 800°C case, the imposed heat load at the end of the 1-hour exposure was approximately 270 MJ/m^2. In comparison, the imposed heat load is approximately 290 MJ/m^2 after a 1 hour exposure to the ASTM E119 standard time-temperature curve and approximately 830 MJ/ m^2 after a 2 hour exposure to the ASTM E119 standard time-temperature curve.

This analysis indicates that a 2-hour rated fire assembly should be able to withstand an imposed heat load of approximately 830 MJ/m^2 without loss of structural integrity. The Arup structural fire analyses indicate that the floor assembly in the northeast area of the 13th floor of WTC7 would have failed after exposure to imposed heat loads of approximately 180 to 270 MJ/m^2, values considerably lower than the 830 MJ/m^2 associated with a 2-hour exposure to the ASTM E119 standard conditions. From this, it is reasonable to conclude that the floor assemblies in the northeast area of the WTC7 building were not designed and constructed in a manner that would have provided the level of performance expected of an assembly with a 2-hour fire resistance rating.

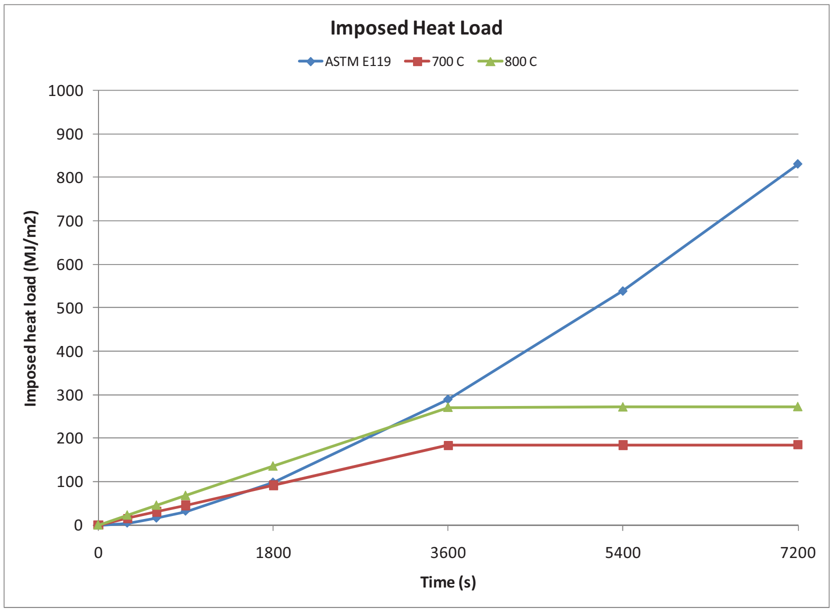


Figure 34. Comparison of imposed heat loads for standard and alternative time-temperature curves.

6. Summary of Opinions

Based on my education and experience in the fields of fire protection engineering and fire science, my review of the documents identified in Exhibit A.2 or in this report, and the information included in the previous sections of this report, I have developed the following opinions to a reasonable degree of scientific and engineering certainty.

1. Very tall buildings, such as the WTC7 building, are generally required to be of fire resistive construction (called Type I in some building codes), one of several construction types recognized by the Building Code of the City of New York, as well as by the model building codes that have existed in the United States for much of the past century. Fire resistive buildings should be able to withstand the fire severity resulting from complete combustion of the contents and finish involved in the intended occupancy without collapsing. The WTC7 building was not able to withstand the fire severity resulting from complete combustion of its contents without collapsing, thereby violating this principle.

2. WTC7 is the only modern fire-resistive high-rise building in the United States that has ever suffered global collapse as a direct result of fire. Other modern fire-resistive high-rise office buildings have suffered uncontrolled fires on multiple floors, but these buildings did not collapse as a result of the fires. On the contrary, these buildings, particularly the FIB, exhibited the type of performance expected of fire-resistive buildings when subjected to uncontrolled fires by maintaining their structural integrity. This exemplary performance record for fire-resistive steel-framed buildings highlights

the fact that the WTC7 building was deficient in its ability to withstand the impact of fire.

3. There is a reasonable expectation that firefighters will not engage in, or be effective in, offensive firefighting in high-rise buildings. This is one of the reasons why high-rise buildings are required to be of fire-resistive construction. Indeed, firefighters could not reasonably be expected to enter high-rise buildings to fight fires if their structural stability was questionable. There have been a number of serious fires in high-rise buildings where firefighters have been unable to suppress the fire on multiple floors of the building. Such fires resulted in complete combustion of the contents occurred on the fire-affected floors, but did not result in total collapse of the buildings.

4. Because a high-rise building of fire-resistive construction should be able to withstand complete combustion of its fuel load without collapsing and with no intervention by manual firefighting or automatic sprinkler protection, the lack of manual firefighting and the inoperative automatic sprinkler protection in the WTC7 building on September 11, 2001, should not have caused the collapse of the building.

5. The design of automatic sprinkler systems in the United States anticipates only a single fire source. Modern automatic sprinkler systems are hydraulically calculated to deliver the designed quantity of water to the area of a single fire source. When multiple fires occur, water is diverted to these additional fires, thereby decreasing the amount of water flowing to each of the multiple fire sources and increasing the probability that the sprinkler system will not control the fires.

6. Office contents fires generally burn for approximately 20 to 30 minutes in any one location until the fuel is consumed and then move on to the next area. In tall buildings provided with a proper and appropriate level of fire resistance, ordinary office contents fires normally run out of fuel before sufficient structural damage can weaken steel to such an extent that it would fail.

7. The photographic and video evidence of the fires on the office floors in WTC7 on September 11, 2001, from the collapse of WTC1 until approximately 5:00 PM, shows that these fires appear to have been travelling fires limited to a few office floors. The office floors in WTC7 started at the seventh floor. The photographic and video evidence of the fires on the office floors of WTC7 indicate that these fires were consistent with ordinary office contents fires; they were not extraordinary fires.

8. After 3:30 PM, photographic evidence shows fires and smoke consistent with a petroleum-based diesel fuel fire emanating from the vicinity of the fifth/sixth floor louvers on the east side of WTC7. Examples of this are shown in Images 7.E.01 to 7.E.04 of the GNA photographic analysis report appended as Exhibit B to this report. Four of the nine generators comprising the Salomon Brothers' Standby Generator System were located in the northeast corner of the fifth floor.

9. The Standby Generator System installed by Solomon Brothers on the fifth floor of WTC7 constituted an electric power generating plant under the NYC Building Code. As such, the area surrounding the generators and associated fuel piping required a higher fire resistance rating than the rest of the building. There is no evidence to indicate that this higher level of fire resistance was provided.

10. WTC7 was generally classified as a Group E occupancy. As an electric power generating plant, the Salomon Brothers' Standby Generator System was classified as Group D-1 occupancy, thus mandating 3-hour fire resistive separation construction. Absence of such 3-hour fire resistive separation of the generator spaces on the fifth floor of WTC7 made it non-compliant with the NYC Building Code.

11. An additional violation of the NYC Building Code was based upon misapplication of UL Design No. D739 to achieve the 2-hour fire resistance rating required of floor assemblies in buildings of Class 1B construction. The level of fireproofing applied at WTC7 would have been adequate to achieve a 2-hour fire resistance rating only if the floor assembly were classified as "restrained."

12. The Design Information Section in the 1983 edition of the UL Fire Resistance Directory provided the following definition for restraint in buildings: "Floor and roof assemblies and individual beams in buildings shall be considered restrained when the surrounding or supporting structure is capable of resisting substantial thermal expansion throughout the range of anticipated elevated temperatures. Constructions not complying with this definition are assumed to be free to rotate and expand and shall therefore be considered as unrestrained." Based on computer modelling completed to date, the structure was not capable of resisting substantial thermal expansion throughout the range of anticipated temperatures. Therefore, the floor assemblies and beams should have been considered as unrestrained.

13. Given that WTC7 constituted an unrestrained assembly, the UL Design No. D739 only achieved a fire resistance rating of only 1 hour, which would not have qualified it for use in a building of Type 1B construction.

14. The problem of inadequate fireproofing was compounded by the long floor spans in the northeast corner of the WTC7. The designer should have evaluated the potential effects of the long span beams and girders on the expected fire performance of the floor assemblies in the WTC7 building, particularly with respect to the issue of thermal restraint. There is no evidence to indicate that this was done; if it was, then the designer failed to appreciate the implications of these issues.

15. The sprayed-on fireproofing material was not properly or adequately applied to the fluted steel decking and floor support structural steel beams and girders as required by the project specifications because the cavities between the upper beam flanges and the fluted steel deck were not filled with the fire protection material applied to the beam as required in the UL Fire Resistance Directory.

16. Failure to construct the WTC 7 with the flute cavities above the beams and girders filled with the fire protection material applied to the beams, as required by the UL Fire Resistance Directory listing for the selected floor assembly and the project specification, reduced the fire resistance of the beams, girders and floor assemblies below the level that would have been achieved if these cavities had been properly filled in compliance with the requirements of the NYCBC.

17. The failure to fill the flute cavities with the fire protection material applied to the beams, as required, permitted the girders and beams to heat up more quickly than expected when exposed to ordinary office contents fires. This more rapid heating would cause the girders, beams and floor assemblies to fail more quickly than expected when subjected to such a fire.

18. Computer modelling completed to date indicates that the improper and inadequate fireproofing of the floor assemblies in the WTC7 building caused a failure which led to the global collapse of the building.

Exhibit A.1
Curriculum Vita
FREDERICK W. MOWRER

Academic Degrees:

1987	**Ph.D.,** Fire Protection Engineering and Combustion Science University of California, Berkeley
1981	**M.S.,** Engineering University of California, Berkeley
1976	**B.S. (with High Honors),** Fire Protection and Safety Engineering Illinois Institute of Technology

Current Positions:

Principal
C P Fire, LLC
4101 College Heights Drive
University Park, Maryland 20782

Visiting Professor / Acting Director
Fire Protection Engineering Programs
California Polytechnic State University
San Luis Obispo, CA 93407

Previous Positions:

1987-2008	Assistant / Associate Professor Department of Fire Protection Engineering University of Maryland College Park, Maryland 20742-3031
1983	Lecturer, Department of Civil Engineering University of California, Berkeley Berkeley, California 94720
1982-1983	Associate Specialist, College of Engineering University of California, Berkeley Berkeley, California 94720
1980-1987	Fire Protection Engineer Pleasant Hill, California 94523
1978-1980	Fire Protection Engineer / Building Code Consultant Rolf Jensen and Associates, Inc. Washington, DC and San Francisco, California
1976-1978	Engineering Representative / Staff Supervisor Insurance Services Office - Southeastern Regional Office Atlanta, Georgia

Professional Registration:

Registered Fire Protection Engineer (#1094)
State of California

Professional Service:

1978-Present Society of Fire Protection Engineers

1987-1989	Computer Committee
1988-1994	Research Committee
1989-1994	Education Registration Committee
	Subject Matter Expert - Fire Dynamics
1992-1994	Nominating Committee
1995-2003	Board of Directors
1995-2000	Vice President
1998-2000	Chair – Technical Steering Committee
2001	President-elect
2002	President
2003	Immediate Past President
2004-Present	Technical Steering Committee member
	2006-Present: Chair

1978-Present National Fire Protection Association

1990-Present	Research Section
	1992-1994 Chairman
	1990-1992 Vice-Chairman
1992-1994	Task group on smoke management in large spaces
1999-2009	Technical Committee on Fire Tests
2005-2009	Chair, Research Advisory Committee
	Fire Protection Research Foundation

1988-2000
2008-Present International Association for Fire Safety Science

1988-1994	Auditor
1989-1994	Working group-model curriculum development
2008-Present	Committee member

2000-2002 International Standards Organization

2000-2002	Convenor – TC 92 / SC 4 / WG 9

Awards and Honors:

2009	Emeritus status, Department of Fire Protection Engineering, University of Maryland
2007	FM Global Best Paper Award, *5th International Seminar on Fire and Explosion Hazards*, Edinburgh, Scotland
2002	Harry C. Bigglestone Award for excellence in written communication of fire protection concepts in *Fire Technology*
2000	Best Technical Paper presented at the 8th International Conference on Nuclear Engineering ICONE-8
1999	Fellow, Society of Fire Protection Engineers
1991	Harry C. Bigglestone Award for excellence in written communication of fire protection concepts in *Fire Technology*
1988	Harry C. Bigglestone Award for excellence in written communication of fire protection concepts in *Fire Technology*
1976	Outstanding Senior Award - Society of Fire Protection Engineers - Chicago Chapter
1976	Clinton Stryker Award for outstanding service to the IIT community
1974	Tau Beta Pi National Engineering Honor Society
1974	Salamander Honorary Fire Protection Engineering Society

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Exhibit A.2
Materials reviewed and relied upon

Documents and materials referenced within this report

Architectural / mechanical / structural design drawings including:

- World Trade Center Architectural Drawings by Emery Roth and Sons PC Architects (TISHMAN 0014654 – 0014699, SOM129665 – 129730)
- Fire Protection Drawings (7WTC-0000438 – 7WTC-0000456 and miscellaneous other drawings)
- Mechanical Drawings (PANYNJ 0102082 – 0102130)
- Plumbing Drawings (PANYNJ0101962, PANYNJ0101945, PANYNJ0101927, PANYNJ0101925)
- World Trade Center 7 Structural Drawings by Irwin G Cantor PC and revisions (TISHMAN 0014700 – 0014790, PANYNJ 0101613 – 0105649, SHCA 0001824, TISHMAN 014778 - 0147780)
- Salomon Brothers Tenant Fit-Out and Alteration Architectural and Structural drawings by Skidmore Owings and Merrill and Irwin G Cantor PC (SOM0103178, SOM 0116971- 0125792, SOM 0125799 – 0125835, SOM 0125843 – 0125846, SOM 0126920 – 0126922, SOM 0128056 – 0128472, SOM 0129166 – 0130169, SOM 0130247 –0130400, SOM 0131221 – 0131257, SOM 0131700 – 0132183, SOM 0132632 –0133124, SOM 0133386 – 0133469)
- Securities Exchange Commission Plans (PANYNJ0028785 – 0104032)
- American Express Plans (miscellaneous documents between AMEX0000218 – 0002673)

Deposition transcripts of M Patti, B Brandes, S Civitillo, T Roche, R Rotanz, R Spadafora, J Spiech, A Varriale, R Weindler, A Zeolla and various firefighters

Expert reports of Prof. Colin Bailey and Prof. Jose Torero

Loss Prevention Reports, including:

- Factory Mutual (Protection Mutual Insurance) Loss Prevention Reports (including but not limited to 7WTC0000915-16, 7WTC0001241-44)
- IRI Loss Prevention Reports
- Kemper Loss Prevention Report

Master Assumption List compiled by Guy Nordenson and Associates

Miscellaneous documents (including but not limited to 7WTC0000728-729, 7WTC0000915-16, 7WTC0001241-44, 7WTC0001676-78, 7WTC0007836-37, 7WTC0013927, 7WTC0001735-36, 7WTC0006666, 7WTC0007874-75, AMEC0003091-105, AMEC0020968, AMEC0020970-71, AMEC0020981, AMEC0020983, AMEC0003058, AMEC0018341, AMEC0020968, AMEC0024111-12, AMEC0037492-93, AMEC0044944, AMEC0050032, AMEC0050042, AMEC0050059, AMEC0050319-320, AMEC0057675-76, AMEC0057998-8000, AMEC0058848-49, AMEC0058886-87, AMEC0059409, AMEC0059411-14, AMEC0059746-53, AMEC0070198-99, AMEC0070204-10, AMEC0073765-73, CANTOR0006301-25, Cantor0006614-15, Cantor0006588-89, CANTOR0007057-59, CANTOR0008430-32, CANTOR0008542-48, CANTOR0010098-99, Cantor0011476, CANTOR0017779-85, CITI7WTC000011-19, CITI7WTC0033014-16, CITI7WTC012855-65, CITI7WTC012873-76, CITI7WTC012881-82, CITI7WTC012888-91, CITI7WTC012922, CITI7WTC014473-77, CITI7WTC014510-11, CITI7WTC014703, CITI7WTC015370, CITI7WTC015966-67, Citi7wtc033014-016, CITI7WTC087223-25, CITI7WTC088652-54, CITI7WTC088691, CONED0070476-77, CONED0076482, CONED0077179, FK0000334-35, FK0002409-10, FK0003046-47, FK0042971-73, FK0043090, FK0043320-21, FK0045230-32, FK0005313-14, FK0010571-72, FK0014881, FK0016010, FK0020978-79, FK0039814, FK0046344, PANYNJ0000026-29, PANYNJ0012904, PANYNJ0012907-8, PANYNJ0012927-29, PANYNJ0012946-51, PANYNJ0022485-90, PANYNJ0029933, PANYNJ0044699-700, PANYNJ0044706-07, PANYNJ0044714-15, PANYNJ0044717-19, PANYNJ004472, PANYNJ0044725, PortAuthority0012475, PortAuthority0012478-479, PortAuthority0012498-500, PortAuthority0012517-522, SOM0000334, SOM0000862-65, SOM001173-74, SOM0001214-16, SOM0011979-81, SOM0012111-14, SOM0014246-47, SOM0051567-69, SOM0058699, SOM0058704-05, SOM0058709-11, SOM0058762-65, SOM0059122-23, SOM0067807, SOM0087666-68, SOM0118312, SPI014170-71, SPI014723-38, SPI022876-80, SPI022901-03, SPI022919-23, SPI022945-47)

Photographs, including but not limited to:

- Tenant Fit-Out Photographs (BERNSTEIN 0000001.01 – 0000206.02)
- Construction Photographs (miscellaneous documents between CITI-7WTC072482 – 073905)
- CITI7WTC0096873 - 97118, PANYNJ9000001-9239

Testwell Craig Laboratories, Inc. Inspection Reports for fireproofing (including but not limited to CANTOR0012002, CANTOR0012016-17, CANTOR0012020-21, CANTOR0012038, CANTOR0012272-3, CANTOR0012471m, CANTOR0012530-1, CANTOR0012814-5, CANTOR0012835-6, CANTOR0014458-60, CANTOR0014739, CANTOR0014741-43, CANTOR0014957-58, CANTOR0015199-202, CANTOR0015939, CANTOR0016277, CANTOR0016280-81, CANTOR0016492-97, CANTOR0020734-35, CANTOR0020740-45, CANTOR0020989-21000, CANTOR0023713-14, CANTOR0023719-20, CANTOR0025255-76, CANTOR0026207-16, SOM0070297, SOM0087666-68)

Video footage of WTC7 collapse

Exhibit A.3
Rate schedule

I have been compensated at the rate of $250 - $295 per hour for time spent working on this project. Reimbursable expenses are being charged at actual cost plus ten percent. Automobile mileage is charged at the current standard mileage rate established by the Internal Revenue Service.

Exhibit A.4
Schedule of testimony

February 1, 2006 – January 31, 2010

Case or File Name	Court	Date of Testimony	Type of Testimony	On Behalf of
CAMP TAKAJO, INC. v. SIMPLEXGRINNELL, LP, AND PITRE PAINTING CO., INC.	SUPERIOR COURT CIVIL ACTION Docket No. CV-04-773, State of Maine	Oct-2005 Mar-2007	Deposition Trial	Plaintiff
DEERE & COMPANY, INC., v. PETERSEN PROPERTIES, LC,	Iowa District Court for Scott County LAW NO. 100203	6&7-Jul-2006 4-Aug-2006 Mar-2007	Deposition	Plaintiff / Counterclaim Defendant
J. Scott Rutherford, III, et al. v. Texas Industries, Inc., et al.	68th Judicial District Court, Dallas County, Texas, Cause No. 03-864-C	1-Sept-2006	Deposition	Defendant
Citizens Insurance Company of America, v. Brigade Fire Protection Inc., et al.	CIRCUIT COURT FOR COUNTY OF LEELANAU, State of Michigan File No. 06-7311-NZ	25-May-2007	Deposition	Plaintiff
The Travelers Indemnity Company, v. Coakley & Williams Construction, Inc., et al.	CIRCUIT COURT FOR PRINCE GEORGE'S COUNTY, MARYLAND	9-May-2008	Deposition	Plaintiff
Liberty Mutual Fire Insurance Company as Subrogee of Heat Treating Service Corporation of America v. Detroit Fire Extinguisher Company, Inc., et al.	State of Michigan Circuit Court for the County of Oakland Case No. 07-087009 NZ	24-Oct-2008	Deposition	Plaintiff
VICTORIA GONZALEZ and ROBERT ROYALTY, Plaintiffs, v. DREW INDUSTRIES INC., et al., Defendants	United States District Court Central District of California Case No. CV 06-08233 DDP	21-Nov-2008	Deposition	Defendant
LIBERTY MUTUAL PROPERTY, Individually and as Subrogee of REDDY ICE HOLDINGS, INC., Plaintiff, v. ROGERS ELECTRICAL SERVICE CORPORATION, Defendant	Superior Court of Fulton County, State of Georgia Civil Action File No. 2008CV149404	27-May-2009 19-Oct-2009	Deposition Trial	Defendant
American International Insurance Company, as subrogee of Michael and Mary Humes, Plaintiff, v. Gabrilson Heating & Air Conditioning Co., an Iowa Corporation, et al. (and associated cross claims)	Iowa District Court for Scott County, File No. LACE110343	21-Aug-2009	Deposition	Defendant / Cross-Claim Plaintiff
GOWANIE GOLF CLUB, INC. v. FIRE EXTINGUISHER SALES & SERVICE, INC.	Circuit Court for the County of Macomb State of Michigan Case No. 08-1007-NO	15-Jan-2010	Deposition	Plaintiff

Exhibit B

PHOTOGRAPHIC ANALYSIS
WORLD TRADE CENTER 7
COLLAPSE INVESTIGATION
New York NY

VOLUME A: PHOTOGRAPHIC TIMELINE

VOLUME B: FIRE PROGRESSION BY LEVEL

Prepared by Guy Nordenson and Associates

Dated: December 16, 2009

(Attached as separate documents)

Guy Nordenson and Associates

PHOTOGRAPHIC ANALYSIS: VOLUME A PHOTOGRAPHIC TIMELINE

WORLD TRADE CENTER 7 COLLAPSE INVESTIGATION New York NY

Prepared for

Gennet, Kallmann, Antin & Robinson PC
and
Greenbaum, Rowe, Smith & Davis LLP

16 December 2009

By

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TABLE OF CONTENTS

A.0 EXECUTIVE SUMMARY

This volume is a compilation of the currently available images taken on 11 September 2001 of World Trade Center 7. These images were all taken after the collapse of World Trade Center 1 but before the collapse of World Trade Center 7. Only images that show discernible debris impact or fire-related damage to the building have been included. The damage apparent in each photograph has been catalogued according to its type and location on the building (see *Appendix 1A - Photographic Damage Index*). The categories of type are as follows: broken window, debris damage, debris damage and broken window, gash, smoke, broken window with internal fire, broken window with external fire, and burned-out. This database of damage makes it possible to discern the patterns of fire and debris damage present on the building in order to give a comprehensive view of the building before its collapse.

This volume also attempts to create a timeline of events based upon these photographs. Many of the images were included in the National Institute of Standards and Technology's *Structural Fire Response and Probable Collapse Sequence of World Trade Center Building 7*. Within this document NIST delineated either precise times or a range of times for each of the images. Also, approximately 28 image files contain metadata with timestamp information. These images afforded an overall timeline into which the remaining untimed photographs could be inserted based upon locations of fires, smoke, and burned-out windows in relation to the NIST and metadata images. These times are understood to be approximate and subject to the accuracy of NIST's timing along with the limitations of the individual photographs' quality and scope.

In order to provide an overview of how fires behaved during the period between WTC1's collapse and WTC7's collapse, this volume has been divided into hourly increments. Each of the volume's sections approximately represents an hour of the day. Within each section are diagrams of the four façade elevations that demonstrate how fires changed throughout the day across the entire building. When there was evidence of changes to the fire within a particular hourly increment, detail elevation diagrams and corresponding images are included as well. These sequences of detail elevations illustrate how each fire moved on a given façade during that hour. In addition to diagrams, the photographic evidence pertaining to the hour is also contained within the section. This assemblage allows each section to comprise all the information available for an increment of time.

The information contained within this volume has been constructed based upon the photographs and corresponding times currently available and is subject to change in the event additional information is obtained.

A.1 DEBRIS DAMAGE FOLLOWING WTC1 COLLAPSE

World Trade Center 1 collapsed at 10:29am on 11 September 2001. During its collapse debris was cast as far as 500ft away, damaging numerous buildings along its periphery. World Trade Center 7 was sited approximately 370ft north of WTC1's north facade and subsequently sustained debris damage. In plan WTC7 was shifted to WTC1's east, with the southwest corner of WTC7 aligning to roughly the western third point of WTC1's north face. Because of this relationship both the south and west facades were damaged by debris from WTC1. The following analysis of photographic evidence helps to describe which areas were affected by the collapse. The damage apparent in each photograph has been catalogued according to its type and location on the building (see Appendix 1A - Photographic Damage Index). However, this information is limited by a few factors. While the condition of a majority of the west facade can be ascertained from these images, the condition of the south face is more difficult to determine. After the collapse of the WTC towers, the site was closed to the public due to safety concerns. This results in a limited number of images showing the south facade. The available images were primarily taken from the southwest, from substantial distances, and from angles which obscure much of the facade. In addition, the south facade was hidden by a veil of smoke for the majority of the day making it difficult to survey the face of the building.

Though the full status of the south facade after WTC1's collapse might not be known, careful scrutiny of the available images does illuminate some important conditions. A large gash is located at approximately the western third point of the south facade on the uppermost floors. This gash appears to be located between columns 19 and 21. Similarly, many images show a large strip between columns 19 and 20 from approximately the 24th to 40th floors. This is most likely a gash that at minimum damaged the floor spandrels at the affected levels. The most severe damage occurs at the lower southwest corner of the building, at points stretching from column 13 to 20. This damage affects floors 6 to 17. Columns, floor spandrels, and beams all appear to be damaged or even omitted in these areas. However, these conclusions are limited to the south façade's restricted photographic evidence.

A.1.1 Debris Damage Diagrams

Figures 1.W.01 and 1.S.01 on pages 4 and 5 represent elevation mappings of the resultant debris damage to WTC7 from the collapse of WTC1 as evidenced in the available images. Because of WTC7's location and orientation, only the south and west facades were affected by WTC1's collapse. Damage types include broken window, debris damage, debris damage and broken window, and gash. Fire-related damage has not been included since fires would have developed after the initial collapse impact. These elevations include damage to both structural and nonstructural elements such as the facade system. In order to more accurately assess potential structural damage, Figures 1.D.01 to 1.D.14 were developed. These diagrams illustrate the specific structural elements damaged by the collapse of WTC1. Lastly, since much of the south facade is not visible within the photographic evidence, a category of not visible has also been incorporated into all diagrams.

A.1.2 Photographs of Damage

The images found on pages 6 to 19 are images that solely show debris damage. While some of these images have been timed by NIST at points later in the day, they have been included in this section because they do not show evidence of fire-related damage and therefore do not aid in the fire progression analysis of sections A.2 to A.8. Each image is presented twice on one page; the top image is the untouched version while columns and level markers have been added to the lower image for reference. In some instances an untouched version of the photograph was not available and in its place an image that NIST has notated was used. These images are also shown twice with additional column and level markers added for full clarity.

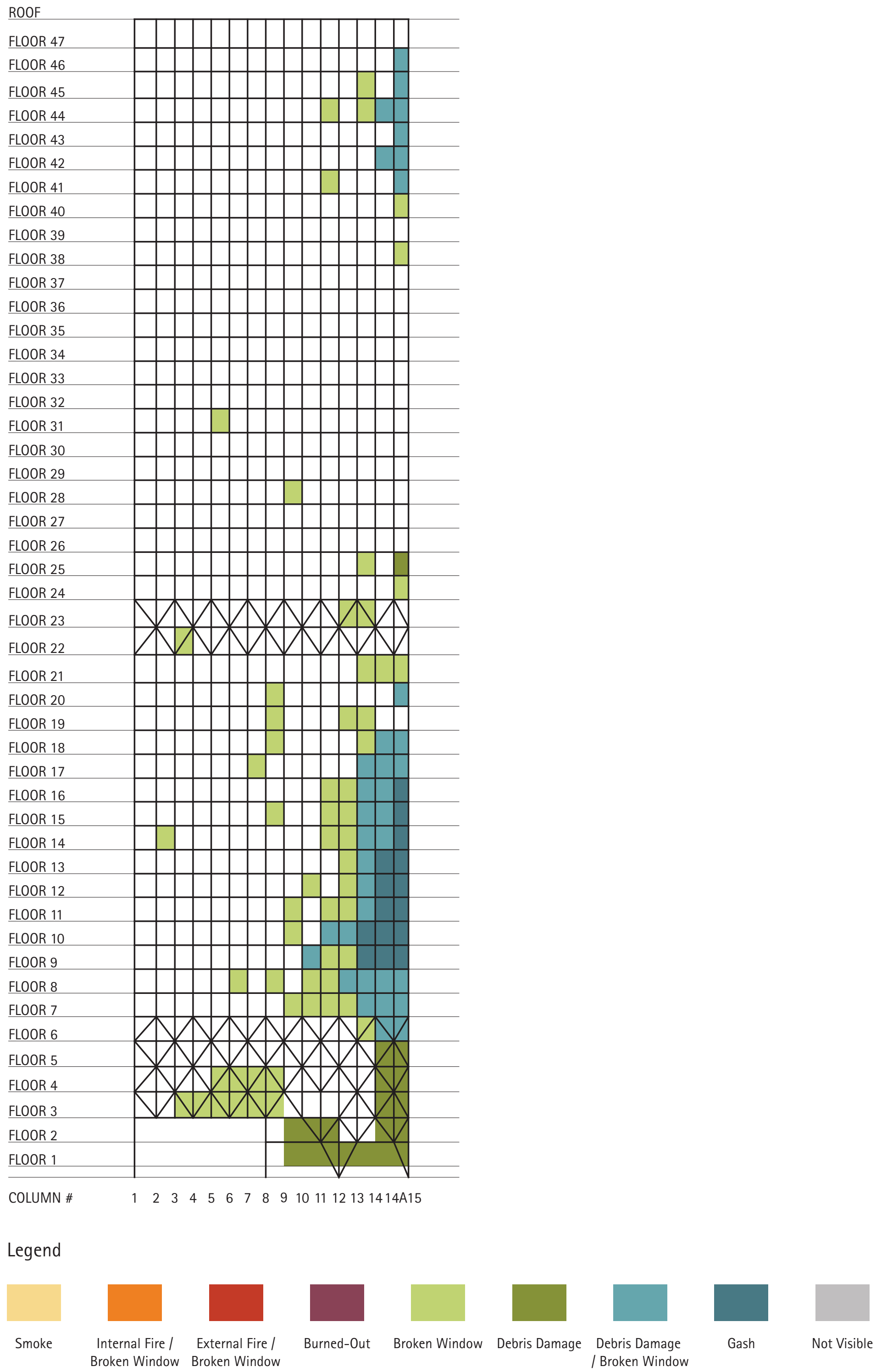


Figure 1.W.01 WTC7 West facade - Debris Damage after WTC1 collapse

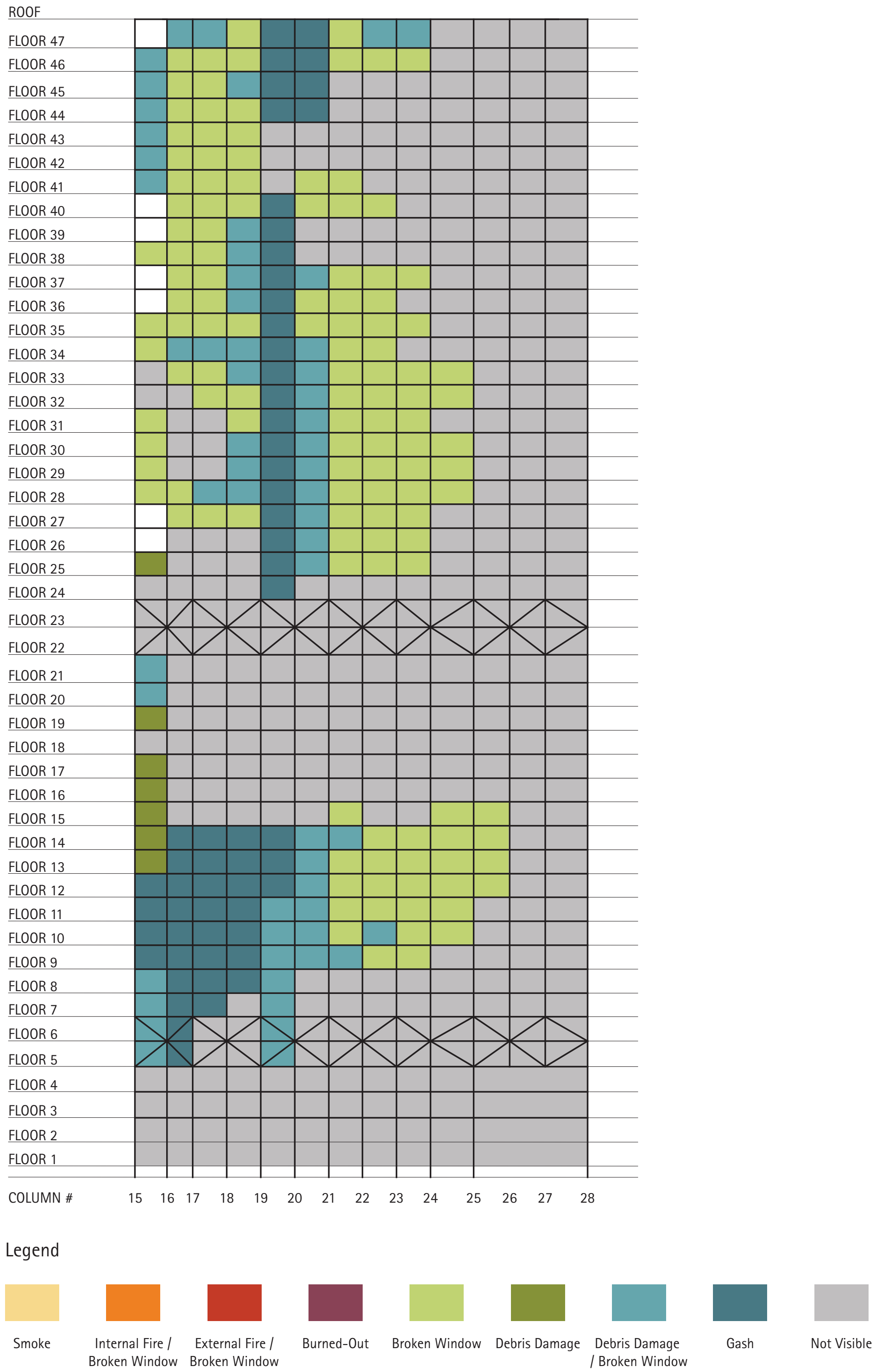
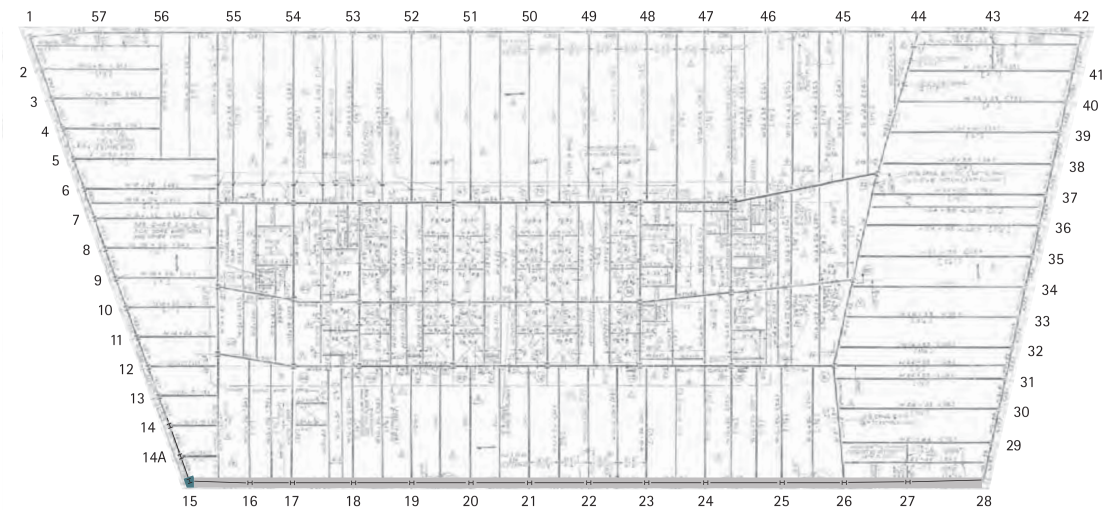


Figure 1.S.01 WTC7 South facade - Debris Damage after WTC1 collapse

Guy Nordenson and Associates



LEGEND

- Structural Element Removed by Debris
- Structural Element Damaged by Debris
- Location Not Visible

Figure 1.D.01 WTC7 Level 17 Planometric Debris Diagram

Volume A - Photographic Timeline
Photographic Analysis Report
World Trade Center 7 Collapse Investigation
16 December 2009

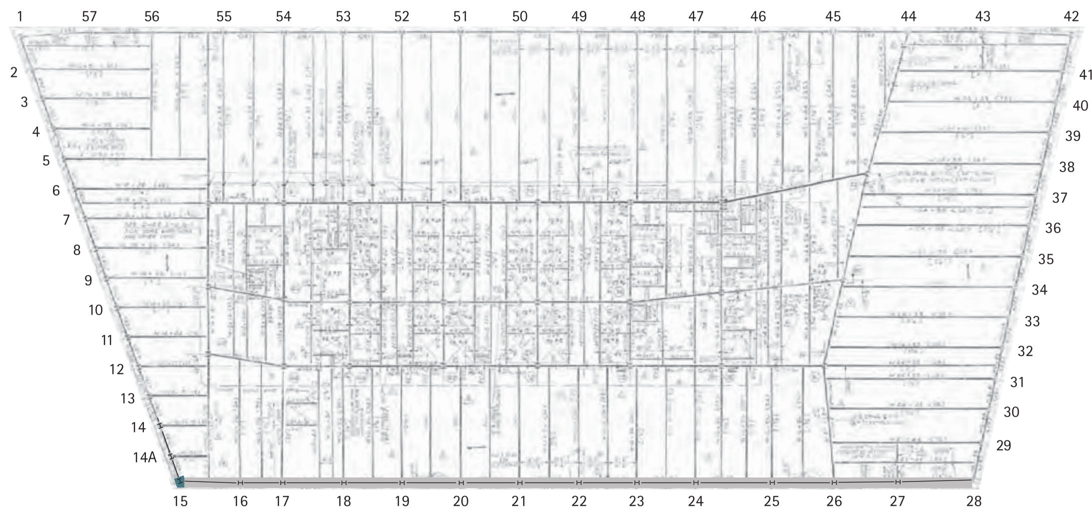
LEVEL 17 SOUTHWEST DAMAGE IMAGES

Image 1.W.05
Image 3.W.06
Image 3.W.11
Image 3.W.27
Image 4.W14
Image 4.W.21
Image 5.W.04
Image 5.W.05
Image 5.W.06
Image 5.W.10
Image 6.W06
Image 6.W.07

Image 3.W.27

Image 5.W.10

Image 6.W.16



LEGEND

Structural Element Removed by Debris

Structural Element Damaged by Debris

Location Not Visible

Figure 1.D.02 WTC7 Level 16 Planometric Debris Diagram

Volume A - Photographic Timeline
Photographic Analysis Report
World Trade Center 7 Collapse Investigation
16 December 2009

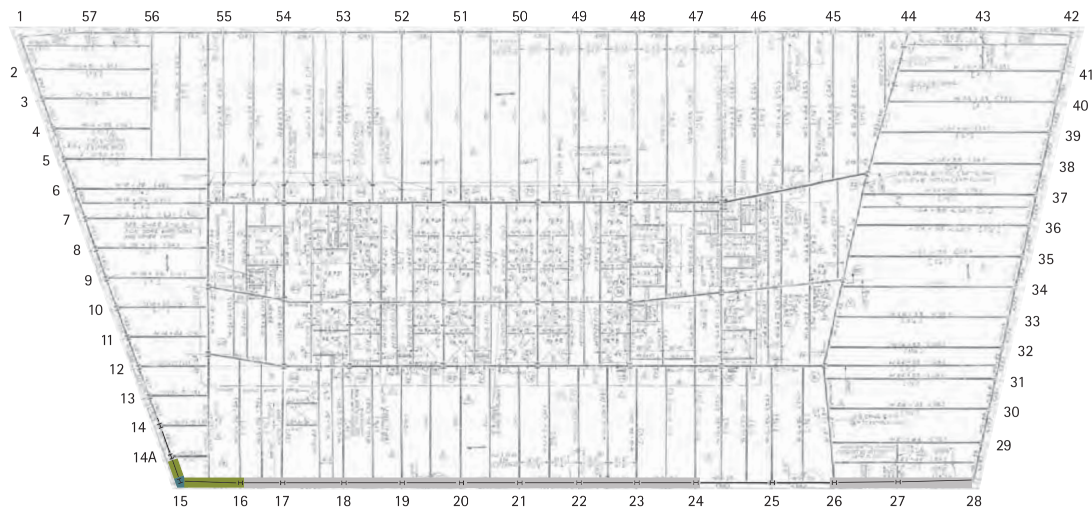
LEVEL 16 SOUTHWEST DAMAGE IMAGES

Image 1.W.05
Image 3.W.27
Image 5.W.04
Image 5.W.05
Image 5.W.06
Image 5.W.10
Image 5.W.24
Image 6.W.06
Image 6.W.07
Image 6.W.16

Image 3.W.27

Image 5.W.10

Image 6.W.16



LEGEND

- Structural Element Removed by Debris
- Structural Element Damaged by Debris
- Location Not Visible

Figure 1.D.03 WTC7 Level 15 Planometric Debris Diagram

LEVEL 15 SOUTHWEST DAMAGE IMAGES

Image 1.W.05
Image 3.W.27
Image 4.W.10
Image 4.W.21
Image 5.W.04
Image 5.W.05
Image 5.W.06
Image 5.W.10
Image 6.W.06
Image 6.W.07
Image 6.W.16
Image 6.W.17
Image 6.W.18

Image 4.W.21

Image 5.W.10

Image 6.W.16

LEGEND

- Structural Element Removed by Debris
- Structural Element Damaged by Debris
- Location Not Visible

Figure 1.D.04 WTC7 Level 14 Planometric Debris Diagram

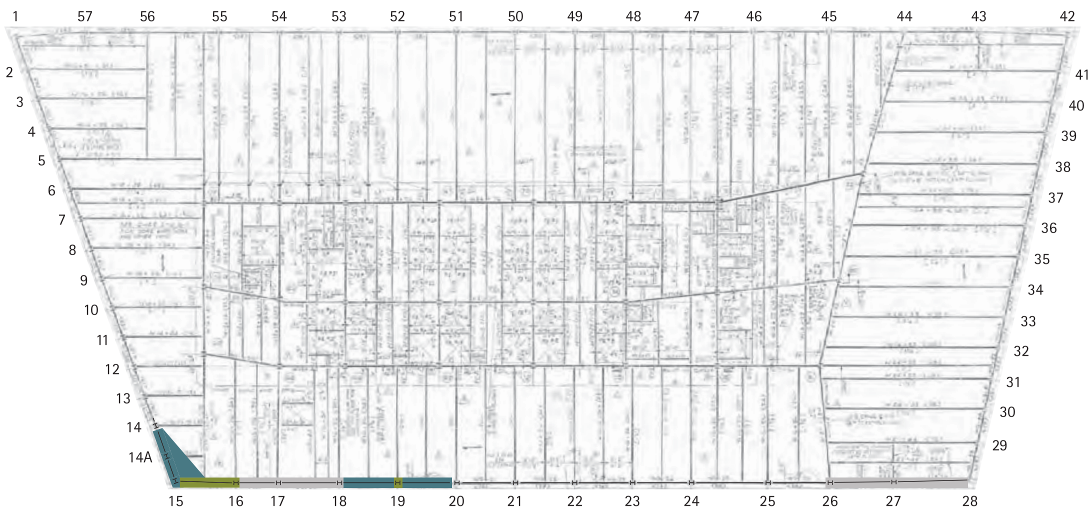
LEVEL 14 SOUTHWEST DAMAGE IMAGES

Image 1.W.05	Image 6.W.06
Image 3.W.27	Image 6.W.07
Image 4.W.10	Image 6.W.16
Image 4.W.21	Image 6.W.17
Image 5.W.04	Image 6.W.18
Image 5.W.05	
Image 5.W.06	
Image 5.W.10	

Image 4.W.21

Image 5.W.10

Image 6.W.16



LEGEND

- Structural Element Removed by Debris
- Structural Element Damaged by Debris
- Location Not Visible

Figure 1.D.05 WTC7 Level 13 Planometric Debris Diagram

Volume A - Photographic Timeline
Photographic Analysis Report
World Trade Center 7 Collapse Investigation
16 December 2009

LEVEL 13 SOUTHWEST DAMAGE IMAGES

Image 1.W.05	Image 6.W.06
Image 3.W.27	Image 6.W.16
Image 4.W.10	Image 6.W.17
Image 4.W.21	Image 6.W.18
Image 5.W.04	
Image 5.W.05	
Image 5.W.06	
Image 5.W.10	

Image 4.W.21

Image 5.W.10

Image 6.W.16

LEGEND

Structural Element Removed by Debris

Structural Element Damaged by Debris

Location Not Visible

Figure 1.D.06 WTC7 Level 12 Planometric Debris Diagram

Volume A - Photographic Timeline
Photographic Analysis Report
World Trade Center 7 Collapse Investigation
16 December 2009

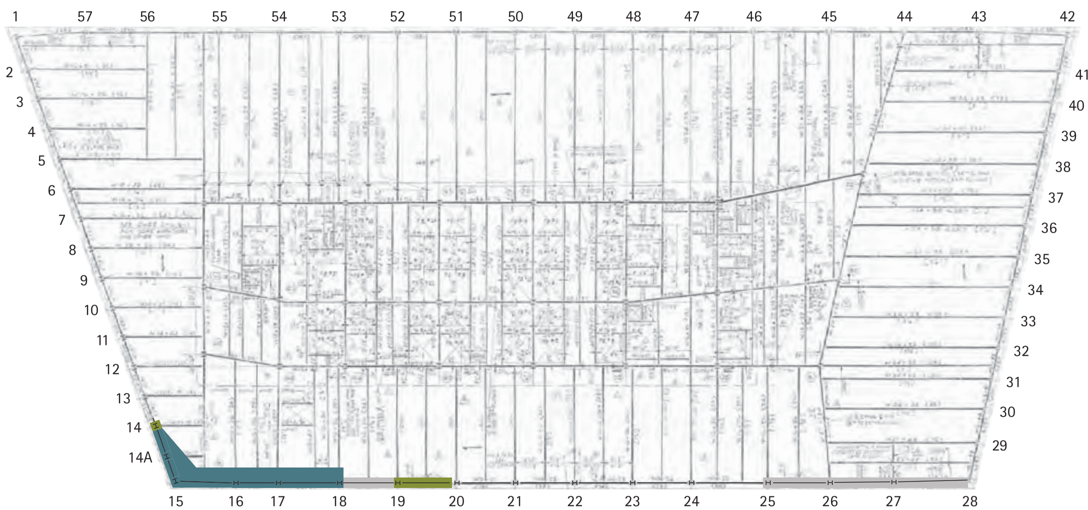
LEVEL 12 SOUTHWEST DAMAGE IMAGES

Image 1.W.05
Image 3.W.27
Image 4.W.10
Image 4.W.21
Image 5.W.04
Image 5.W.05
Image 5.W.06
Image 5.W.10
Image 6.W.16
Image 6.W.17
Image 6.W.18

Image 4.W.21

Image 5.W.10

Image 6.W.16



LEGEND

Structural Element Removed by Debris

Structural Element Damaged by Debris

Location Not Visible

Figure 1.D.07 WTC7 Level 11 Planometric Debris Diagram

Volume A - Photographic Timeline
Photographic Analysis Report
World Trade Center 7 Collapse Investigation
16 December 2009

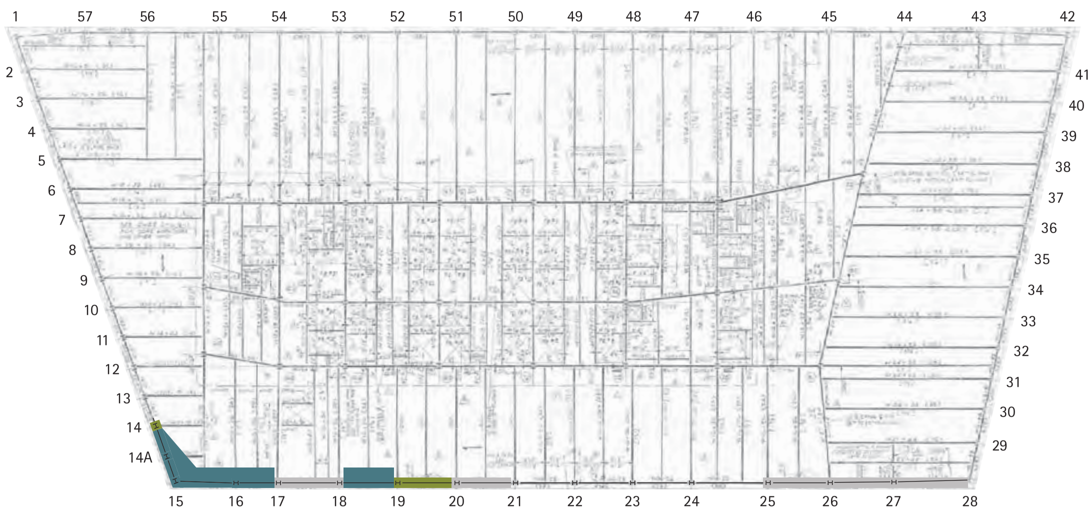
LEVEL 11 SOUTHWEST DAMAGE IMAGES

Image 1.W.05
Image 3.W.27
Image 4.W.08
Image 4.W.10
Image 4.W.21
Image 5.W.04
Image 5.W.05
Image 5.W.06
Image 5.W.10
Image 6.W.16
Image 6.W.17
Image 6.W.18

Image 3.W.27

Image 4.W.21

Image 5.W.10



LEGEND

Structural Element Removed by Debris

Structural Element Damaged by Debris

Location Not Visible

Figure 1.D.08 WTC7 Level 10 Planometric Debris Diagram

Volume A - Photographic Timeline
Photographic Analysis Report
World Trade Center 7 Collapse Investigation
16 December 2009

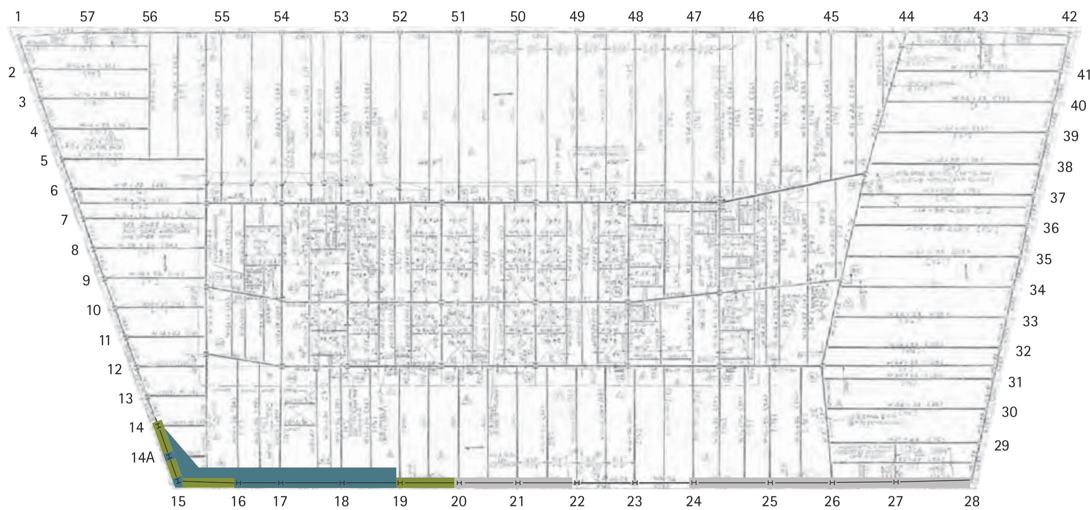
LEVEL 10 SOUTHWEST DAMAGE IMAGES

Image 1.W.05
Image 3.W.27
Image 4.W.08
Image 4.W.10
Image 4.W.13
Image 4.W.21
Image 5.W.04
Image 5.W.05
Image 5.W.06
Image 6.W.17
Image 6.W.18

Image 4.W.21

Image 5.W.05

Image 5.W.06



LEGEND

Structural Element Removed by Debris

Structural Element Damaged by Debris

Location Not Visible

Figure 1.D.09 WTC7 Level 9 Planometric Debris Diagram

Volume A - Photographic Timeline
Photographic Analysis Report
World Trade Center 7 Collapse Investigation
16 December 2009

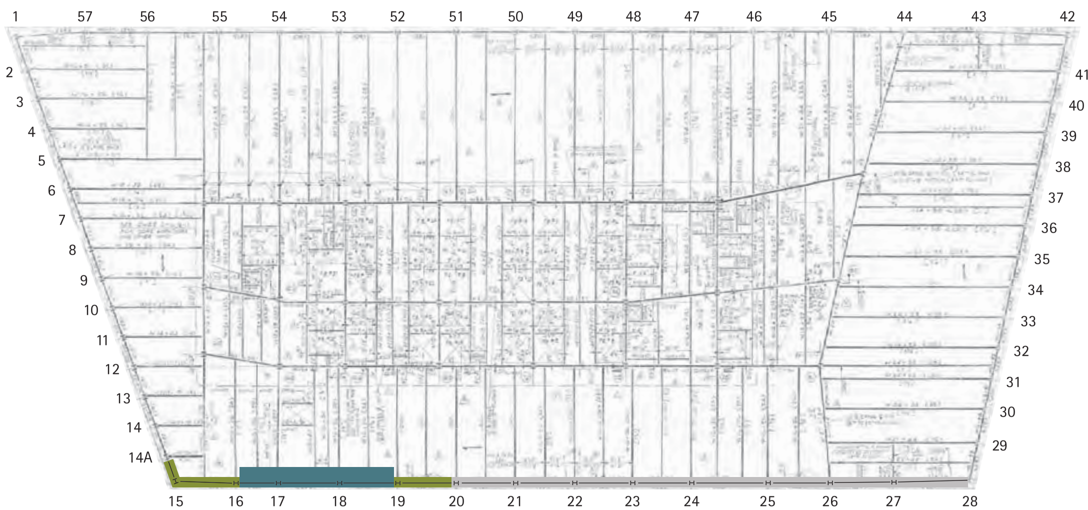
LEVEL 9 SOUTHWEST DAMAGE IMAGES

Image 1.W.05
Image 3.W.27
Image 4.W.10
Image 4.W.13
Image 4.W.21
Image 5.W.04
Image 5.W.05
Image 5.W.06
Image 6.W.17
Image 6.W.18

Image 4.W.21

Image 5.W.05

Image 5.W.06



LEGEND

Structural Element Removed by Debris

Structural Element Damaged by Debris

Location Not Visible

Figure 1.D.10 WTC7 Level 8 Planometric Debris Diagram

Volume A - Photographic Timeline
Photographic Analysis Report
World Trade Center 7 Collapse Investigation
16 December 2009

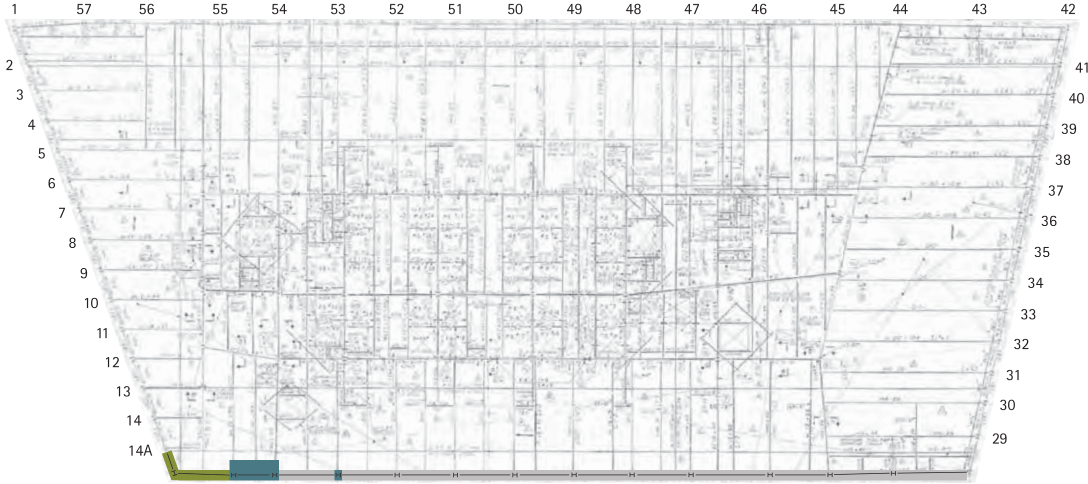
LEVEL 8 SOUTHWEST DAMAGE IMAGES

Image 1.W.05
Image 3.W.27
Image 4.W.10
Image 4.W.13
Image 4.W.21
Image 5.W.04
Image 5.W.05
Image 5.W.06
Image 5.W.07
Image 6.W.17
Image 6.W.18

Image 4.W.21

Image 4.W.22

Image 5.W.04



LEGEND

- Structural Element Removed by Debris
- Structural Element Damaged by Debris
- Location Not Visible

Figure 1.D.11 WTC7 Level 7 Planometric Debris Diagram

Volume A - Photographic Timeline
Photographic Analysis Report
World Trade Center 7 Collapse Investigation
16 December 2009

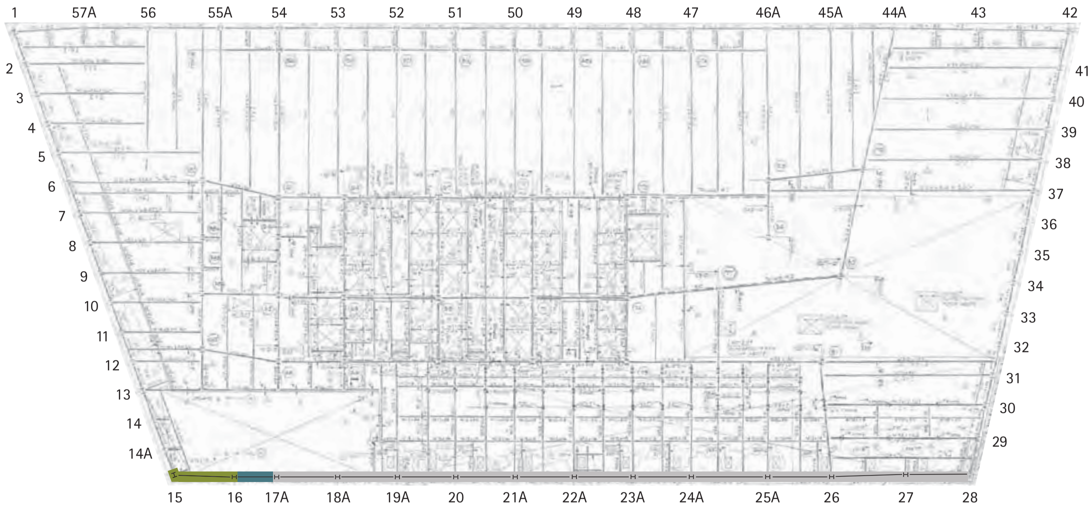
LEVEL 7 SOUTHWEST DAMAGE IMAGES

Image 1.W.05
Image 4.W.10
Image 4.W.13
Image 4.W.21
Image 5.W.04
Image 5.W.05
Image 5.W.06
Image 5.W.07

Image 1.W.05

Image 4.W.21

Image 5.W.04



LEGEND

Structural Element Removed by Debris

Structural Element Damaged by Debris

Location Not Visible

Figure 1.D.12 WTC7 Level 6 Planometric Debris Diagram

Volume A - Photographic Timeline
Photographic Analysis Report
World Trade Center 7 Collapse Investigation
16 December 2009

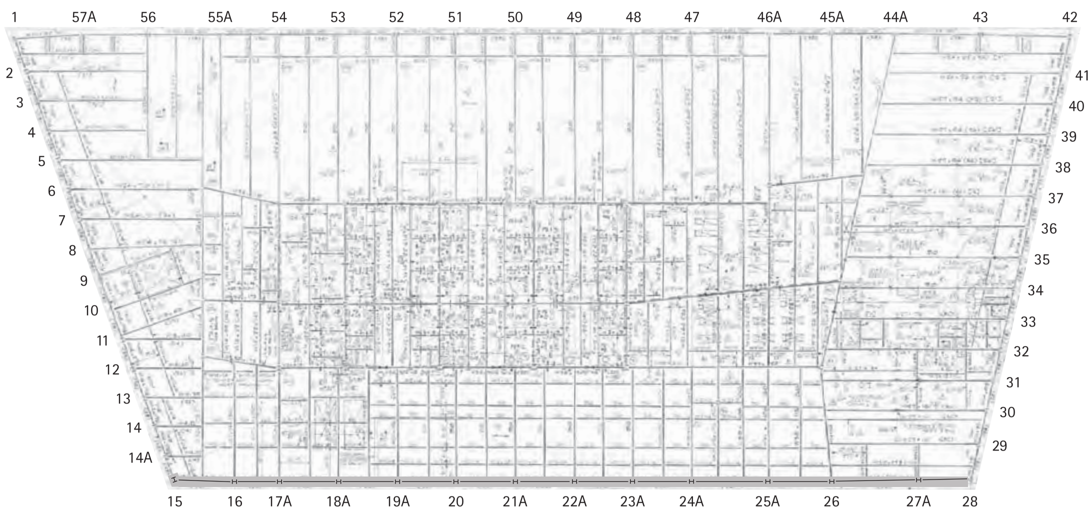
LEVEL 6 SOUTHWEST DAMAGE IMAGES

Image 1.W.05
Image 4.W.10
Image 4.W.13
Image 4.W.21
Image 5.W.04
Image 5.W.05
Image 5.W.06
Image 5.W.07

Image 4.W.13

Image 4.W.21

Image 5.W.04



LEGEND

Structural Element Removed by Debris

Structural Element Damaged by Debris

Location Not Visible

Figure 1.D.13 WTC7 Level 5 Planometric Debris Diagram

LEVEL 5 SOUTHWEST DAMAGE IMAGES

Image 4.W.13
Image 4.W.21
Image 5.W.04
Image 5.W.05
Image 5.W.07

Image 4.W.13

Image 4.W.21

Image 5.W.04

Guy Nordenson and Associates

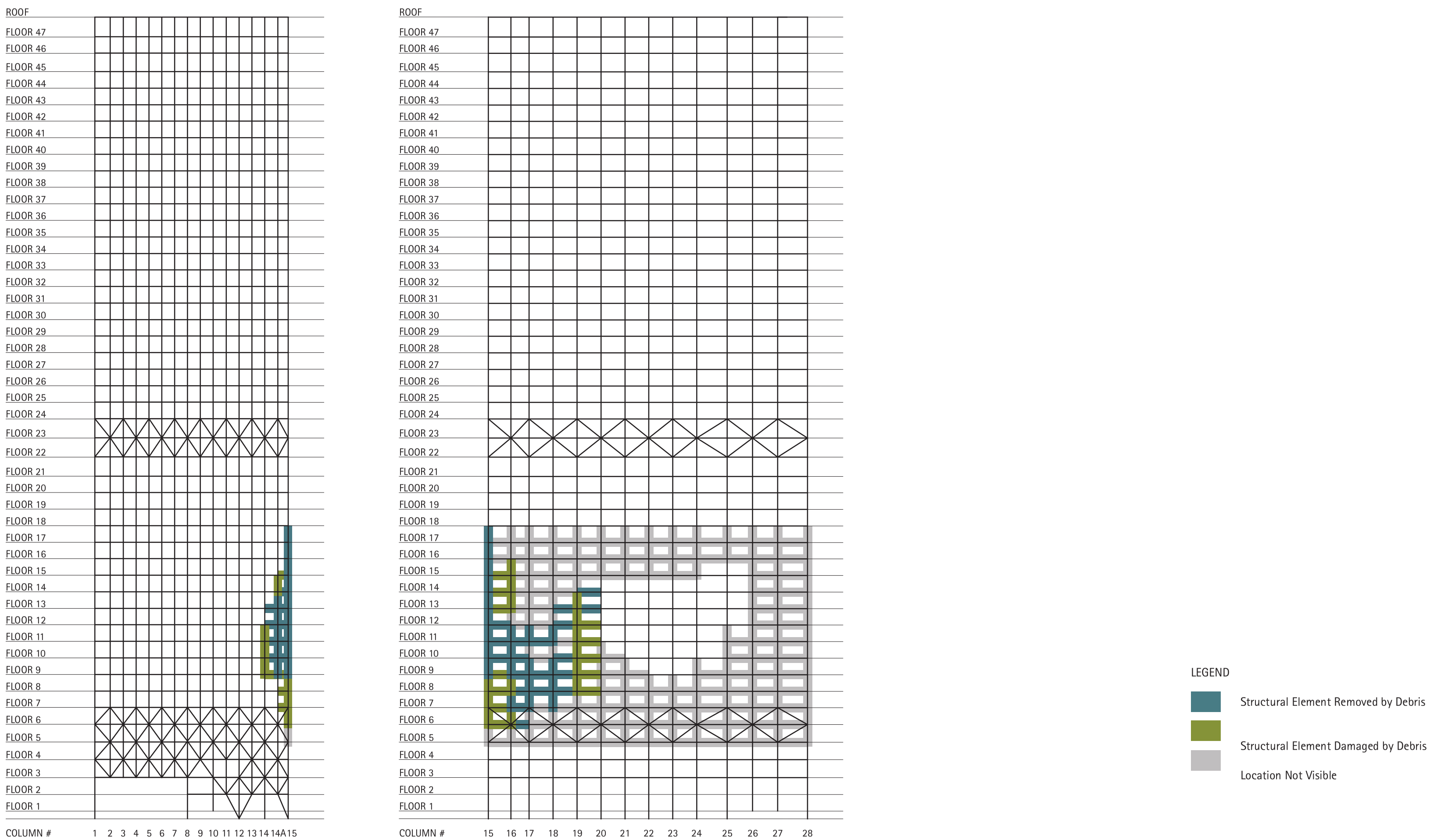
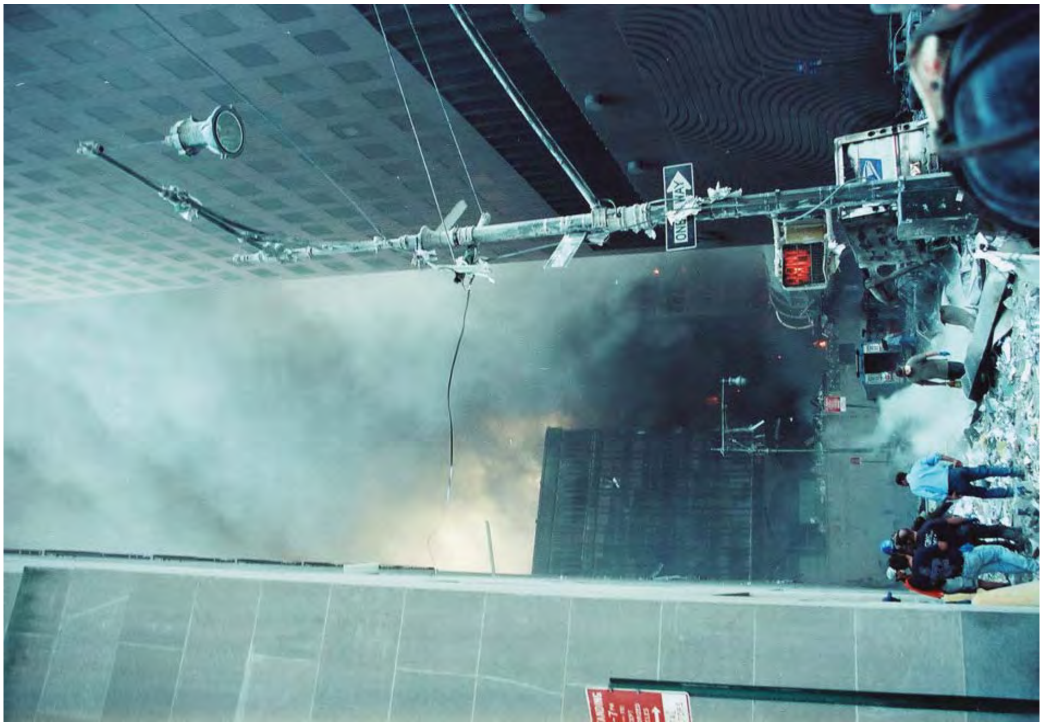


Figure 1.D.14 WTC7 West and South Elevation Debris Diagrams

JA-3415

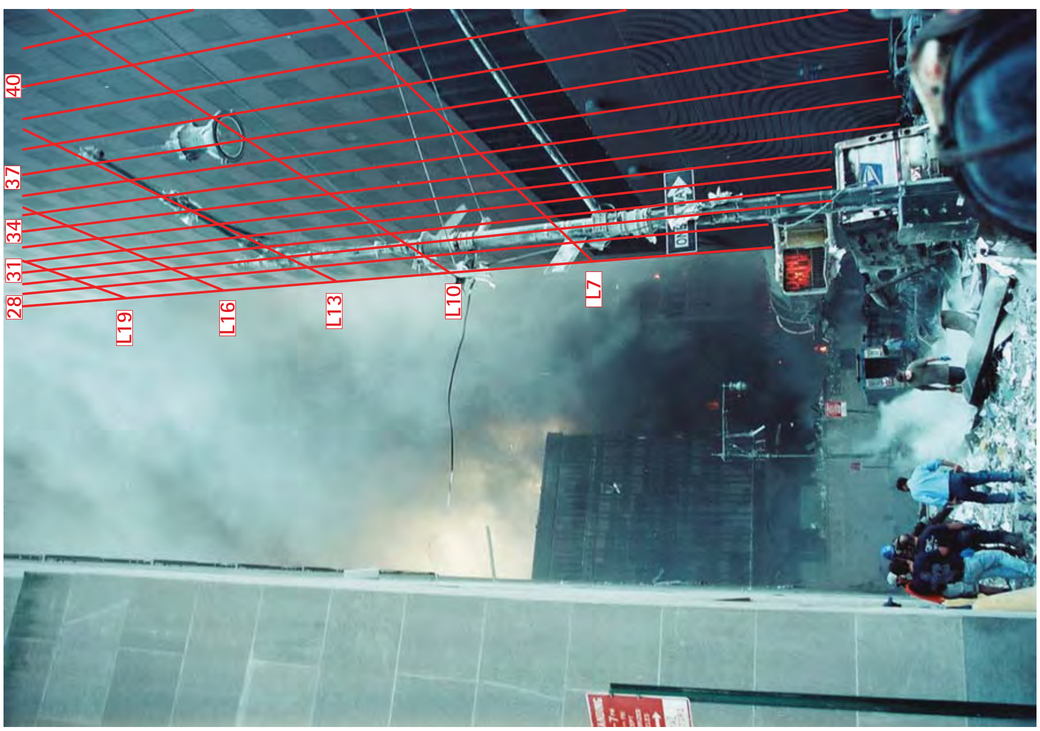
Image 1.E.01 East facade

Image 1.E.01 with columns and floor levels overlaid



(Bottom)

Image 1.E.02 East facade



(Bottom)

Image 1.E.02 with columns and floor levels overlaid

Image 1.N.01 Northeast corner

Image 1.N.01 with columns and floor levels overlaid

Image 1.N.02 Northeast corner

Image 1.N.02 with columns and floor levels overlaid

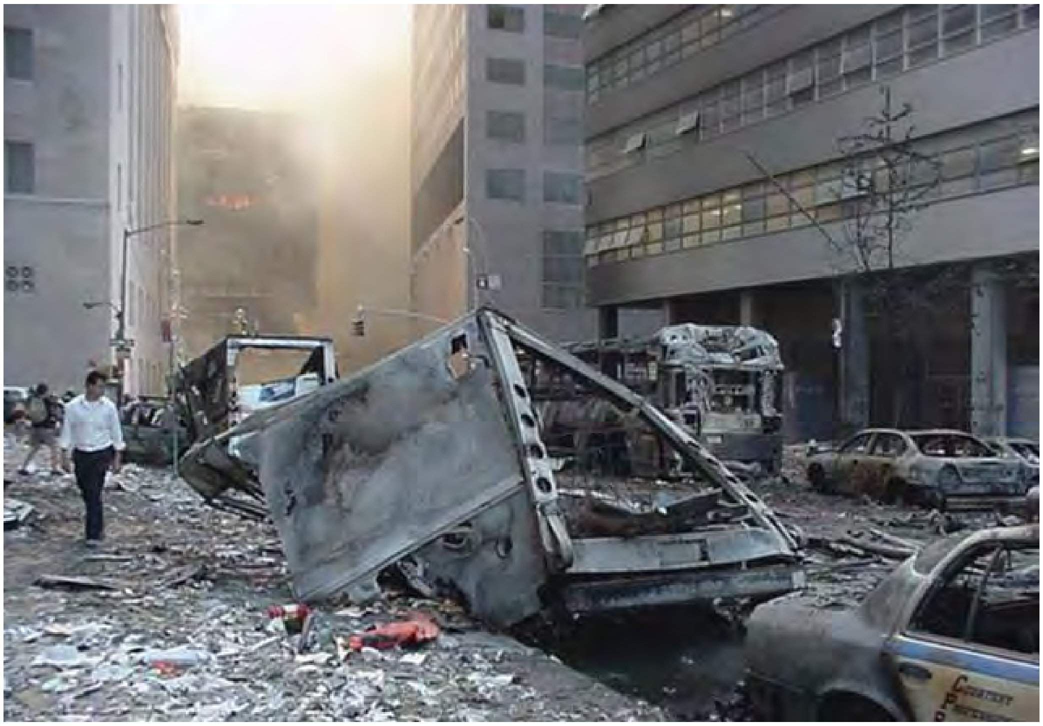


Image 1.N.03 Northeast corner

Image 1.N.03 with columns and floor levels overlaid

Image 1.W.01 Northwest corner

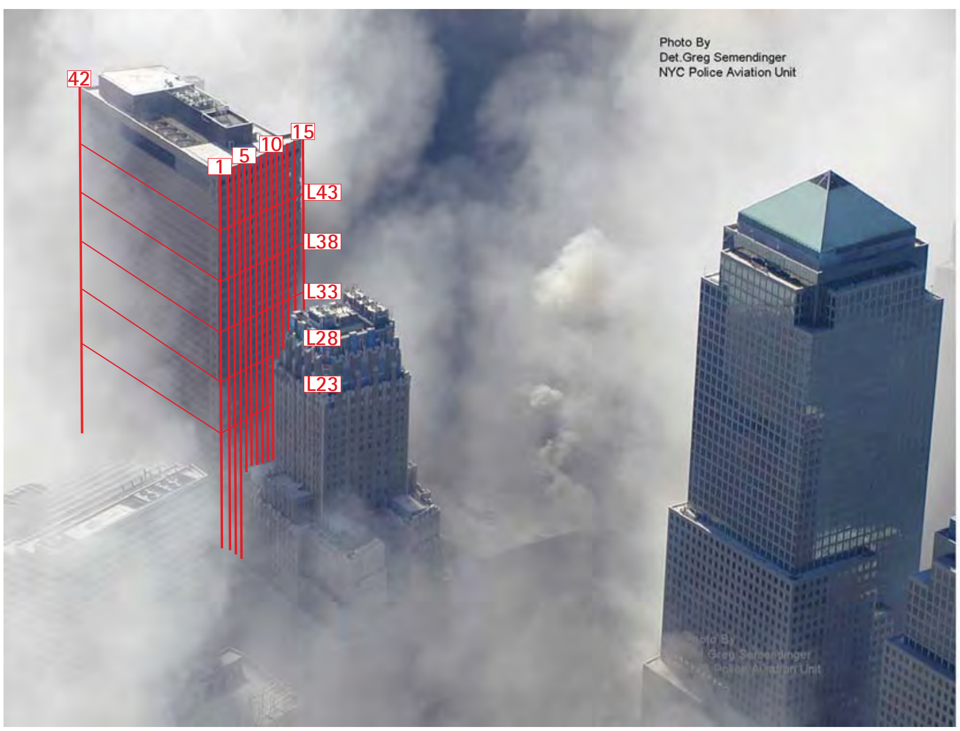


Image 1.W.01 with columns and floor levels overlaid

(Bottom)

Image 1.W.02 Northwest corner

(Bottom)

Image 1.W.02 with columns and floor levels overlaid

Image 1.W.03 West facade

Image 1.W.03 with columns and floor levels overlaid

(Bottom)

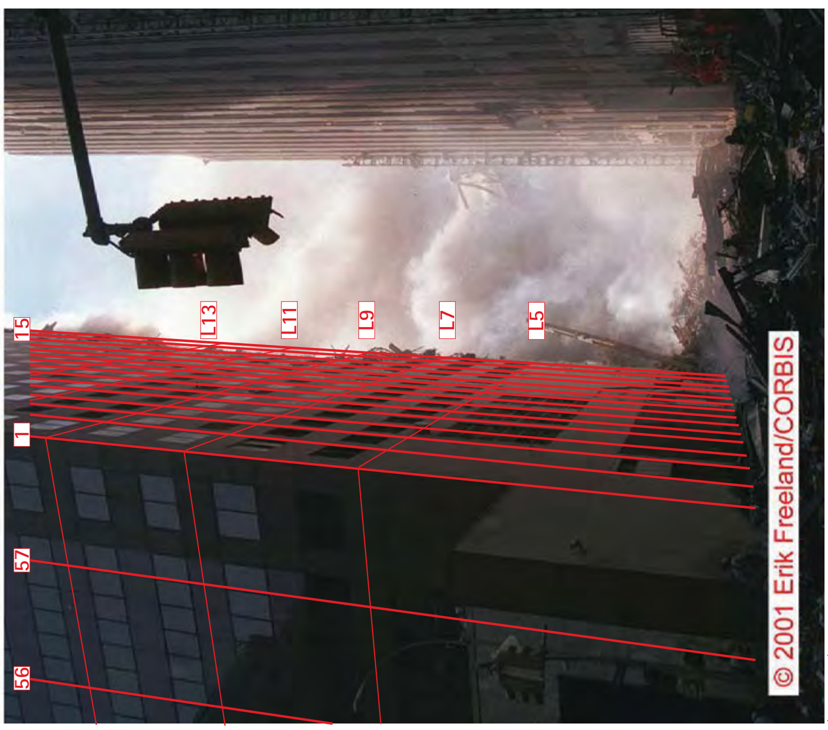
Image 1.W.04 Northwest corner

(Bottom)

Image 1.W.04 with columns and floor levels overlaid

(Bottom)

Image 1.W.05 Northwest corner



(Bottom)

Image 1.W.05 with columns and floor levels overlaid

(Bottom)

Image 1.W.06 West facade

(Bottom)

Image 1.W.06 with columns and floor levels overlaid

Image 1.W.07 West facade

Image 1.W.07 with columns and floor levels overlaid

Image 1.W.08 West facade

Image 1.W.08 with columns and floor levels overlaid

(Bottom)

Image 1.W.09 Southwest corner

(Bottom)

Image 1.W.09 with columns and floor levels overlaid

Image 1.W.10 Southwest corner

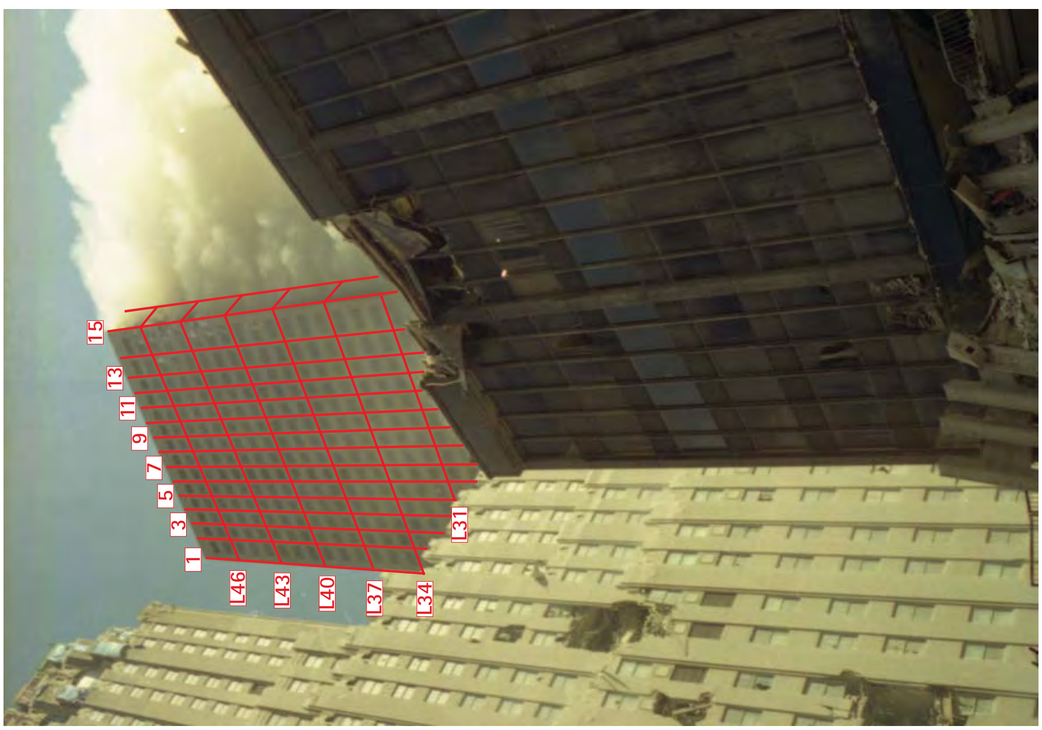


Image 1.W.10 with columns and floor levels overlaid

Image 1.W.11 Southwest corner

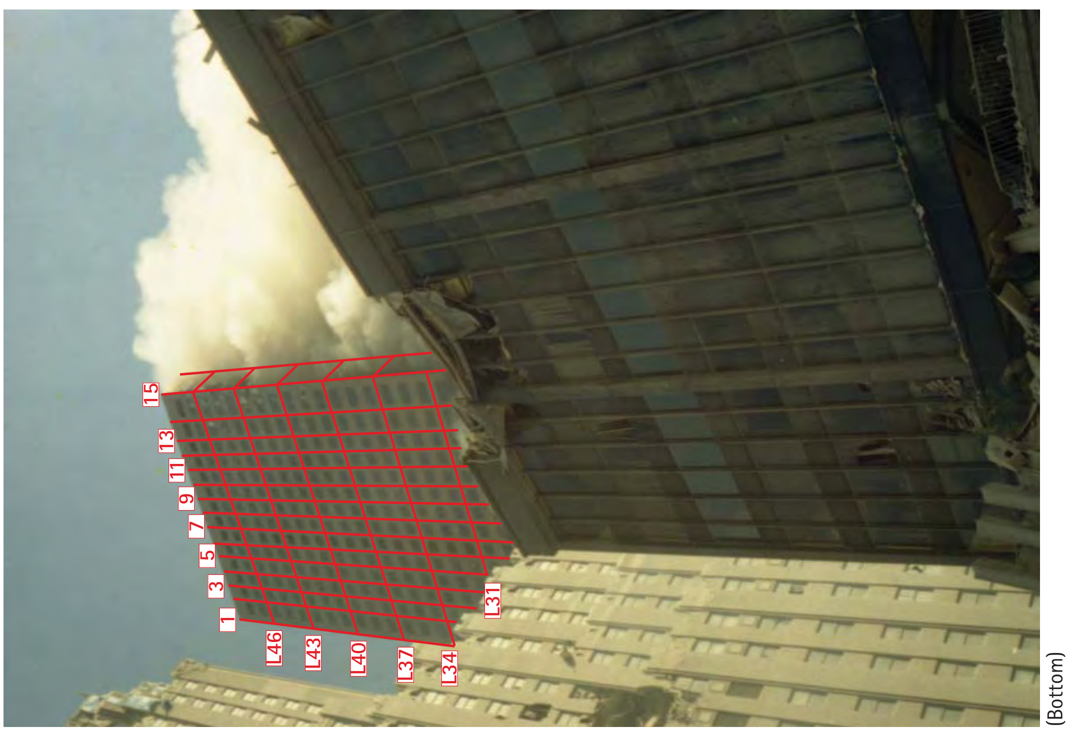


Image 1.W.11 with columns and floor levels overlaid

Image 1.W.12 West facade

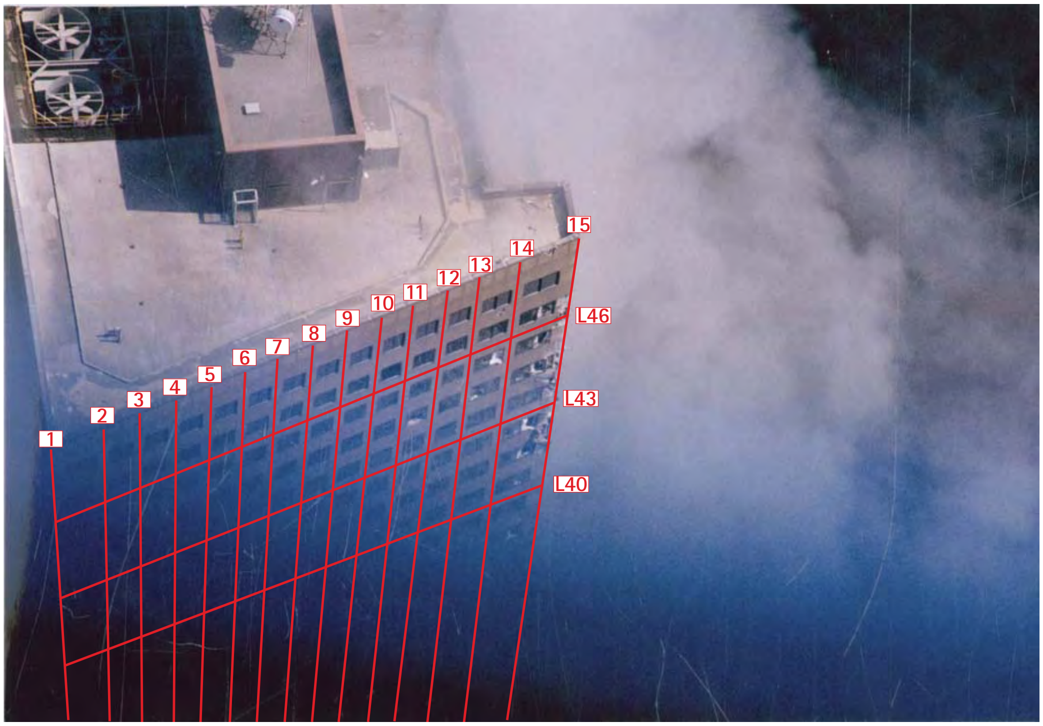


Image 1.W.12 with columns and floor levels overlaid

Image 1.W.13 Northwest corner

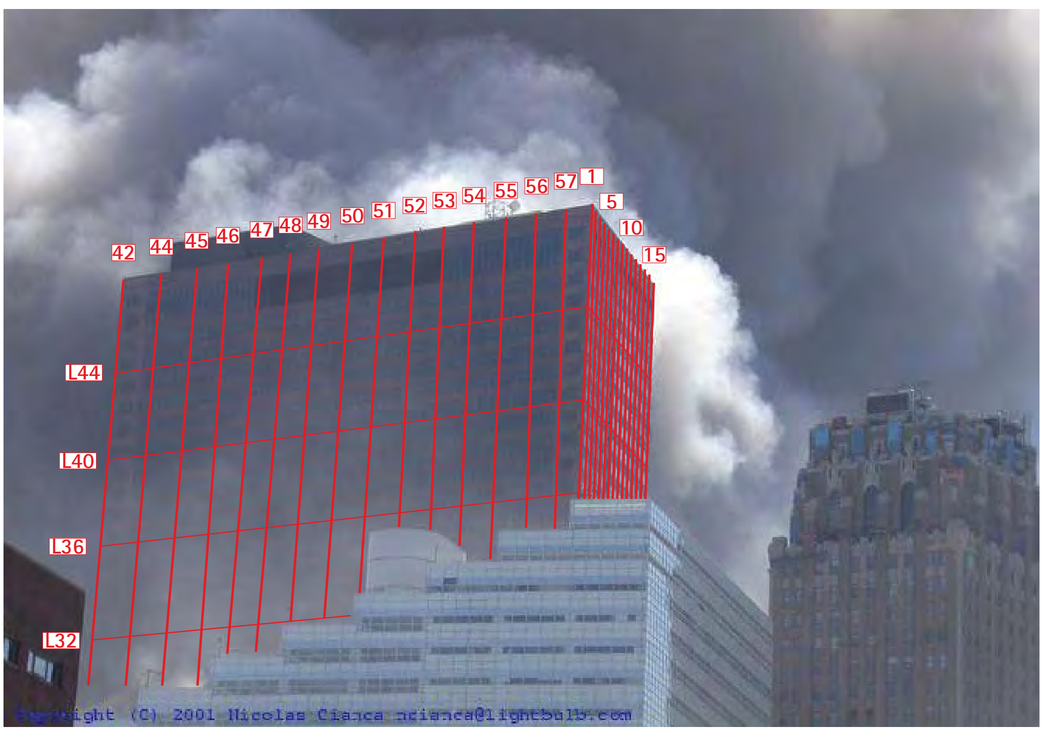


Image 1.W.13 with columns and floor levels overlaid

Image 1.W.14 Northwest corner

Image 1.W.14 with columns and floor levels overlaid

Image 1.W.15 Northwest corner

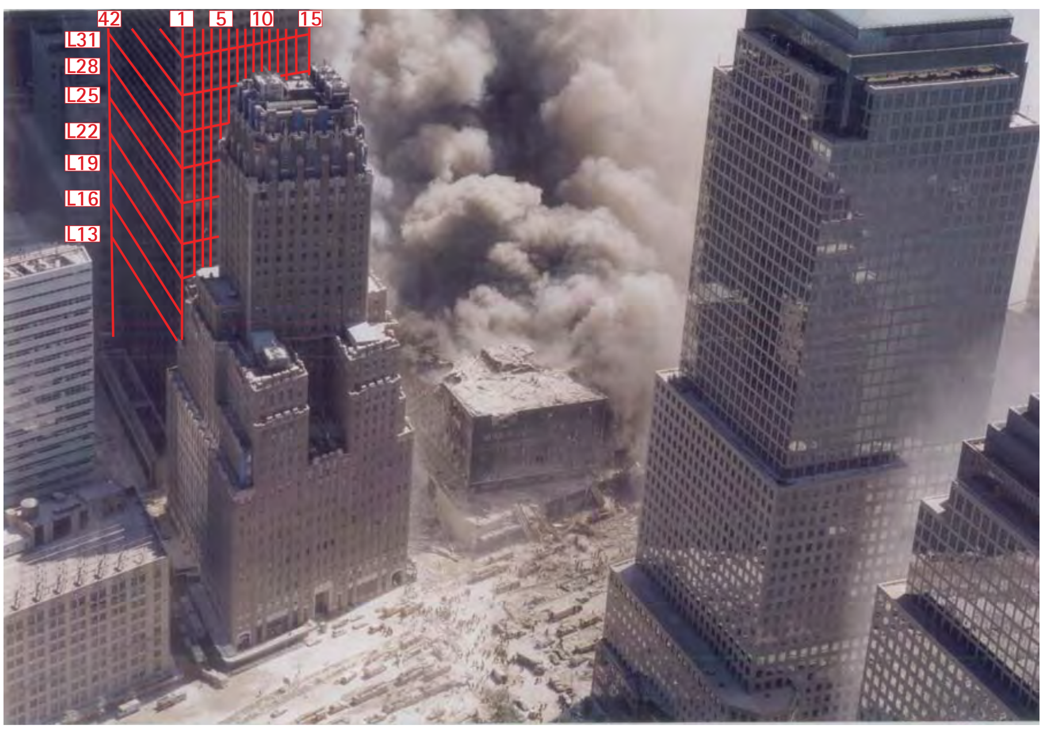
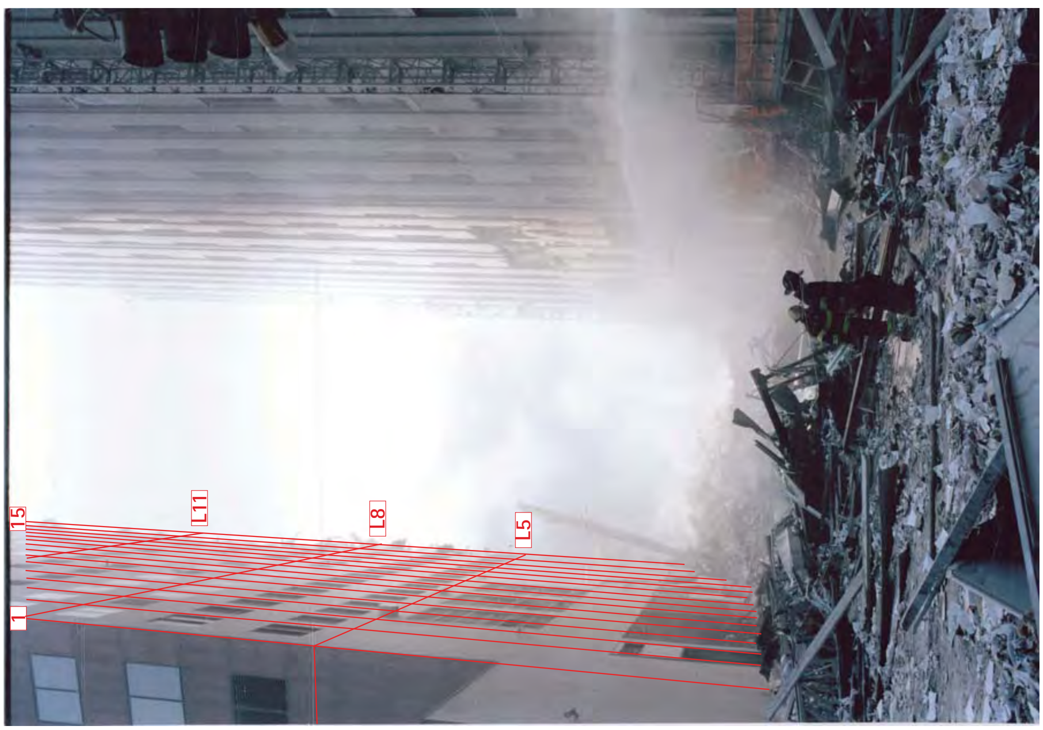


Image 1.W.15 with columns and floor levels overlaid

(Bottom)

Image 1.W.16 Northwest corner



(Bottom)

Image 1.W.16 with columns and floor levels overlaid

Image 1.S.01 Southwest corner

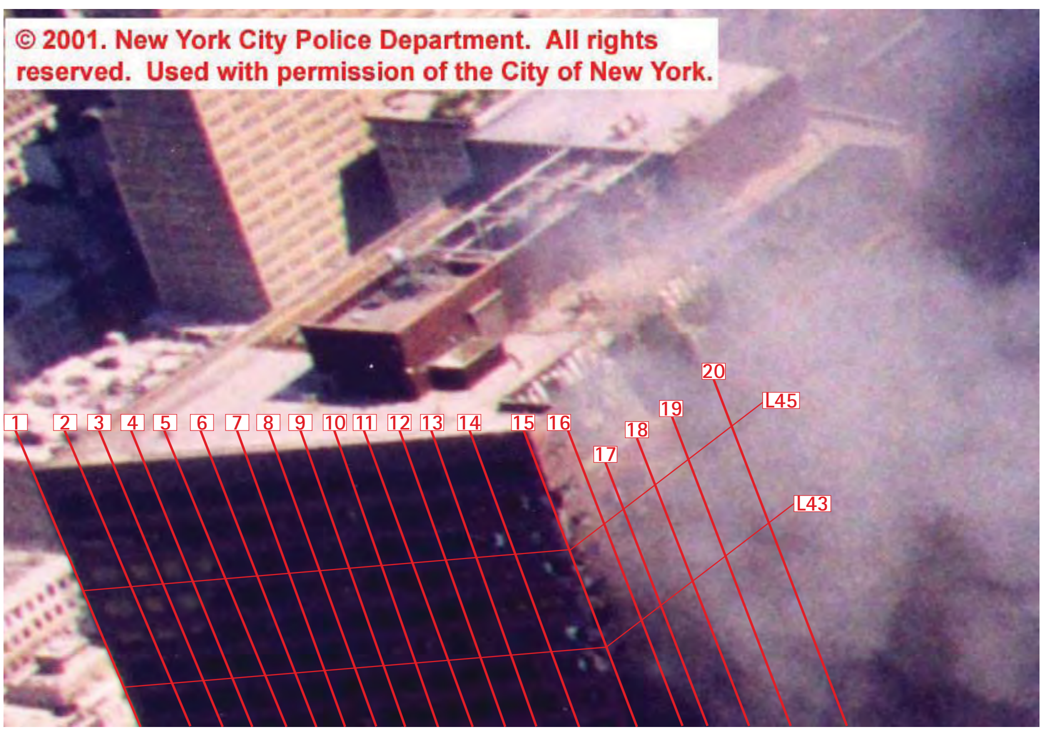


Image 1.S.01 with columns and floor levels overlaid

Image 1.S.02 Southwest corner

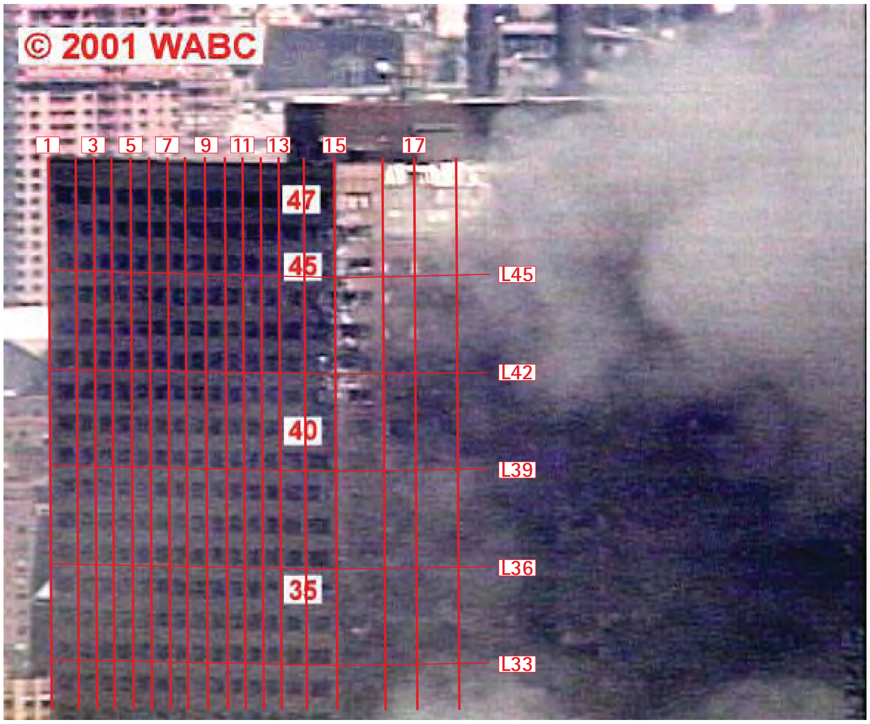


Image 1.S.02 with columns and floor levels overlaid

(Bottom)

Image 1.S.03 Southwest corner

(Bottom)

Image 1.S.03 with columns and floor levels overlaid

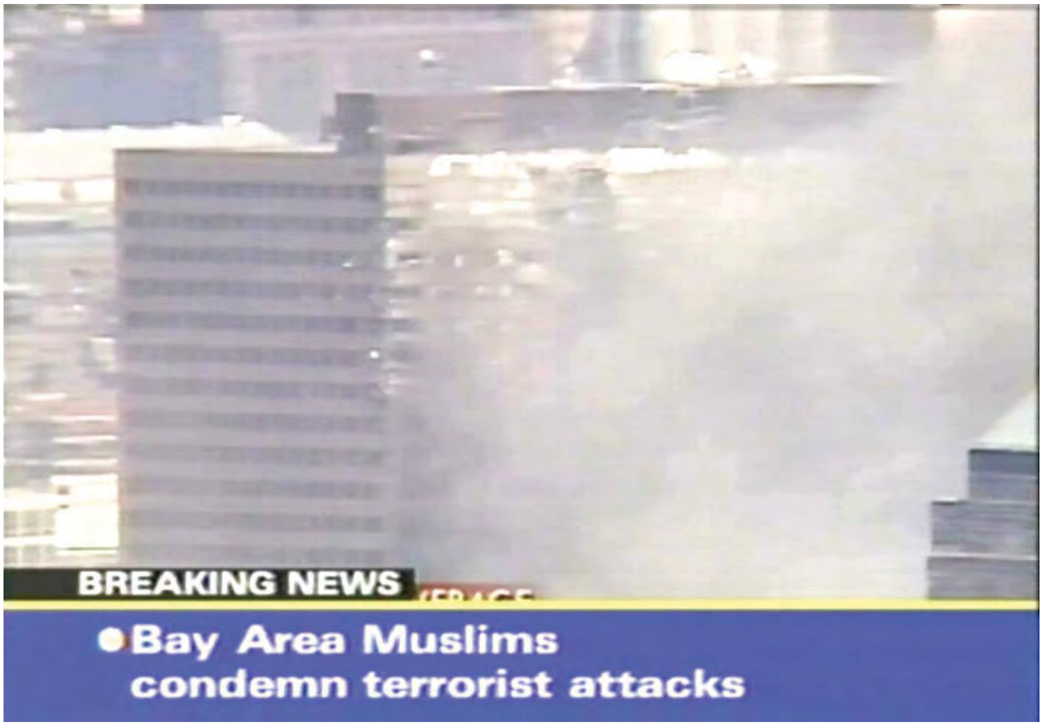


Image 1.S.04 Southwest corner

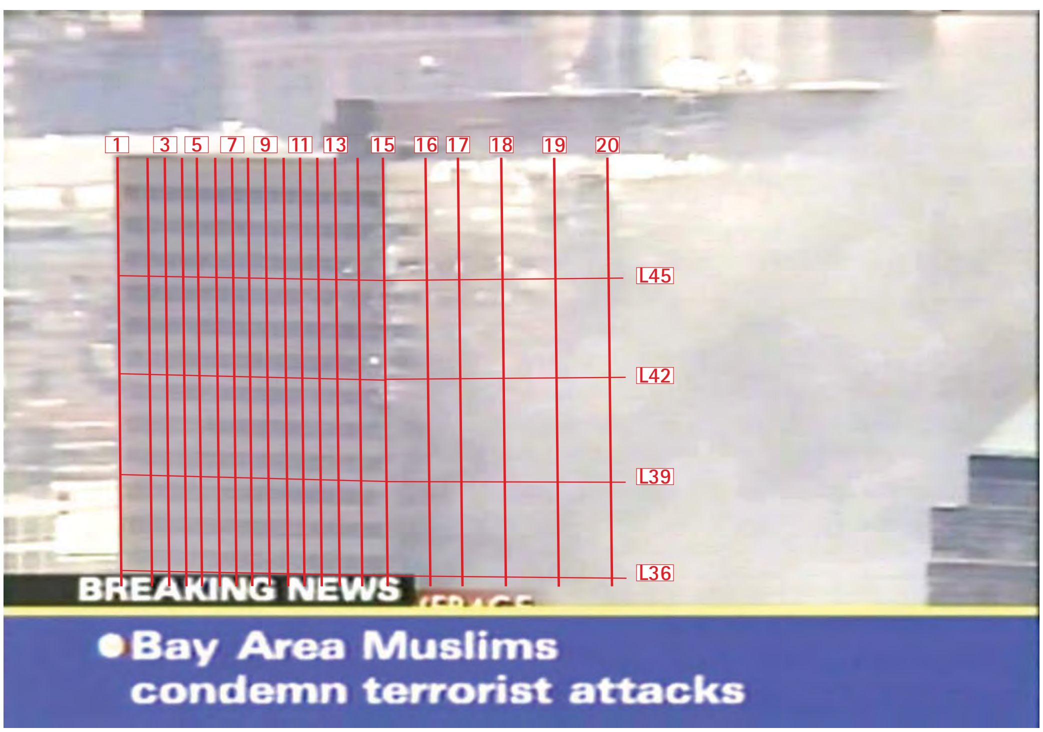


Image 1.S.04 with columns and floor levels overlaid

Image 1.S.05 Southeast corner

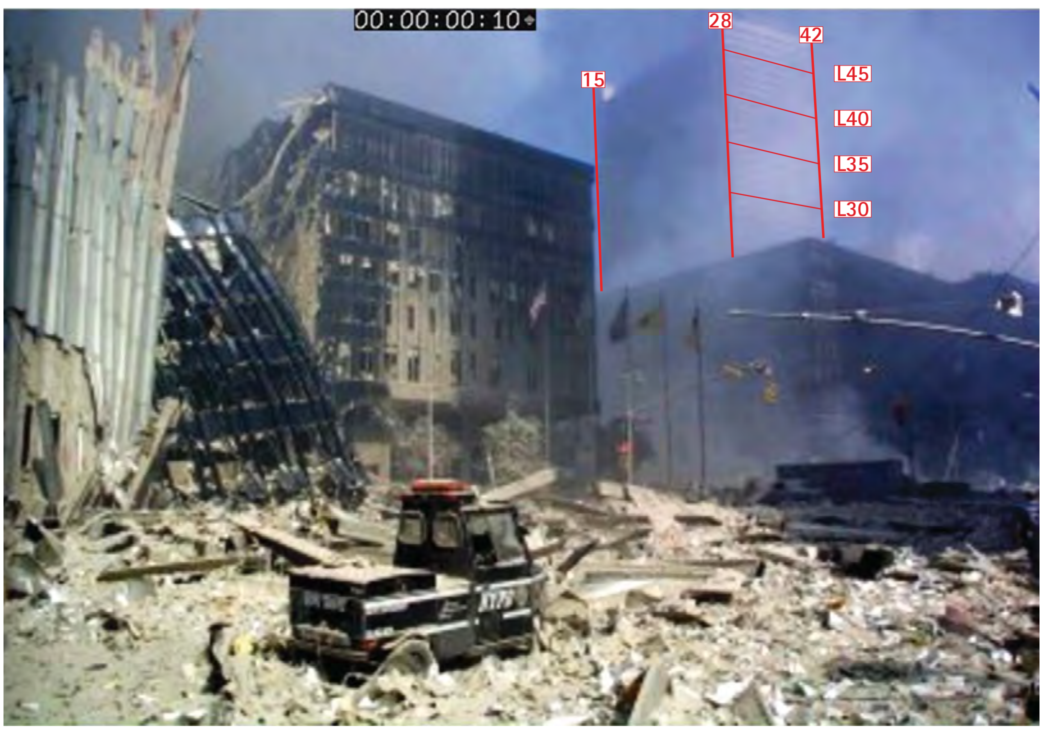


Image 1.S.05 with columns and floor levels overlaid

A.2 FIRE PROGRESSION – WTC1 COLLAPSE TO 12PM

East Facade - No available visual evidence of fire-related damage during this time period.

North Facade - No available visual evidence of fire-related damage during this time period.

West Facade - The only available visual evidence of fire during this time period occurs on the west facade. The earliest images show windows on level 29 already burned-out, indicating that a fire had burned soon after WTC1's collapse in this location.

South Facade - No available visual evidence of fire-related damage during this time period.

A.2.1 Fire Damage Diagrams

Figures 2.E.01, 2.N.01, 2.W.01, and 2.S.01 on pages 48 to 51 depict the condition of each elevation at the end of this time period as evidenced in the available images. These diagrams are cumulative and contain the fire-related damage timed up until 12:00pm as well as the debris damage from WTC1's collapse. Fire damage types include smoke, broken window with internal fire, broken window with external fire, and burned-out. The fire-related damage on these figures represents a compilation of the last available visual evidence for each area within this time increment; therefore, these diagrams are only an approximation of what the elevation might have looked like at 12:00pm.

A.2.2 Photographs of Damage

The images found on pages 52 to 53 are all the images that show fire-related damage and are attributed to the time period from WTC1's collapse until 12:00pm. Each image is presented twice on one page; the top image is the untouched version while columns and level markers have been added to the lower image for reference. In some instances an untouched version of the photograph was not available and in its place an image that NIST has notated is used instead. These images are also shown twice with additional column and level markers added for full clarity.

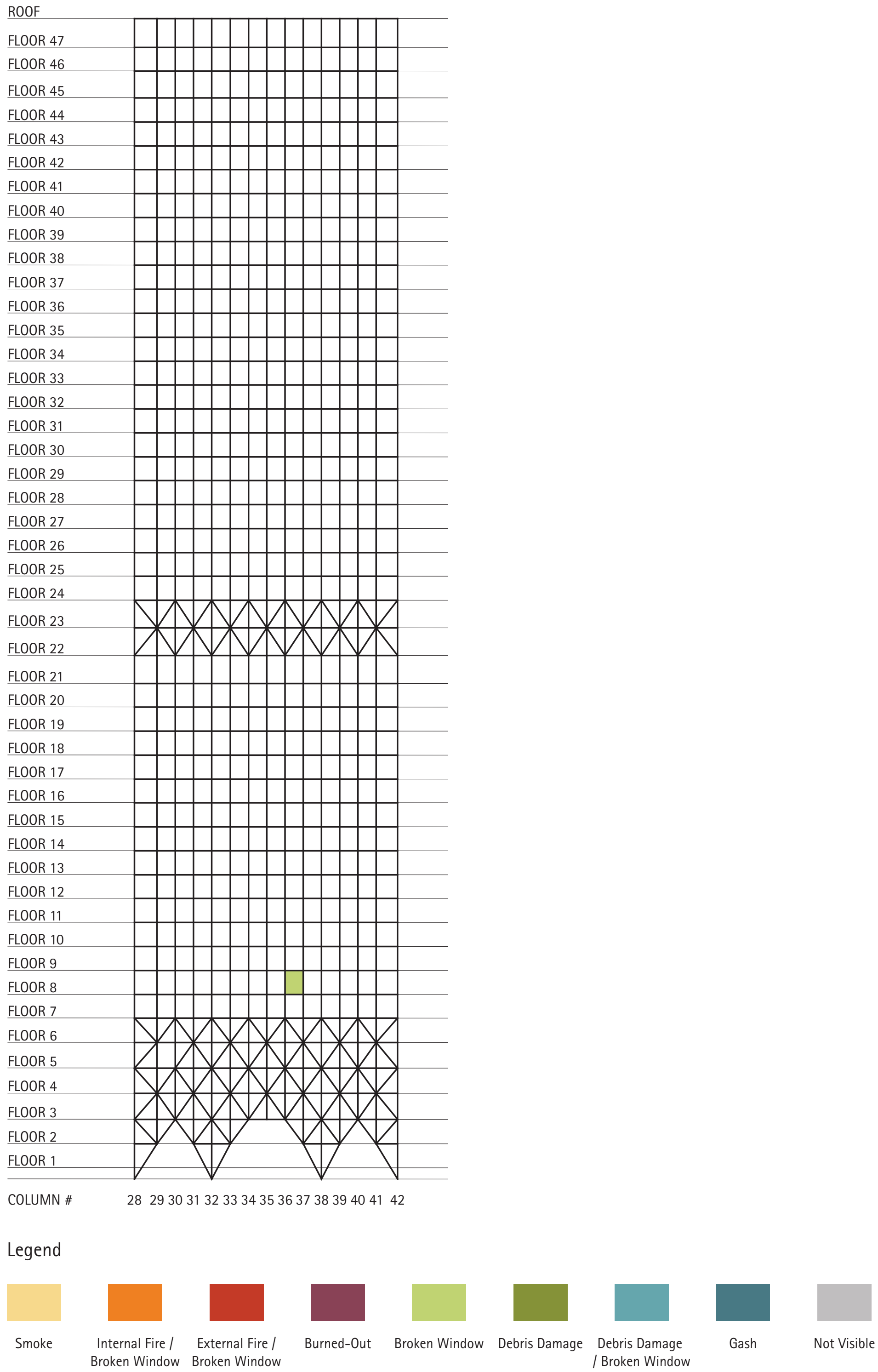


Figure 2.E.01 WTC7 East facade – Debris and Fire Damage at approximately 12PM

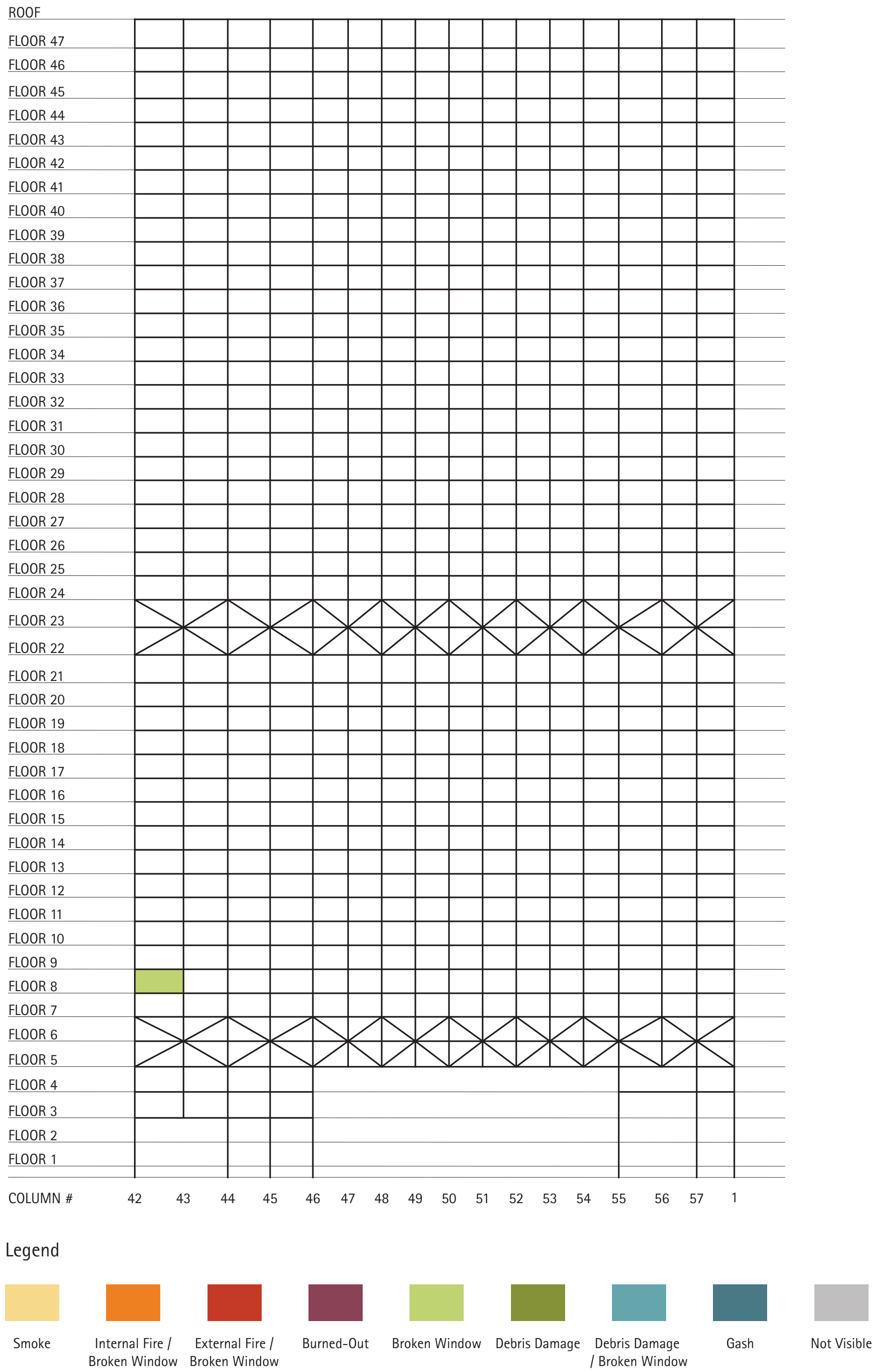


Figure 2.N.01 WTC7 North facade – Debris and Fire Damage at approximately 12PM

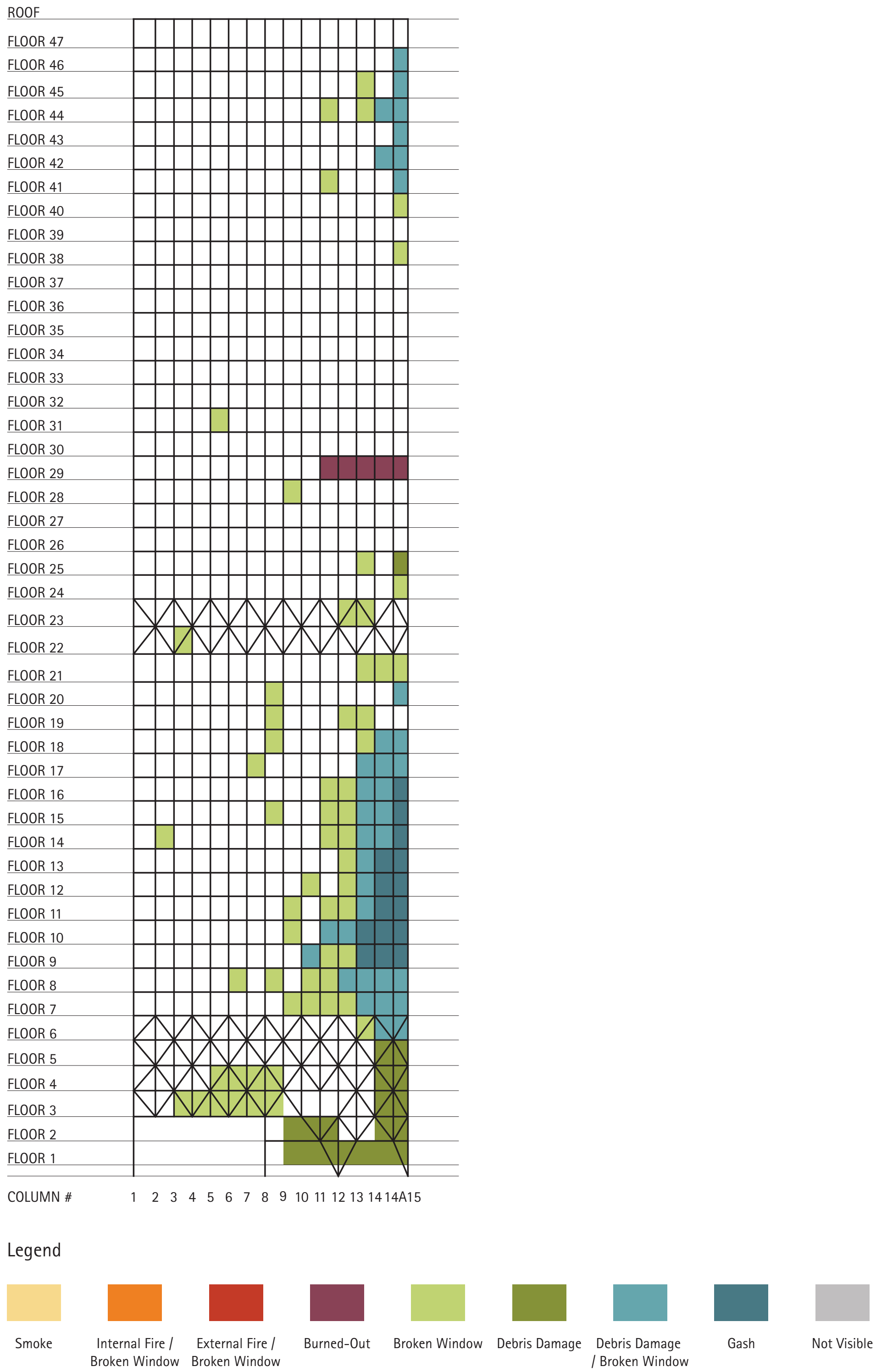
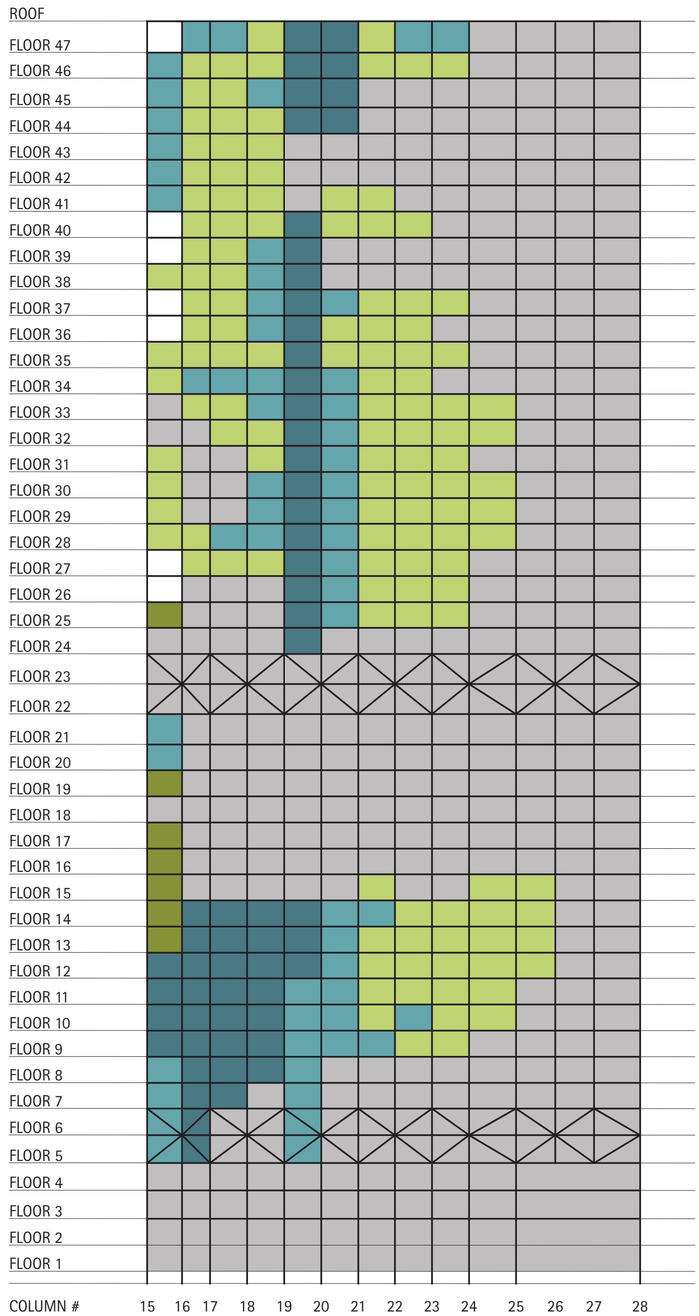


Figure 2.W.01 WTC7 West Facade – Debris and Fire Damage at approximately 12PM



Legend

Smoke | Internal Fire / Broken Window | External Fire / Broken Window | Burned-Out | Broken Window | Debris Damage | Debris Damage / Broken Window | Gash | Not Visible

Figure 2.S.01 WTC7 South facade - Debris and Fire Damage at approximately 12PM

Image 2.W.01 Southwest corner, approximately 10:30AM-12:30PM

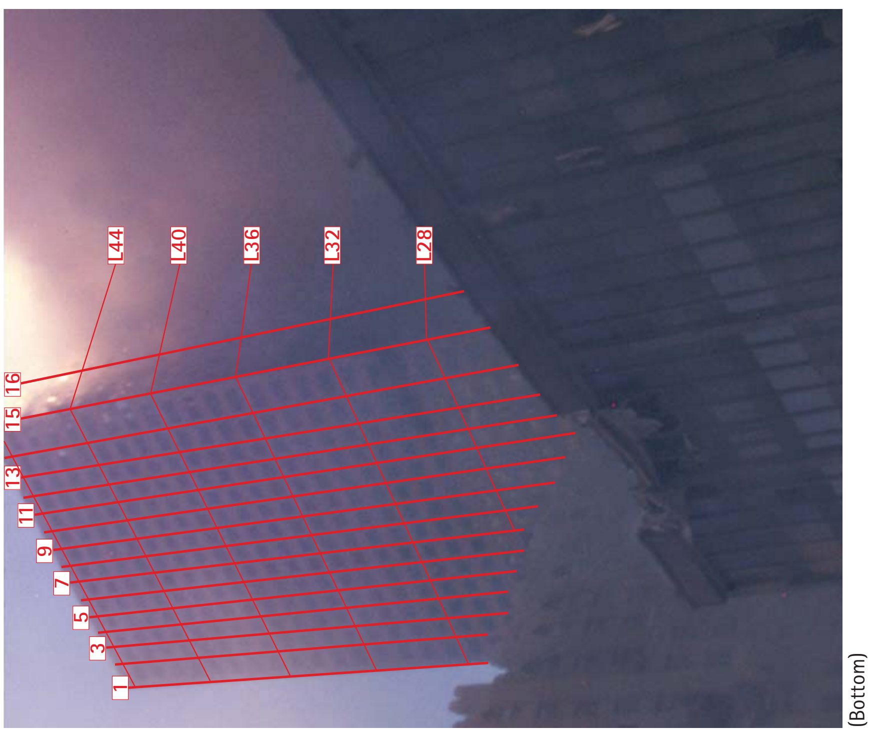


Image 2.W.01 with columns and floor levels overlaid

(Bottom)

Image 2.W.02 Northwest corner, 11:33:21AM

(Bottom)

Image 2.W.02 with columns and floor levels overlaid

A.3 FIRE PROGRESSION – 12PM TO 1PM

East Facade - No available visual evidence of fire-related damage during this time period.

North Facade: -No available visual evidence of fire-related damage during this time period.

West Facade - Visual evidence of the west facade during this time period shows that fires burned on levels 29 and 30 but burned-out by the end of the hour. Smoke and fire were visible on floor 22 throughout the hour. The earliest images of level 19 show windows already burned-out, indicating that a fire may have burned soon after WTC1's collapse in this location. Lastly, in the second half of the hour smoke became visible on level 18.

South Facade - Photographs during this time period show that a fire resided on level 30 which continued to burn in the latest photographs during this hour. A fire burned previously to available photographs during this time period on level 29, showing an area already burned-out on this floor.

A.3.1 Fire Damage Diagrams

Figures 3.E.01, 3.N.01, 3.W.01, and 3.S.01 on pages 56 to 60 depict the condition of each elevation at the end of this time period as evidenced in the available images. These diagrams are cumulative and contain the fire-related damage timed up until 1:00pm as well as the debris damage from WTC1's collapse. Fire damage types include smoke, broken window with internal fire, broken window with external fire, and burned-out. The fire-related damage on these figures represents a compilation of the last available visual evidence for each area within hour; therefore, these diagrams are only an approximation of what the elevation might have looked like at 1:00pm.

Figures 3.W.02 3.W.03 and 3.S.02 on pages 58 to 60 depict a series of sequential images showing the progression of fire in particular areas of the west and south façades during this time increment. While the full elevation diagrams represent the condition of each facade at the end of the time period, the detail elevation mappings illustrate how fire traveled or altered throughout the hour in a specific area. Debris damage has been omitted from these diagrams for clarity.

A.3.2 Photographs of Damage

The images found on pages 61 to 93 are all the images that show fire-related damage and are attributed to the time period from 12:00pm until 1:00pm. Each image is presented twice on one page; the top image is the untouched version while columns and level markers have been added to the lower image for reference. In some instances an untouched version of the photograph was not available and in its place an image that NIST has notated is used instead. These images are also shown twice with additional column and level markers added for full clarity.

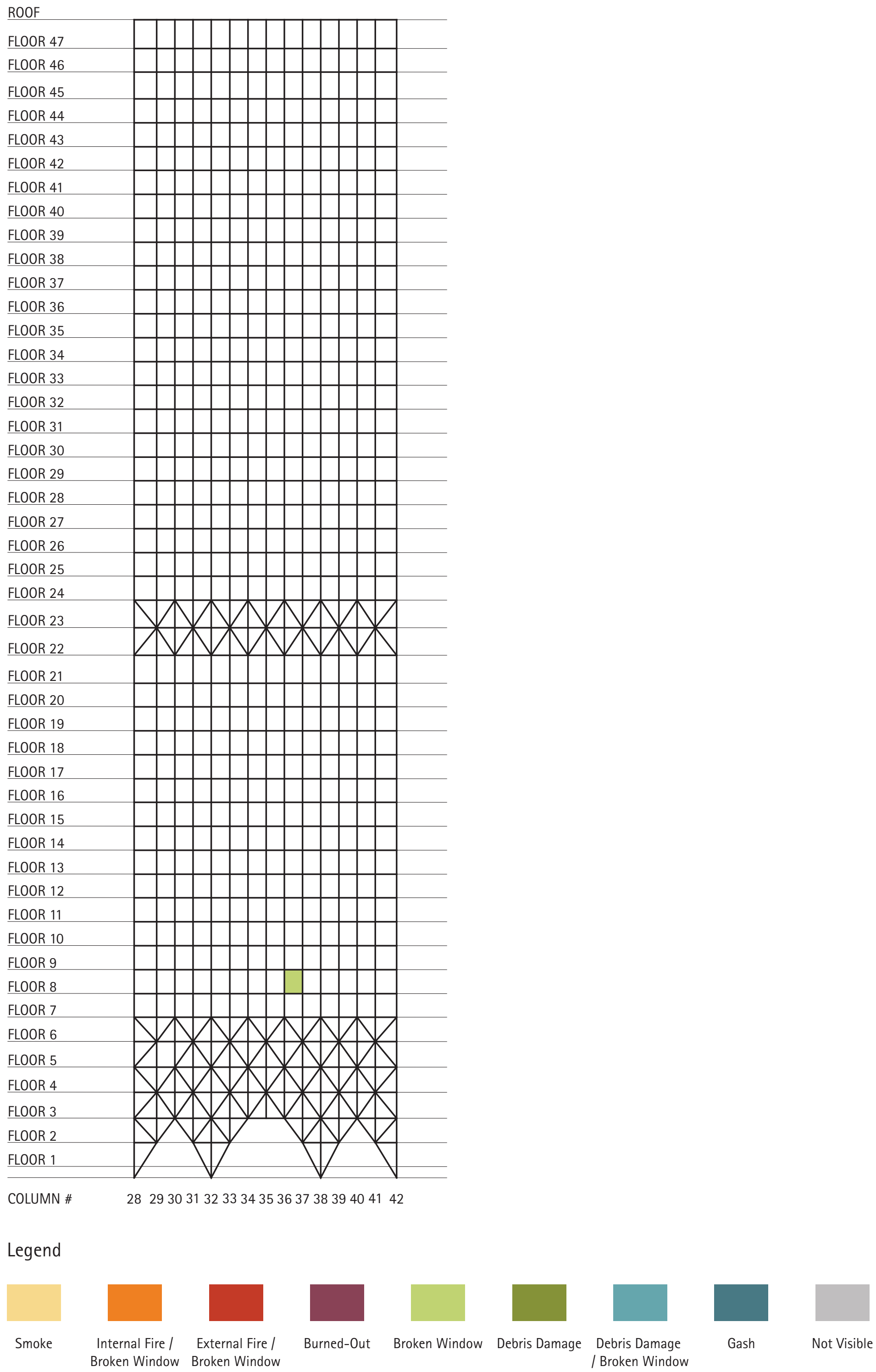


Figure 3.E.01 WTC7 East facade – Debris and Fire Damage at approximately 1PM

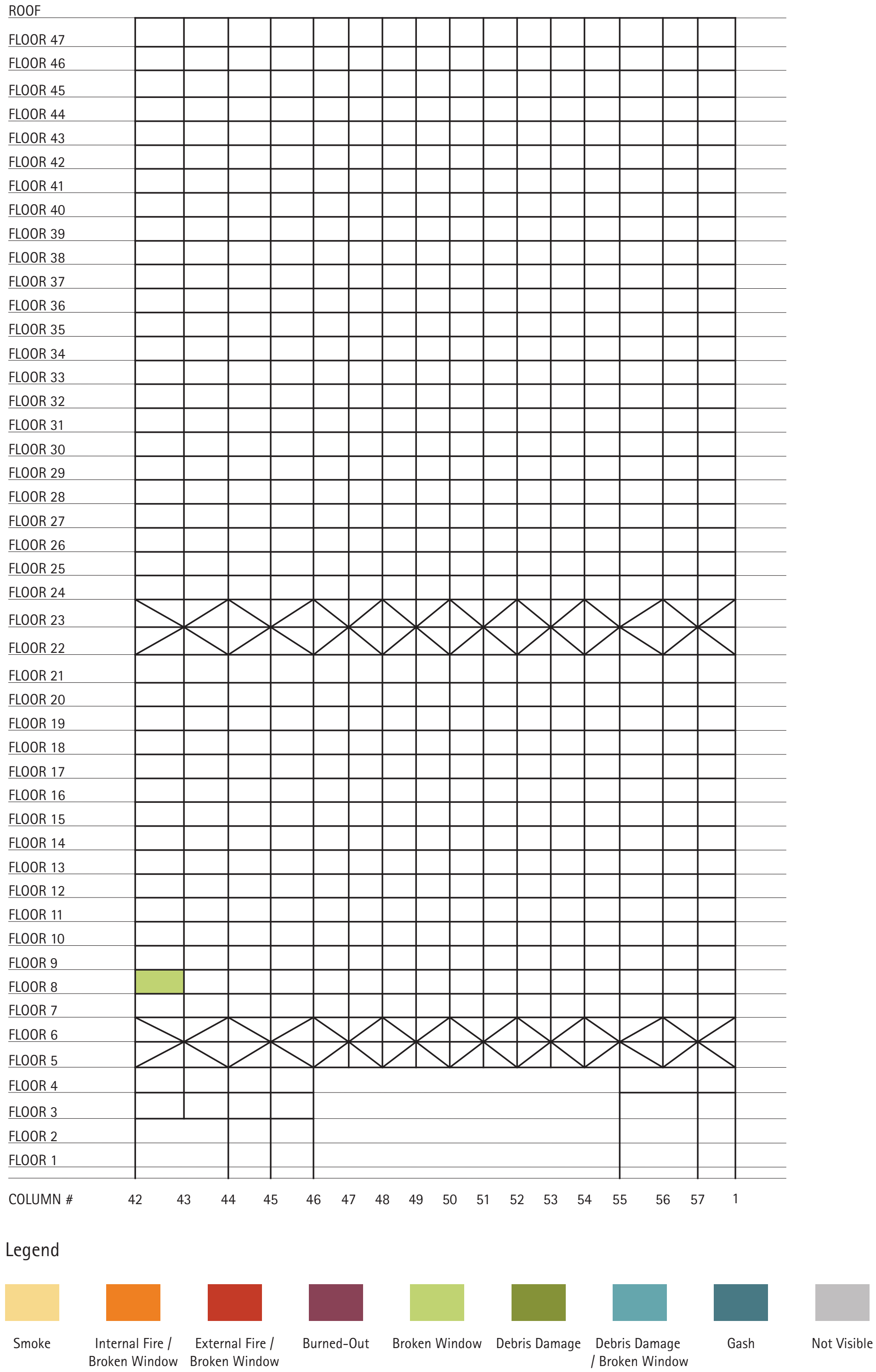
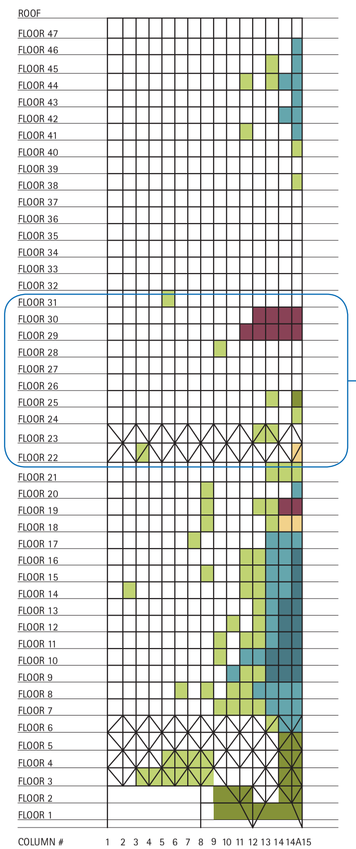


Figure 3.N.01 WTC7 North facade – Debris and Fire Damage at approximately 1PM



See Figures 3.W.02 - 3.W.03 for more detail on the fire progression in this region

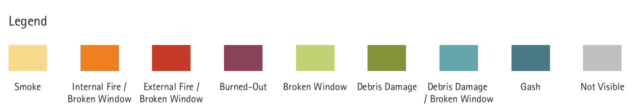


Figure 3.W.01 WTC7 West Facade - Debris and Fire Damage at approximately 1PM

Volume A - Photographic Timeline
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World Trade Center 7 Collapse Investigation
16 December 2009

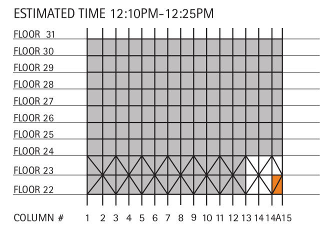


Diagram of Image 3.W.02

Image 3.W.02

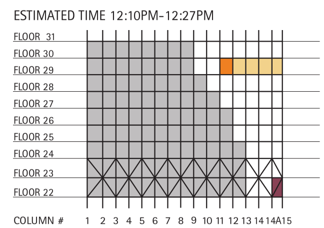


Diagram of Image 3.W.03

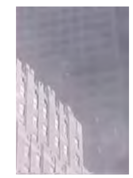


Image 3.W.03

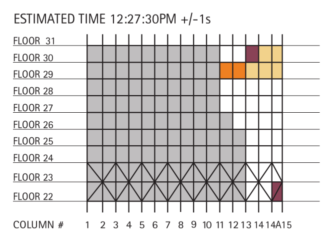


Diagram of Image 3.W.07

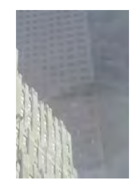


Image 3.W.07

Figure 3.W.02 WTC7 West Facade - Detailed Fire Progression from 12PM to 1PM

ESTIMATED TIME 12:28PM +/-180s

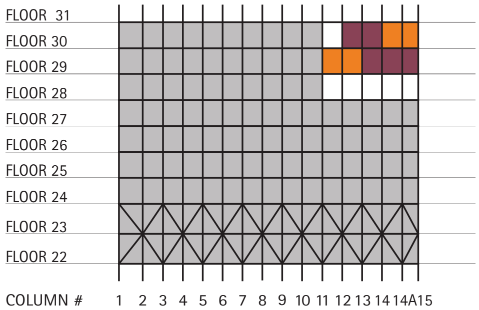


Diagram of Image 3.W.12

Image 3.W.12

ESTIMATED TIME 12:47:40PM +/-1s

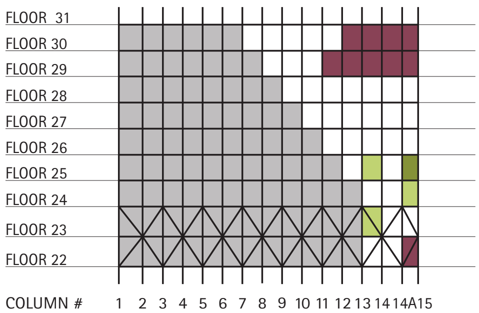


Diagram of Image 3.W.27

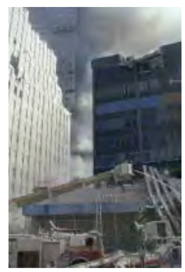


Image 3.W.27

ESTIMATED TIME 12:47PM-1:03PM

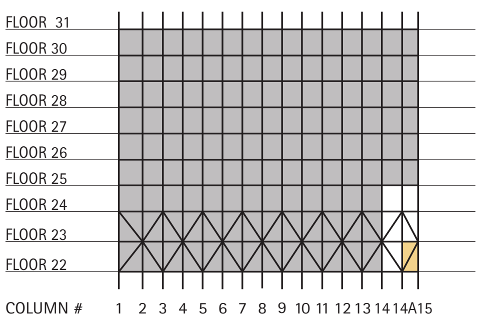


Diagram of Image 3.W.32

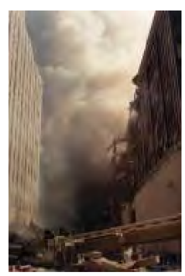
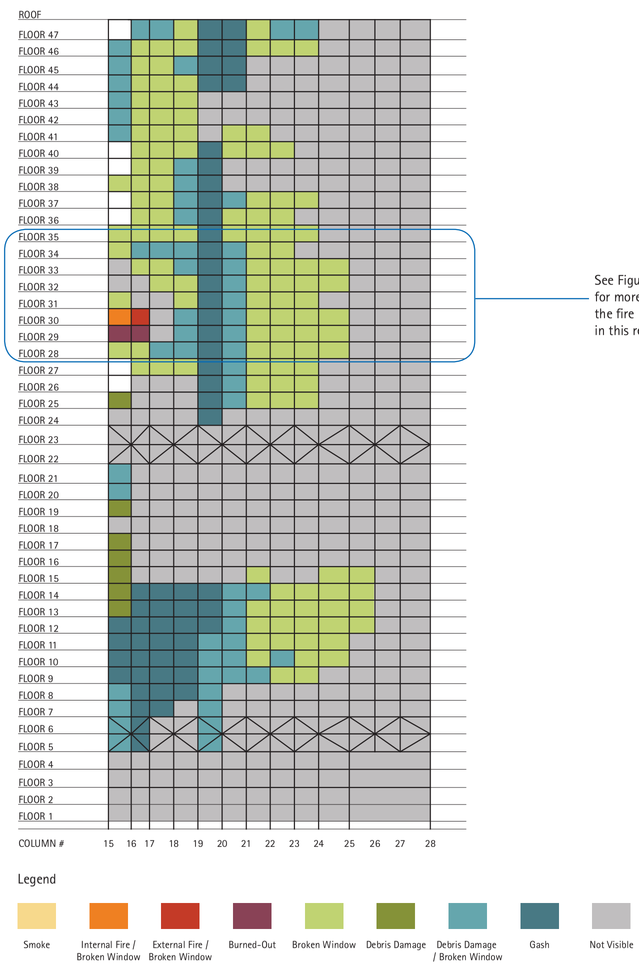


Image 3.W.32

Legend

Smoke | Internal Fire / Broken Window | External Fire / Broken Window | Burned-Out | Broken Window | Debris Damage | Debris Damage / Broken Window | Gash | Not Visible

Figure 3.W.03 WTC7 West Facade - Detailed Fire Progression from 12PM to 1PM



See Figure 3.S.02 for more detail on the fire progression in this region

Figure 3.S.01 WTC7 South Facade - Debris and Fire Damage at Approximately 1PM

ESTIMATED TIME 12:28PM-12:31PM

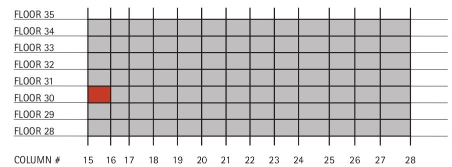


Diagram of Image 3.W.11

Image 3.W.11

ESTIMATED TIME 12:28PM +/-180s

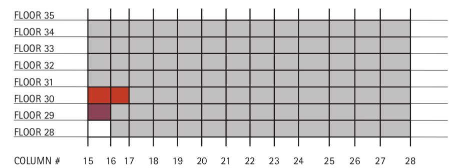


Diagram of Image 3.W.12

Image 3.W.12

ESTIMATED TIME 12:30PM-1:00PM

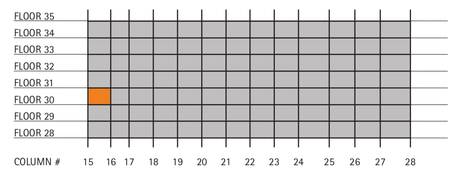


Diagram of Image 3.W.22

Image 3.W.22

ESTIMATED TIME AFTER 12:40PM

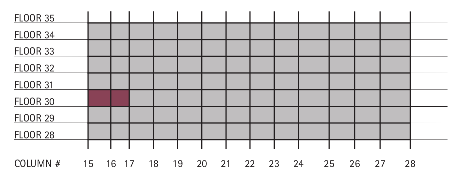


Diagram of Image 3.S.01

Image 3.S.01

Figure 3.S.02 WTC7 South Facade - Detailed Fire Progression from 12PM to 1PM

Image 3.W.01 West facade, approximately 12:10PM-12:25PM

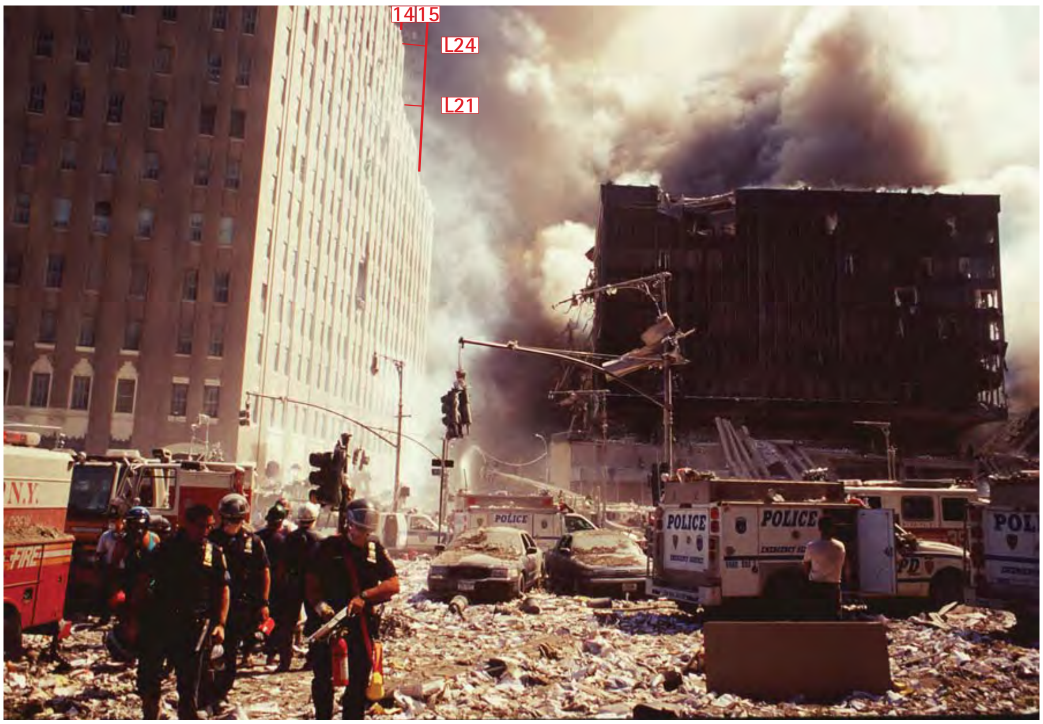


Image 3.W.01 with columns and floor levels overlaid

Image 3.W.02 Southwest corner, 12:10PM–12:25PM

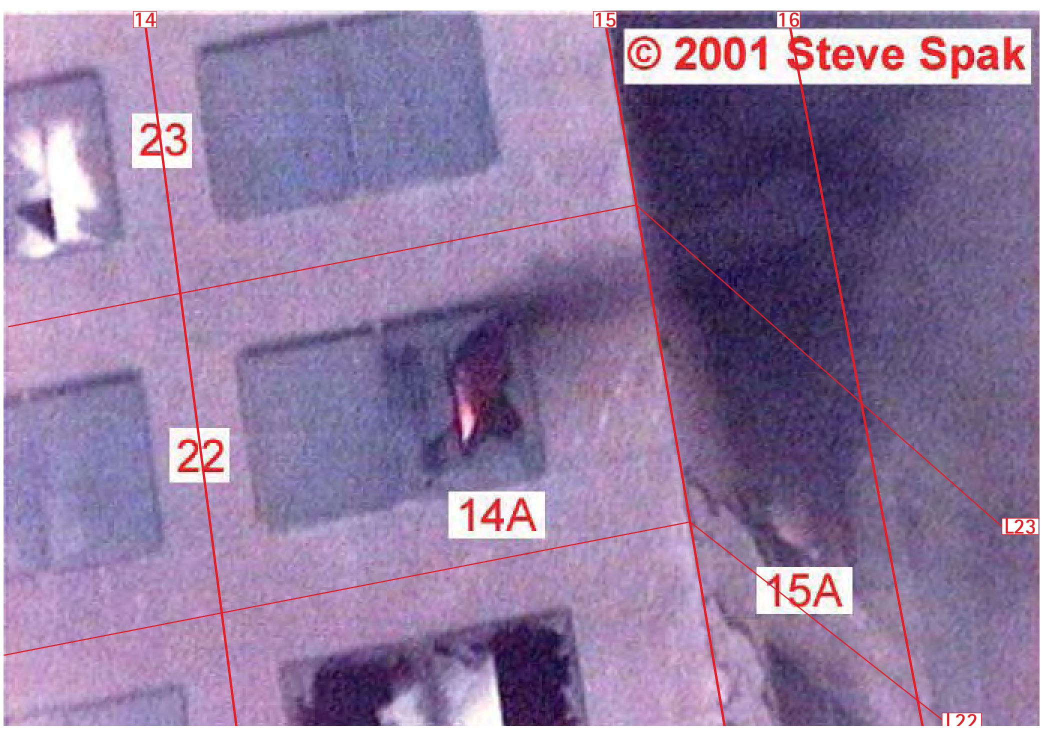


Image 3.W.02 with columns and floor levels overlaid

Image 3.W.03 West facade, approximately 12:10PM-12:27PM

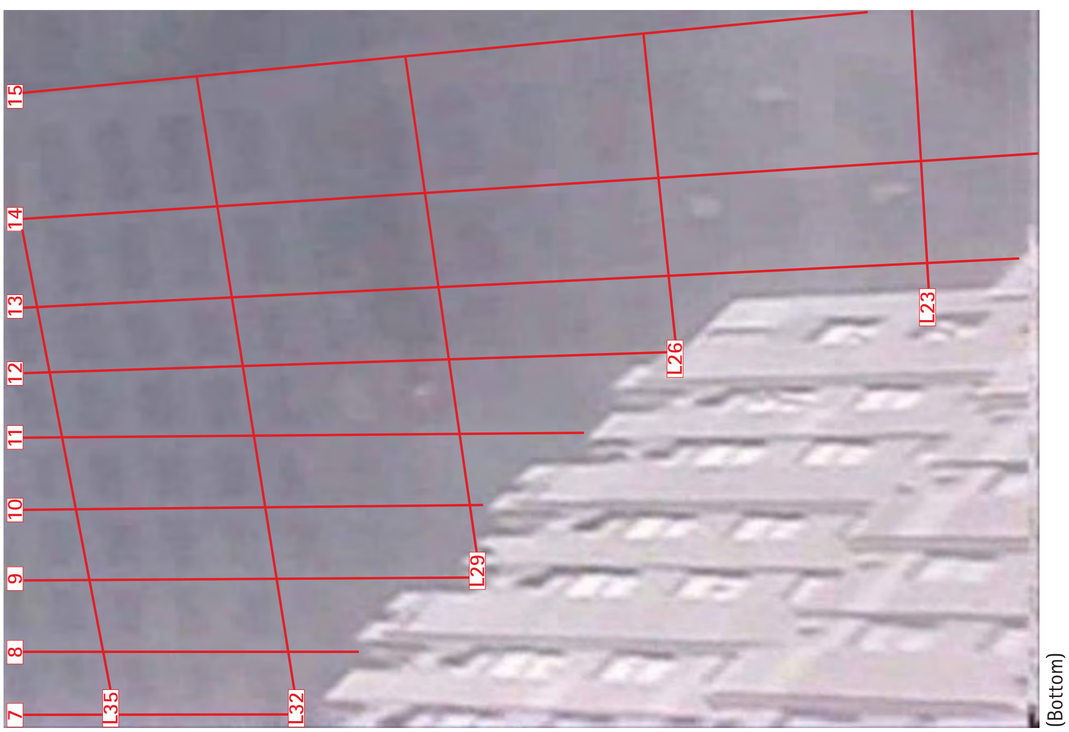


Image 3.W.03 with columns and floor levels overlaid

Image 3.W.04 West facade, approximately 12:10PM-12:28PM

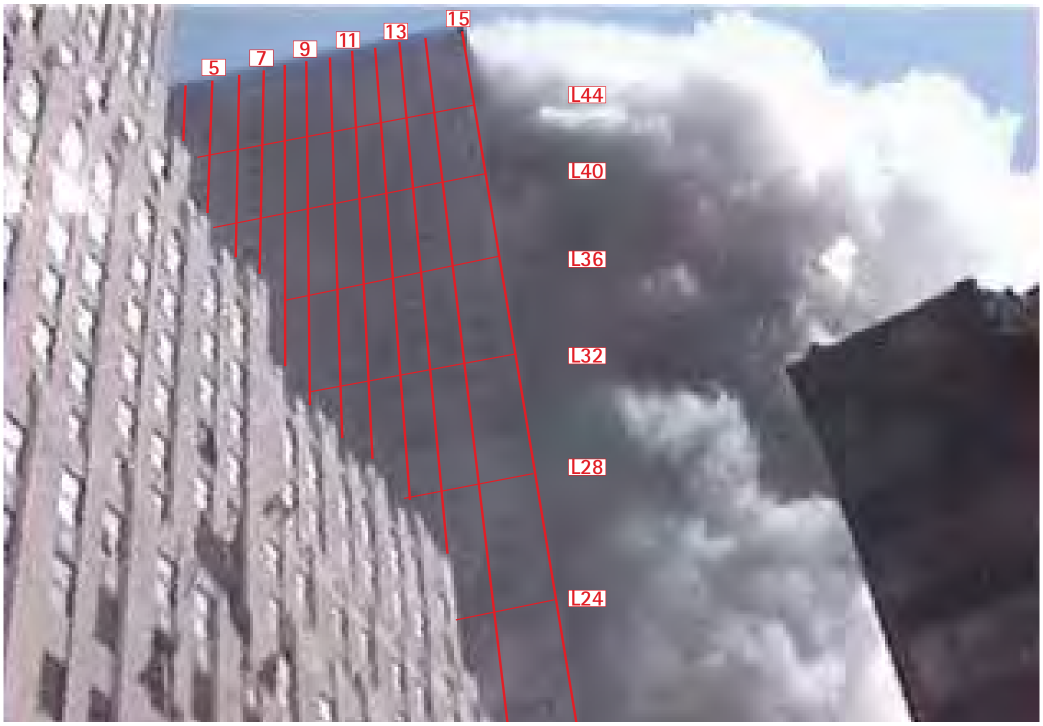
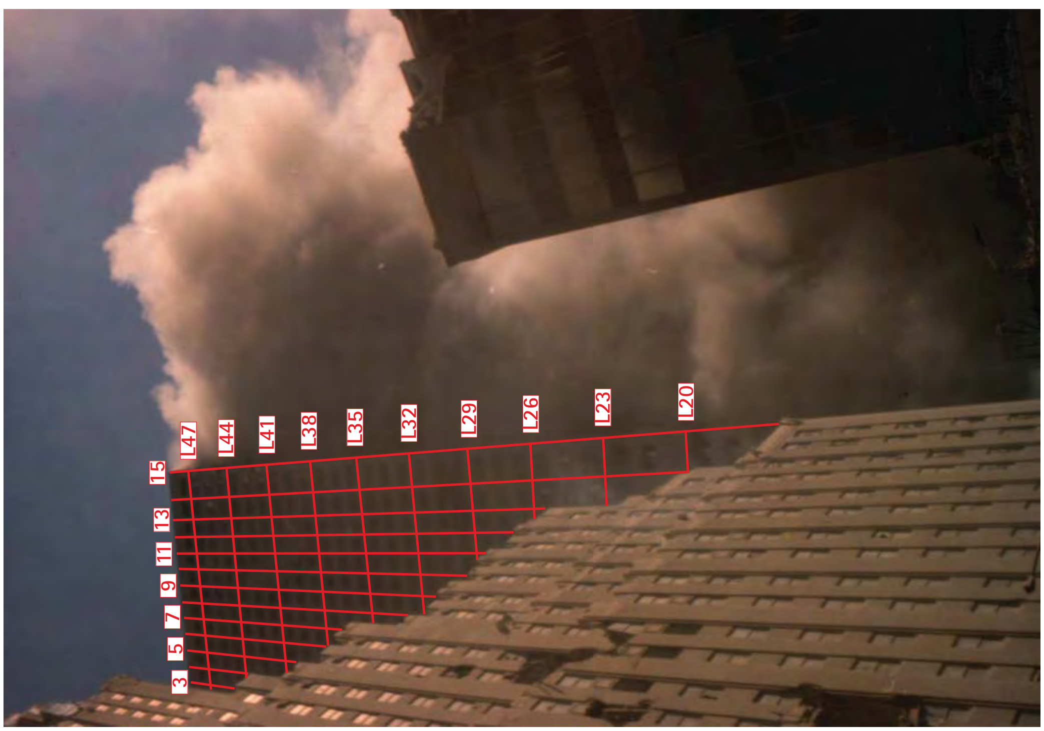


Image 3.W.04 with columns and floor levels overlaid

(Bottom)

Image 3.W.05 Southwest corner, approximately 12:10PM–12:28PM

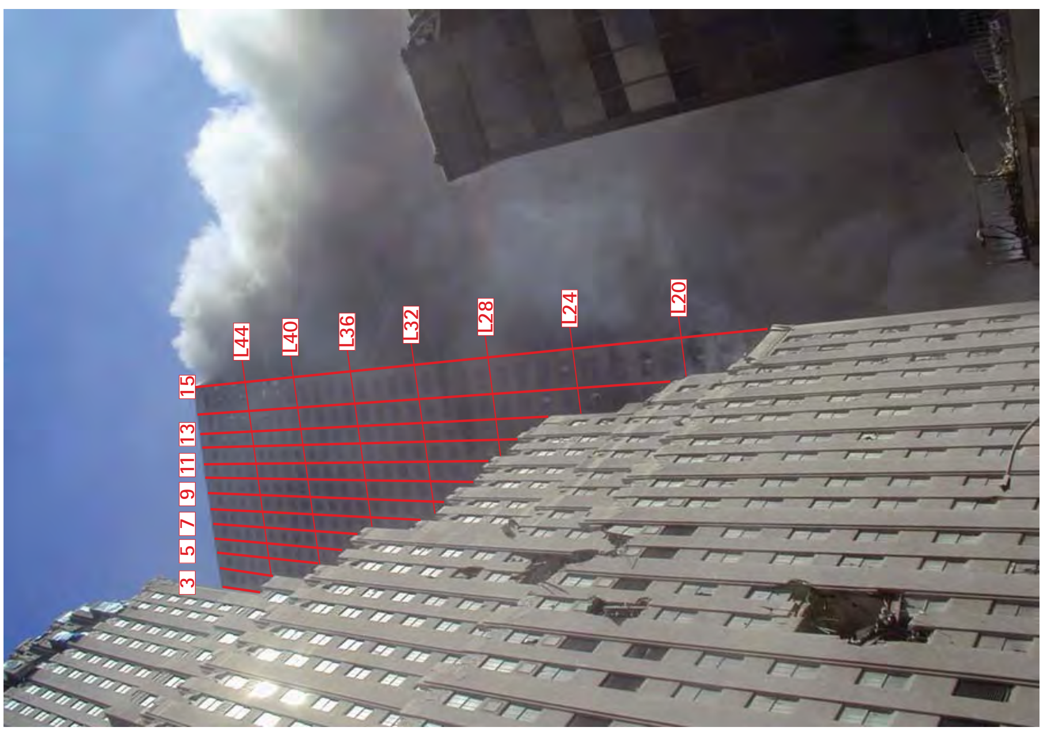


(Bottom)

Image 3.W.05 with columns and floor levels overlaid

(Bottom)

Image 3.W.06 West facade, 12:27:17PM +/-1s



(Bottom)

Image 3.W.06 with columns and floor levels overlaid

Image 3.W.07 Southwest corner, 12:27:30PM +/-1s

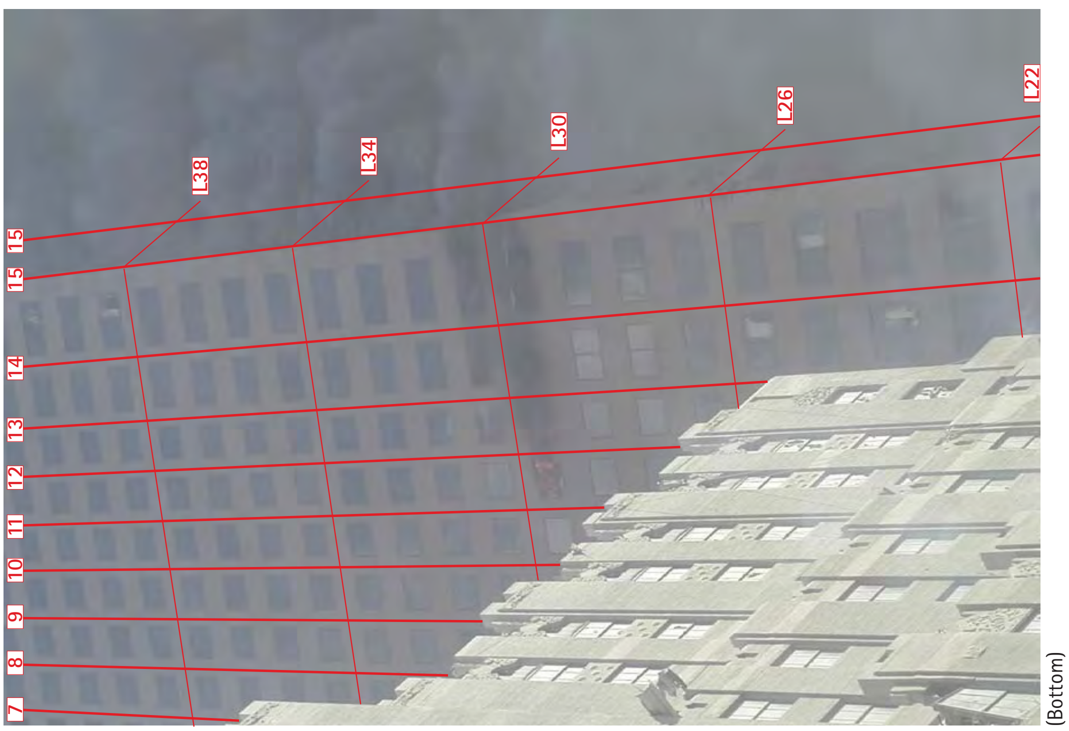


Image 3.W.07 with columns and floor levels overlaid

Image 3.W.08 Southwest corner, approximately 12:27PM-12:28PM

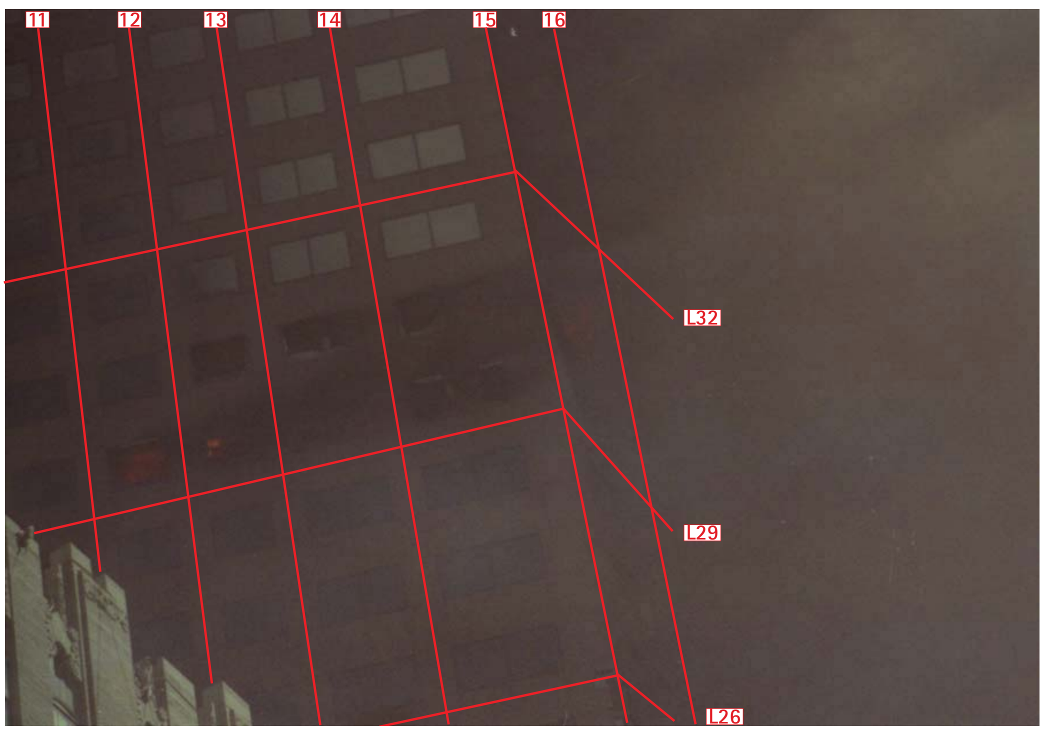


Image 3.W.08 with columns and floor levels overlaid

Image 3.W.09 Southwest corner, 12:28:40PM +/-1s

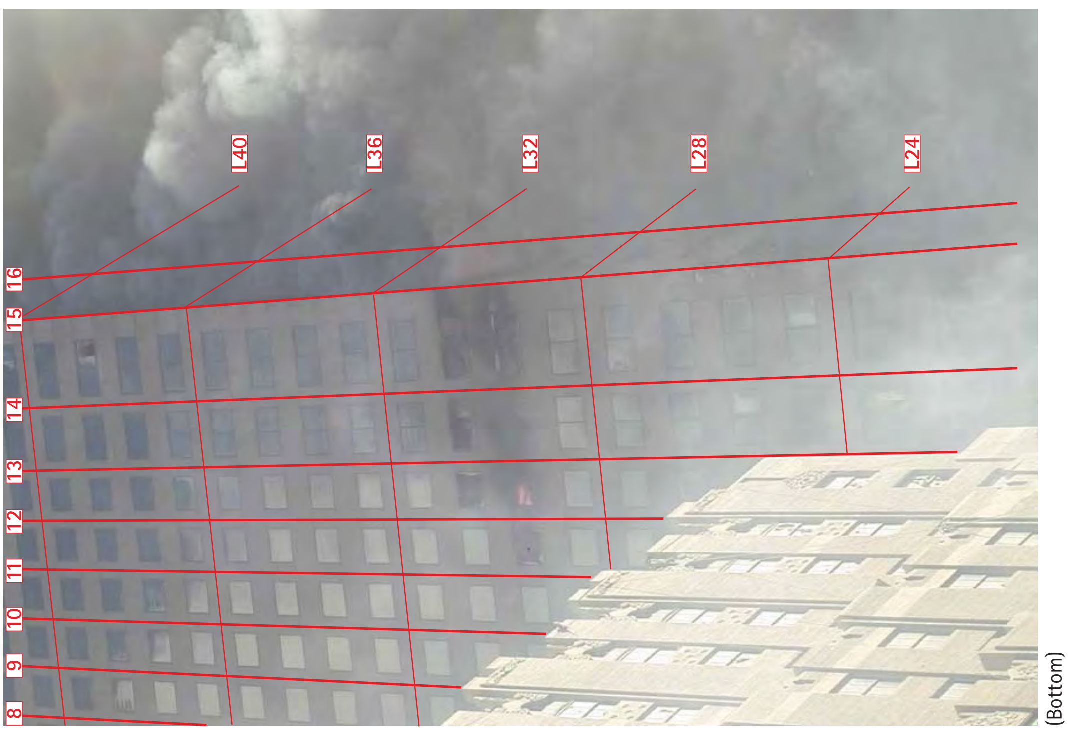


Image 3.W.09 with columns and floor levels overlaid

Image 3.W.10 Southwest corner, approximately 12:28PM-12:31PM

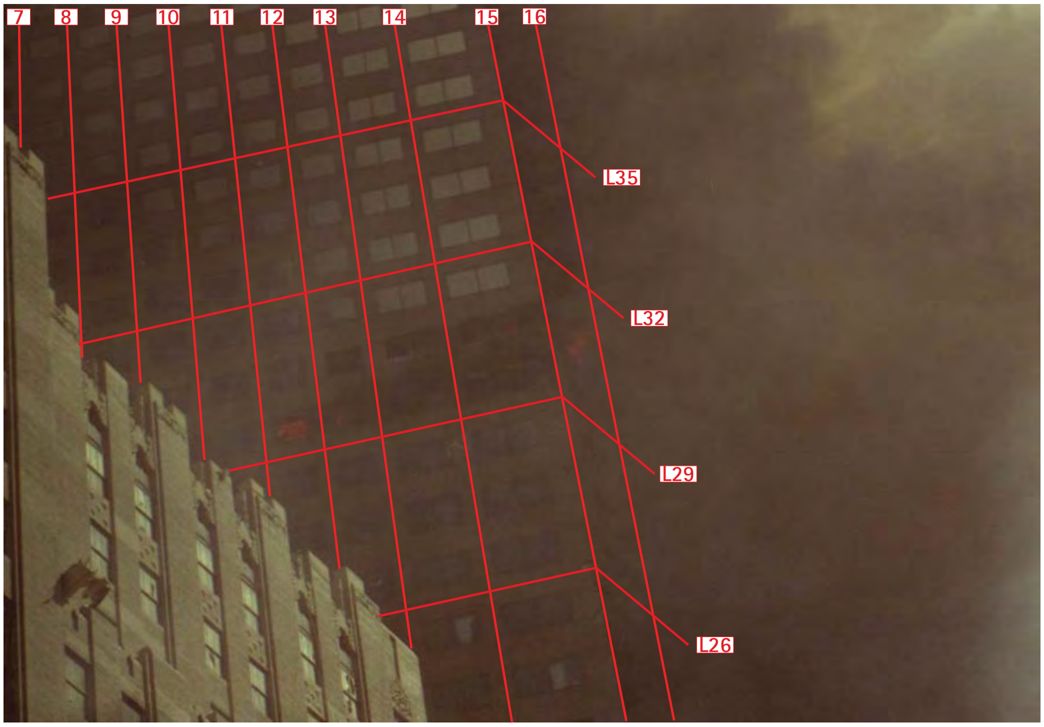
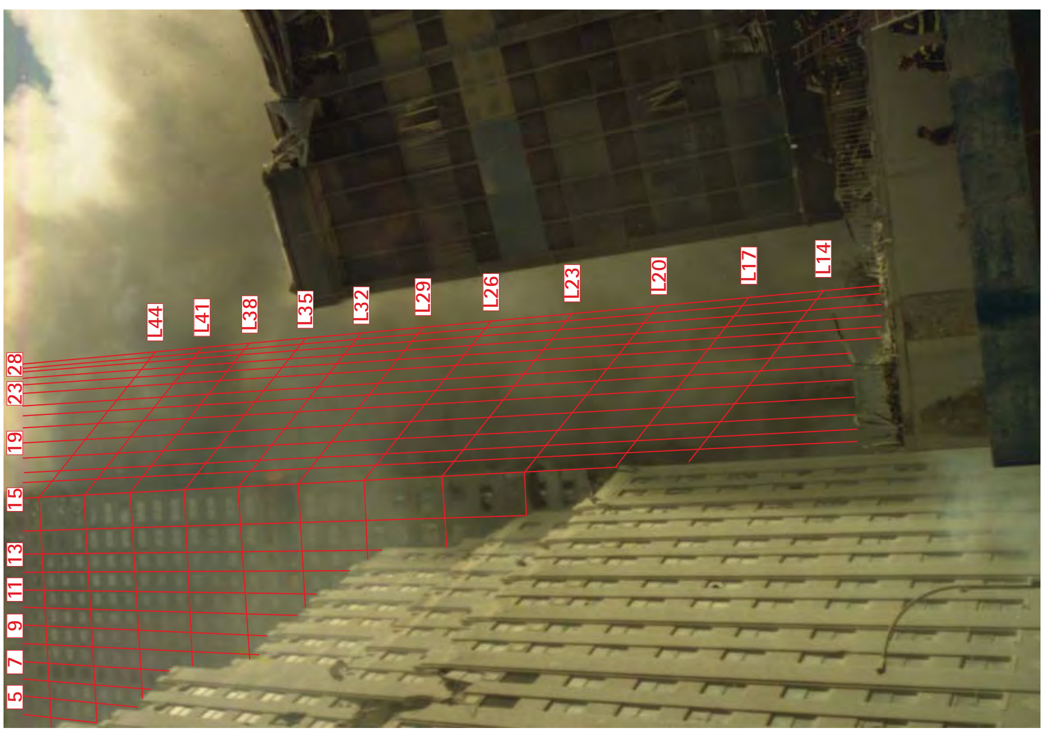


Image 3.W.10 with columns and floor levels overlaid

(Bottom)

Image 3.W.11 Southwest corner, approximately 12:28PM-12:31PM



(Bottom)

Image 3.W.11 with columns and floor levels overlaid

JA-3467

Image 3.W.12 Southwest corner, 12:28PM +/-180S

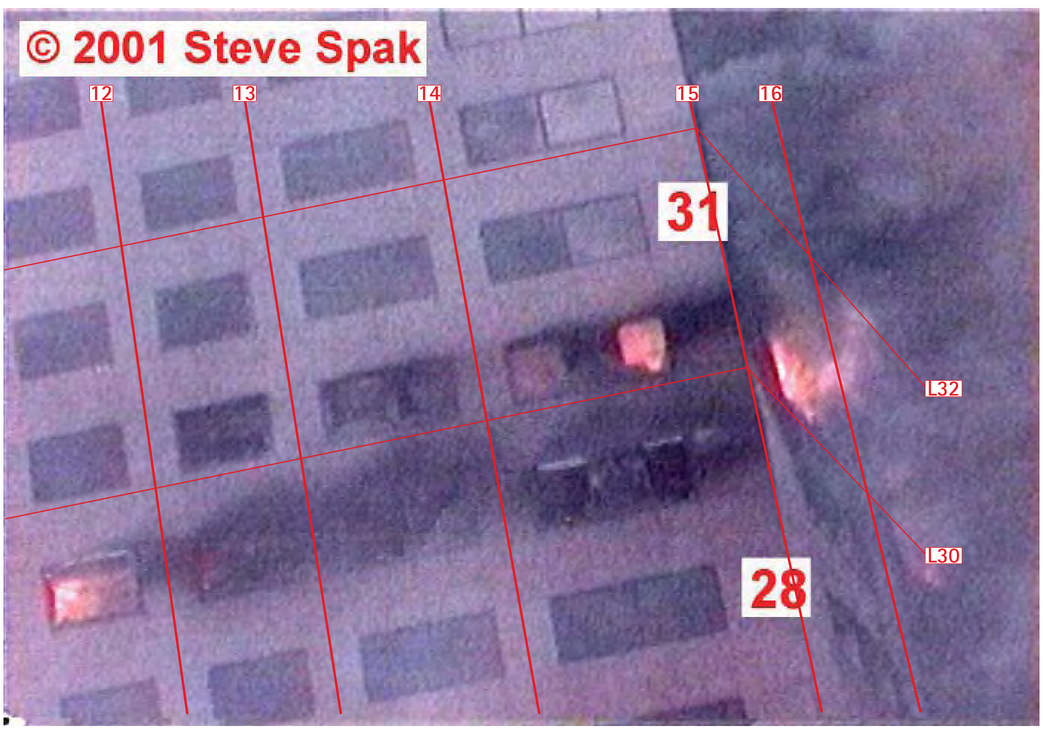


Image 3.W.12 with columns and floor levels overlaid

Image 3.W.13 Southwest corner, approximately 12:28PM-12:32PM

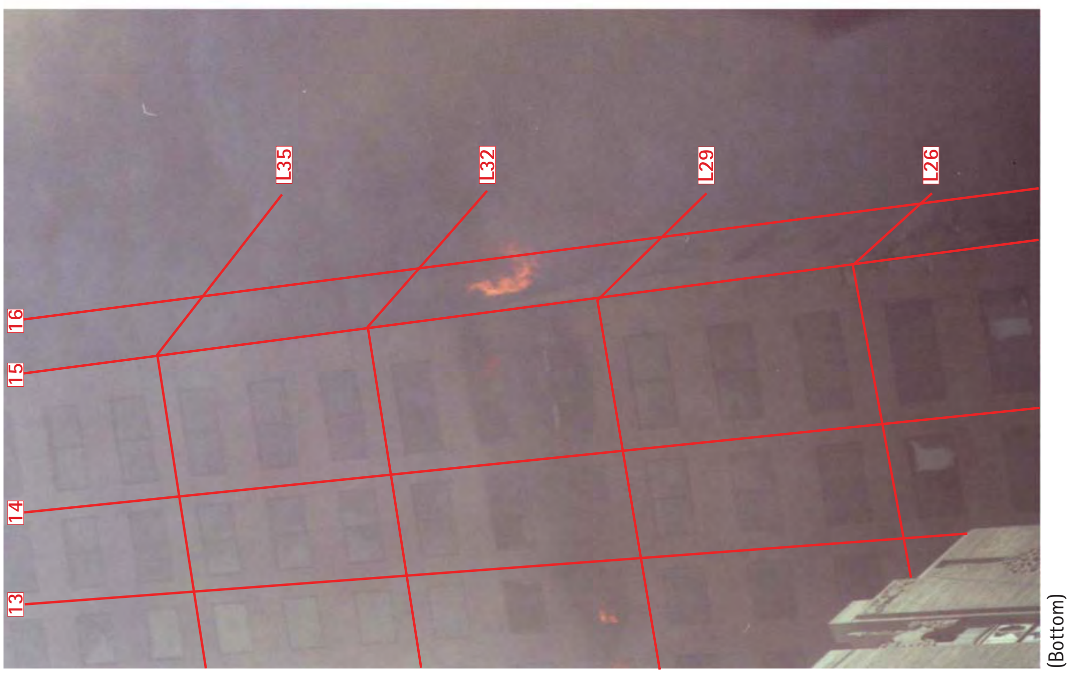


Image 3.W.13 with columns and floor levels overlaid

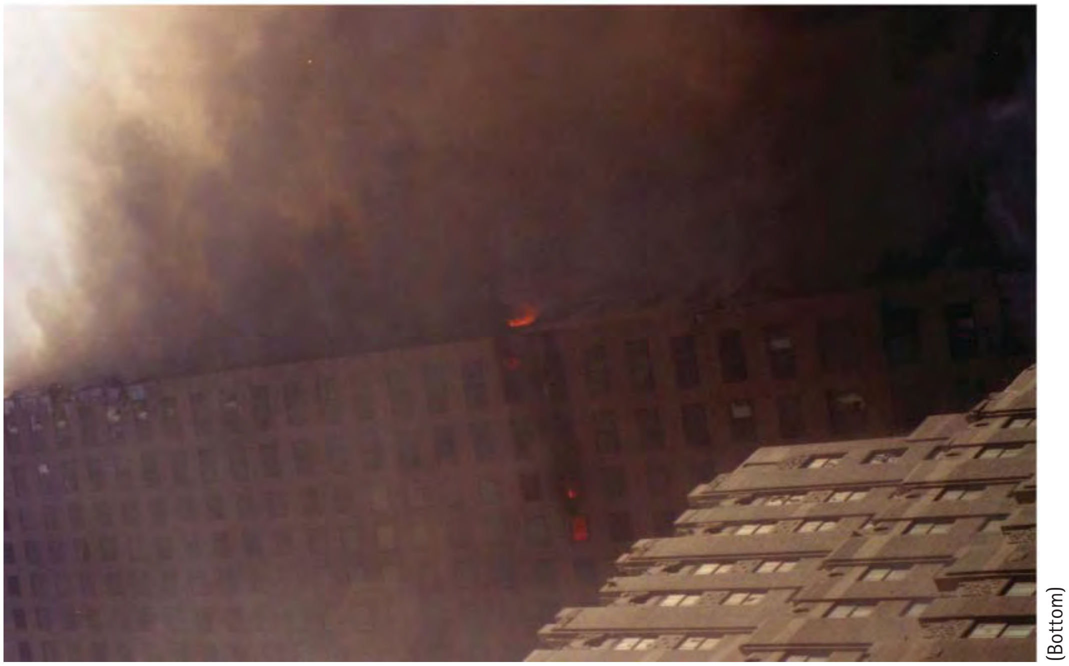


Image 3.W.14 Southwest corner, approximately 12:28PM–12:32PM

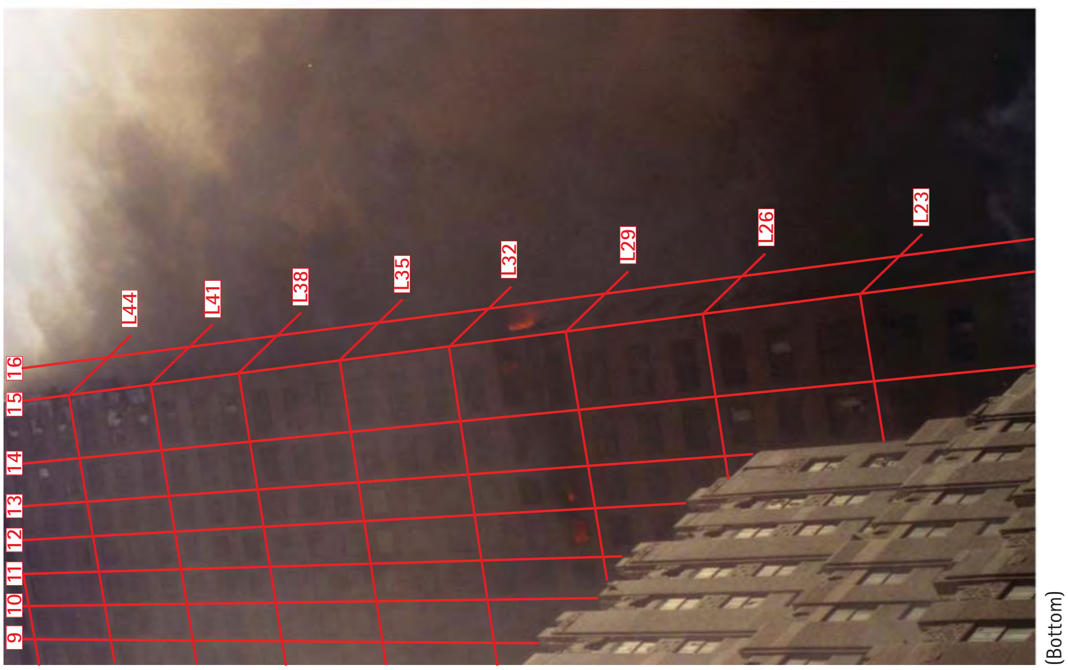


Image 3.W.14 with columns and floor levels overlaid

(Bottom)

Image 3.W.15 Southwest corner, approximately 12:28PM-12:32PM

(Bottom)

Image 3.W.15 with columns and floor levels overlaid

Image 3.W.16 Southwest corner, approximately 12:28PM-12:32PM

Image 3.W.16 with columns and floor levels overlaid

Image 3.W.17 Southwest corner, 12:33:03PM +/-1s

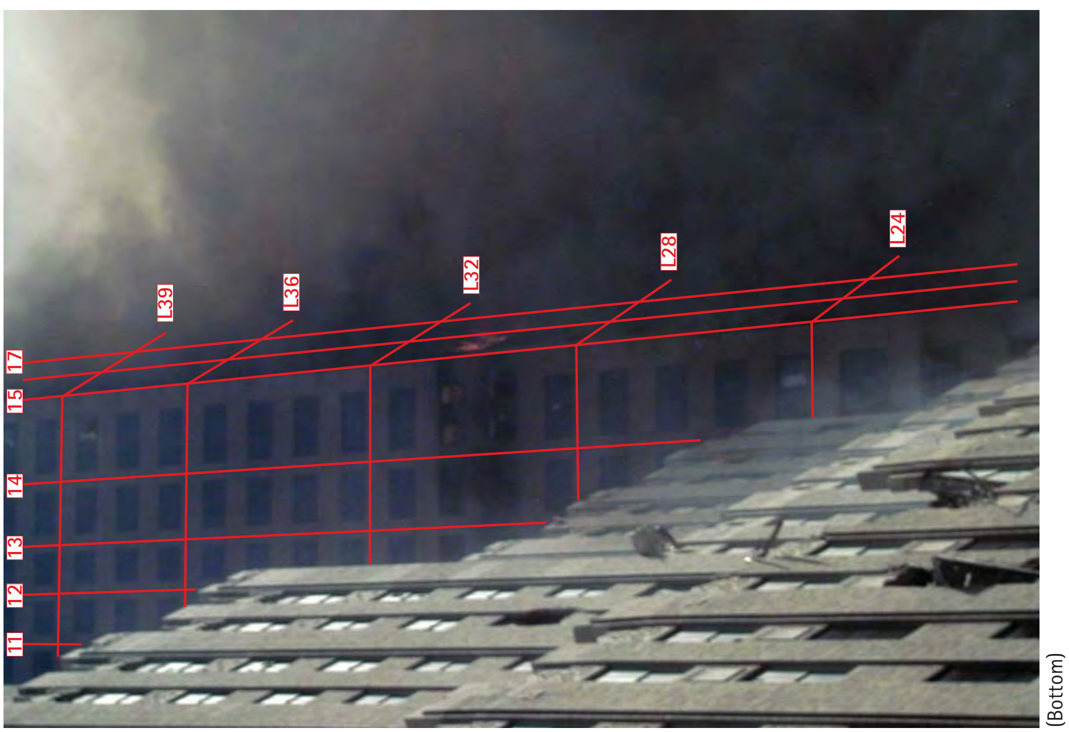


Image 3.W.17 with columns and floor levels overlaid

Image 3.W.18 Southwest corner, 12:33:03PM +/-1S

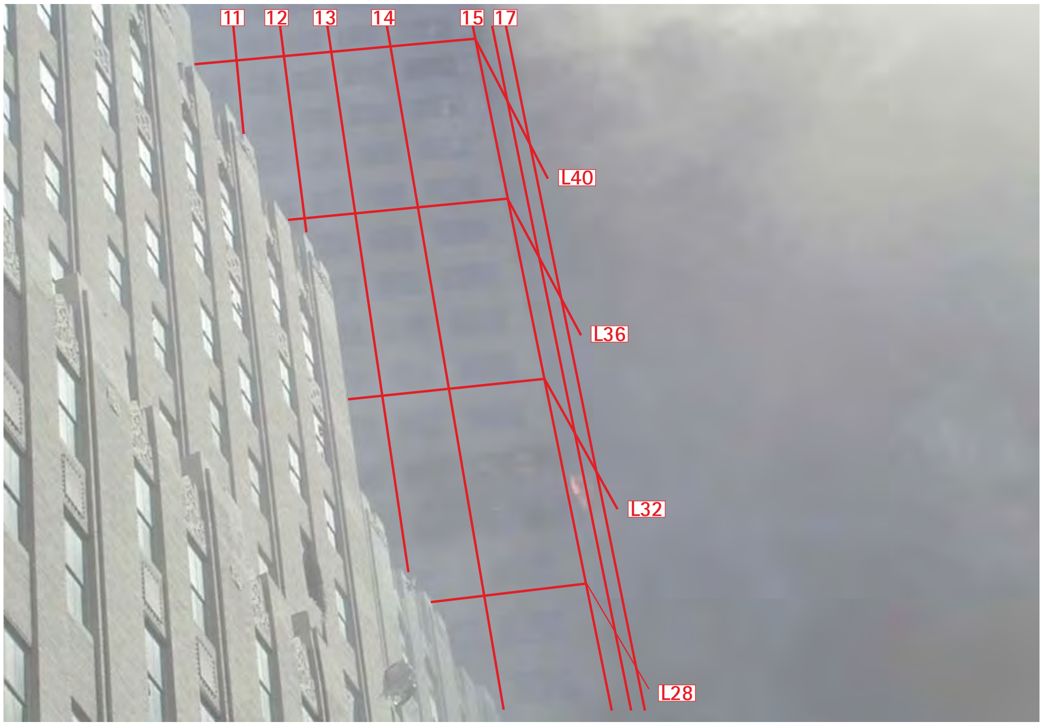


Image 3.W.18 with columns and floor levels overlaid

Image 3.W.19 West facade, approximately 12:30PM-1:00PM

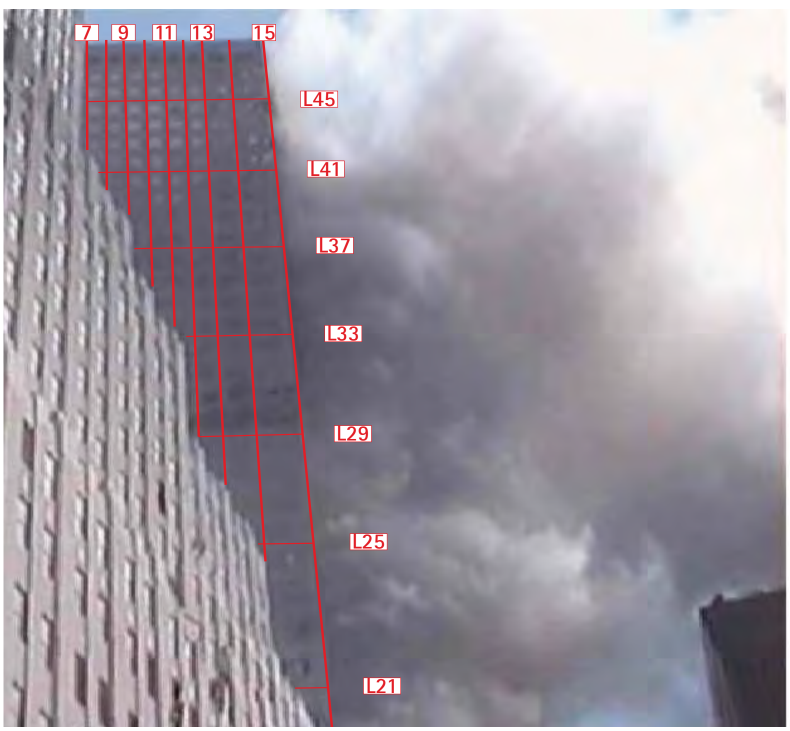


Image 3.W.19 with columns and floor levels overlaid

Image 3.W.20 Southwest corner, shortly before 12:46:39PM

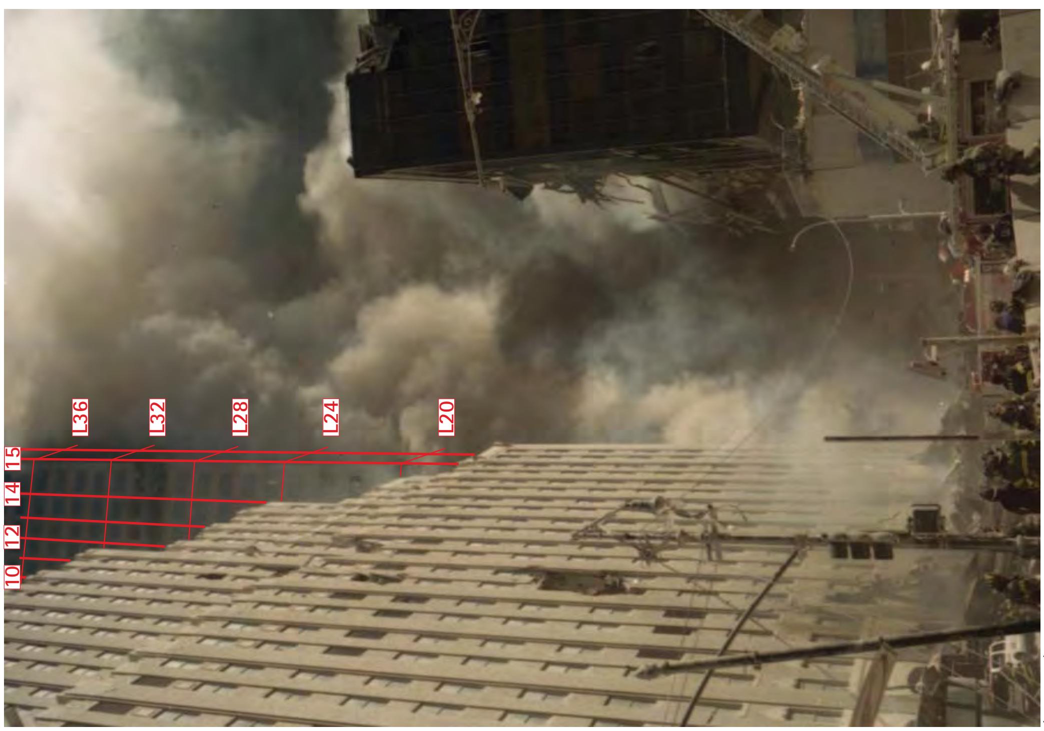
Image 3.W.20 with columns and floor levels overlaid

Image 3.W.21 Southwest corner, shortly after 12:30PM

Image 3.W.21 with columns and floor levels overlaid

(Bottom)

Image 3.W.22 Southwest corner, approximately 12:30PM-1:00PM



(Bottom)

Image 3.W.22 with columns and floor levels overlaid

Image 3.W.23 Southwest corner, approximately 12:30PM-1:00PM

Image 3.W.23 with columns and floor levels overlaid

Image 3.W.24 Southwest corner, approximately after 12:40PM

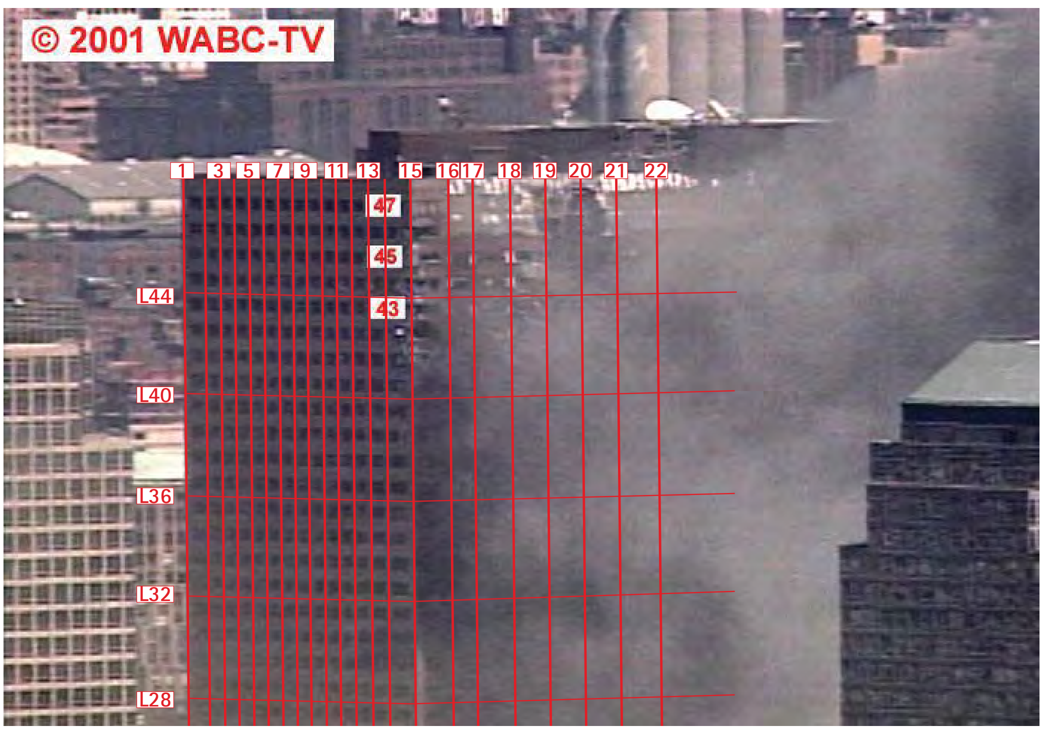


Image 3.W.24 with columns and floor levels overlaid

Image 3.W.25 Southwest corner, 12:46:39PM

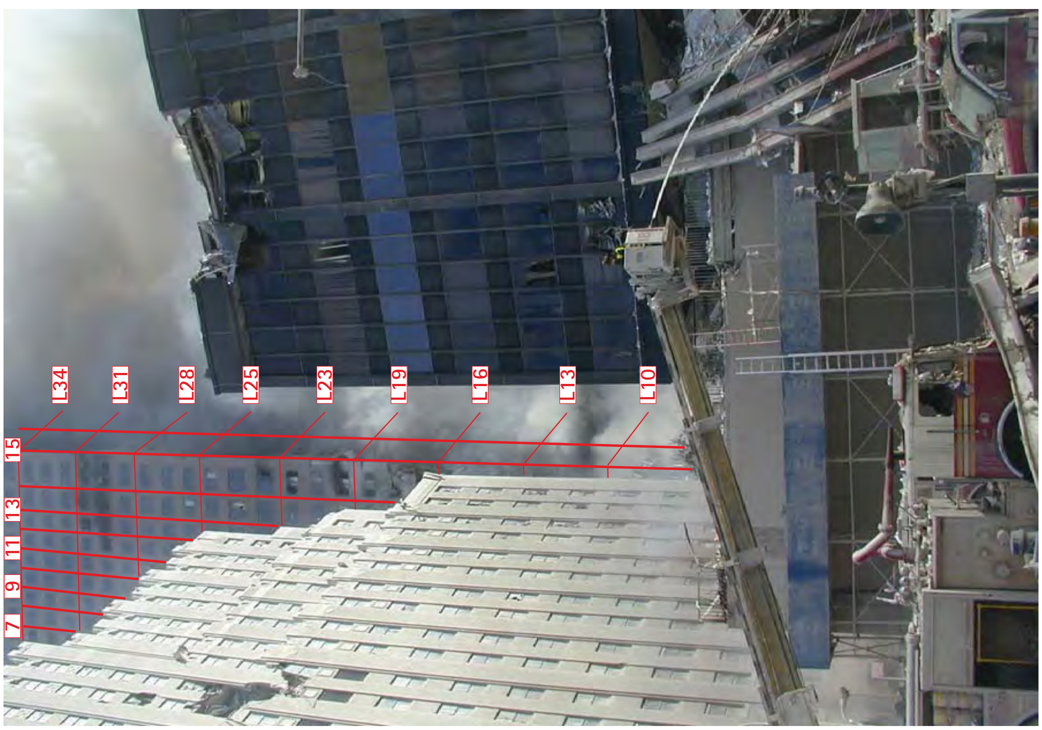
Image 3.W.25 with columns and floor levels overlaid

Image 3.W.26 Southwest corner, 12:46:48PM +/-1S

Image 3.W.26 with columns and floor levels overlaid

(Bottom)

Image 3.W.27 Southwest corner, 12:47:40PM +/-1s



(Bottom)

Image 3.W.27 with columns and floor levels overlaid

Image 3.W.28 Northwest corner, approximately 12:30PM–2:00PM

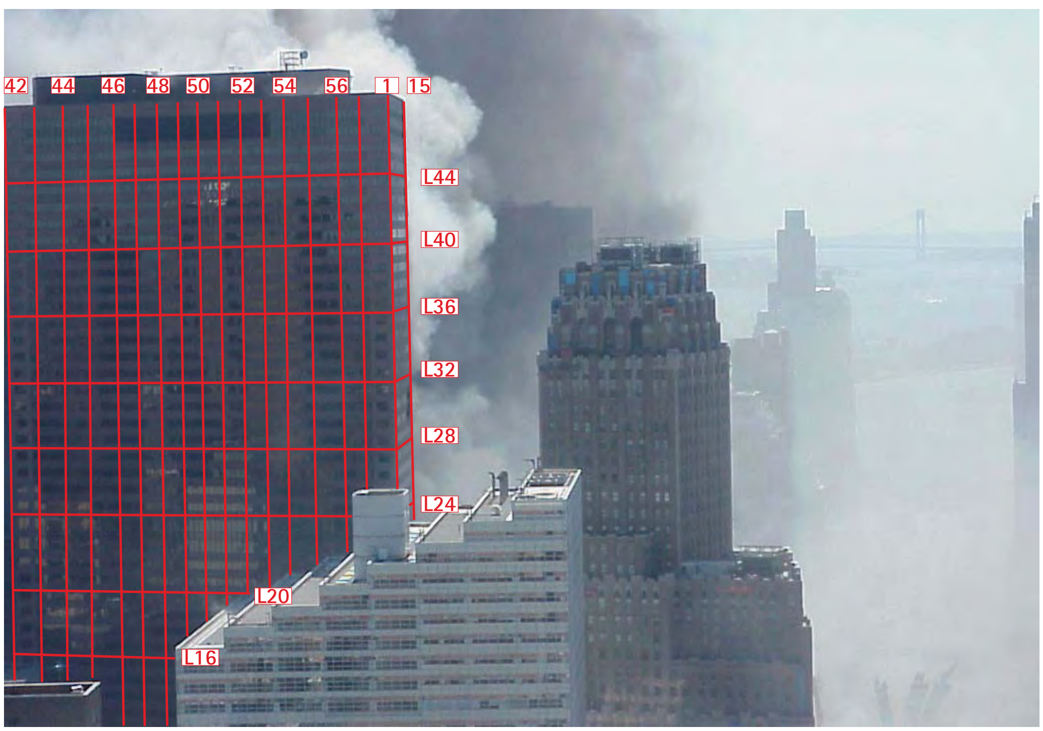


Image 3.W.28 with columns and floor levels overlaid

(Bottom)

Image 3.W.29 West facade, approximately 12:30PM-2:00PM

(Bottom)

Image 3.W.29 with columns and floor levels overlaid

Image 3.W.30 West facade, approximately 12:30PM-2:00PM

Image 3.W.30 with columns and floor levels overlaid

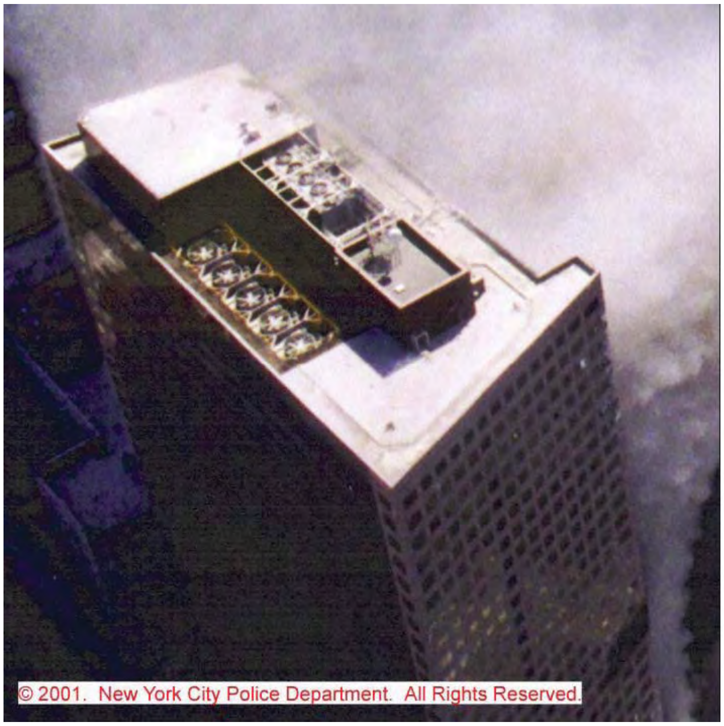


Image 3.W.31 Northwest corner, approximately 12:30PM-2:00PM

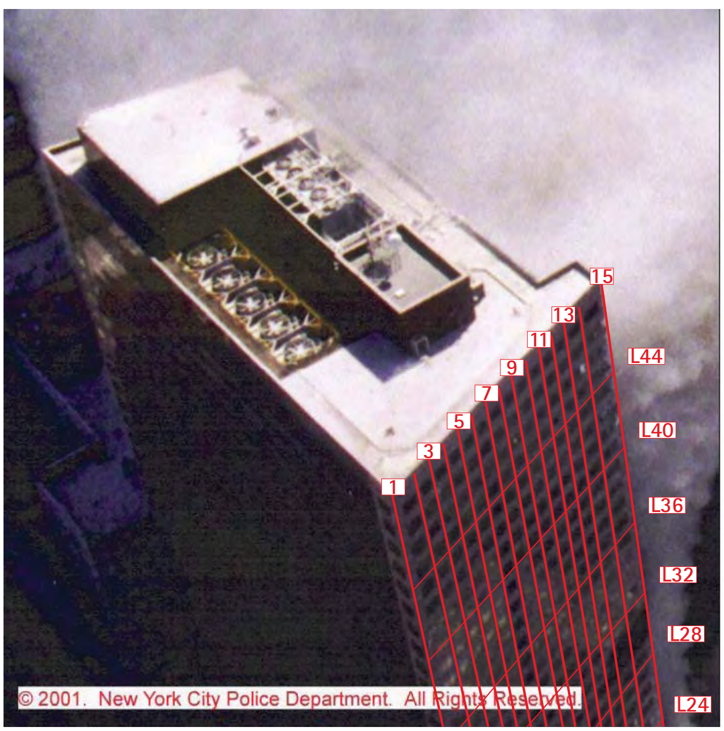
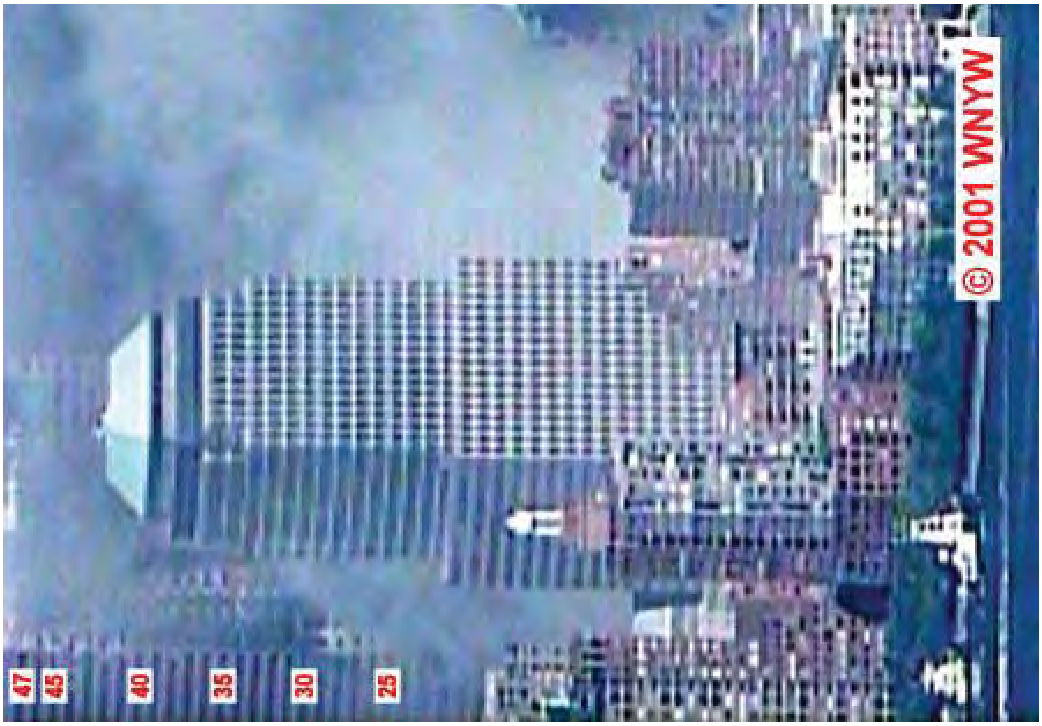


Image 3.W.31 with columns and floor levels overlaid

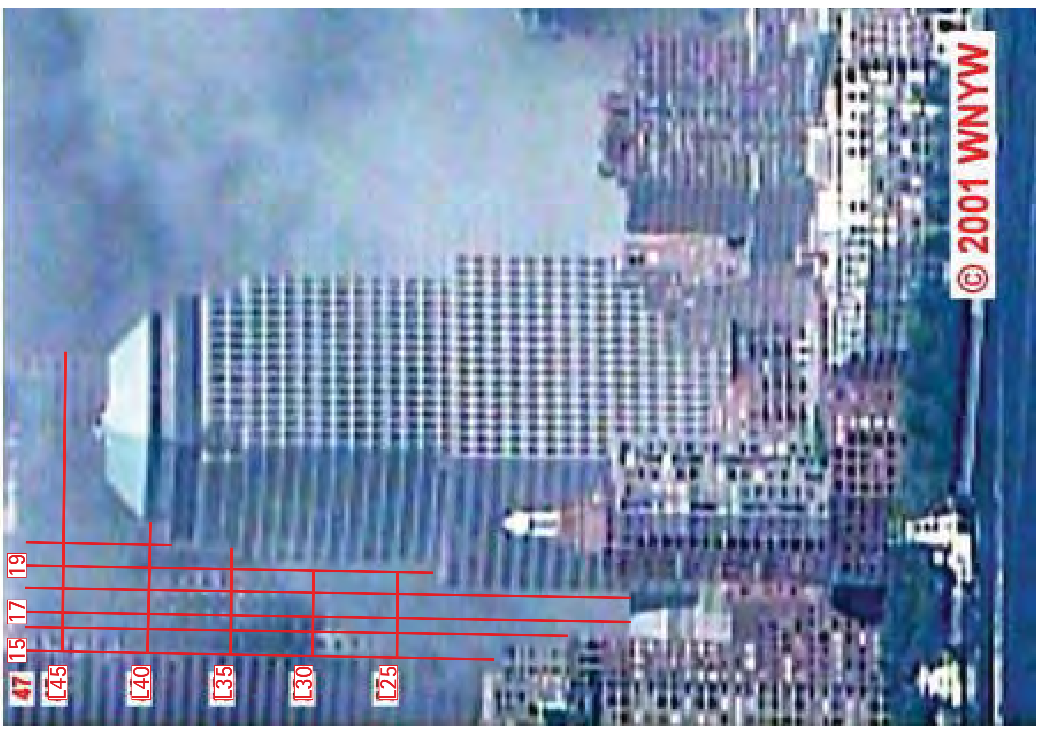
Image 3.W.32 Southwest corner, approximately 12:47PM-1:03PM

Image 3.W.32 with columns and floor levels overlaid



(Bottom)

Image 3.S.01 Southwest corner, approximately after 12:40PM



(Bottom)

Image 3.S.01 with columns and floor levels overlaid

A.4 FIRE PROGRESSION - 1PM TO 2PM

East Facade - No available visual evidence of fire-related damage during this time period.

North Facade - No available visual evidence of fire-related damage during this time period.

West Facade - During this time period, visual evidence shows that an additional window on level 22 broke and both windows are shown with smoke until they burned-out at the end of the hour. Smoke continued to stream from level 18, while smoke also became visible on levels 17 and 12. Additionally, both smoke and burn stains appeared at floor 7.

South Facade - No available visual evidence of fire-related damage during this time period so both levels 29 and 30 are shown as burned-out.

A.4.1 Fire Damage Diagrams

Figures 4.E.01, 4.N.01, 4.W.01, and 4.S.01 on pages 96 to 100 depict the condition of each elevation at the end of this time period as evidenced in the available images. These diagrams are cumulative and contain the fire-related damage timed up until 2:00pm as well as the debris damage from WTC1's collapse. Fire damage types include smoke, broken window with internal fire, broken window with external fire, and burned-out. The fire-related damage on these figures represents a compilation of the last available visual evidence for each area within hour; therefore, these diagrams are only an approximation of what the elevation might have looked like at 2:00pm.

Figures 4.W.02 and 4.W.03 on pages 98 and 99 depicts a series of sequential images showing the progression of fire in a particular area of the west facade during this time increment. While the full elevation diagrams represent the condition of each facade at the end of the time period, the detail elevation mappings illustrate how fire traveled or altered throughout the hour in a specific area. Debris damage has been omitted from these diagrams for clarity.

A.4.2 Photographs of Damage

The images found on pages 100 to 127 are all the images that show fire-related damage and are attributed to the time period from 1:00pm until 2:00pm. Each image is presented twice on one page; the top image is the untouched version while columns and level markers have been added to the lower image for reference. In some instances an untouched version of the photograph was not available and in its place an image that NIST has notated is used instead. These images are also shown twice with additional column and level markers added for full clarity.

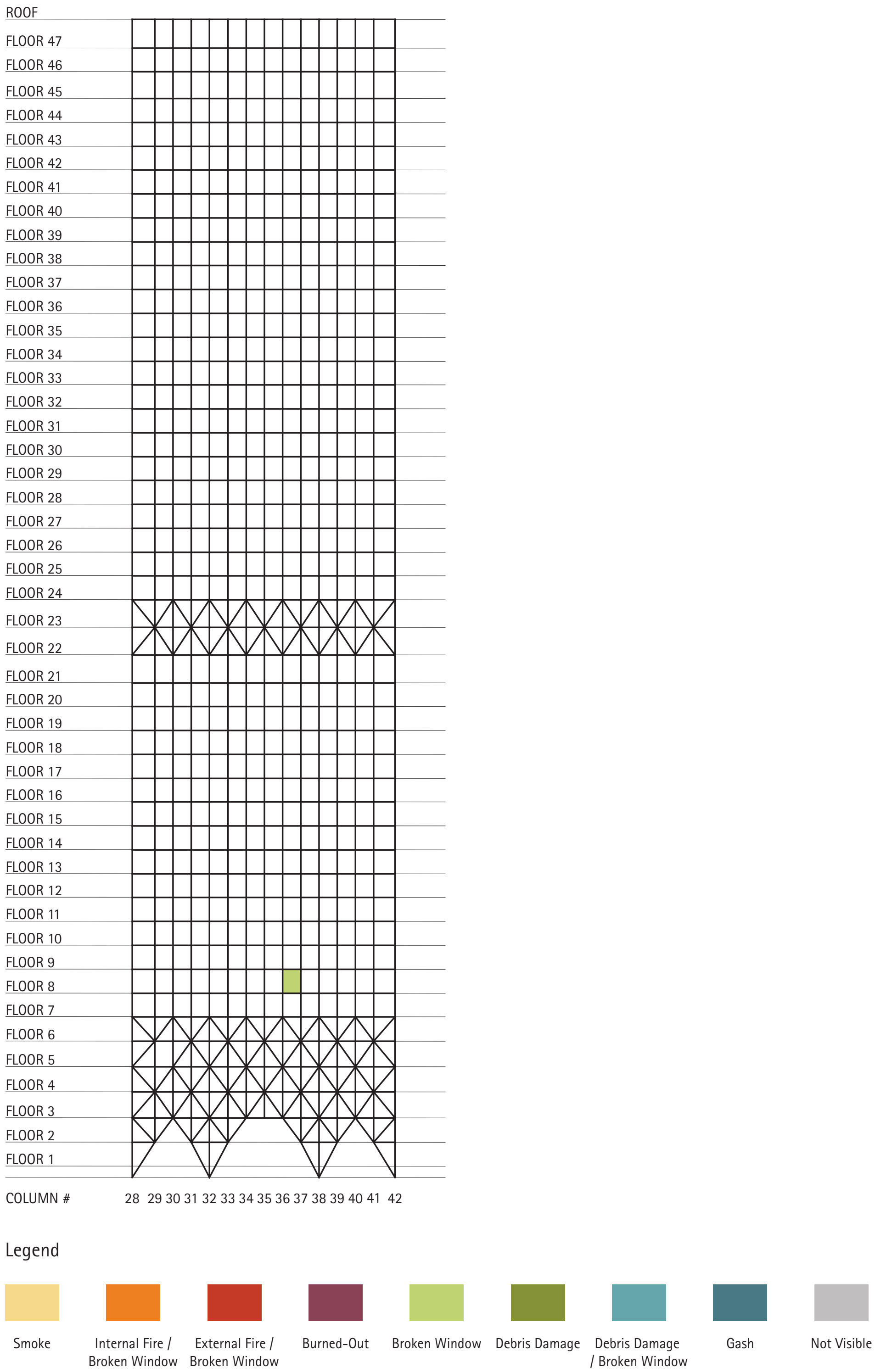


Figure 4.E.01 WTC7 East facade - Debris and Fire Damage at approximately 2PM

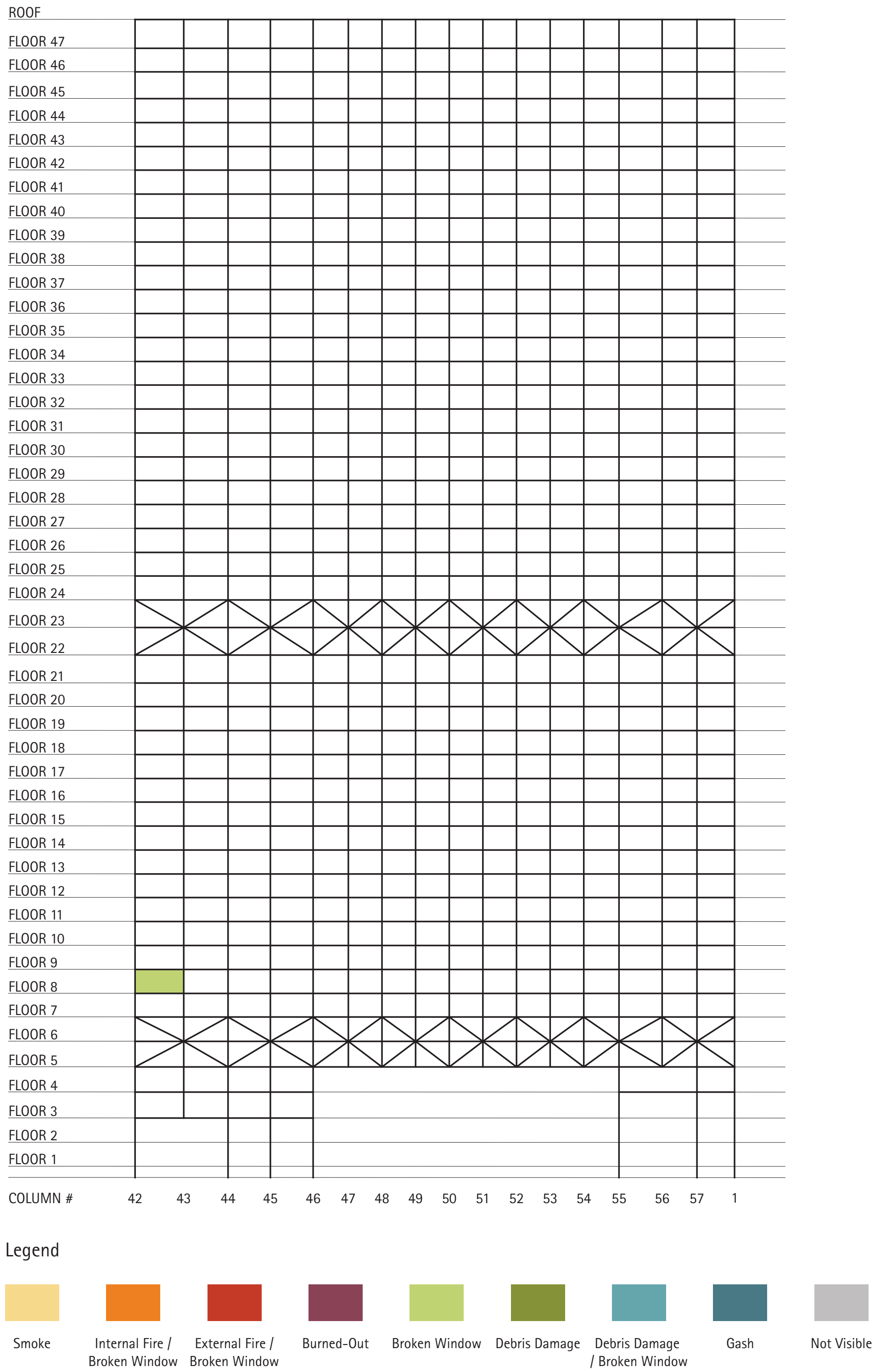


Figure 4.N.01 WTC7 North facade – Debris and Fire Damage at approximately 2PM

Guy Nordenson and Associates

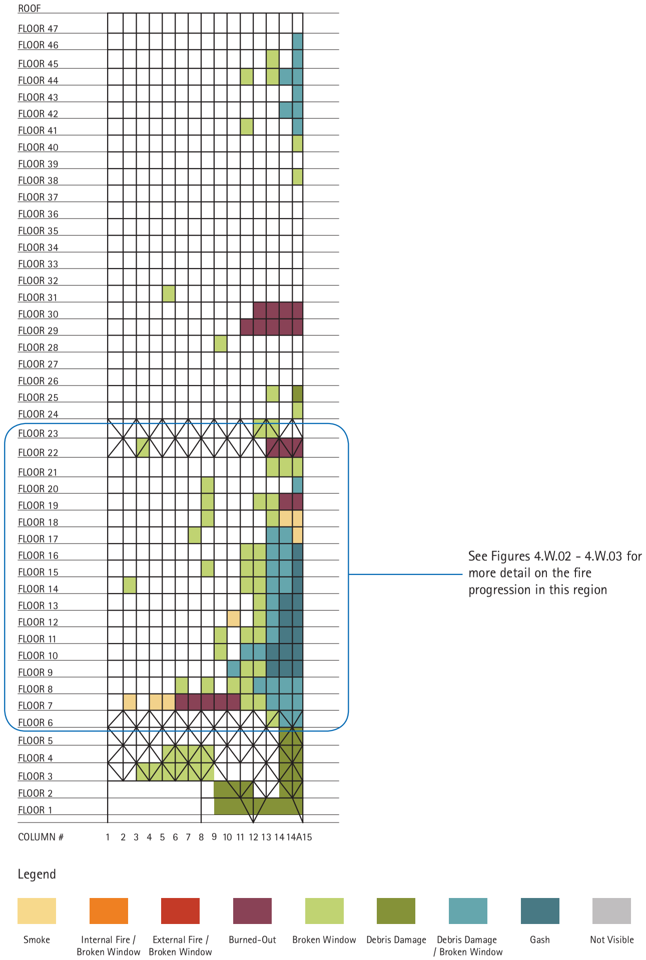


Figure 4.W.01 WTC7 West Facade - Debris and Fire Damage at approximately 2PM

Volume A - Photographic Timeline
Photographic Analysis Report
World Trade Center 7 Collapse Investigation
16 December 2009

ESTIMATED TIME 1:29:46PM +/-1s

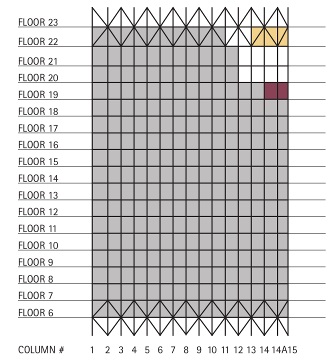


Diagram of Image 4.W.09

Image 4.W.09

ESTIMATED TIME 1:30PM-2:30PM

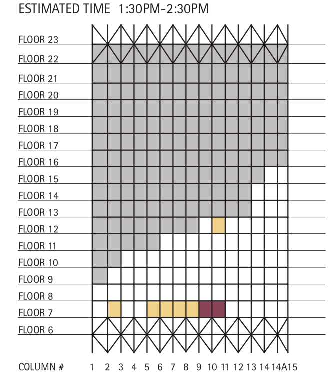


Diagram of Image 4.W.10

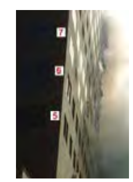


Image 4.W.10

Figure 4.W.02 WTC7 West Facade - Detailed Fire Progression from 1PM to 2PM

ESTIMATED TIME 1:30PM TO 2:30PM

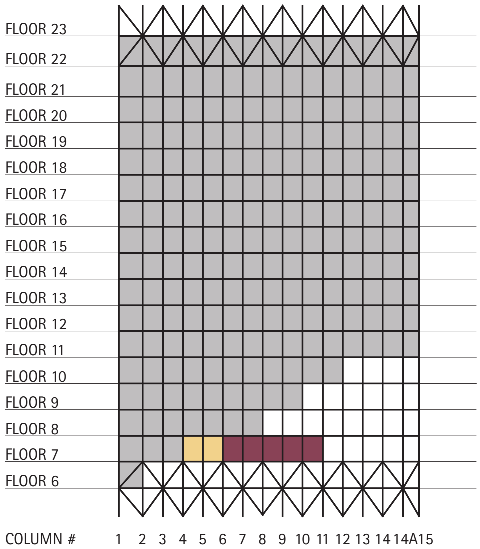


Diagram of Image 4.W.13

Image 4.W.13

ESTIMATED TIME SHORTLY AFTER 1:30PM

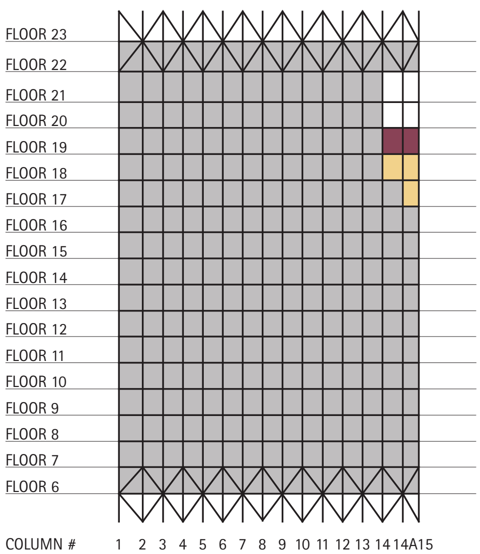


Diagram of Image 4.W.21

Image 4.W.21

Legend

Smoke | Internal Fire / Broken Window | External Fire / Broken Window | Burned-Out | Broken Window | Debris Damage | Debris Damage / Broken Window | Gash | Not Visible

Figure 4.W.03 WTC7 West Facade - Detailed Fire Progression from 1PM to 2PM

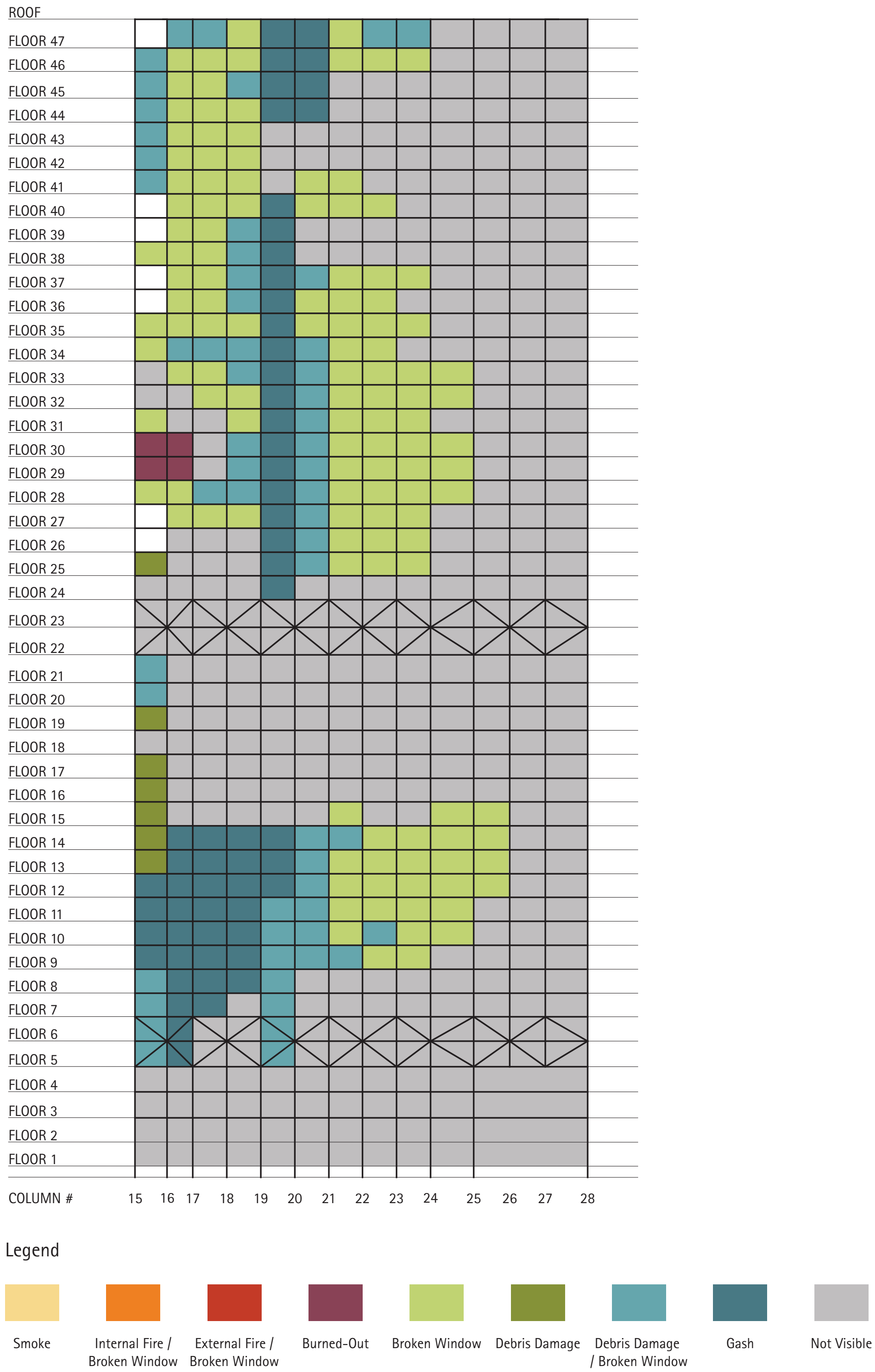
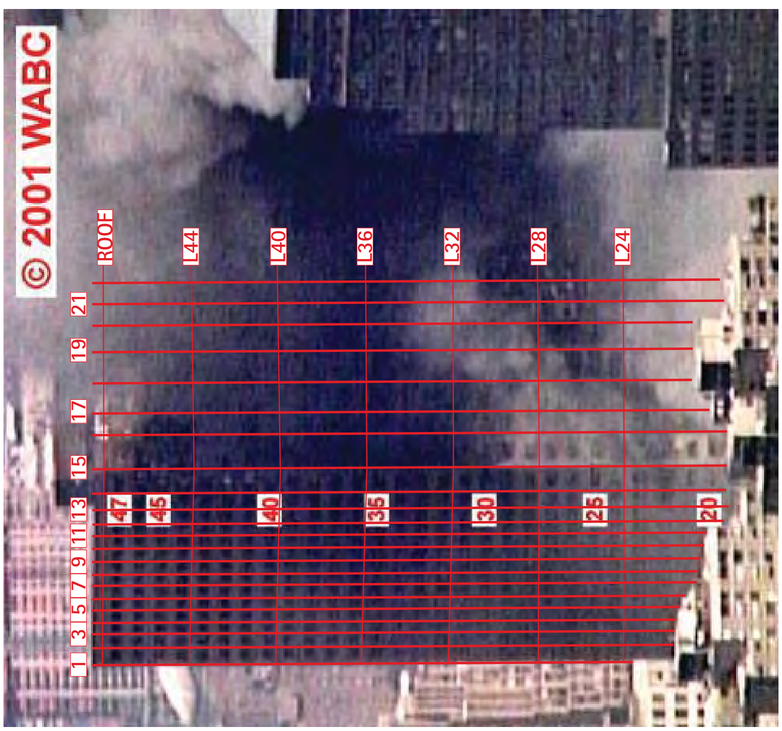


Figure 4.S.01 WTC7 South facade - Debris and Fire Damage at approximately 2PM

(Bottom)

Image 4.W.01 Southwest corner, around 1:00PM



(Bottom)

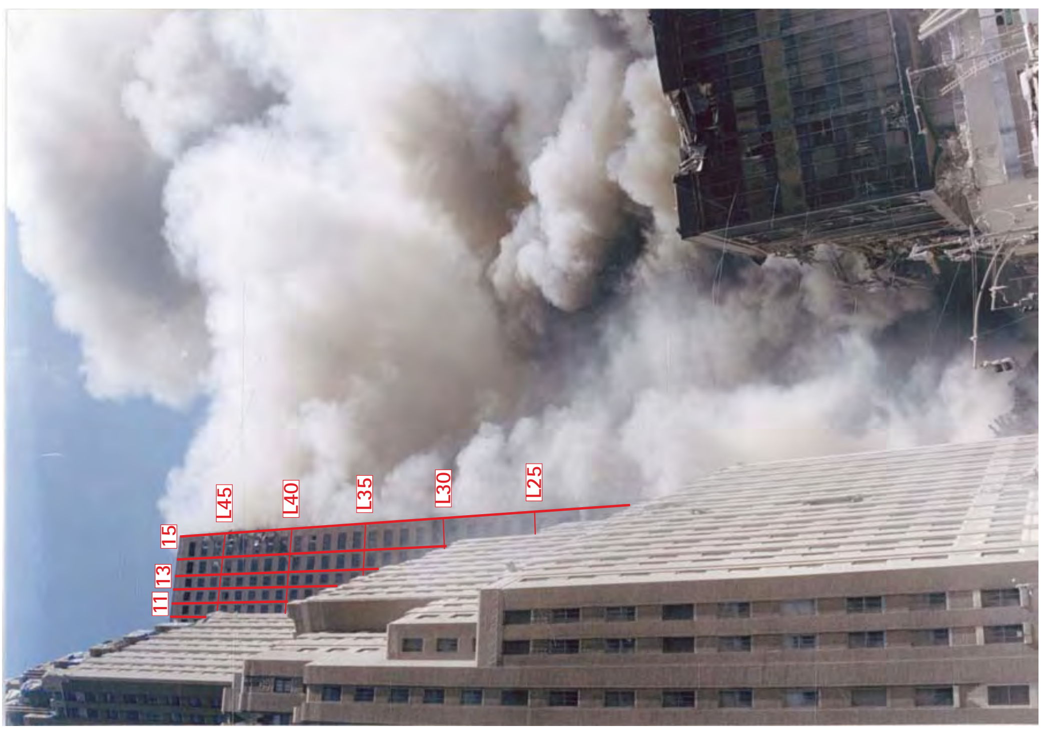
Image 4.W.01 with columns and floor levels overlaid

Image 4.W.02 Southwest corner, 1:03:44PM +/-1s

Image 4.W.02 with columns and floor levels overlaid

(Bottom)

Image 4.W.03 West facade, approximately 1:00PM-1:45PM



(Bottom)

Image 4.W.03 with columns and floor levels overlaid

Image 4.W.04 West facade, approximately 1:00PM-2:00PM

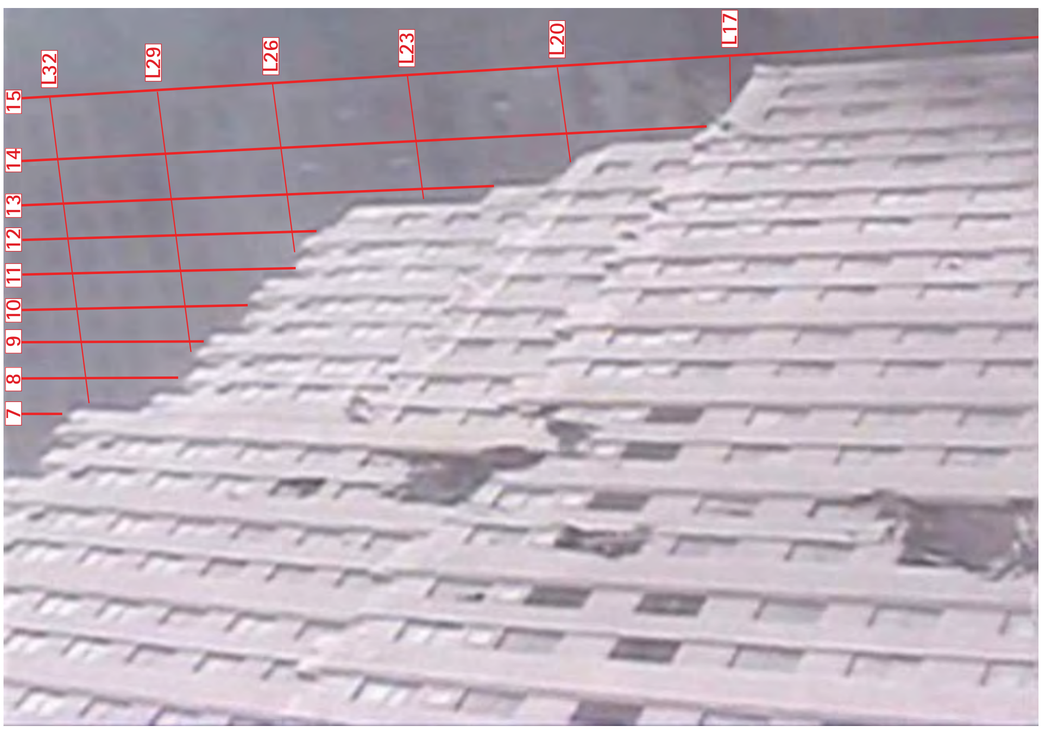


Image 4.W.04 with columns and floor levels overlaid

(Bottom)

Image 4.W.05 West facade, approximately 1:00PM-1:45PM

(Bottom)

Image 4.W.05 with columns and floor levels overlaid

(Bottom)

Image 4.W.06 West facade, 1:12:04PM +/-1s

(Bottom)

Image 4.W.06 with columns and floor levels overlaid

(Bottom)

Image 4.W.07 West facade, approximately 1:00PM-2:00PM

(Bottom)

Image 4.W.07 with columns and floor levels overlaid

(Bottom)

Image 4.W.08 Southwest corner, approximately 1:00PM-2:00PM

(Bottom)

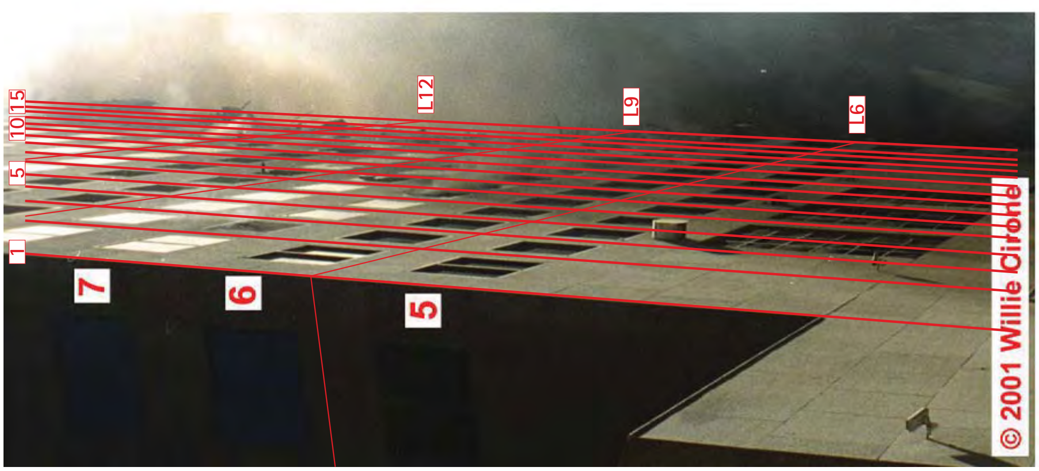
Image 4.W.08 with columns and floor levels overlaid

Image 4.W.09 Southwest corner, 1:29:46PM +/-1s

Image 4.W.09 with columns and floor levels overlaid

(Bottom)

Image 4.W.10 Northwest corner, 1:30PM-2:30PM



(Bottom)

Image 4.W.10 with columns and floor levels overlaid

Image 4.W.11 Northwest corner, approximately 1:30PM–2:30PM

Image 4.W.11 with columns and floor levels overlaid

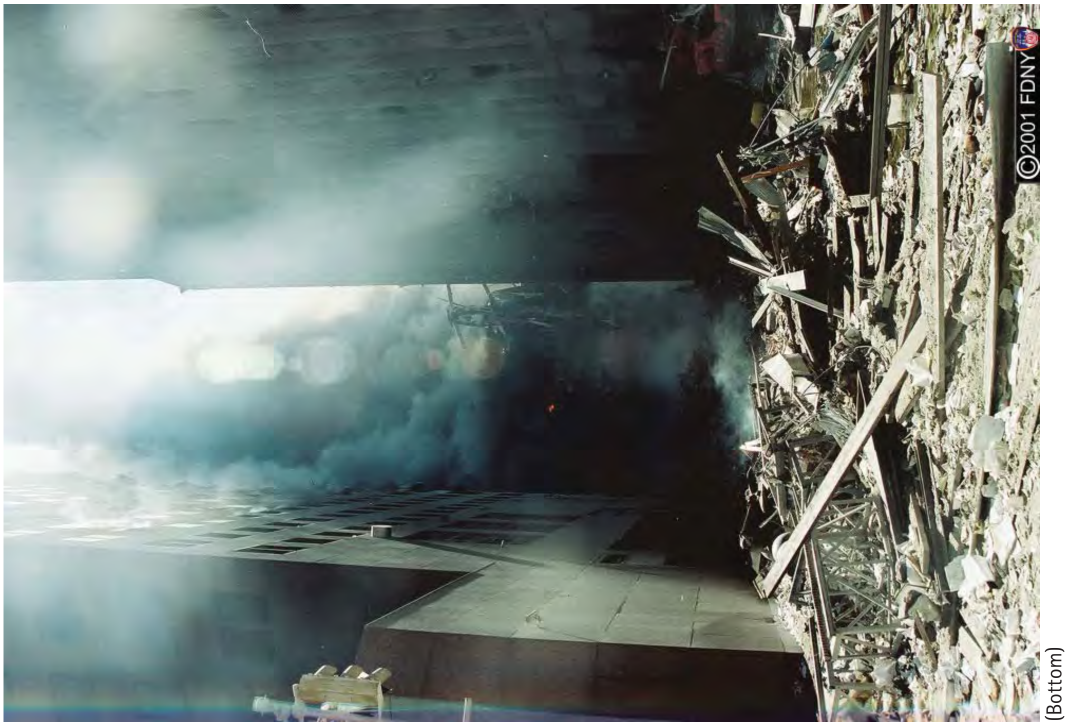


Image 4.W.12 Northwest corner, approximately 1:30PM–2:30PM

Image 4.W.12 with columns and floor levels overlaid

Image 4.W.13 Northwest corner, approximately 1:30PM–2:30PM

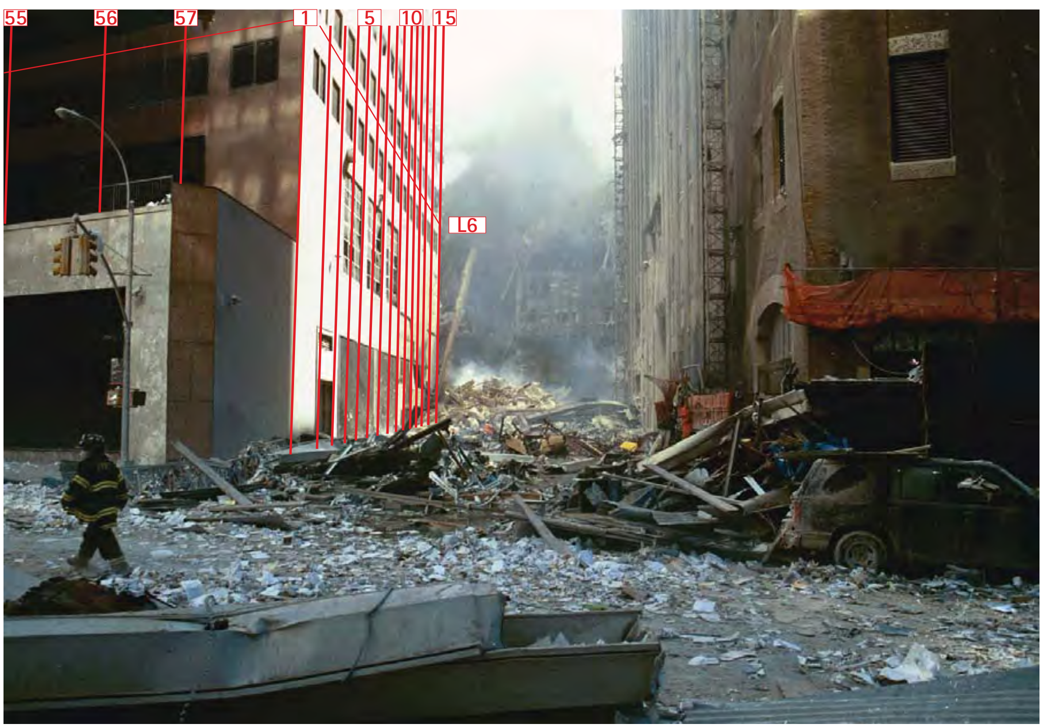
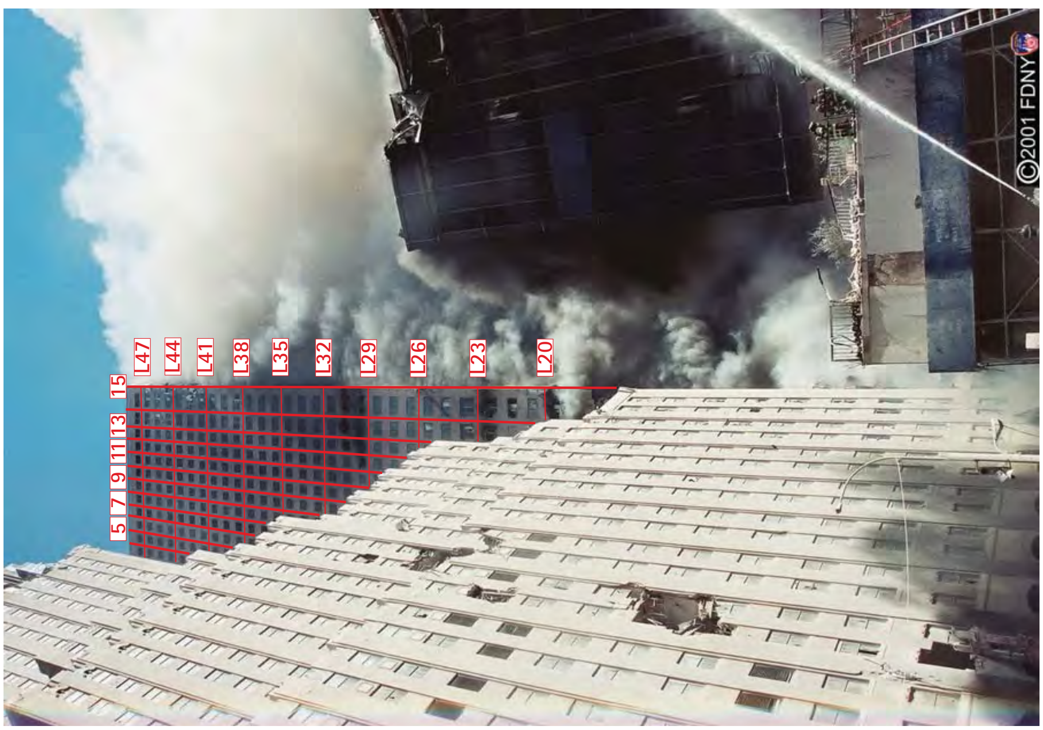


Image 4.W.13 with columns and floor levels overlaid

(Bottom)

Image 4.W.14 West facade, approximately 1:00PM-2:00PM



(Bottom)

Image 4.W.14 with columns and floor levels overlaid

Image 4.W.15 Southwest corner, approximately 1:30PM-2:00PM

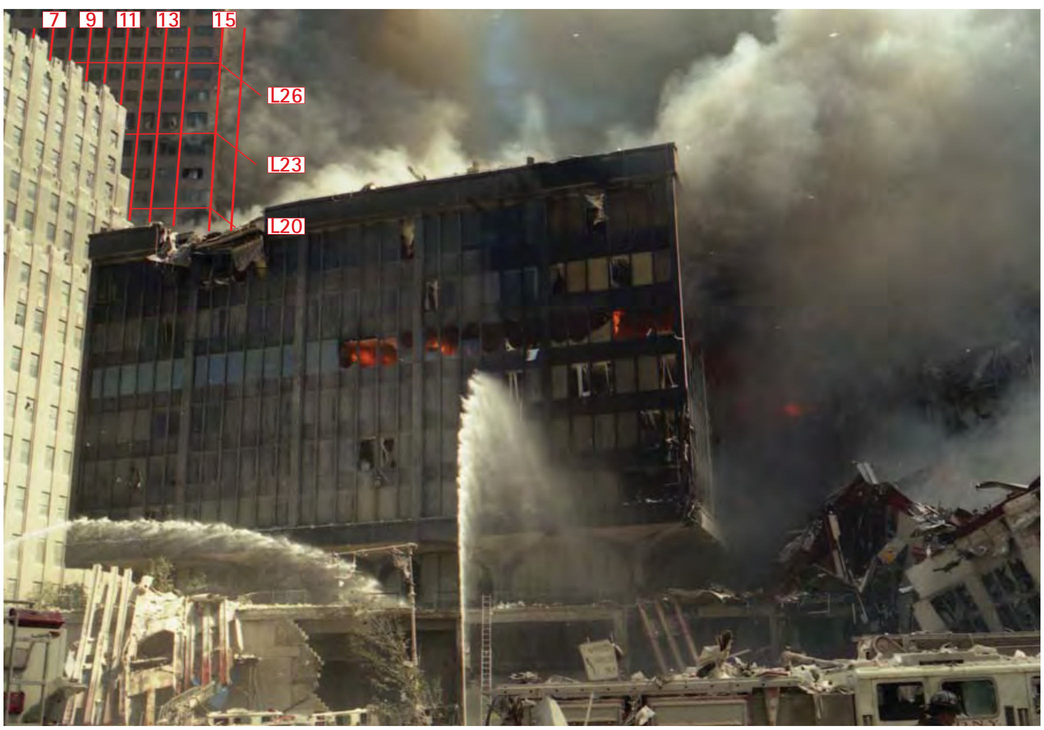


Image 4.W.15 with columns and floor levels overlaid

Image 4.W.16 West facade, approximately 1:30PM - 2:30PM

Image 4.W.16 with columns and floor levels overlaid

Image 4.W.17 West facade, approximately 1:30PM-2:00PM

Image 4.W.17 with columns and floor levels overlaid

Image 4.W.18 West facade, approximately 1:30PM-2:00PM

Image 4.W.18 with columns and floor levels overlaid

Image 4.W.19 West facade, approximately 1:30PM - 2:00PM

Image 4.W.19 with columns and floor levels overlaid

Image 4.W.20 Southwest corner, approximately 1:30PM-2:00PM

Image 4.W.20 with columns and floor levels overlaid

Image 4.W.21 Southwest corner, shortly after 1:30PM

Image 4.W.21 with columns and floor levels overlaid

(Bottom)

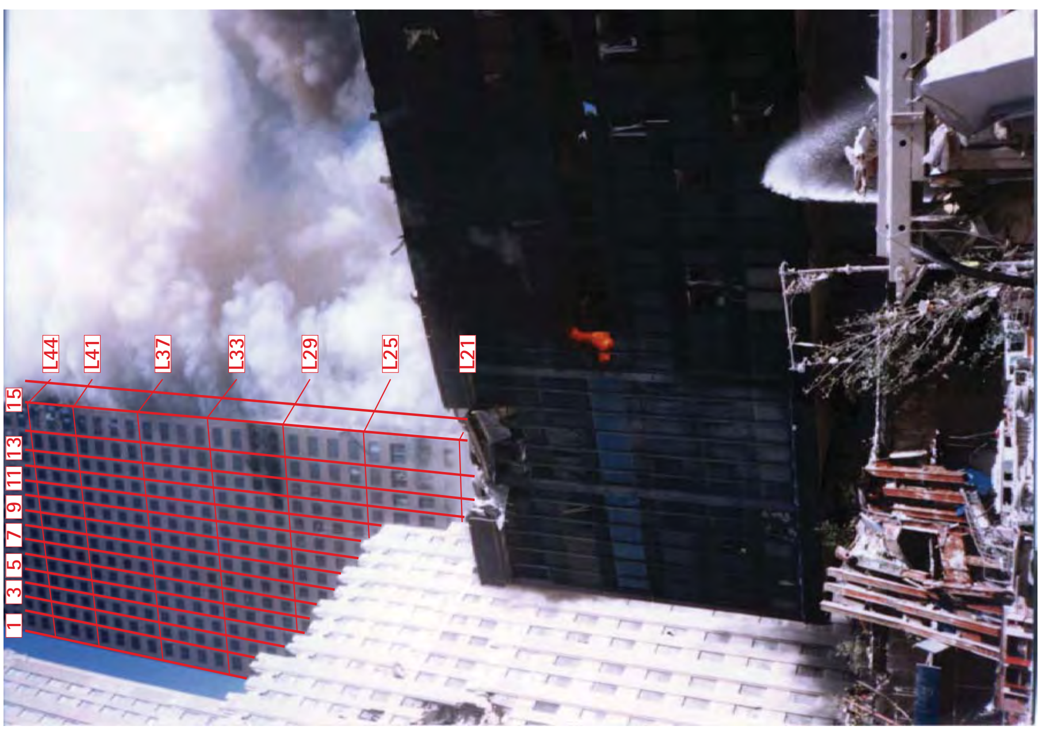
Image 4.W.22 Southwest corner, shortly after 1:30PM

(Bottom)

Image 4.W.22 with columns and floor levels overlaid

(Bottom)

Image 4.W.23 Southwest corner, approximately 1:30PM-2:00PM



(Bottom)

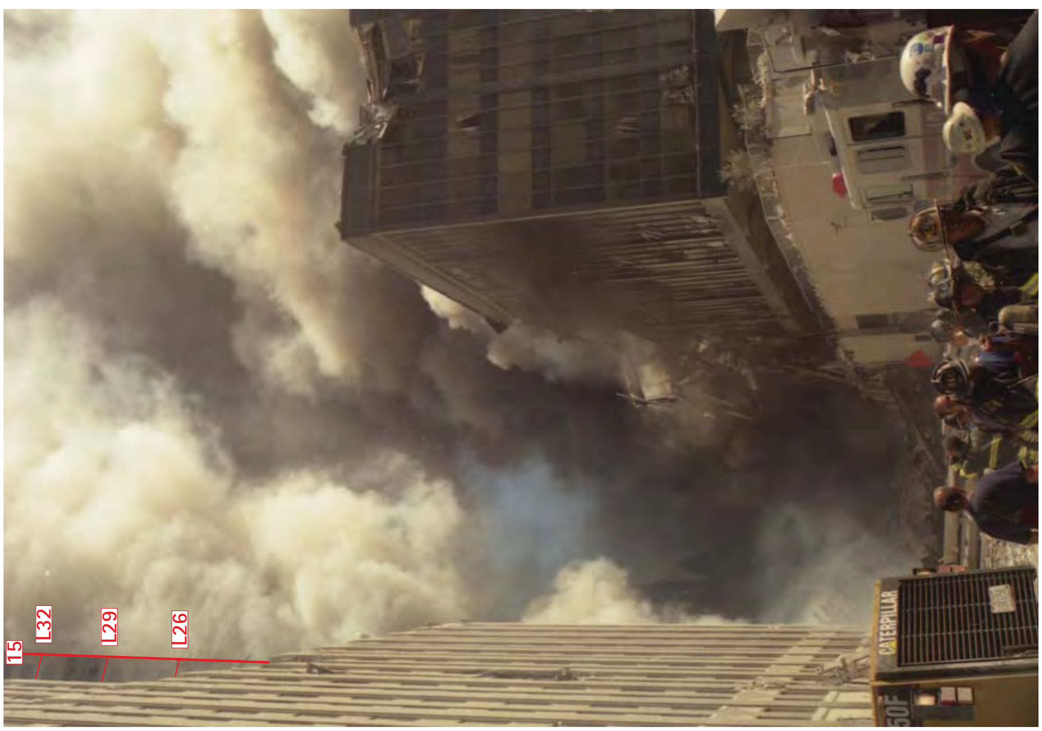
Image 4.W.23 with columns and floor levels overlaid

Image 4.W.24 West facade, approximately 1:30PM-2:00PM

Image 4.W.24 with columns and floor levels overlaid

(Bottom)

Image 4.W.25 West facade, approximately 1:00PM-2:00PM

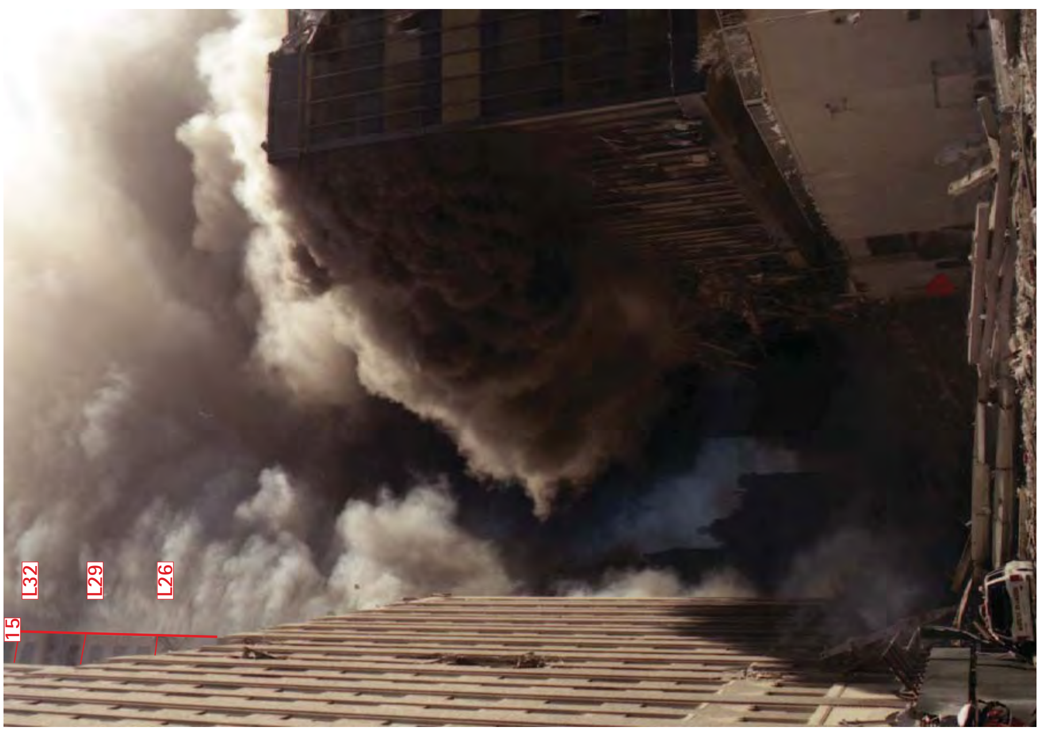


(Bottom)

Image 4.W.25 with columns and floor levels overlaid

(Bottom)

Image 4.W.26 West facade, approximately 1:00PM -2:00PM



(Bottom)

Image 4.W.26 with columns and floor levels overlaid

(Bottom)

Image 4.W.27 West facade, approximately 1:30PM-2:00PM

(Bottom)

Image 4.W.27 with columns and floor levels overlaid

A.5 FIRE PROGRESSION - 2PM TO 3PM

East Facade - A large succession of images show that fires burned on levels 11, 12 and 13 for at least the first half of the hour. On each floor it appears that fires originated in the southern portion of the facade and began moving north, not yet reaching the northeast corner during this time period.

North Facade - During this time period, visual evidence shows that fires were burning on levels 7 and 12 at the end of the hour. Also, a photograph shows that at the middle of the hour windows had already burned-out on level 7 near the northwest corner.

West Facade - Photographs during this time period show that smoke is once again present on levels 17 and 18. Similarly, smoke is visible at new locations on floors 7, 17, and 18. By the end of the hour many of these windows have subsequently burned-out along with an additional window on level 30.

South Facade - The visual evidence for this time period shows that windows at the southwest corner on levels 21 to 23 and 31 to 33 have burned-out. Furthermore photographs show that additional windows are burned-out at levels 29 and 30.

A.5.1 Fire Damage Diagrams

Figures 5.E.01, 5.N.01, 5.W.01, and 5.S.01 on pages 130 to 134 depict the condition of each elevation at the end of this time period as evidenced in the available images. These diagrams are cumulative and contain the fire-related damage timed up until 3:00pm as well as the debris damage from WTC1's collapse. Fire damage types include smoke, broken window with internal fire, broken window with external fire, and burned-out. The fire-related damage on these figures represents a compilation of the last available visual evidence for each area within hour; therefore, these diagrams are only an approximation of what the elevation might have looked like at 3:00pm.

Figures 5.E.02 5.E.03 and 5.W.02 on pages 130, 131, and 133 depict a series of sequential images showing the progression of fire in particular areas of the east and west façades during this time increment. While the full elevation diagrams represent the condition of each facade at the end of the time period, the detail elevation mappings illustrate how fire traveled or altered throughout the hour in a specific area. Debris damage has been omitted from these diagrams for clarity.

A.5.2 Photographs of Damage

The images found on pages 135 to 201 are all the images that show fire-related damage and are attributed to the time period from 2:00pm until 3:00pm. Each image is presented twice on one page; the top image is the untouched version while columns and level markers have been added to the lower image for reference. In some instances an untouched version of the photograph was not available and in its place an image that NIST has notated is used instead. These images are also shown twice with additional column and level markers added for full clarity.

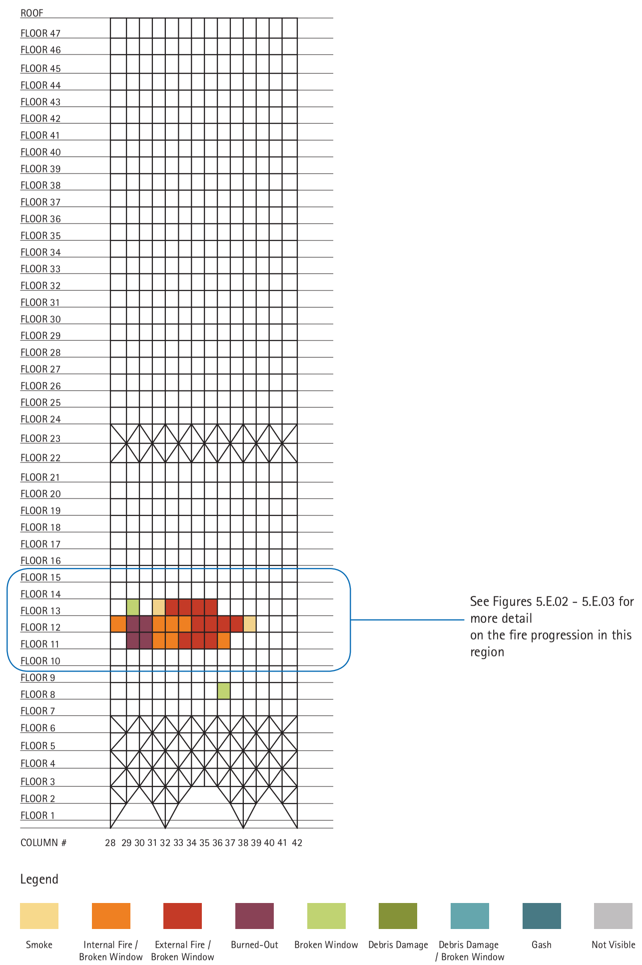


Figure 5.E.01 WTC7 East Facade - Debris and Fire Damage at approximately 3PM

Volume A - Photographic Timeline
Photographic Analysis Report
World Trade Center 7 Collapse Investigation
16 December 2009

ESTIMATED TIME 2:00PM-2:08PM

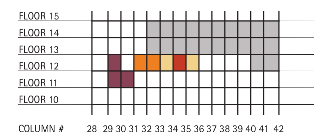


Diagram of Image 5.E.02

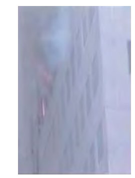


Image 5.E.02

ESTIMATED TIME 2:11:19PM +/-1s

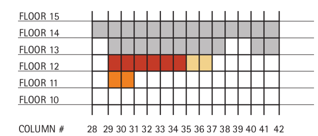


Diagram of Image 5.E.13

Image 5.E.13

ESTIMATED TIME 2:14:29PM +/-1s

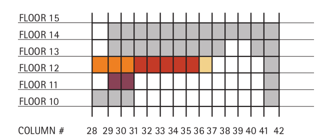


Diagram of Image 5.E.22

Image 5.E.22

ESTIMATED TIME 2:15PM TO 2:28PM

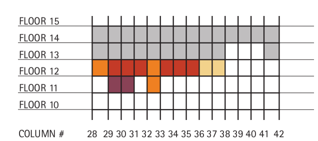


Diagram of Image 5.E.30

Image 5.E.30

Figure 5.E.02 WTC7 East Facade - Detailed Fire Progression from 2PM to 3PM

ESTIMATED TIME 2:15PM-2:28PM

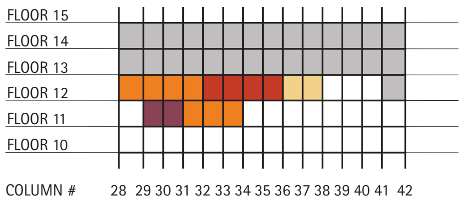


Diagram of Image 5.E.32

Image 5.E.32

ESTIMATED TIME 2:28:43PM +/-1s

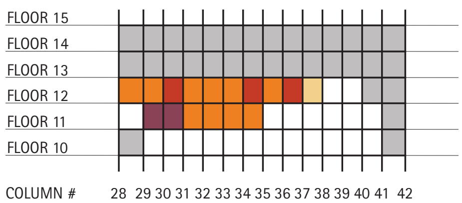


Diagram of Image 5.E.53

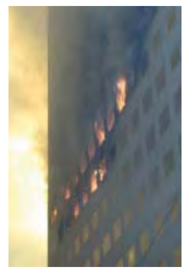


Image 5.E.53

ESTIMATED TIME 2:28PM TO 3:10PM

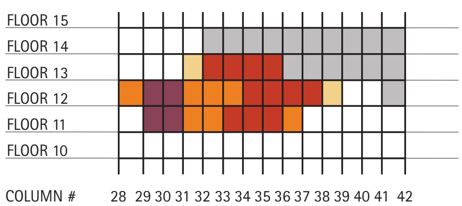


Diagram of Image 5.E.54

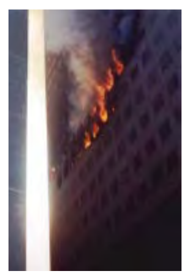


Image 5.E.54

Legend

Figure 5.E.03 WTC7 East Facade - Detailed Fire Progression from 2PM to 3PM

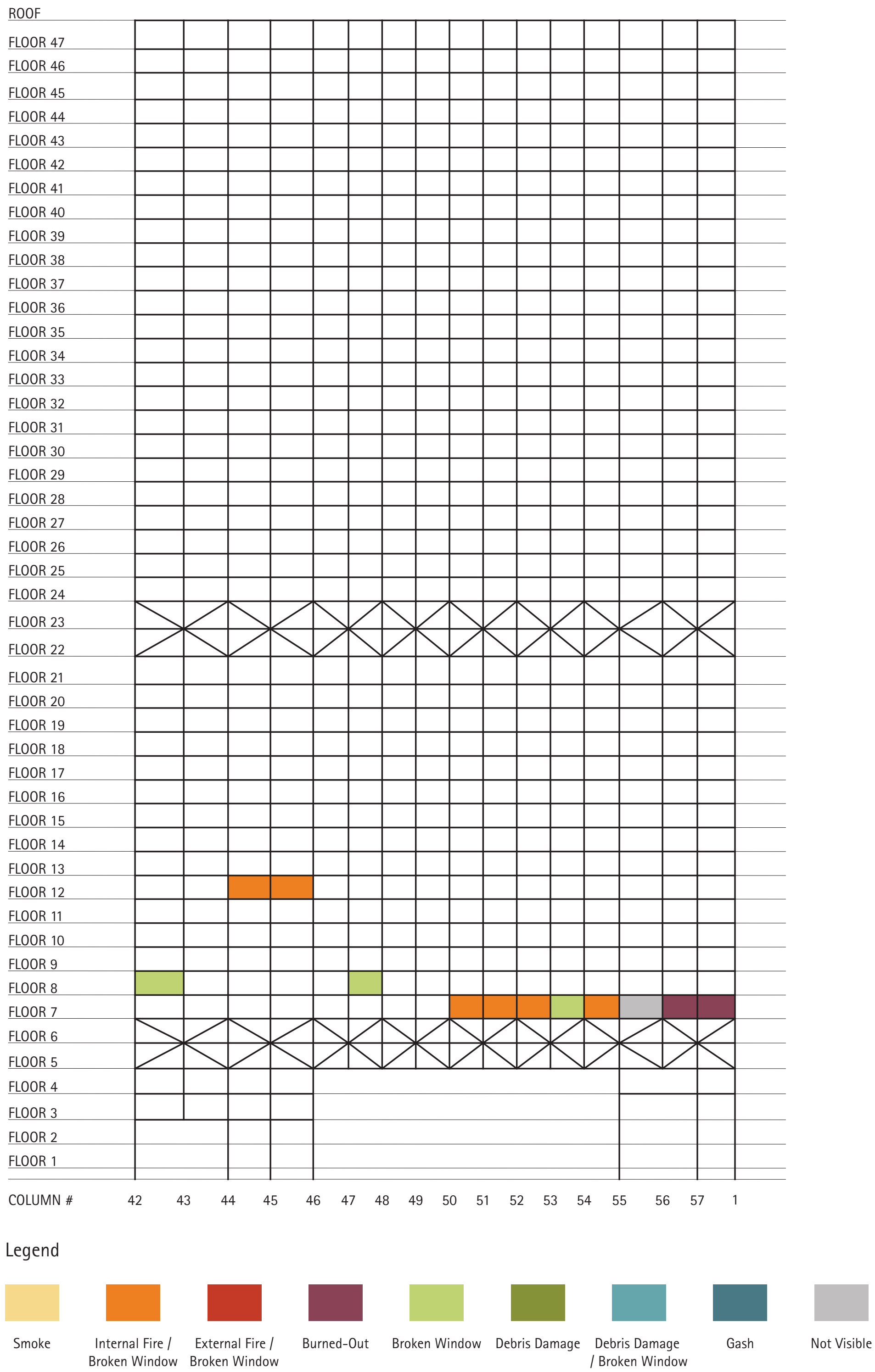


Figure 5.N.01 WTC7 North facade – Debris and Fire Damage at approximately 3PM

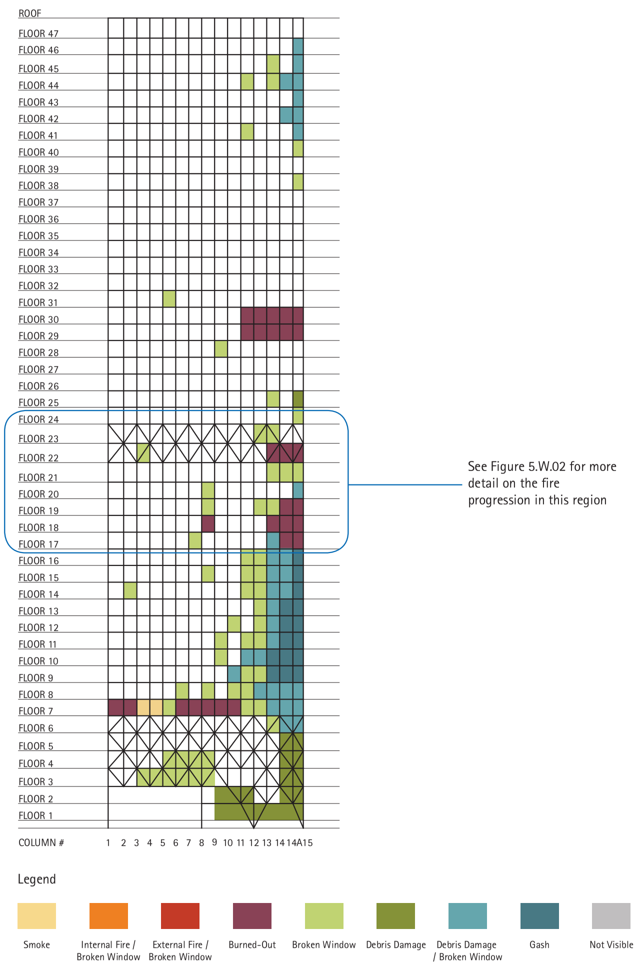


Figure 5.W.01 WTC7 West Facade - Debris and Fire Damage at approximately 3PM

ESTIMATED TIME 2:00PM TO 3:00PM

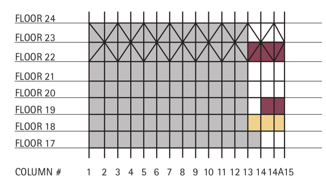


Diagram of Image 5.W.04

Image 5.W.04

ESTIMATED TIME 2:15PM TO 2:45PM

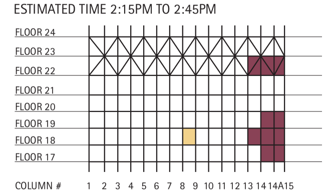


Diagram of Image 5.W.06

Image 5.W.06

ESTIMATED TIME 2:00PM TO 3:30PM

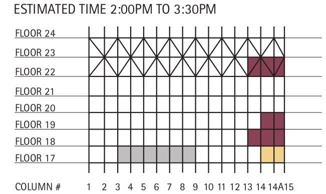


Diagram of Image 5.W.09

Image 5.W.09

ESTIMATED TIME 2:30PM TO 3:00PM

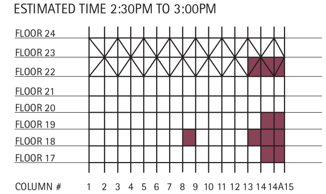


Diagram of Image 5.W.10

Image 5.W.10

Figure 5.W.02 WTC7 West Facade - Detailed Fire Progression from 2PM to 3PM

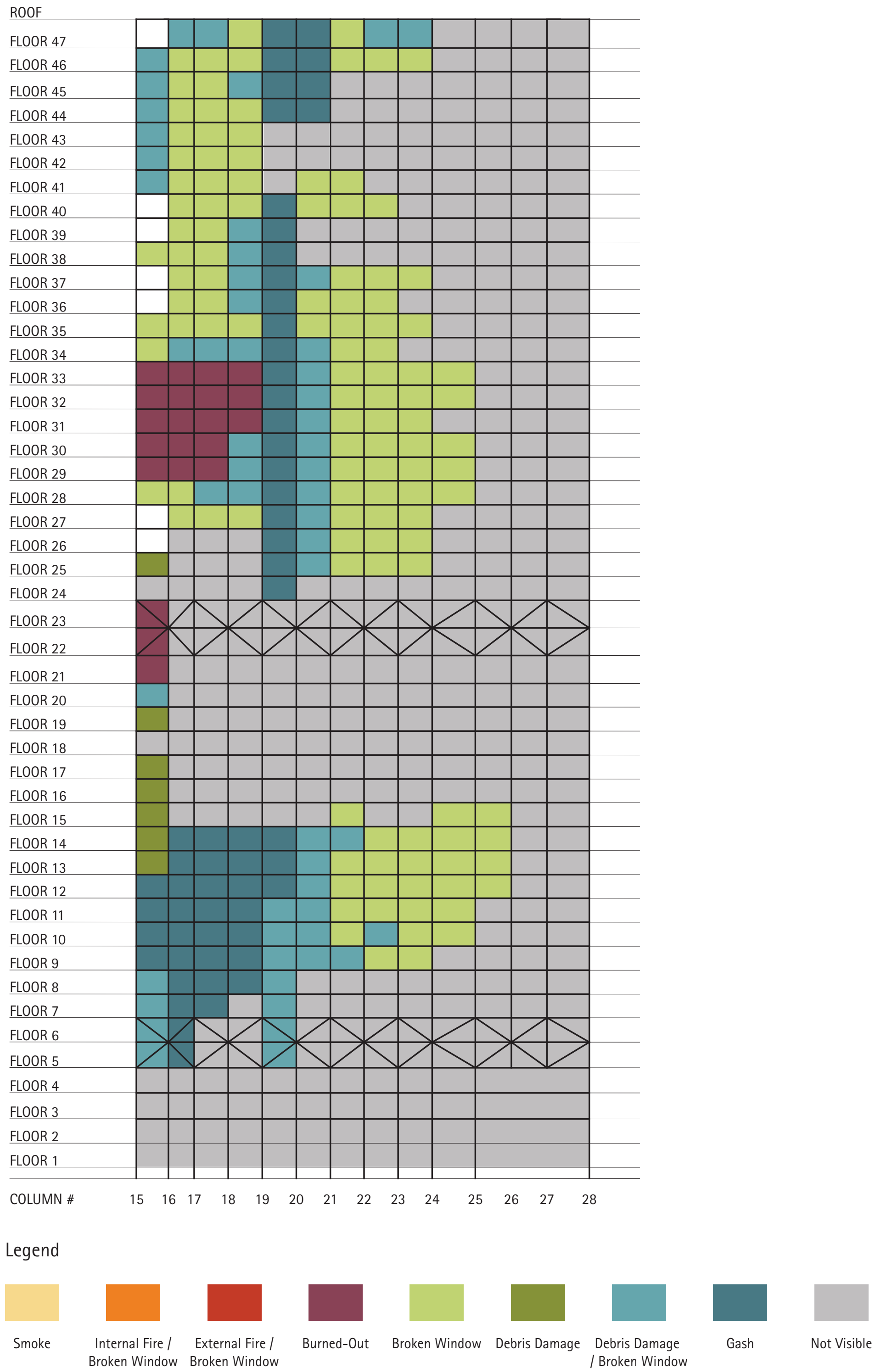


Figure 5.S.01 WTC7 South facade - Debris and Fire Damage at approximately 3PM

(Bottom)

Image 5.E.01 Northeast corner, approximately 2:00PM-2:28PM

(Bottom)

Image 5.E.01 with columns and floor levels overlaid

Image 5.E.02 Northeast corner, approximately 2:00PM-2:08PM

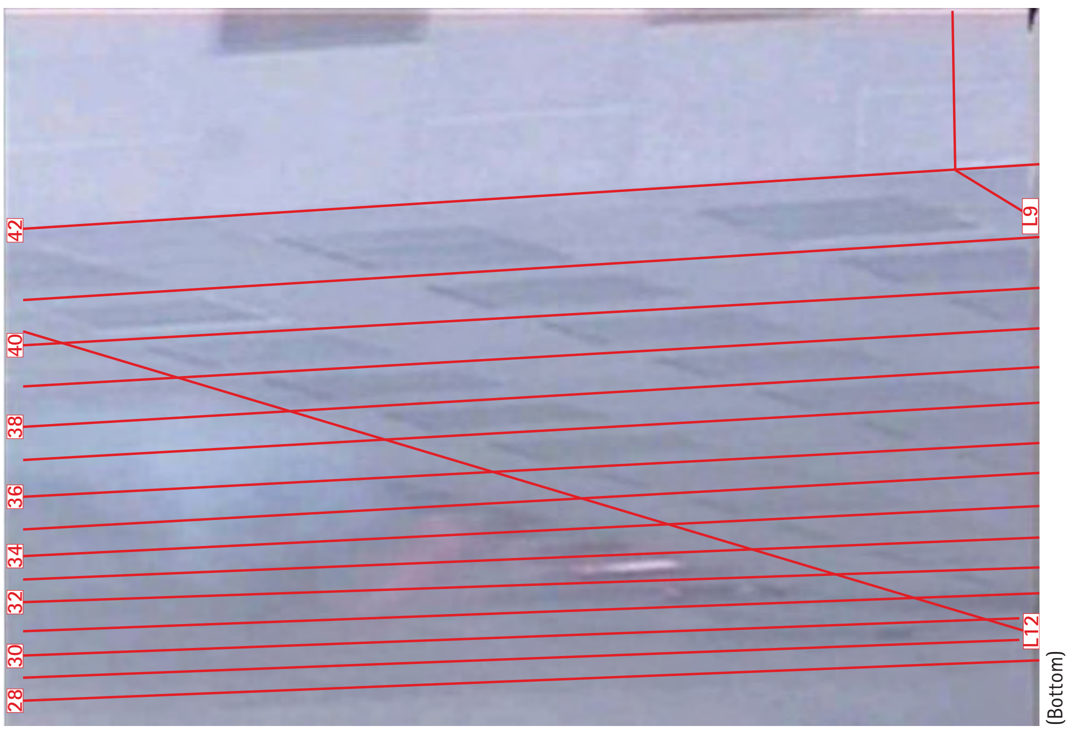


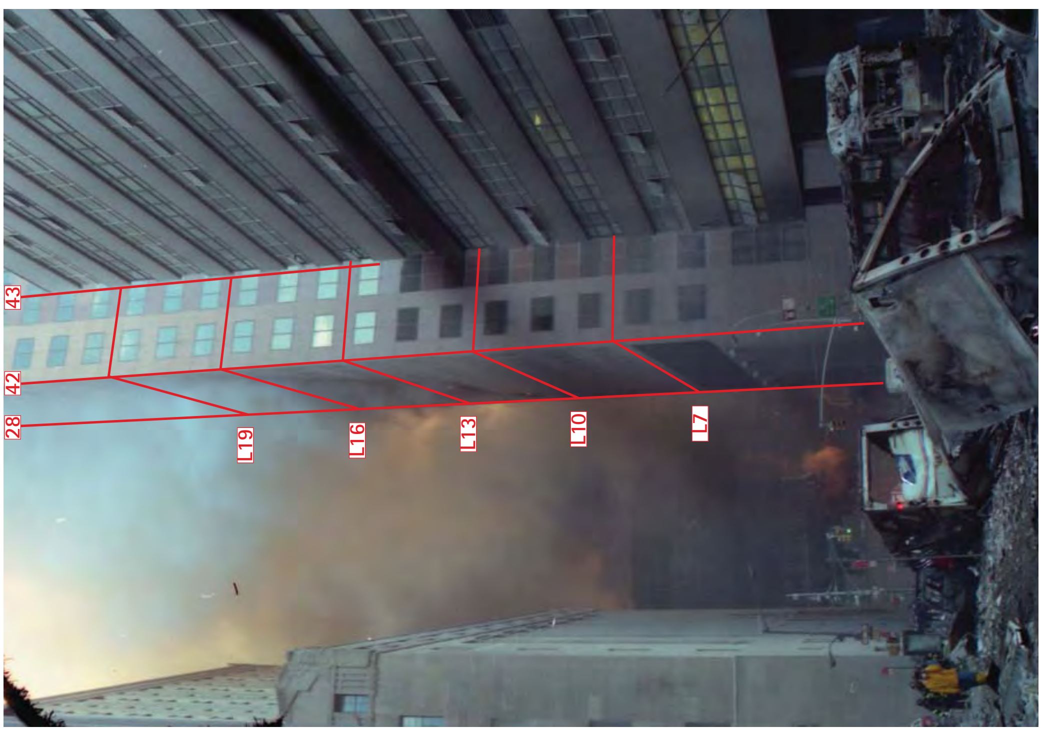
Image 5.E.02 with columns and floor levels overlaid

Image 5.E.03 Northeast corner, approximately 2:00PM-2:08PM

Image 5.E.03 with columns and floor levels overlaid

(Bottom)

Image 5.E.04 Northeast corner, approximately 2:00PM-2:08PM

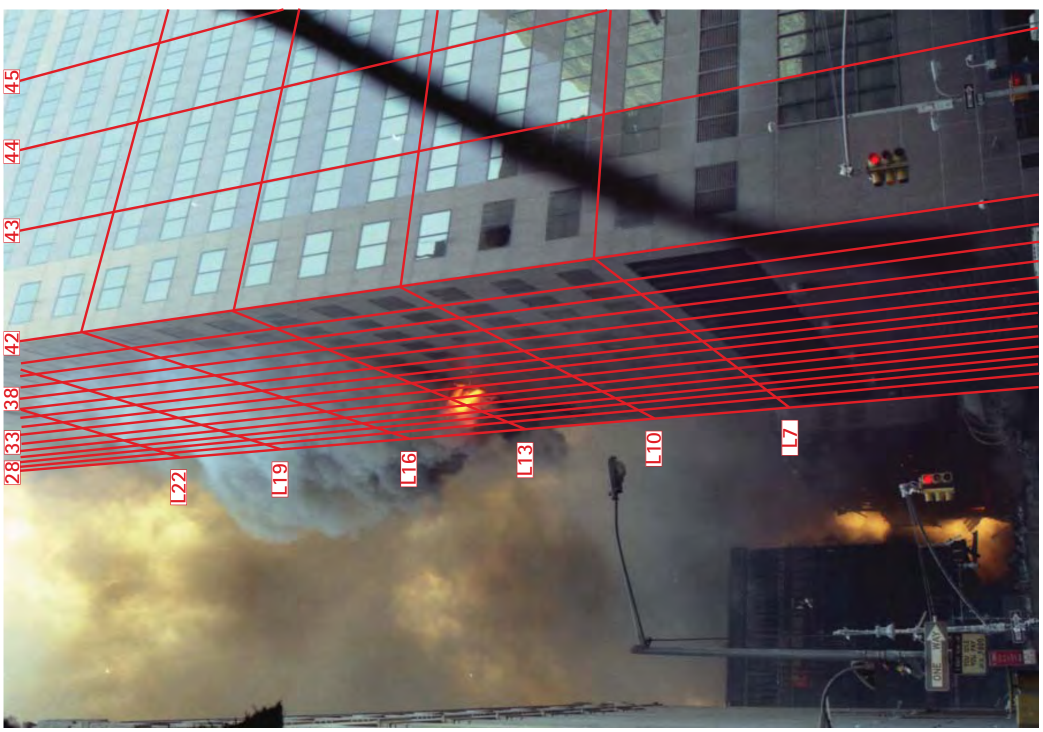


(Bottom)

Image 5.E.04 with columns and floor levels overlaid

(Bottom)

Image 5.E.05 Northeast corner, approximately 2:00PM-2:08PM



(Bottom)

Image 5.E.05 with columns and floor levels overlaid

Image 5.E.06 Northeast corner, approximately 2:00PM-2:08PM

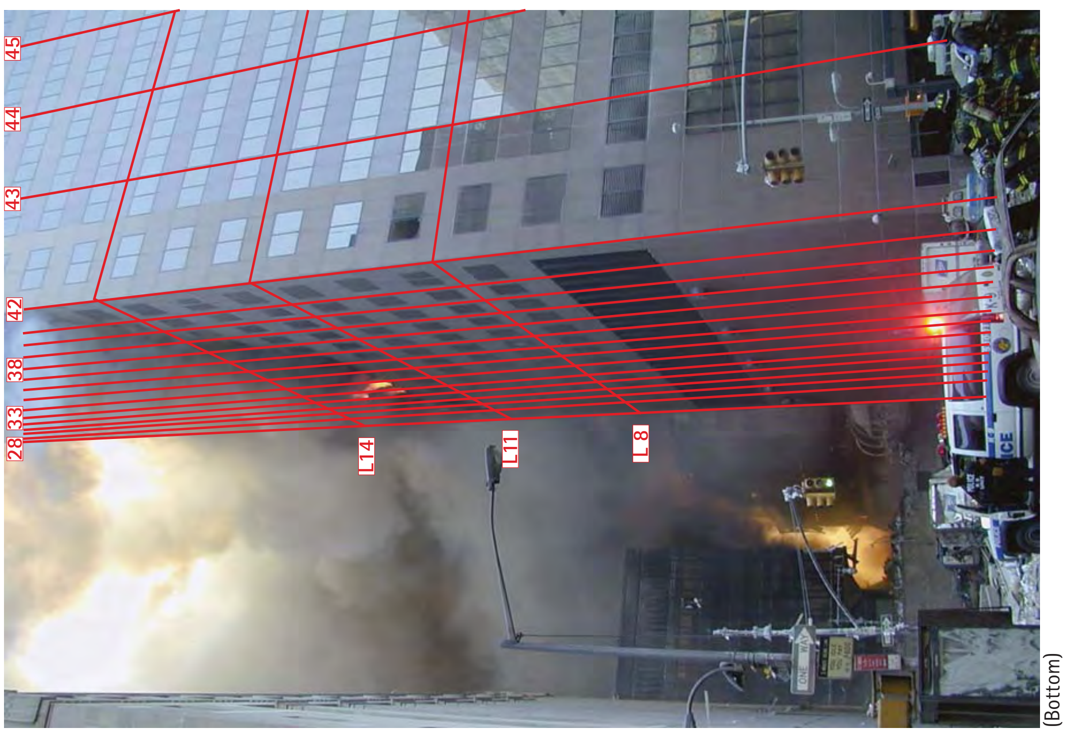


Image 5.E.06 with columns and floor levels overlaid

Image 5.E.07 Northeast corner, approximately 2:00PM–2:08PM

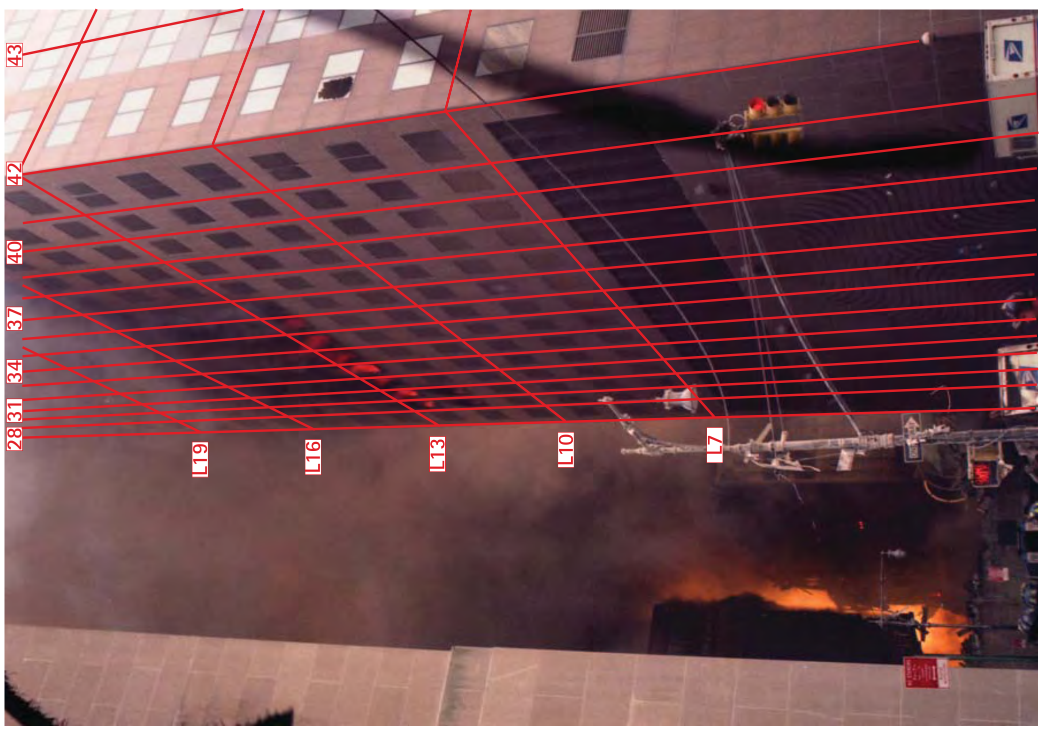


Image 5.E.07 with columns and floor levels overlaid

Image 5.E.08 Northeast corner, 2:08:28PM +/-1S

Image 5.E.08 with columns and floor levels overlaid

Image 5.E.09 Northeast corner, 2:08:45PM +/-1S

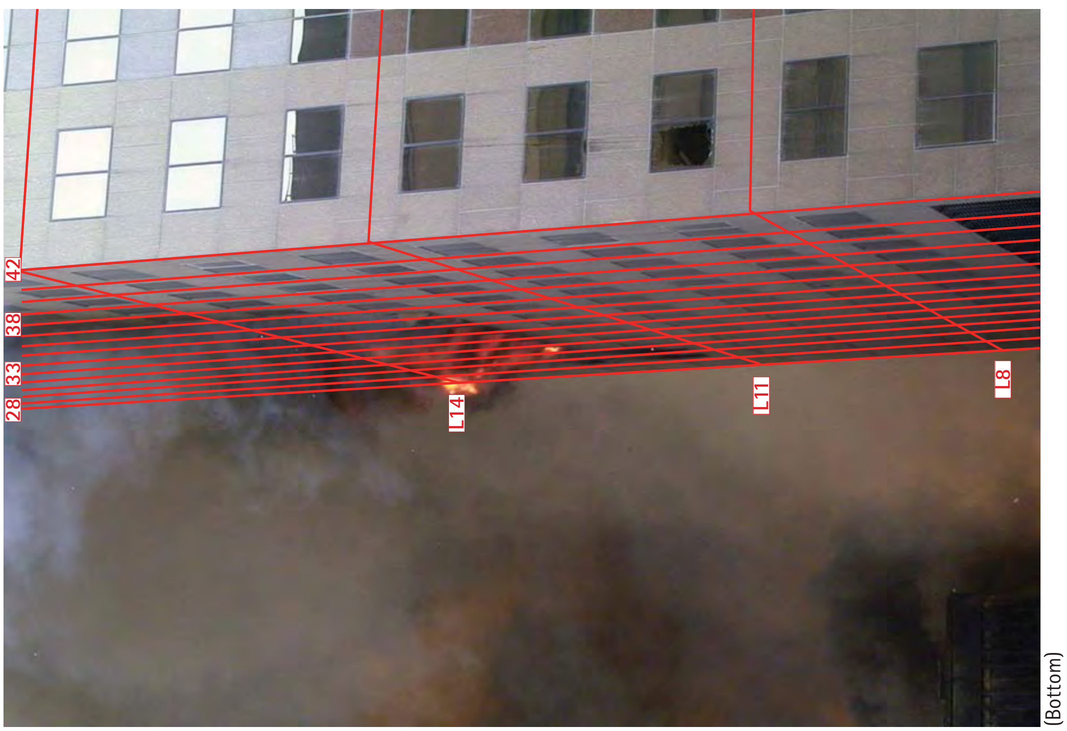
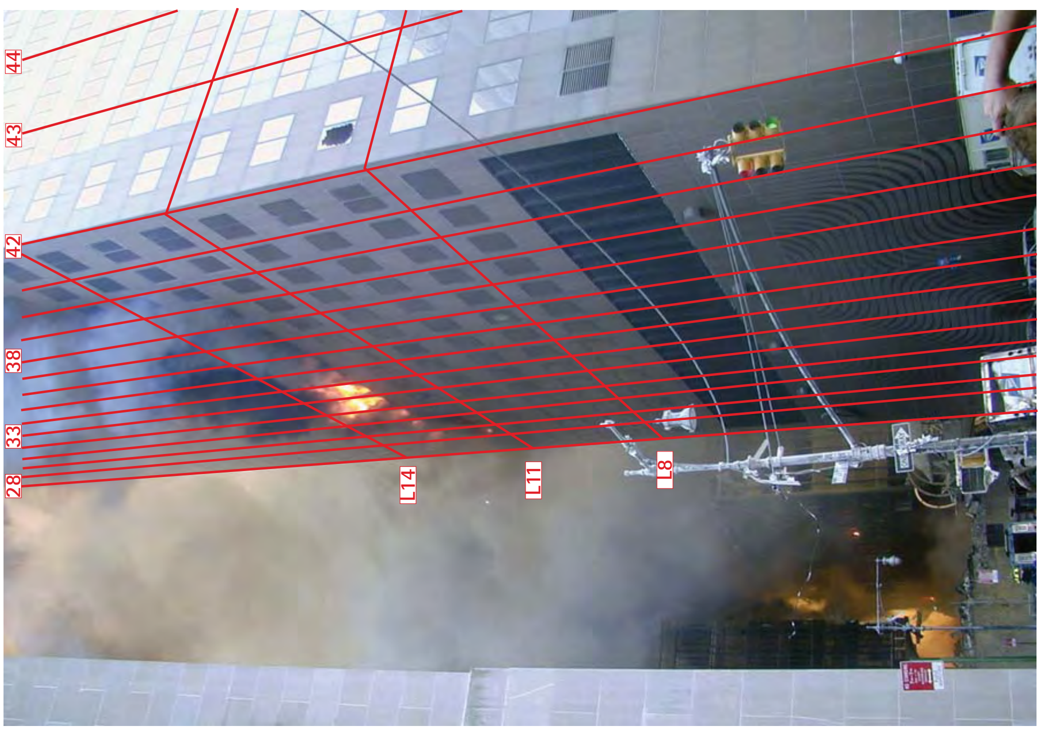


Image 5.E.09 with columns and floor levels overlaid

(Bottom)

Image 5.E.10 Northeast corner, 2:09:54PM +/-1S



(Bottom)

Image 5.E.10 with columns and floor levels overlaid

Image 5.E.11 East facade, 2:10:56PM +/-1S

Image 5.E.11 with columns and floor levels overlaid

Image 5.E.12 Northeast corner, 2:11:09PM +/-1S

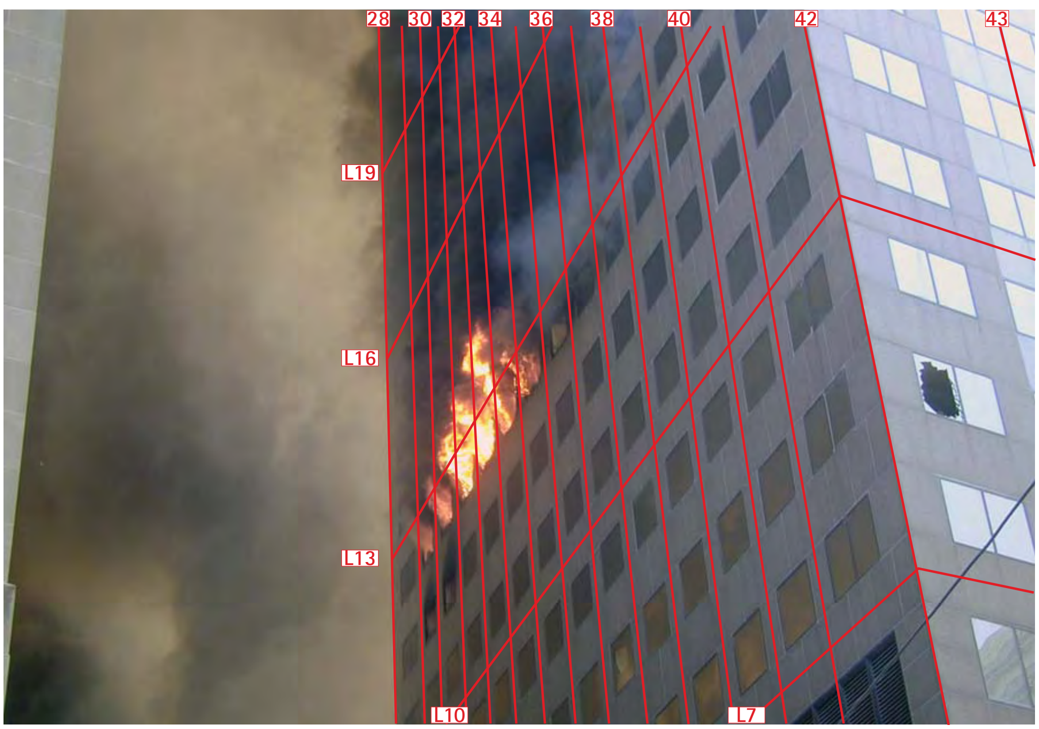


Image 5.E.12 with columns and floor levels overlaid

Image 5.E.13 Northeast corner, 2:11:19PM +/-1S

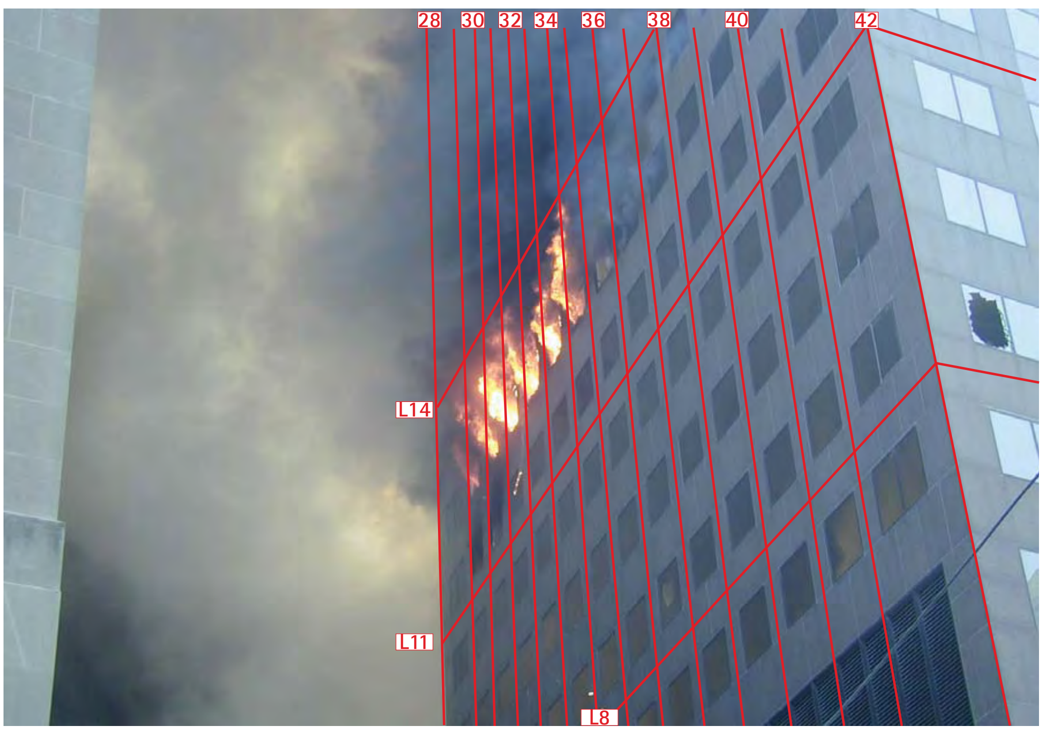


Image 5.E.13 with columns and floor levels overlaid

Image 5.E.14 East facade, 2:11:26PM +/-1S

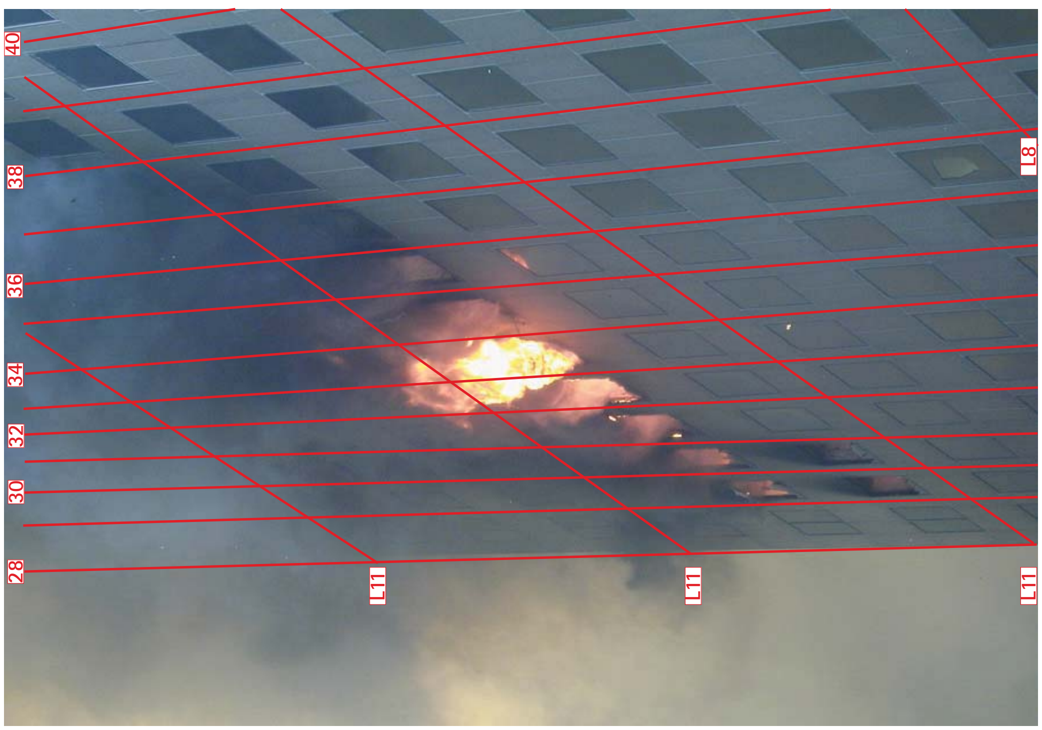


Image 5.E.14 with columns and floor levels overlaid

Image 5.E.15 East facade, 2:12:57PM +/-1S

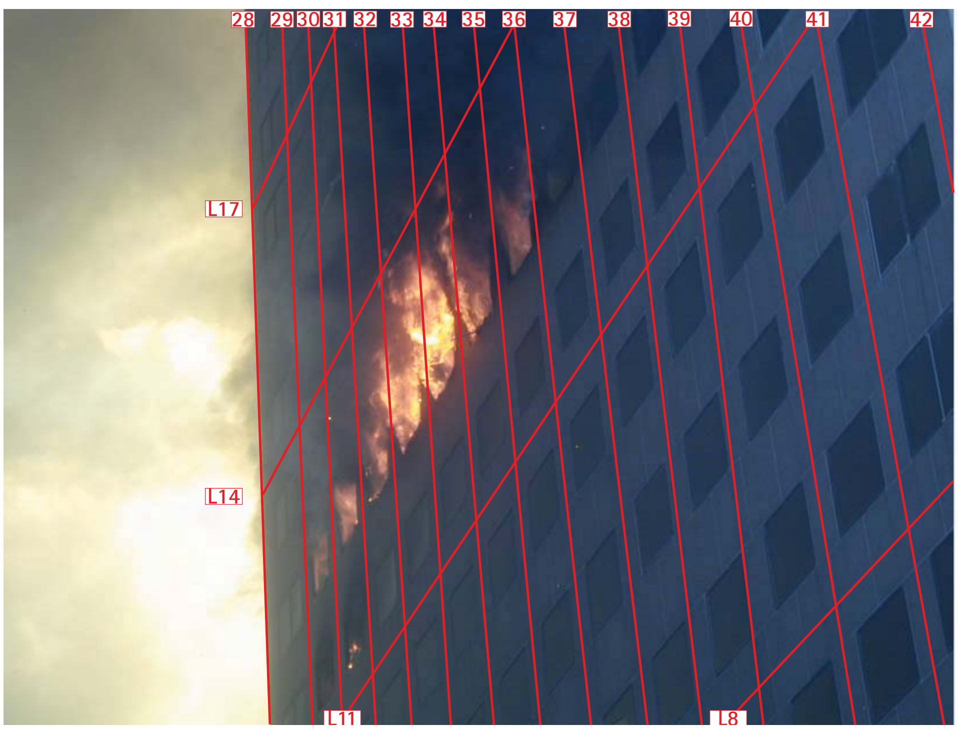
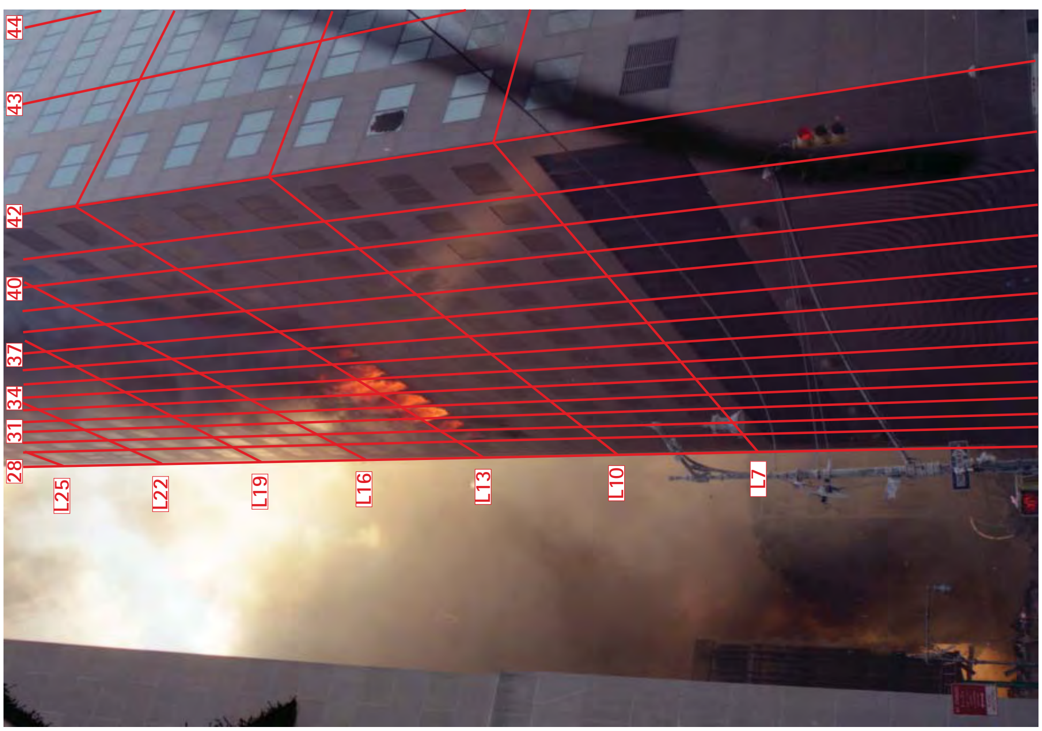


Image 5.E.15 with columns and floor levels overlaid

(Bottom)

Image 5.E.16 Northeast corner, approximately 2:08PM–2:13PM



(Bottom)

Image 5.E.16 with columns and floor levels overlaid

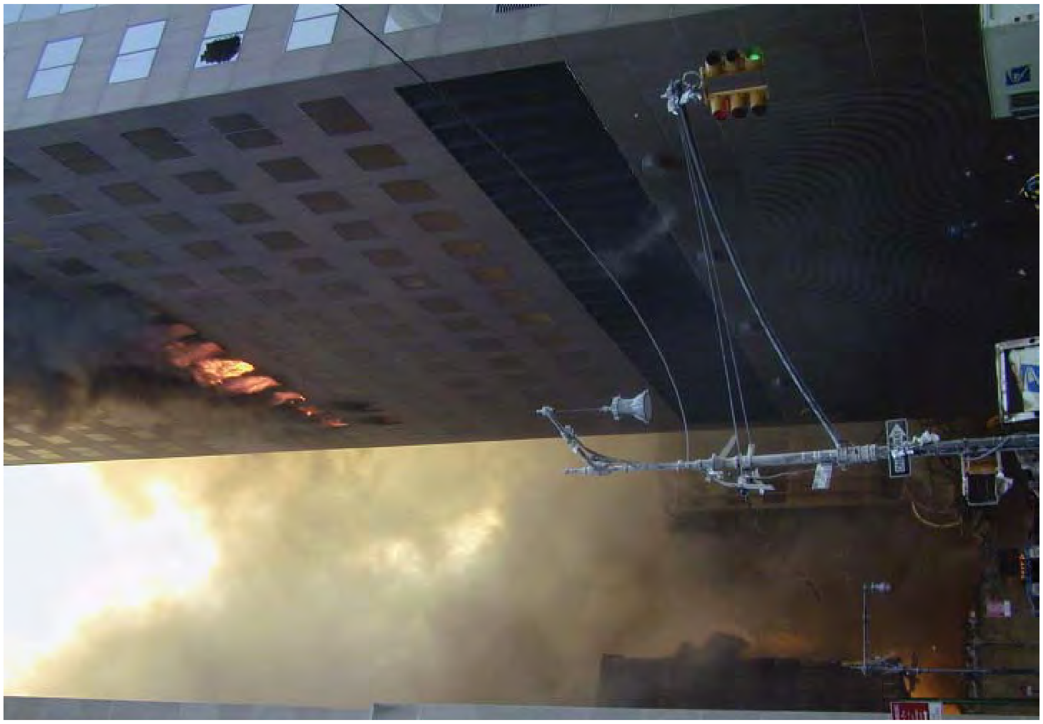
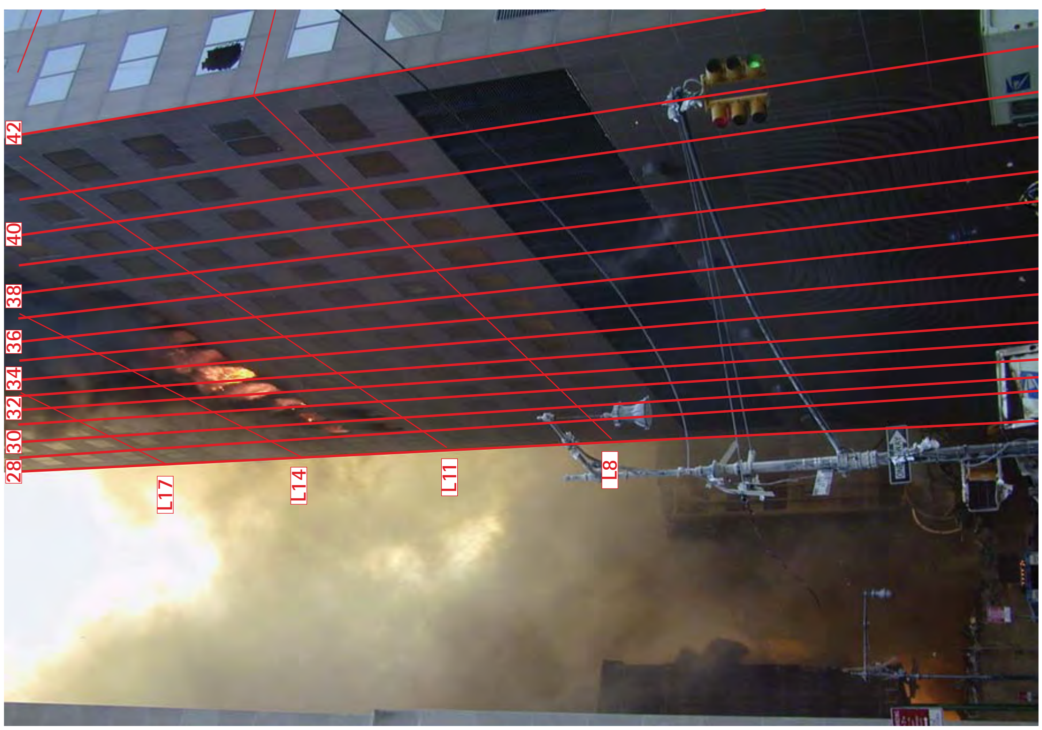

(Bottom)

Image 5.E.17 Northeast corner, 2:13:04PM +/-1S

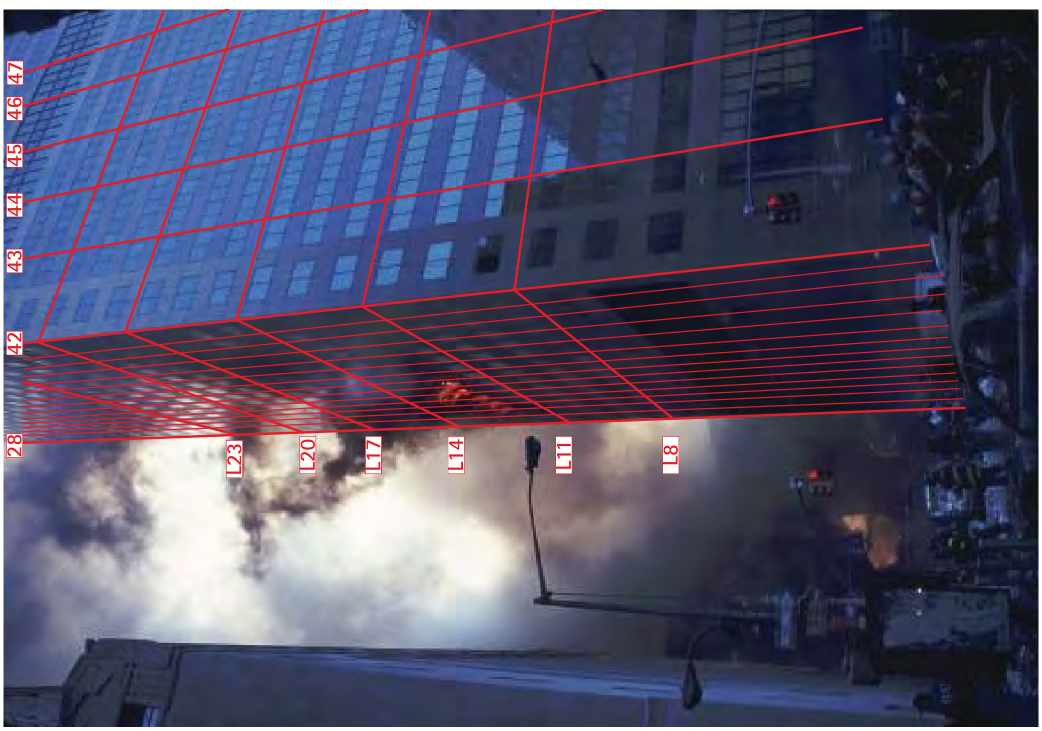


(Bottom)

Image 5.E.17 with columns and floor levels overlaid

(Bottom)

Image 5.E.18 Northeast corner, approximately 2:08PM-2:28PM



(Bottom)

Image 5.E.18 with columns and floor levels overlaid

Image 5.E.19 Northeast corner, approximately 2:08PM-2:28PM

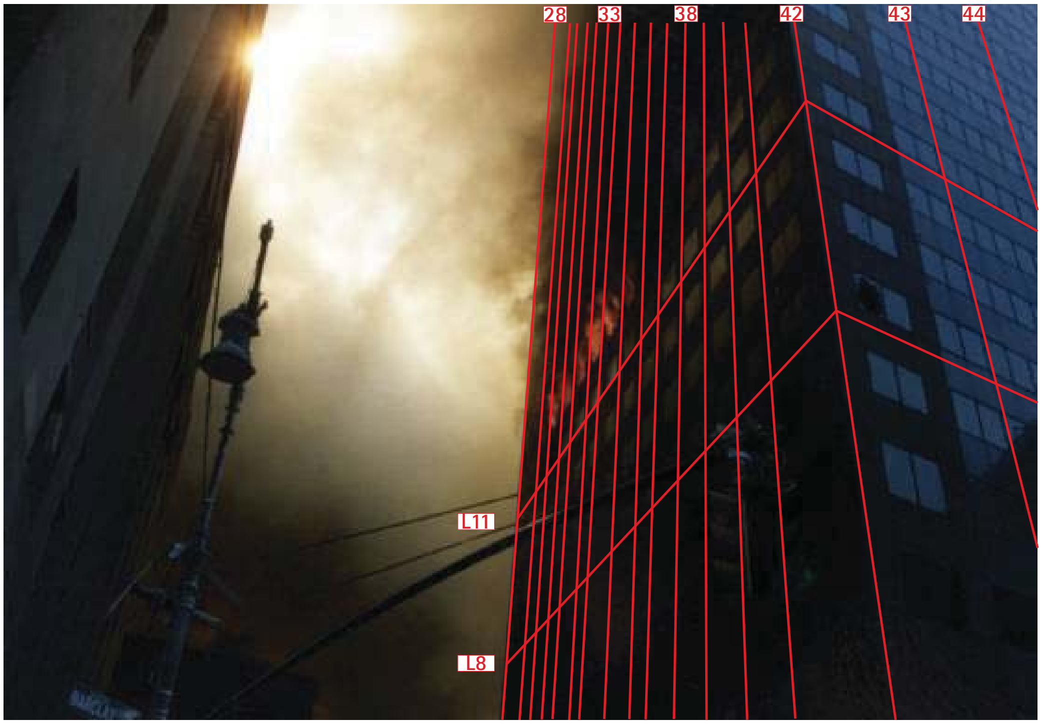
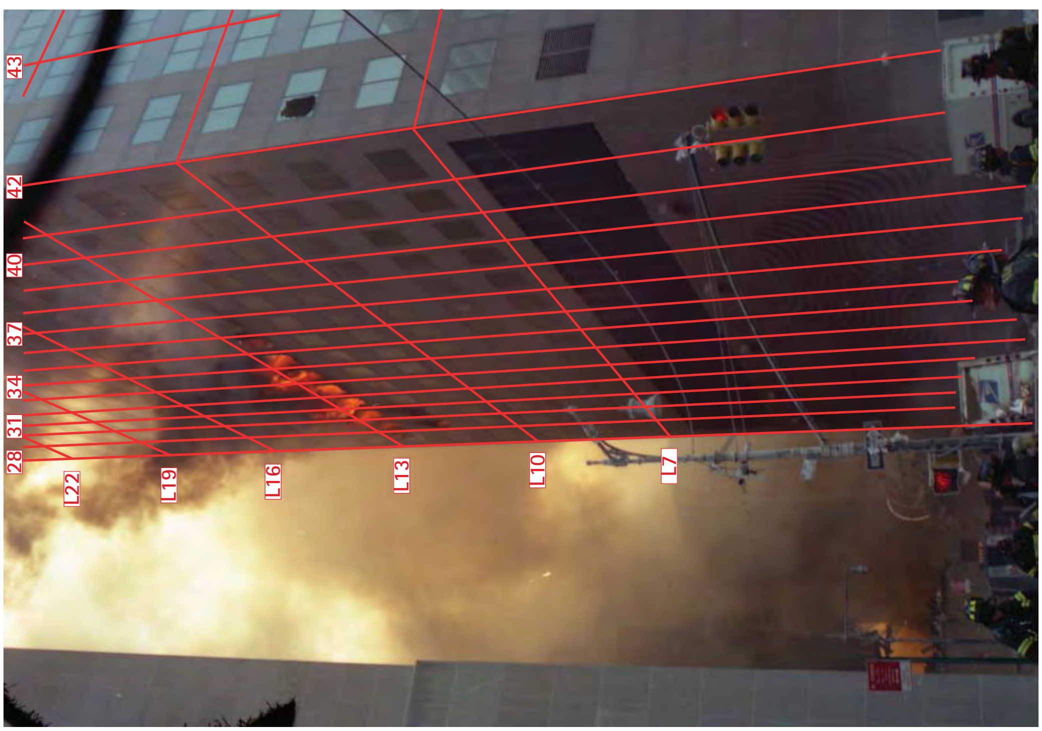


Image 5.E.19 with columns and floor levels overlaid

(Bottom)

Image 5.E.20 Northeast corner, approximately 2:13PM-2:27PM



(Bottom)

Image 5.E.20 with columns and floor levels overlaid

Image 5.E.21 Northeast corner, 2:14:09PM +/-1S

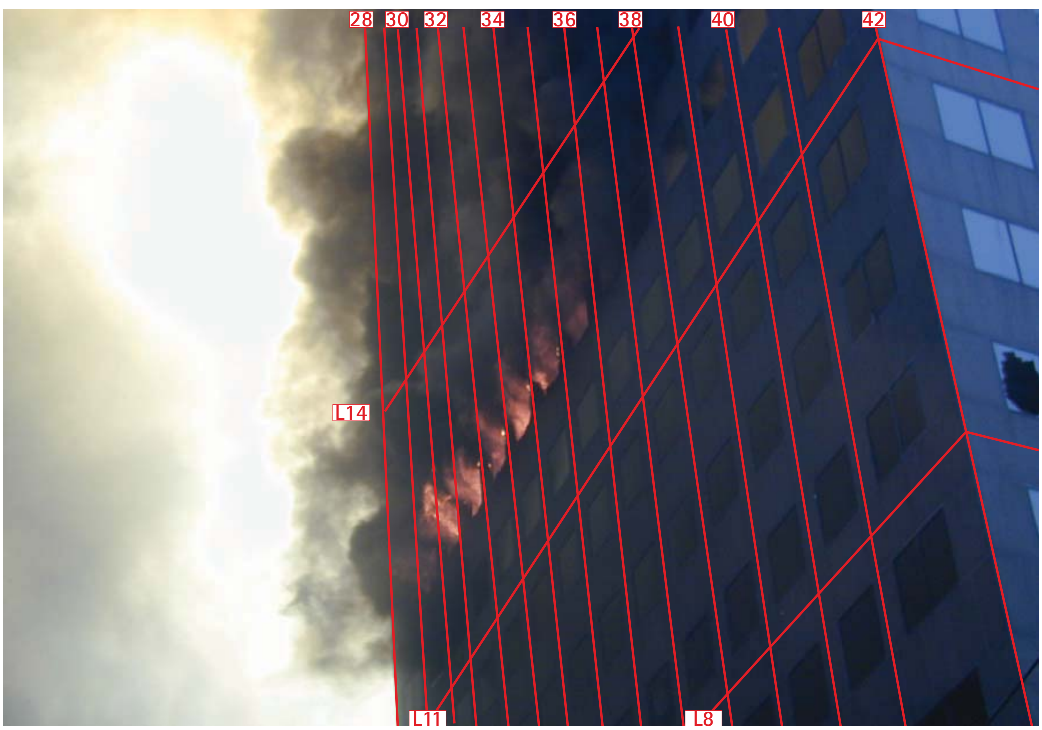


Image 5.E.21 with columns and floor levels overlaid

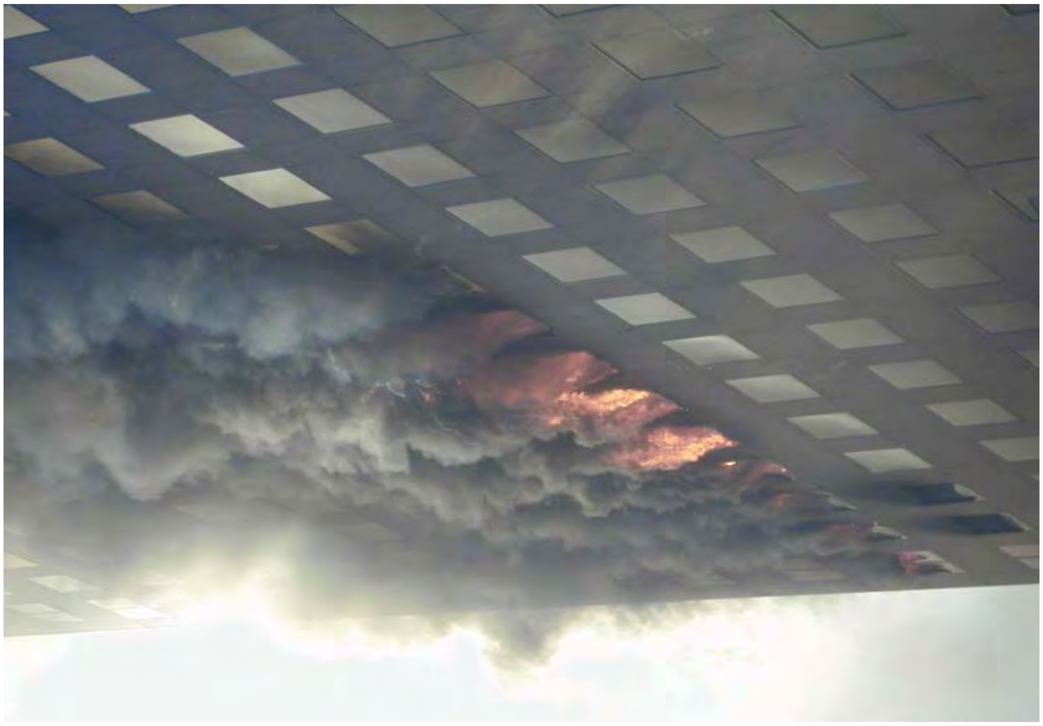


Image 5.E.22 East facade, 2:14:29PM +/-1S

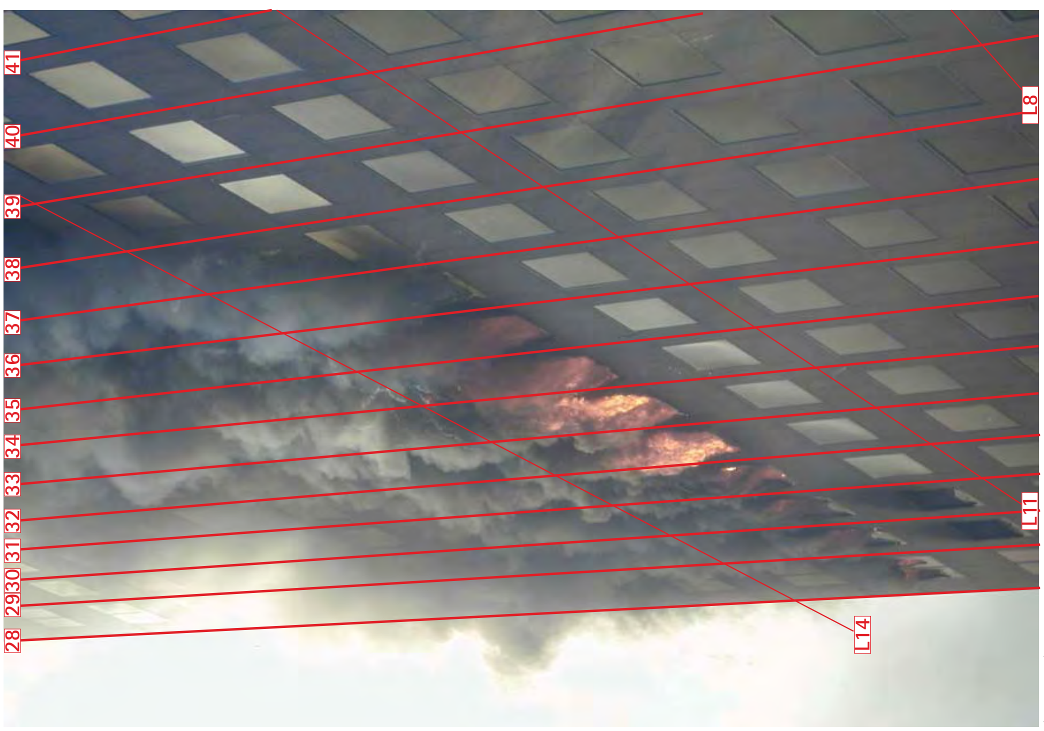


Image 5.E.22 with columns and floor levels overlaid

Image 5.E.23 East facade, 2:14:33PM +/-1S

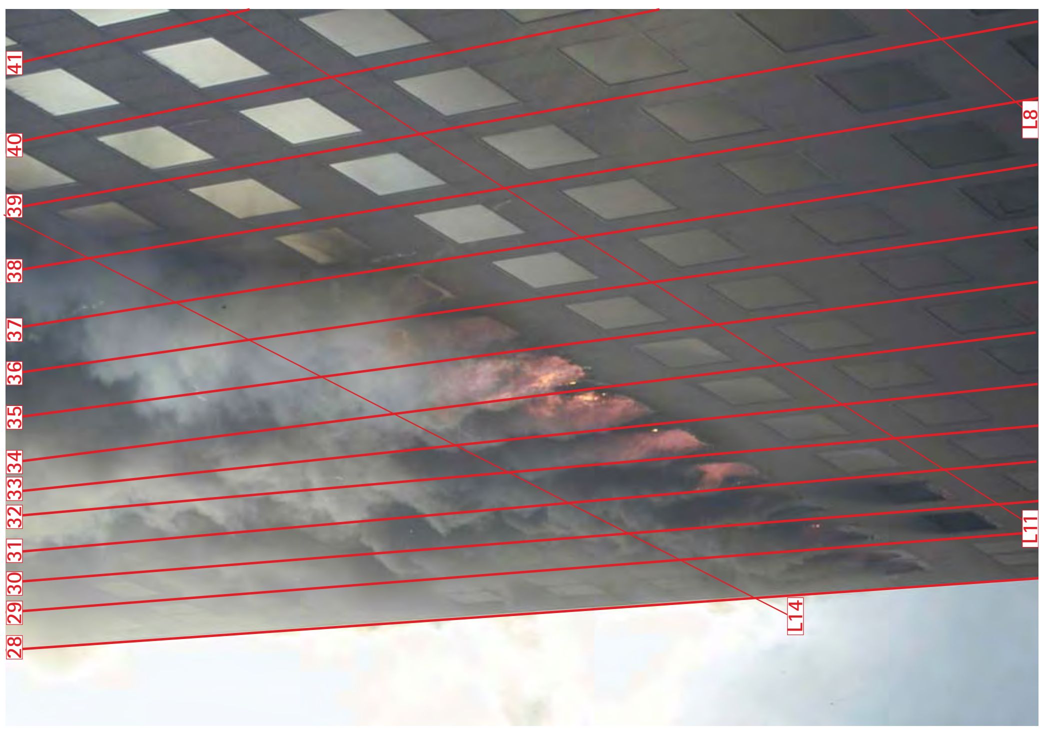


Image 5.E.23 with columns and floor levels overlaid

Image 5.E.24 Northeast corner, approximately 2:13PM-2:28PM

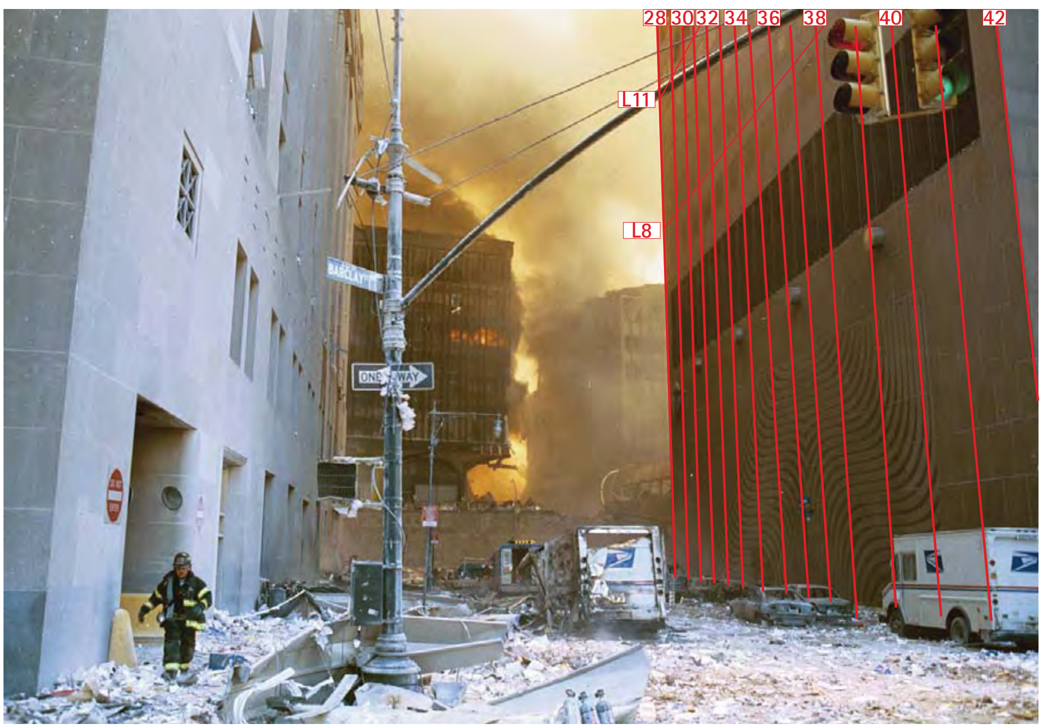


Image 5.E.24 with columns and floor levels overlaid

Image 5.E.25 East facade, approximately 2:13PM-2:27PM

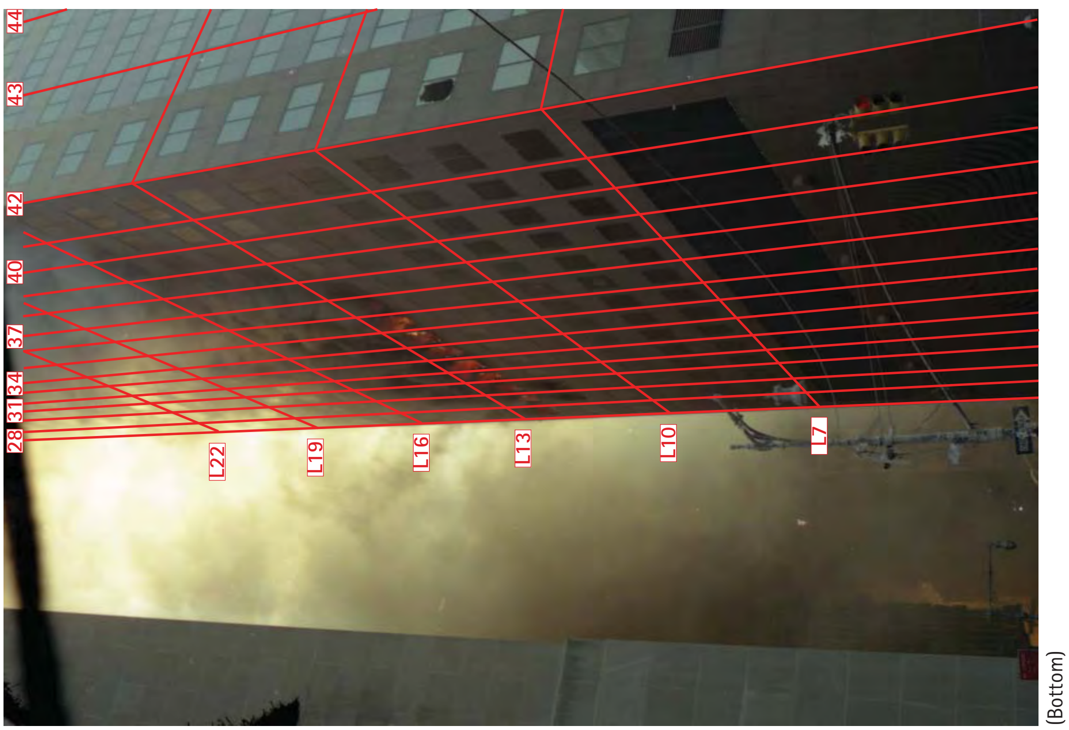
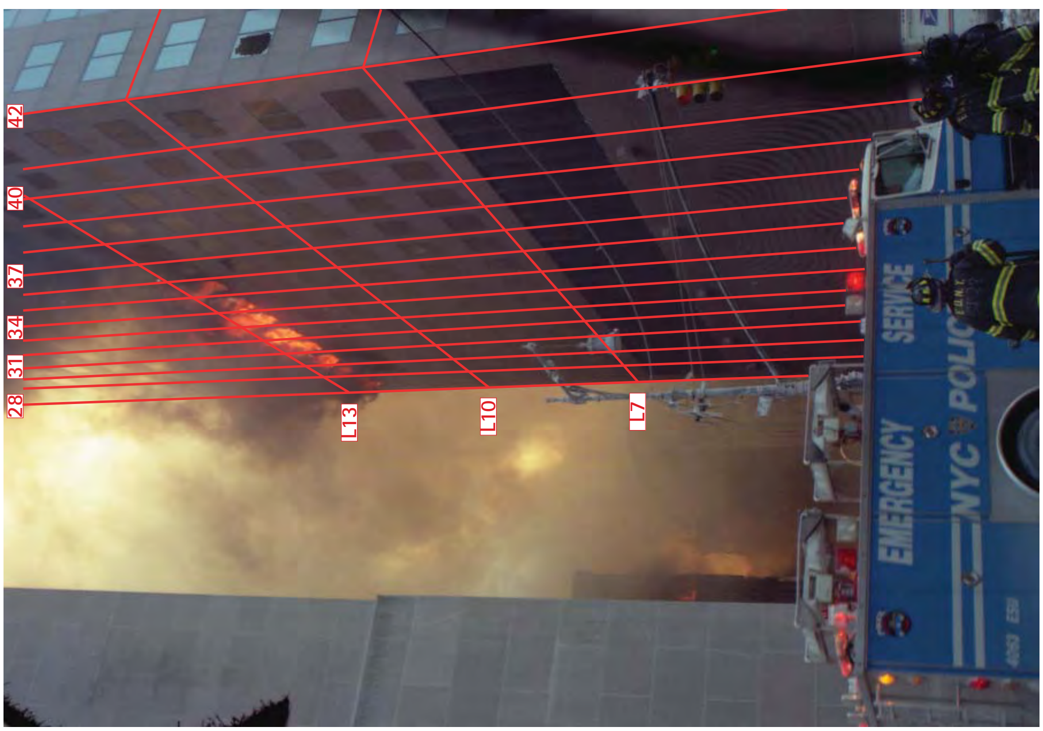


Image 5.E.25 with columns and floor levels overlaid

(Bottom)

Image 5.E.26 Northeast corner, approximately 2:13PM–2:27PM



(Bottom)

Image 5.E.26 with columns and floor levels overlaid

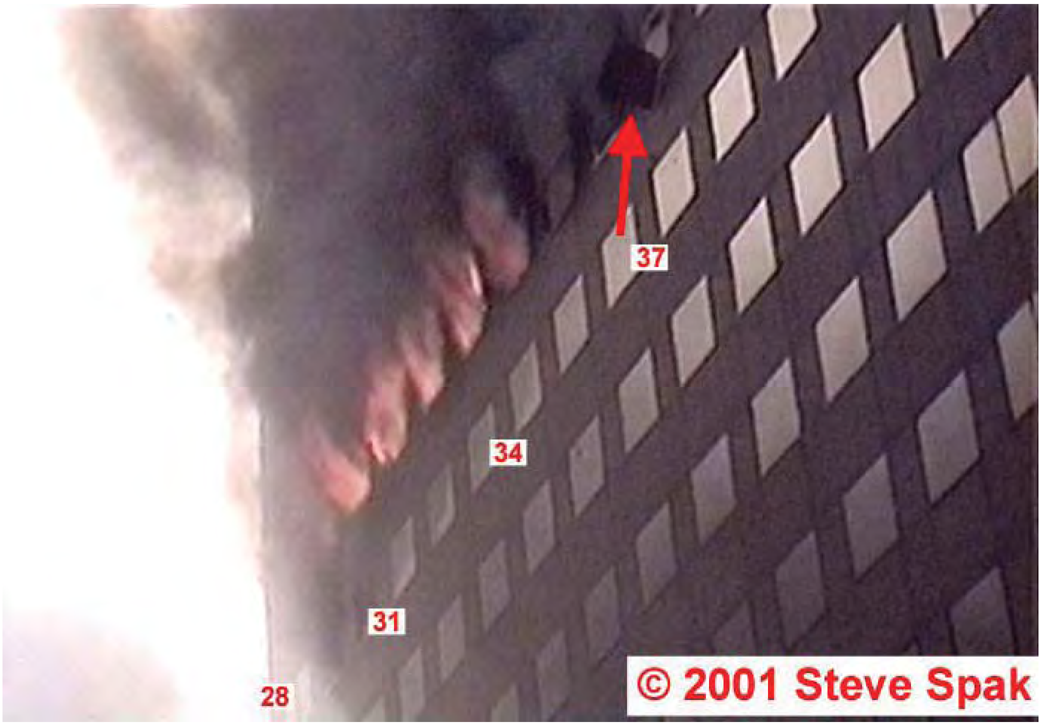
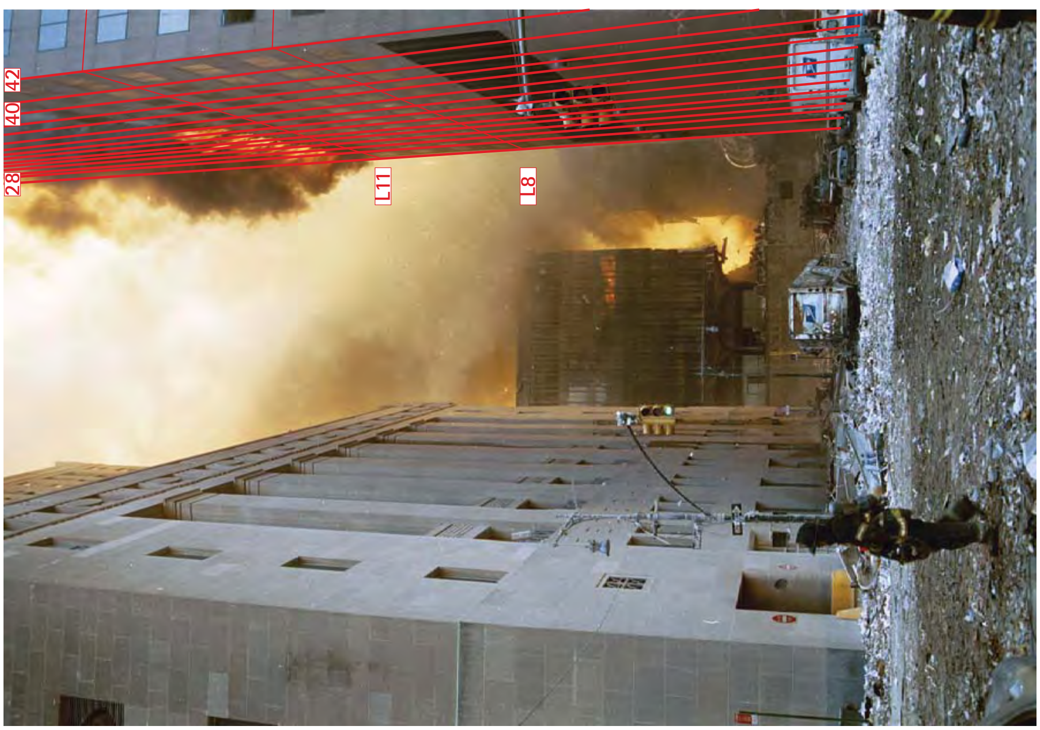


Image 5.E.27 East facade, 2:15PM-2:27PM

Image 5.E.27 with columns and floor levels overlaid

(Bottom)

Image 5.E.28 Northeast corner, approximately 2:15PM-2:28PM



(Bottom)

Image 5.E.28 with columns and floor levels overlaid

Image 5.E.29 Northeast corner, approximately 2:15PM-2:28PM

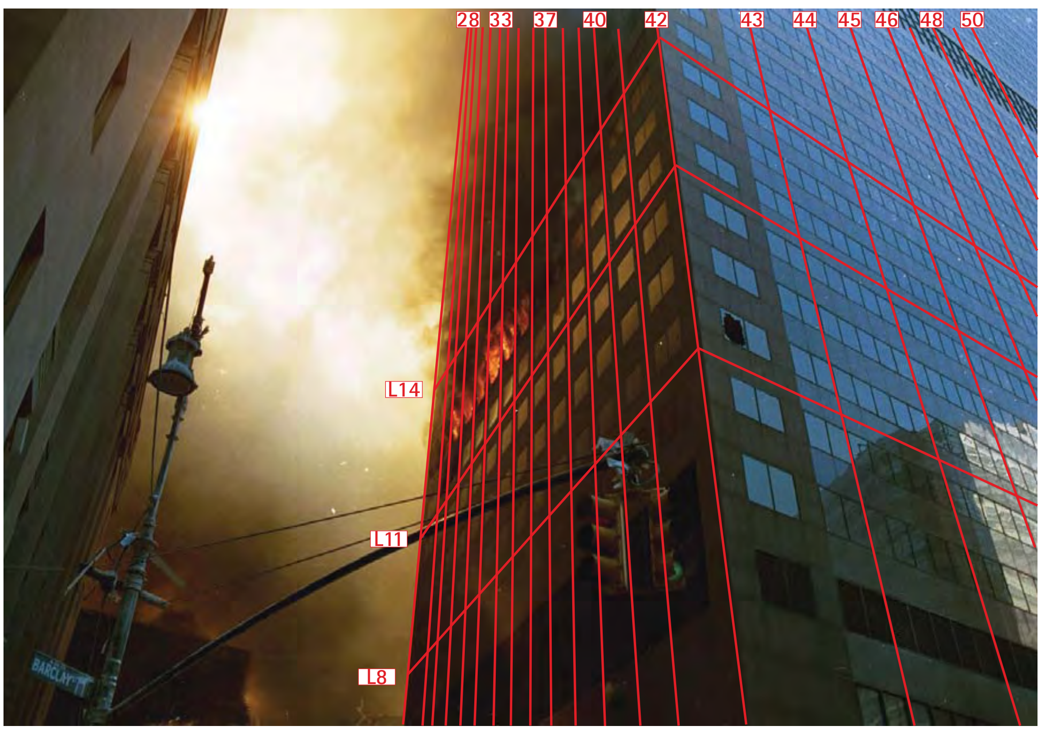
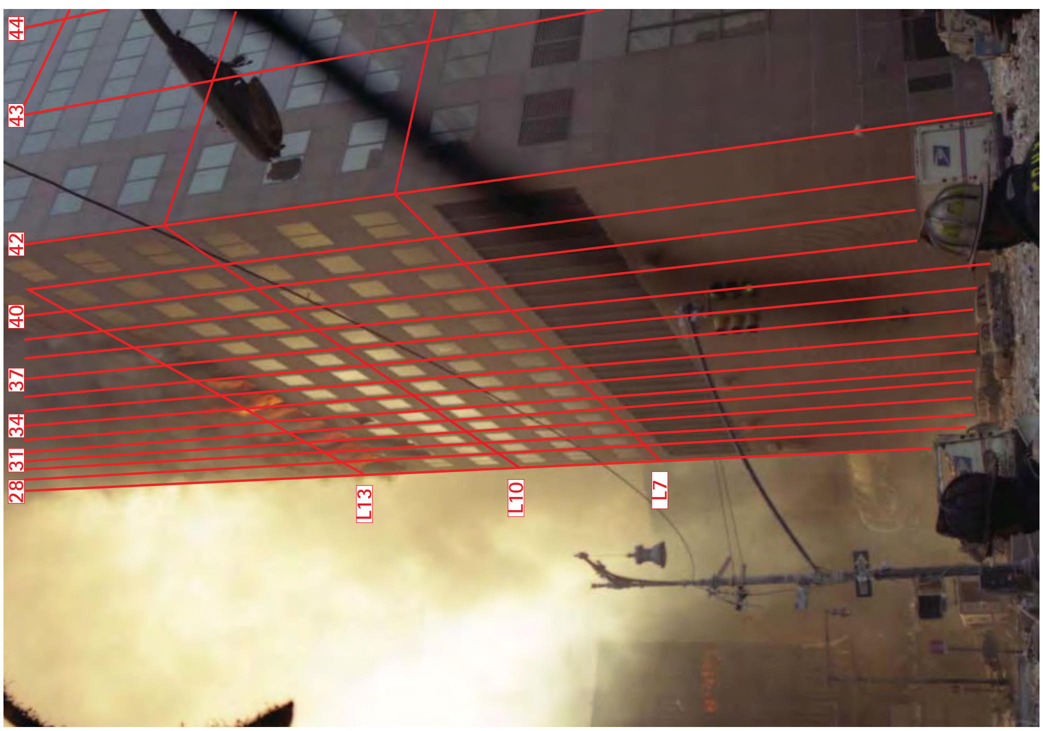


Image 5.E.29 with columns and floor levels overlaid

(Bottom)

Image 5.E.30 Northeast corner, approximately 2:15PM-2:28PM



(Bottom)

Image 5.E.30 with columns and floor levels overlaid

Image 5.E.31 East facade, approximately 2:15PM-2:28PM

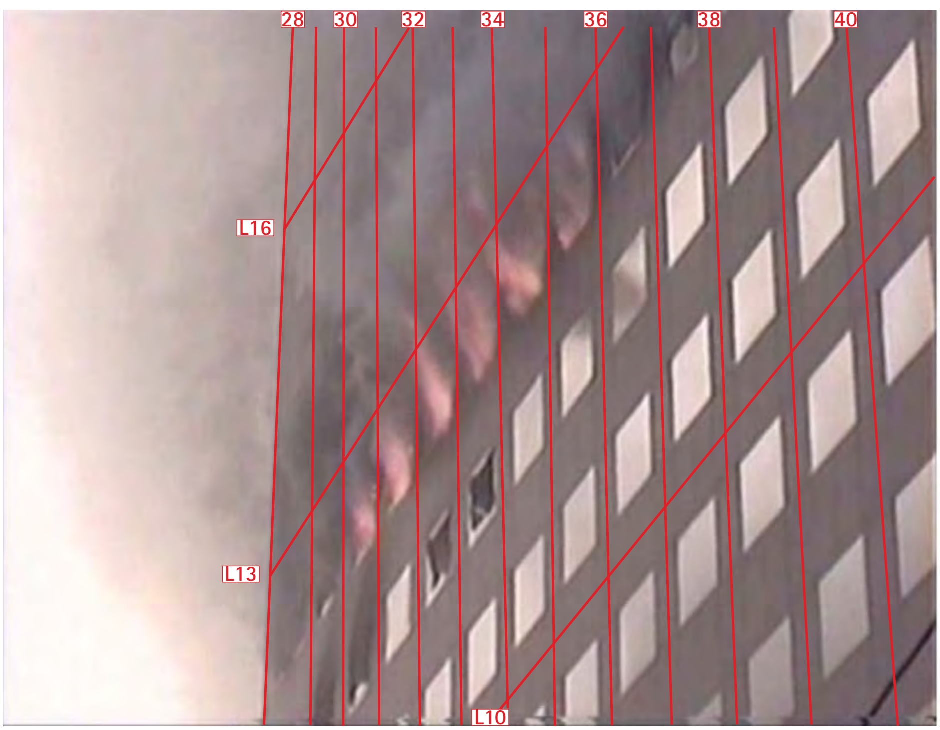


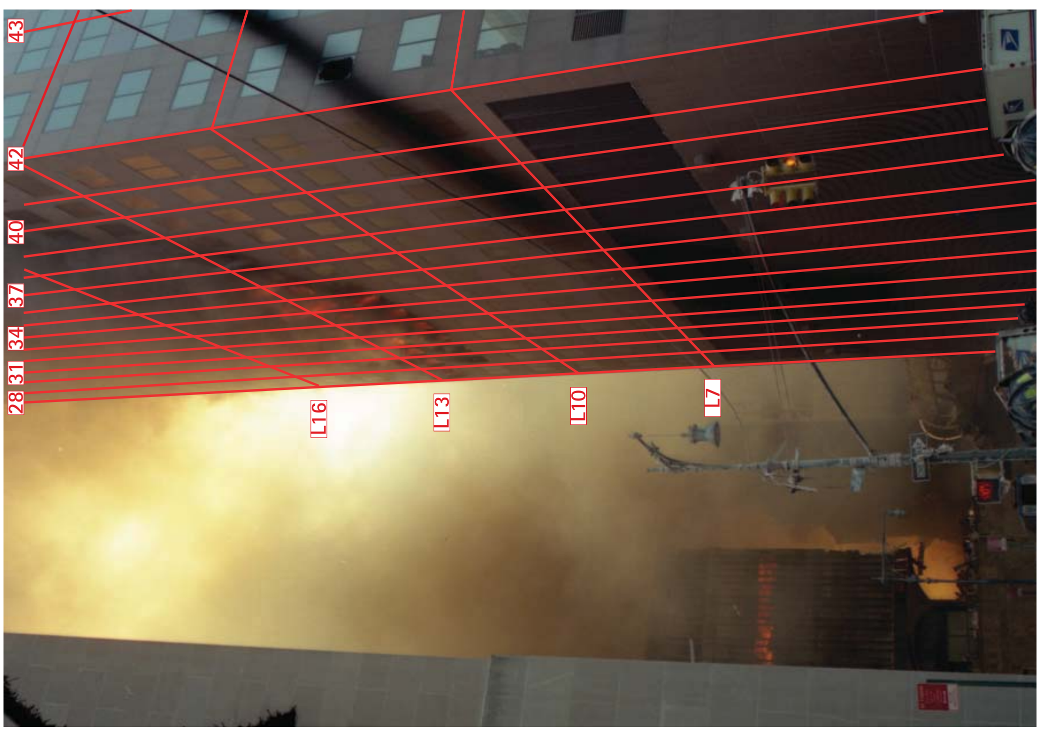
Image 5.E.31 with columns and floor levels overlaid

Image 5.E.32 Northeast corner, approximately 2:15PM-2:28PM

Image 5.E.32 with columns and floor levels overlaid

(Bottom)

Image 5.E.33 Northeast corner, approximately 2:15PM–2:28PM



(Bottom)

Image 5.E.33 with columns and floor levels overlaid

Image 5.E.34 Northeast corner, approximately 2:15PM-2:28PM

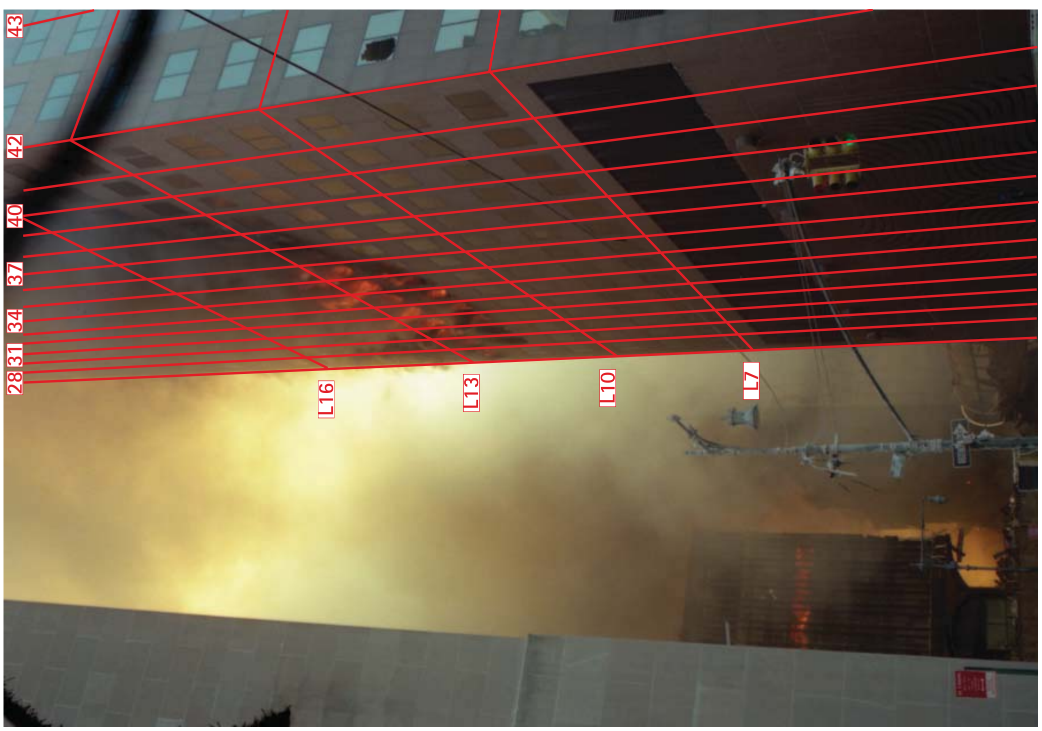
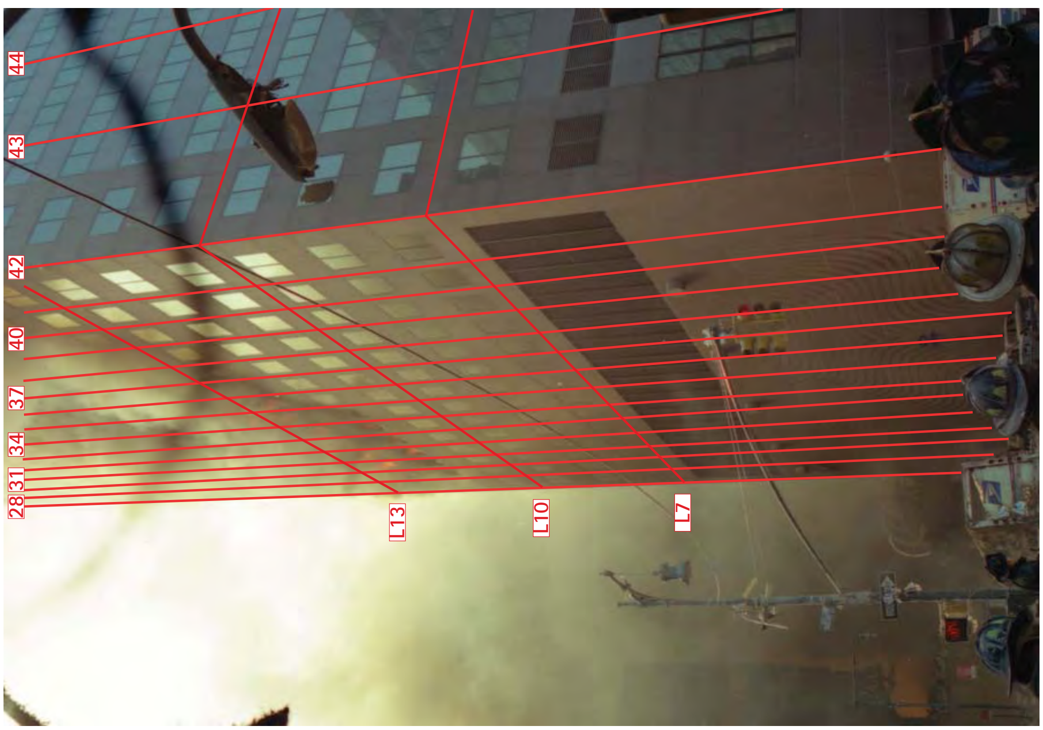


Image 5.E.34 with columns and floor levels overlaid


(Bottom)

Image 5.E.35 Northeast corner, approximately 2:15PM-2:28PM



(Bottom)

Image 5.E.35 with columns and floor levels overlaid

Image 5.E.36 Northeast corner, approximately 2:15PM-2:28PM

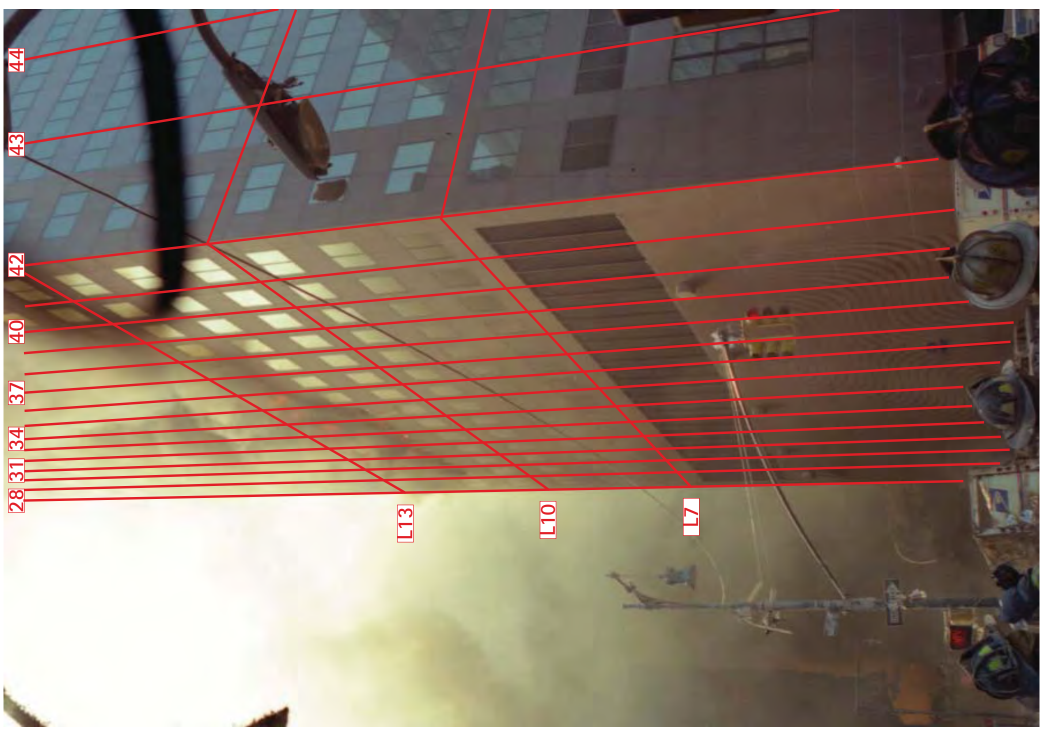


Image 5.E.36 with columns and floor levels overlaid

Volume A - Photographic Timeline
Photographic Analysis Report
World Trade Center 7 Collapse Investigation
16 December 2009

(Bottom)

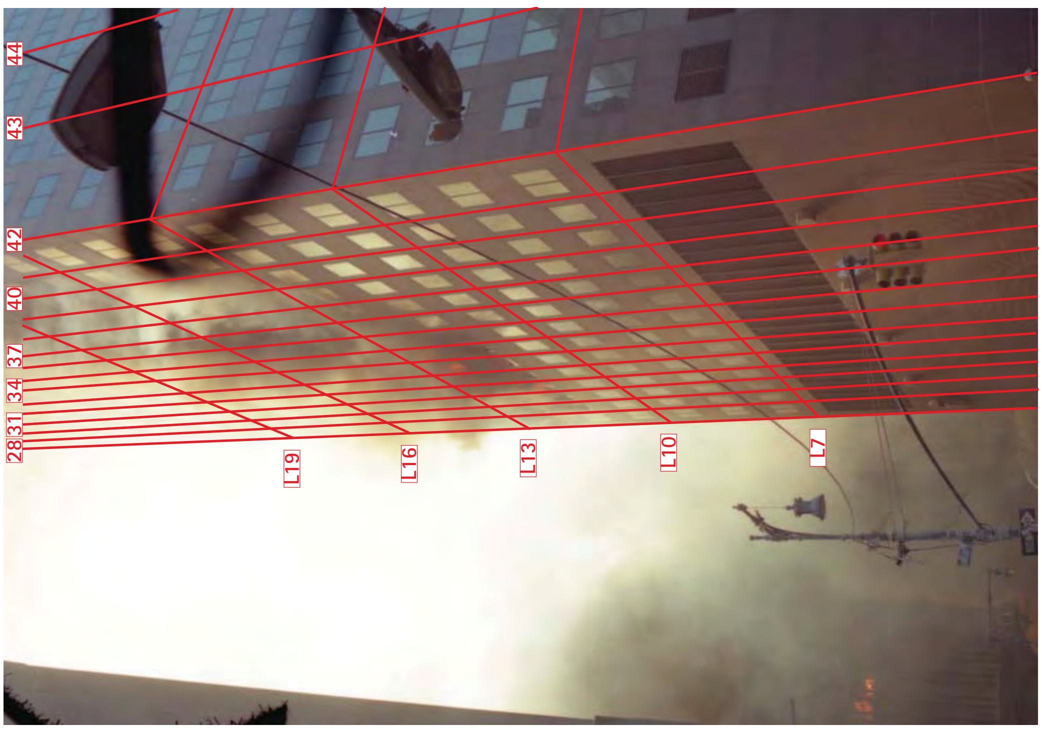
Image 5.E.37 Northeast corner, approximately 2:15PM-2:28PM

(Bottom)

Image 5.E.37 with columns and floor levels overlaid

(Bottom)

Image 5.E.38 Northeast corner, approximately 2:15PM-2:28PM



(Bottom)

Image 5.E.38 with columns and floor levels overlaid

Image 5.E.39 Northeast corner, approximately 2:15PM–2:28PM

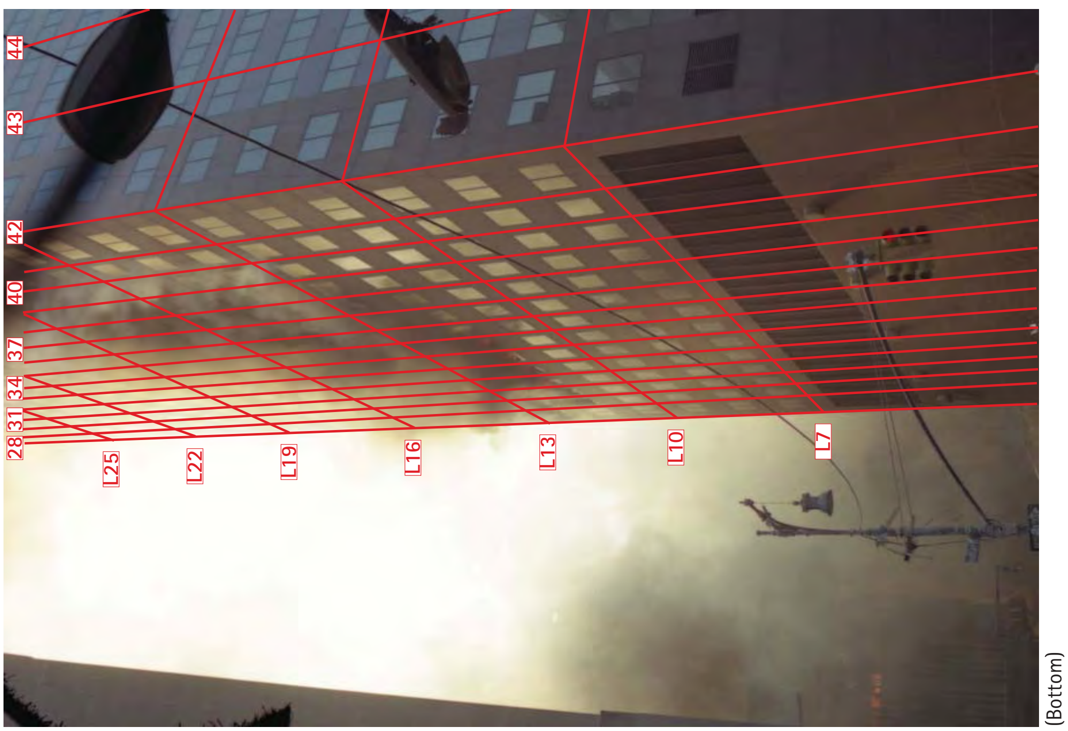
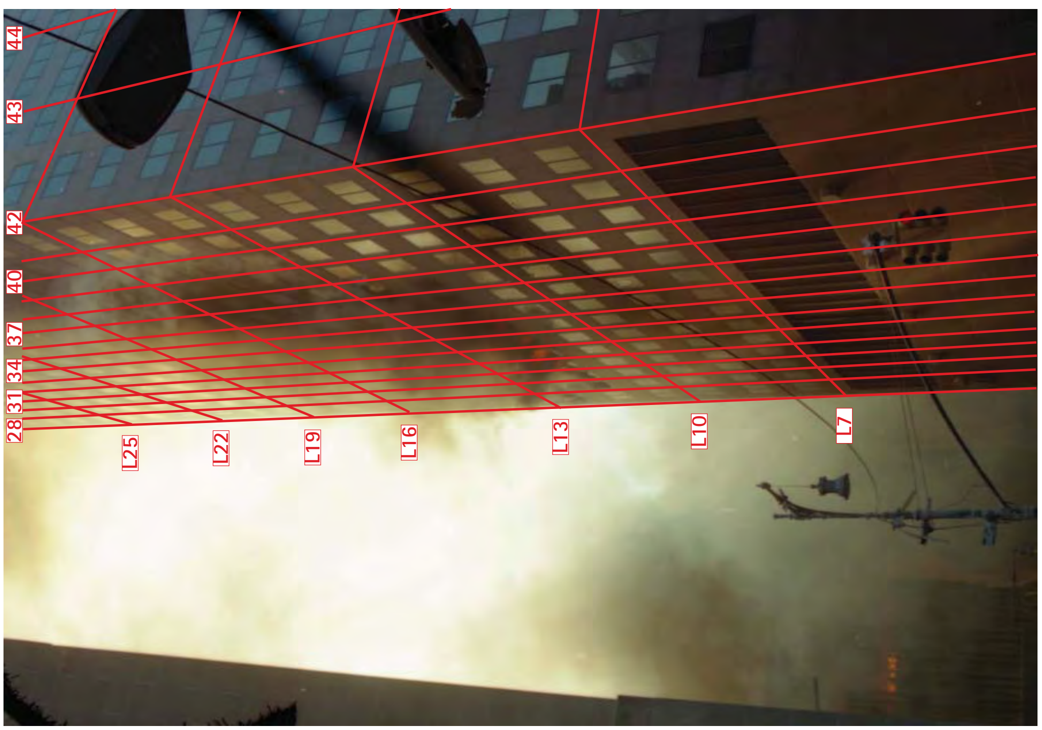


Image 5.E.39 with columns and floor levels overlaid

(Bottom)

Image 5.E.40 Northeast corner, approximately 2:15PM-2:28PM



(Bottom)

Image 5.E.40 with columns and floor levels overlaid

Image 5.E.41 Northeast corner, approximately 2:15PM–2:28PM

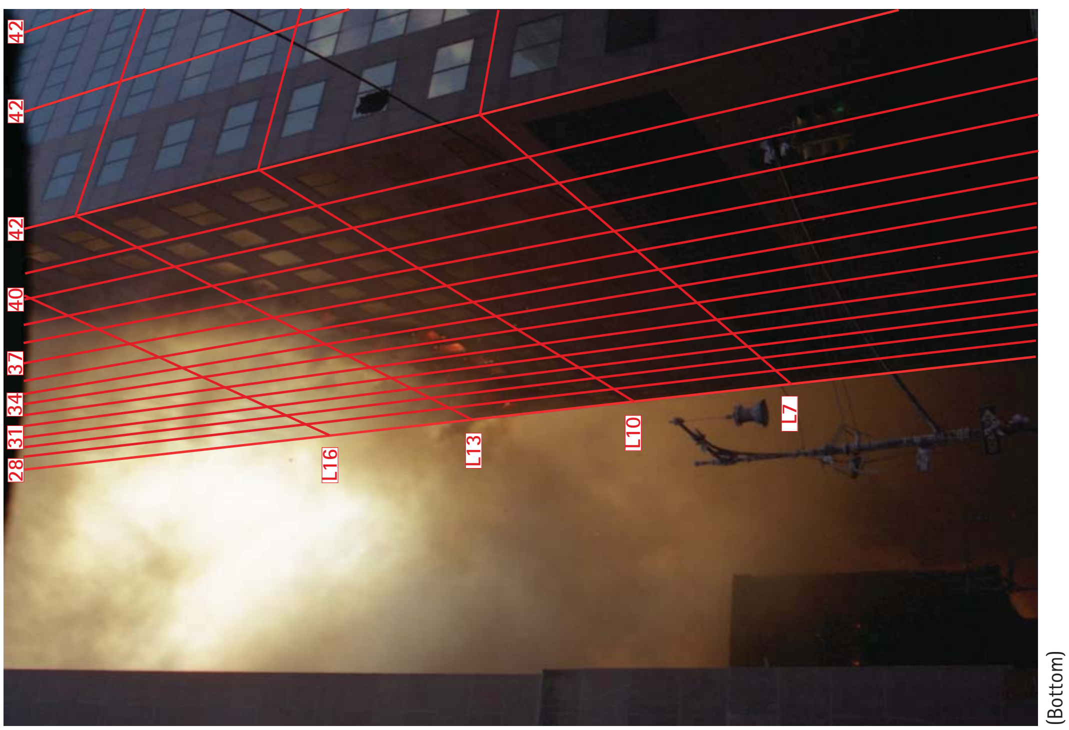


Image 5.E.41 with columns and floor levels overlaid

Image 5.E.42 Northeast corner, approximately 2:15PM–2:28PM

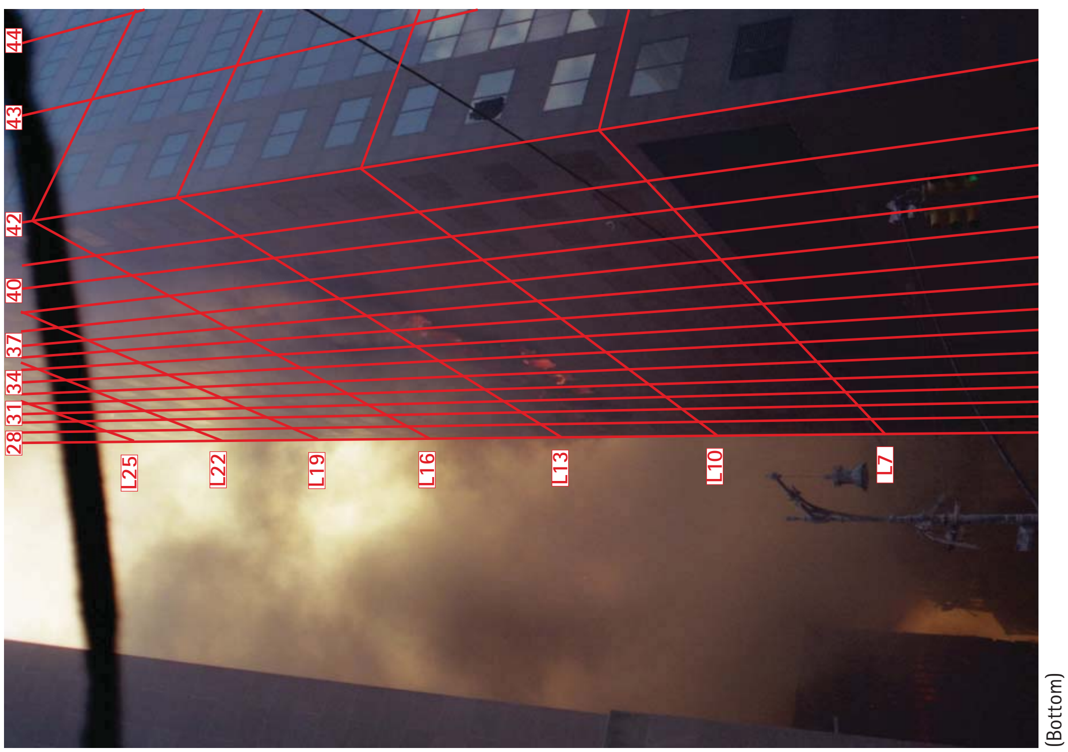


Image 5.E.42 with columns and floor levels overlaid

Image 5.E.43 Northeast corner, approximately 2:15PM-2:28PM

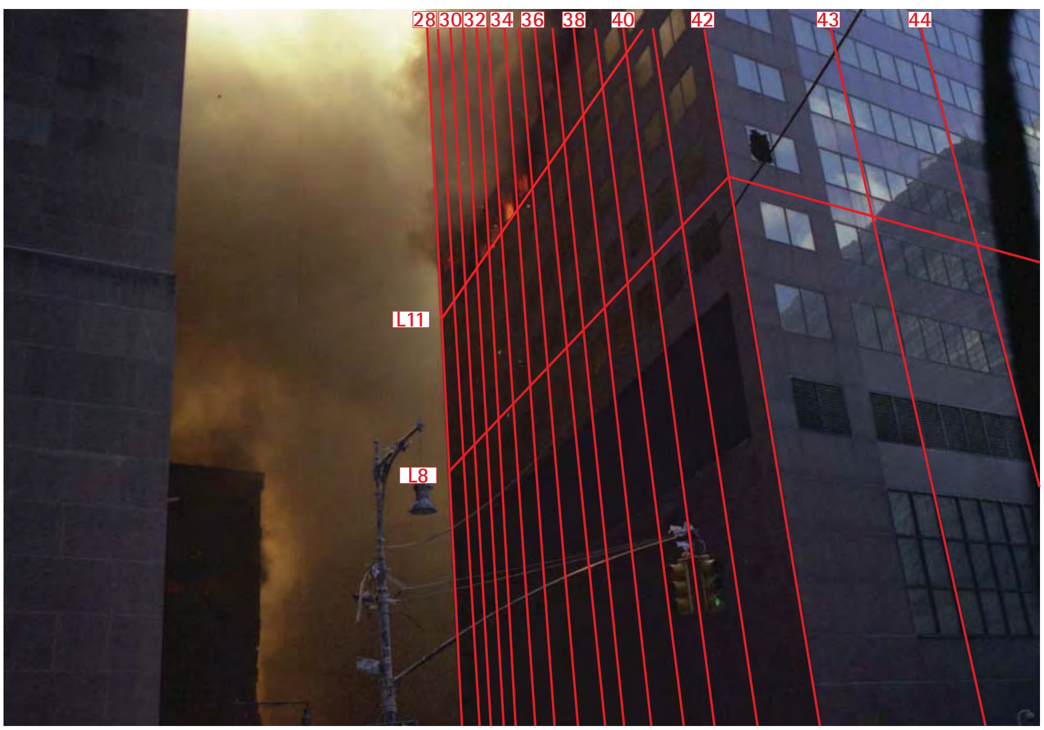


Image 5.E.43 with columns and floor levels overlaid

Image 5.E.44 Northeast corner, approximately 2:15PM-2:28PM

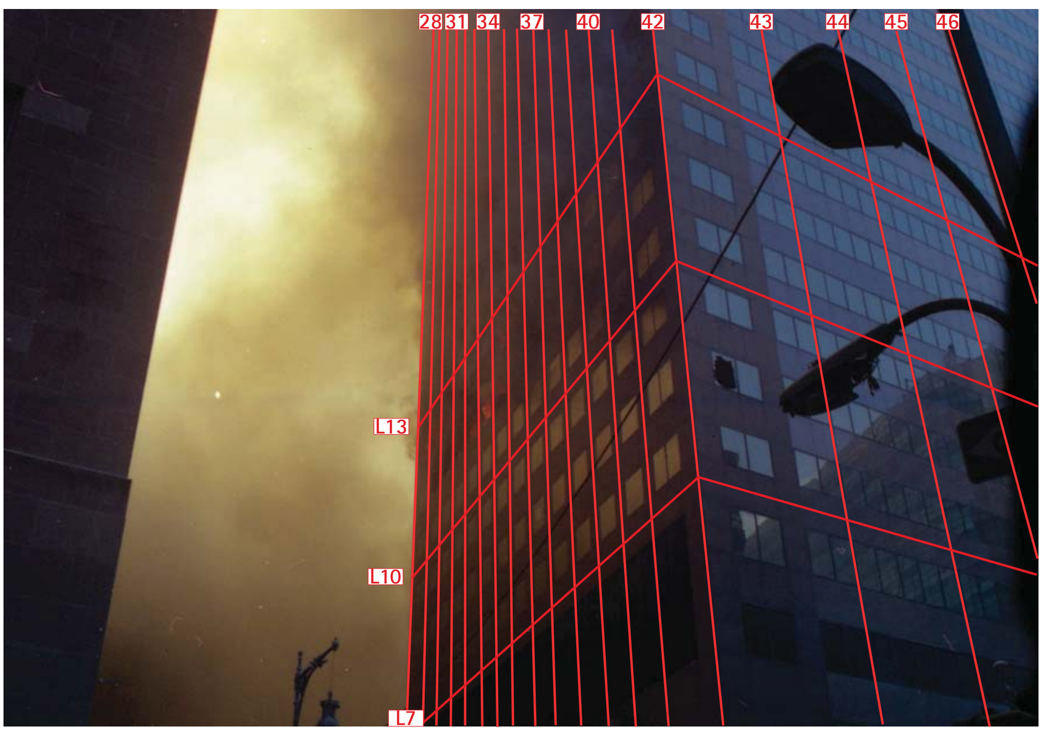
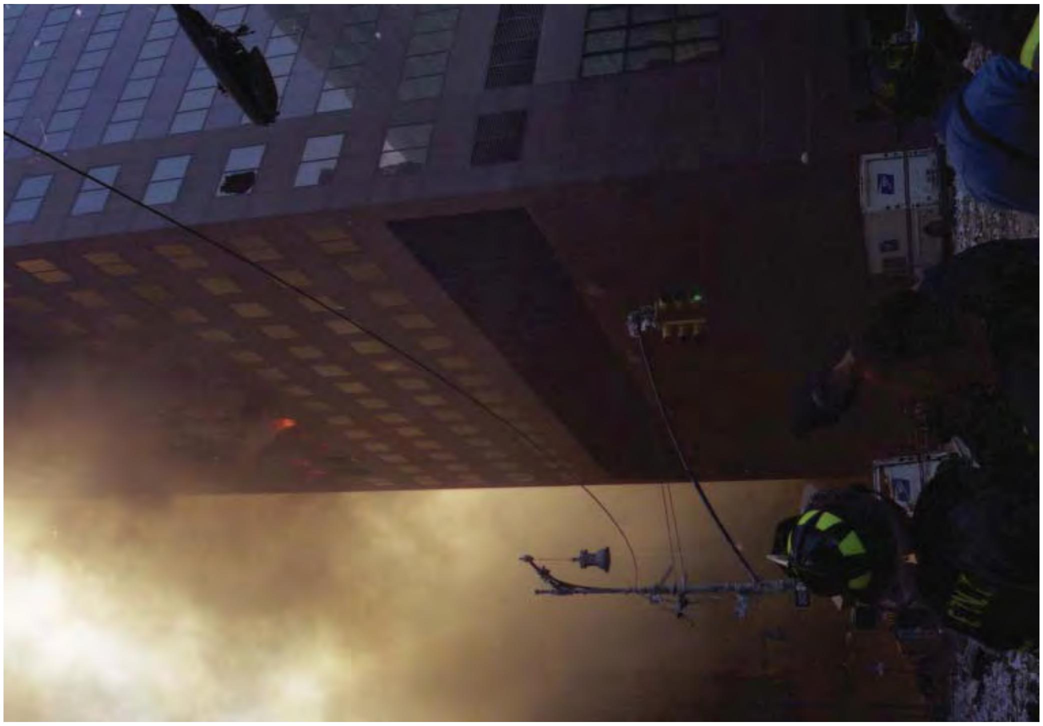
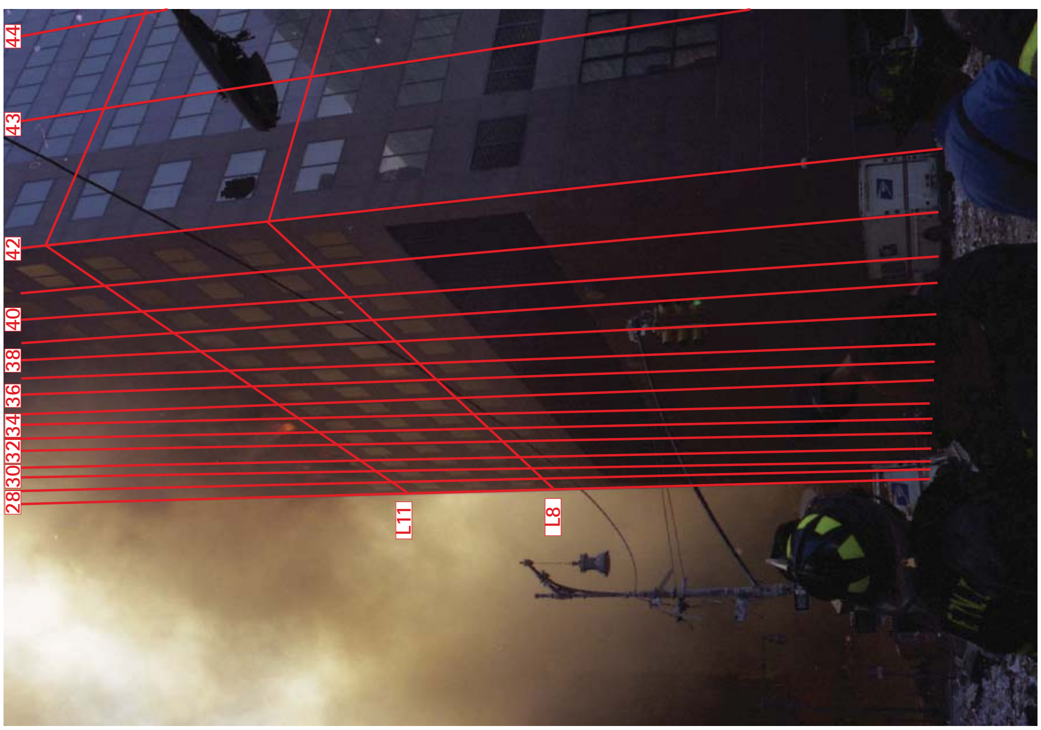


Image 5.E.44 with columns and floor levels overlaid



(Bottom)

Image 5.E.45 Northeast corner, approximately 2:15PM–2:28PM



(Bottom)

Image 5.E.45 with columns and floor levels overlaid

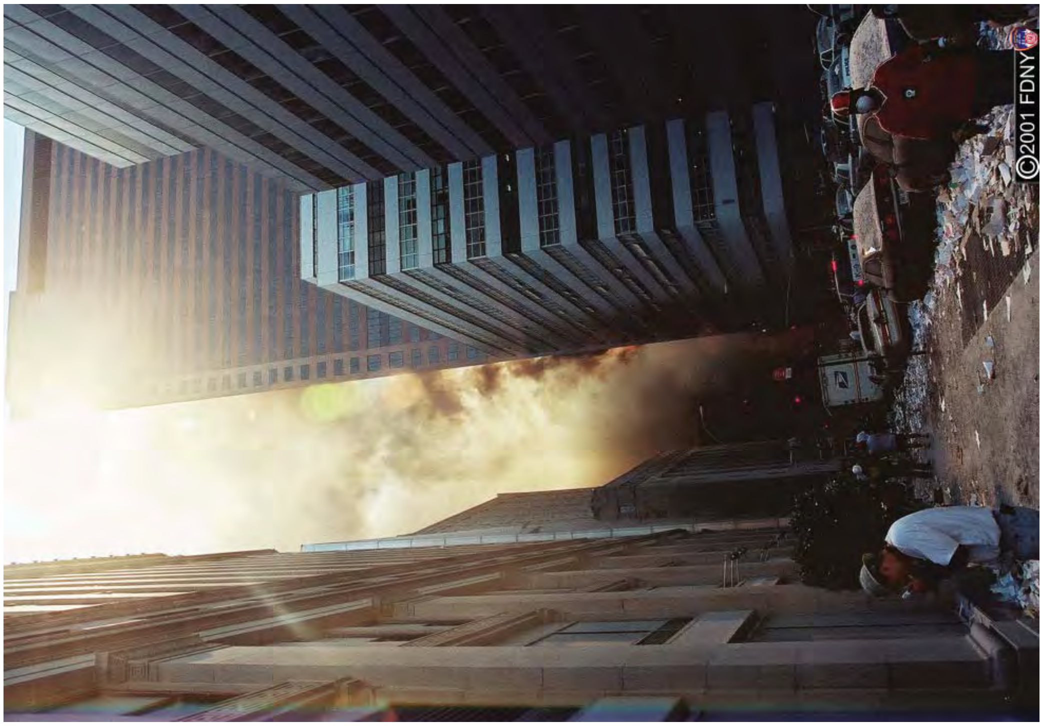


Image 5.E.46 Northeast corner, approximately 2:00PM-3:00PM

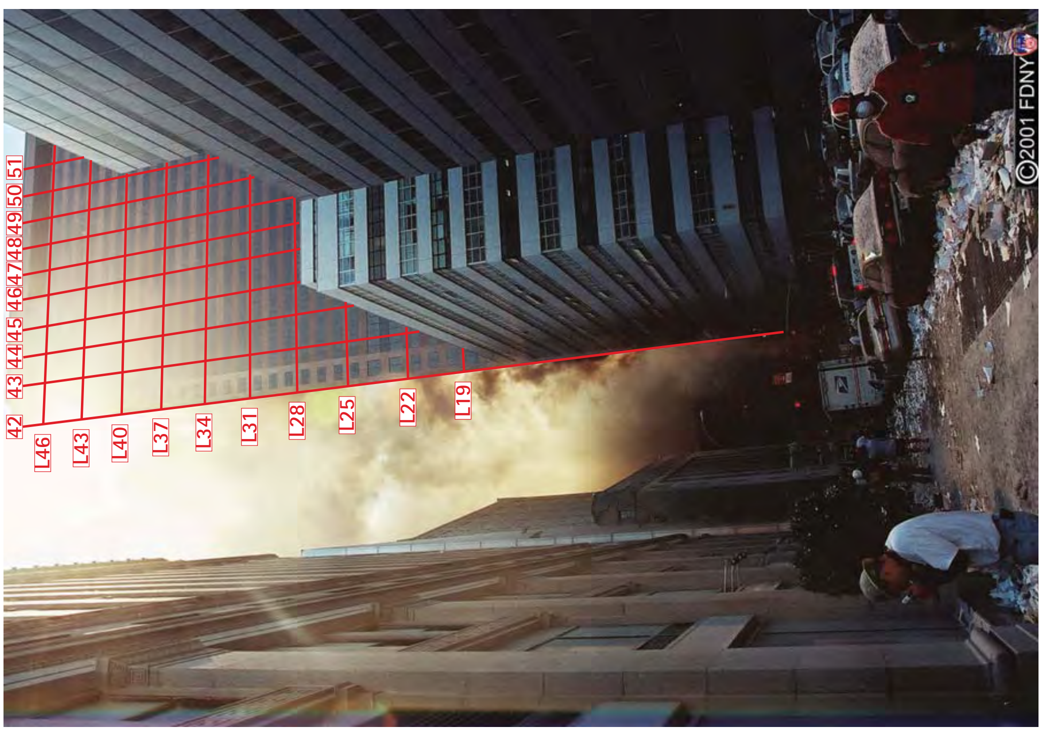


Image 5.E.46 with columns and floor levels overlaid

Image 5.E.47 Northeast corner, approximately 2:15PM-2:28PM

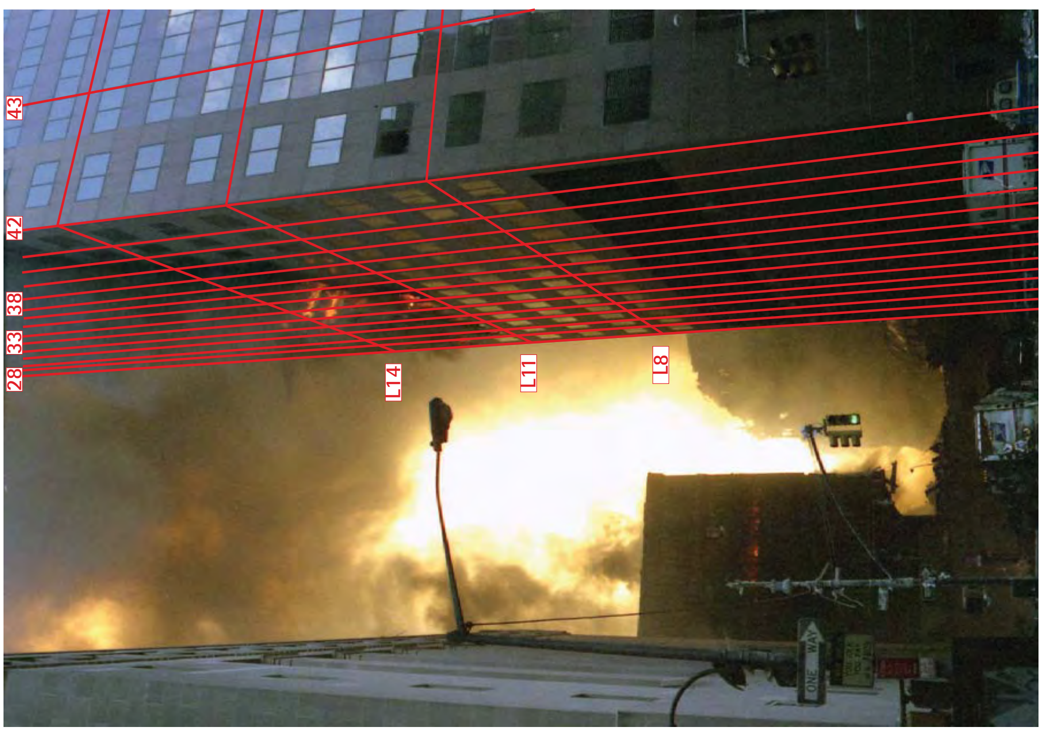
Image 5.E.47 with columns and floor levels overlaid

Image 5.E.48 Northeast corner, approximately 2:00PM-3:00PM

Image 5.E.48 with columns and floor levels overlaid

(Bottom)

Image 5.E.49 Northeast corner, approximately 2:15PM–2:28PM



(Bottom)

Image 5.E.49 with columns and floor levels overlaid

(Bottom)

Image 5.E.50 Northeast corner, approximately 2:15PM-2:28PM

(Bottom)

Image 5.E.50 with columns and floor levels overlaid

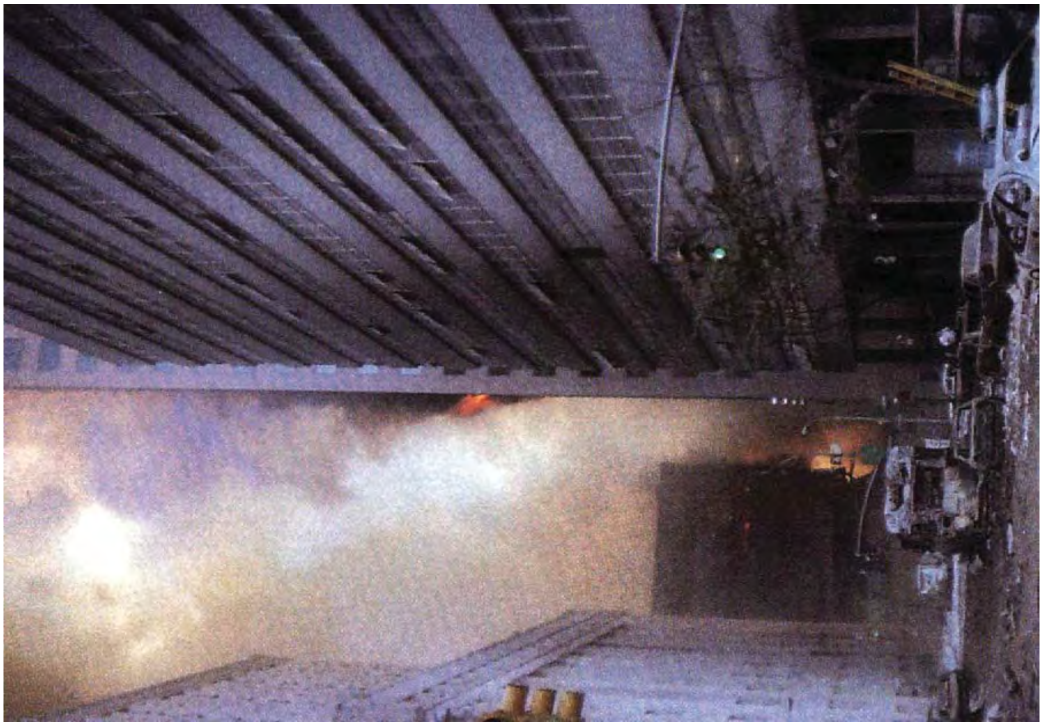


Image 5.E.51 Northeast corner, approximately 2:00PM-3:00PM

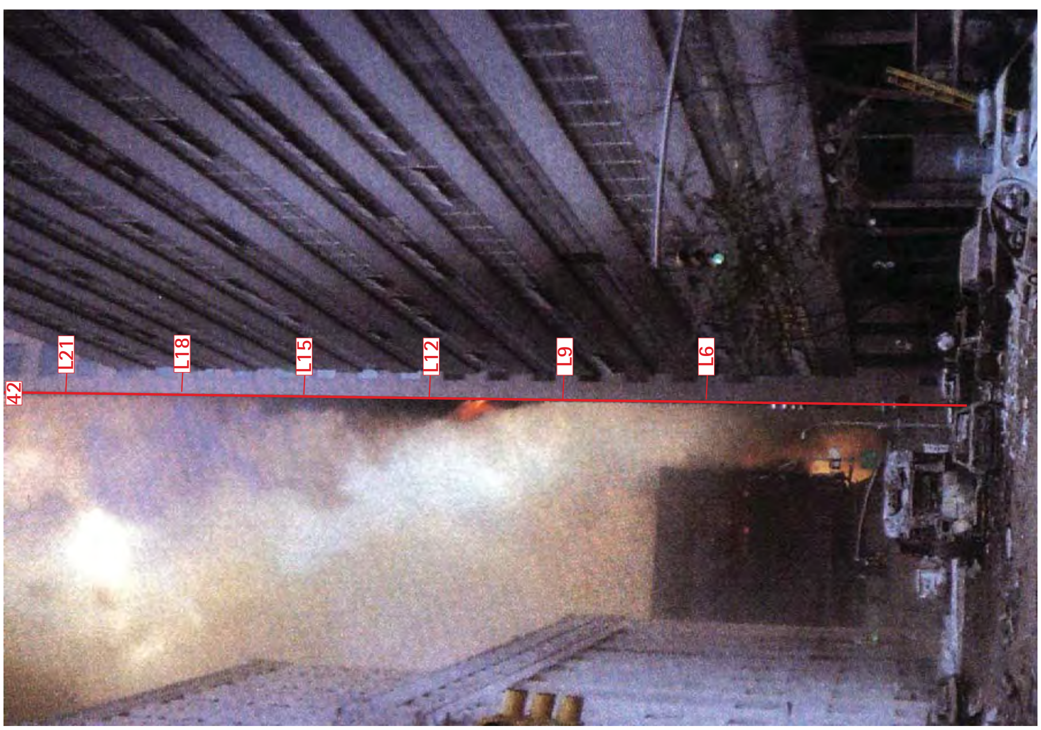
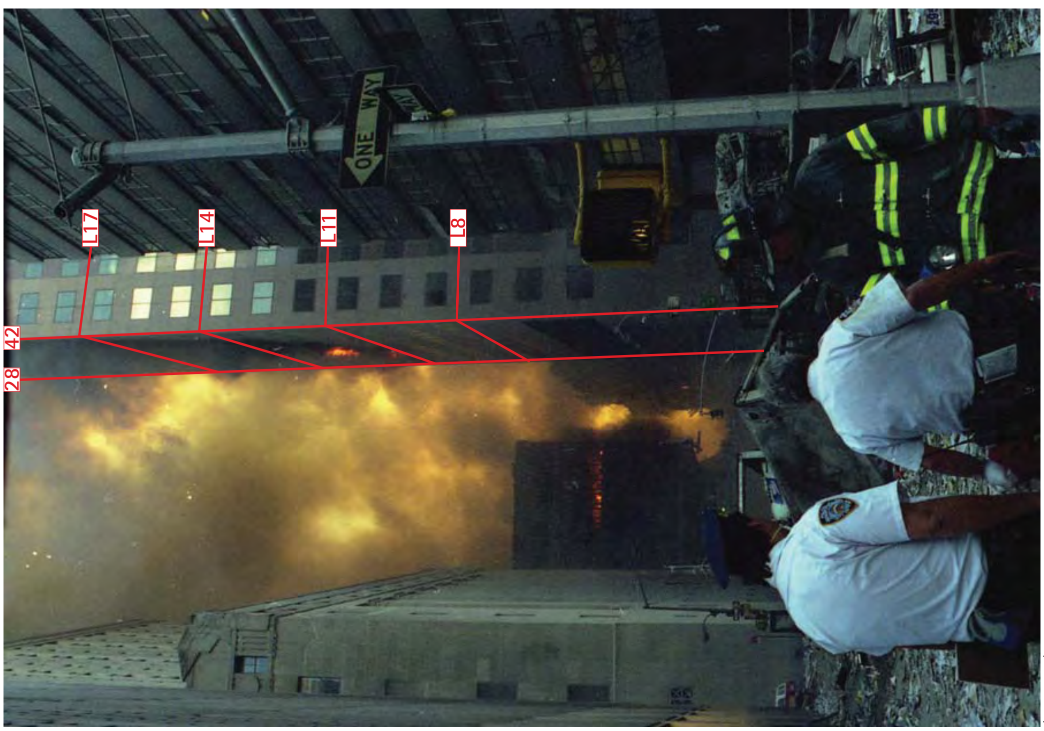


Image 5.E.51 with columns and floor levels overlaid

(Bottom)

Image 5.E.52 Northeast corner, approximately 2:15PM–2:28PM



(Bottom)

Image 5.E.52 with columns and floor levels overlaid

Image 5.E.53 East facade, 2:28:43PM +/-1S

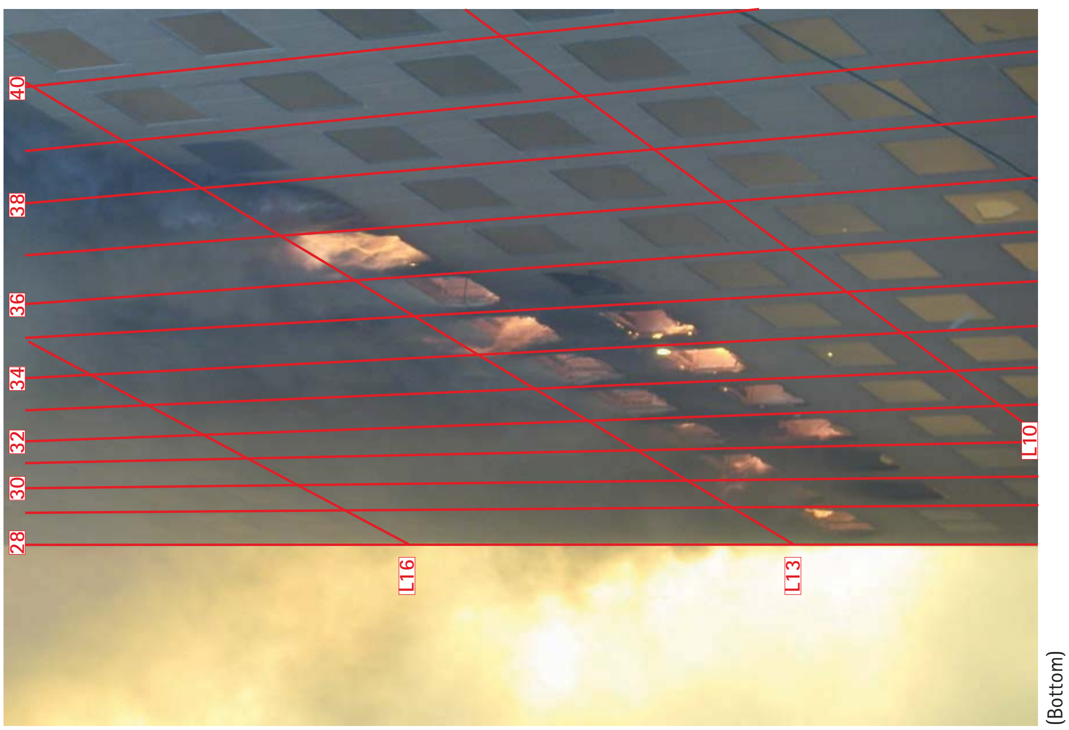


Image 5.E.53 with columns and floor levels overlaid

Image 5.E.54 East facade, approximately 2:28PM-3:10PM

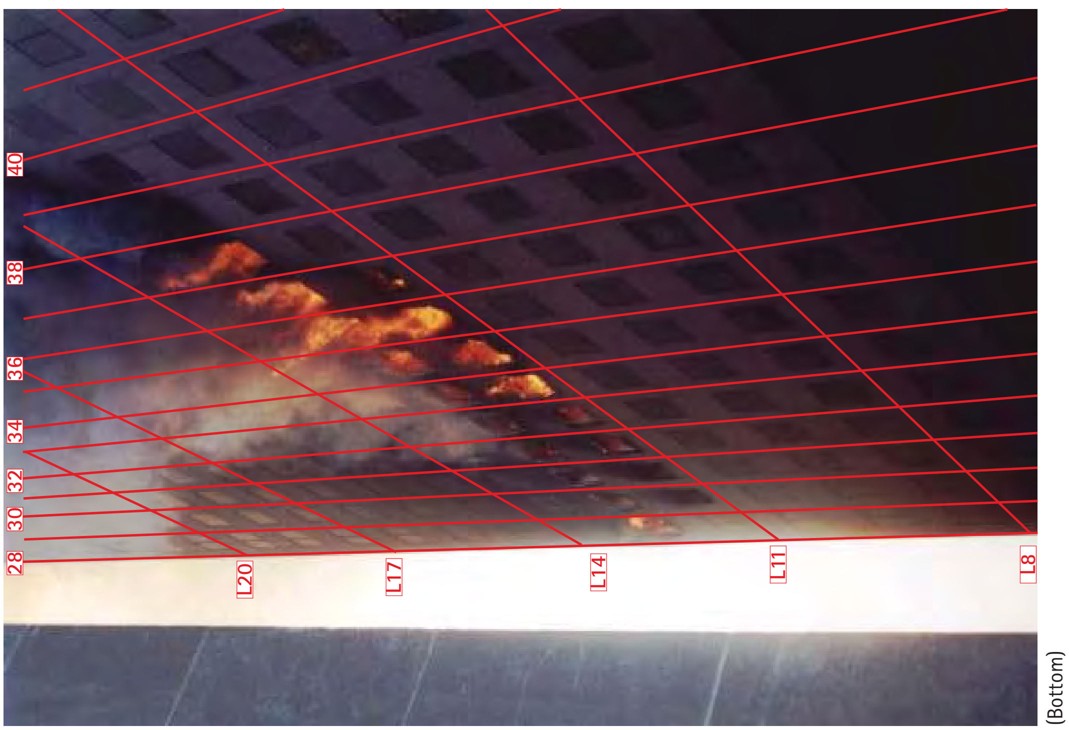


Image 5.E.54 with columns and floor levels overlaid

Image 5.N.01 North facade, 2:57PM +/-300S

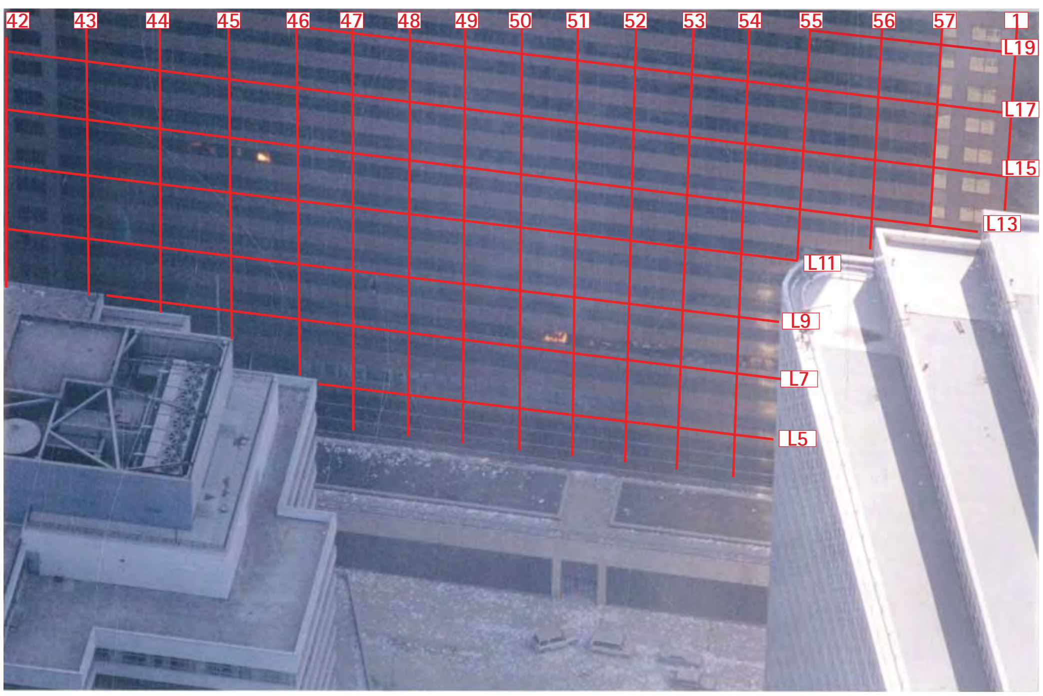


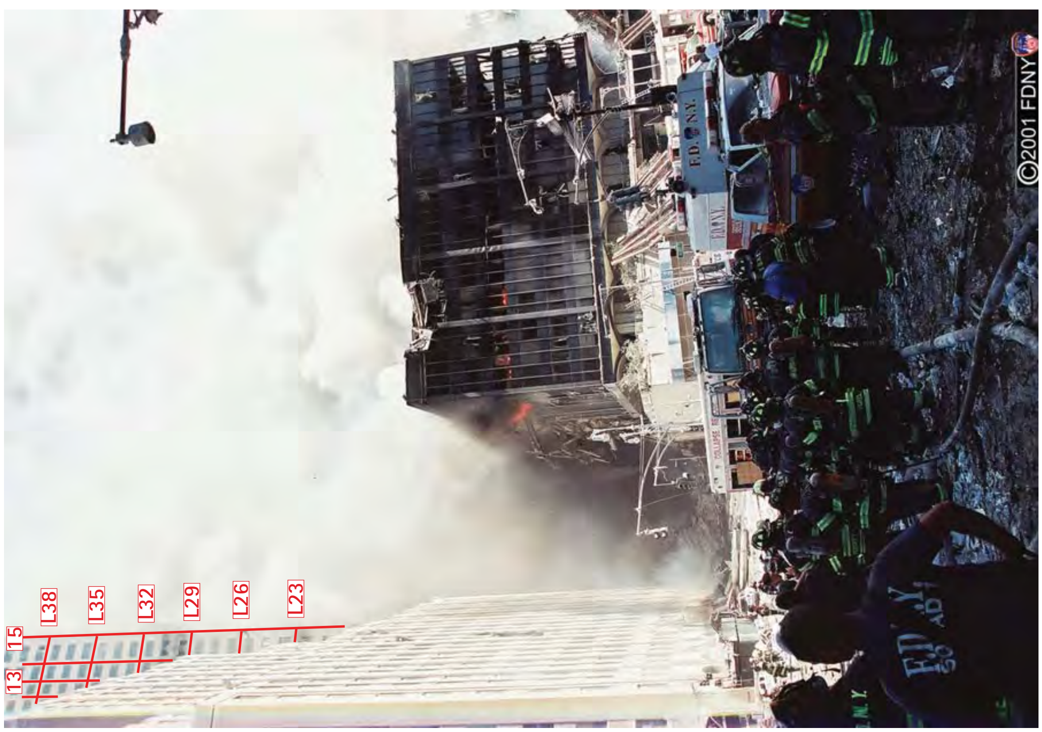
Image 5.N.01 with columns and floor levels overlaid

Image 5.W.01 West facade, approximately 2:00PM-3:00PM

Image 5.W.01 with columns and floor levels overlaid

(Bottom)

Image 5.W.02 West facade, approximately 2:00PM-3:00PM



(Bottom)

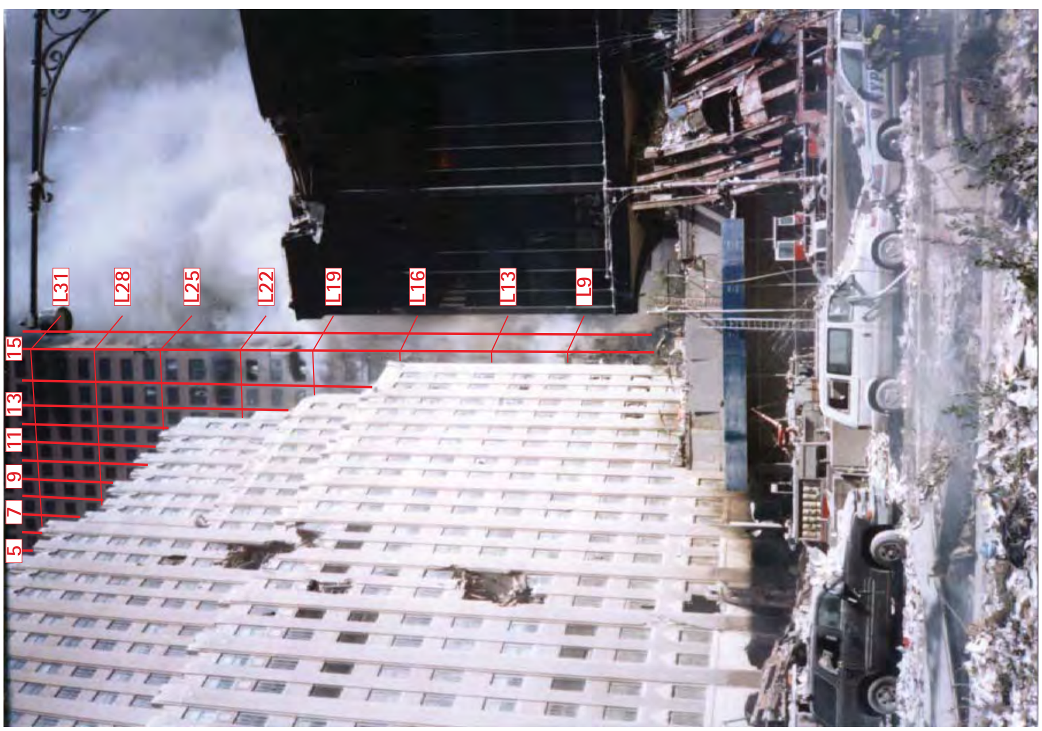
Image 5.W.02 with columns and floor levels overlaid

Image 5.W.03 West facade, approximately 2:00PM-3:00PM

Image 5.W.03 with columns and floor levels overlaid

(Bottom)

Image 5.W.04 Southwest corner, approximately 2:00PM-3:00PM

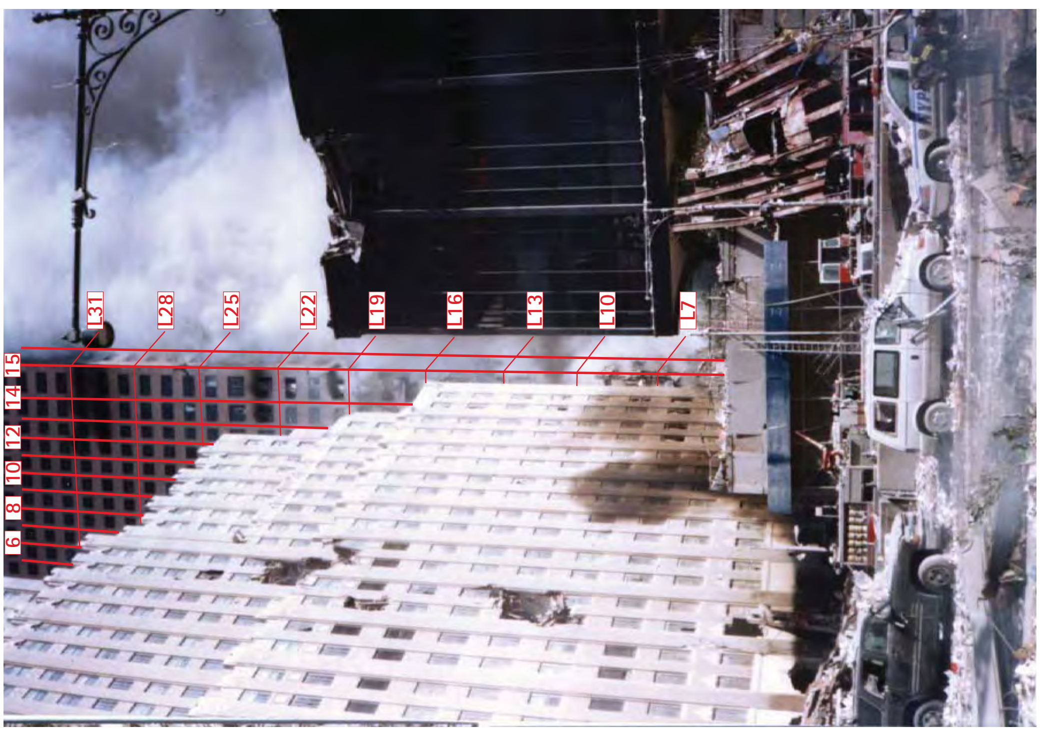


(Bottom)

Image 5.W.04 with columns and floor levels overlaid

(Bottom)

Image 5.W.05 Southwest corner, approximately 2:00PM-3:00PM



(Bottom)

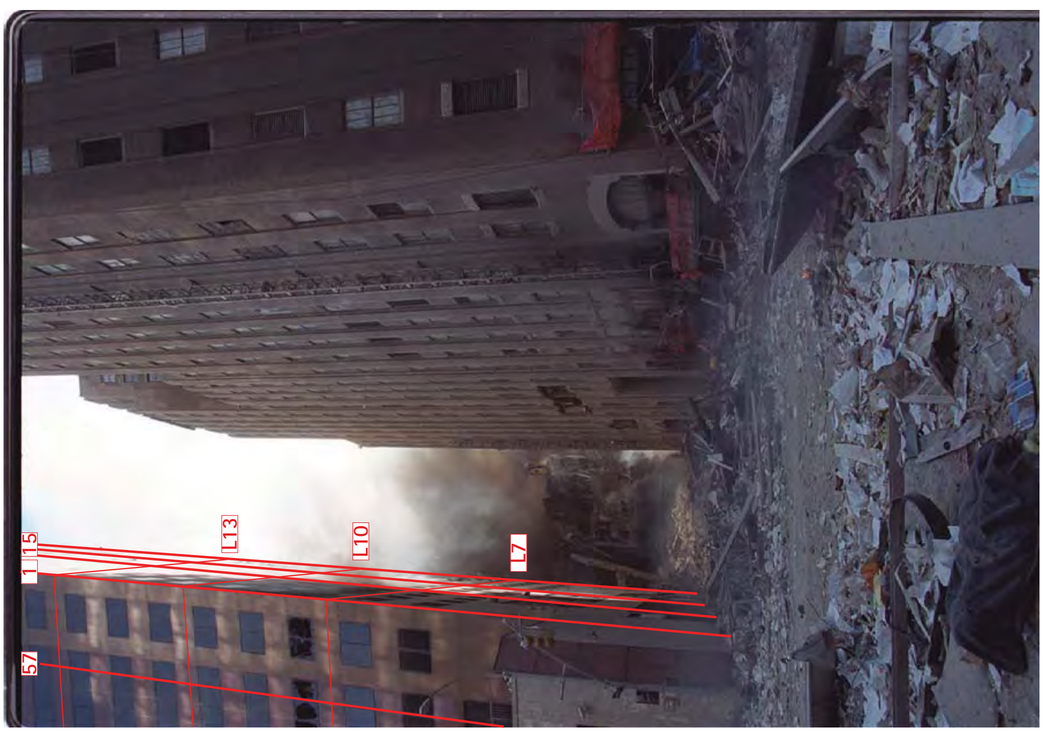
Image 5.W.05 with columns and floor levels overlaid

Image 5.W.06 Northwest corner, 2:15PM-2:45PM

Image 5.W.06 with columns and floor levels overlaid

(Bottom)

Image 5.W.07 Northwest corner, 2:21:10PM



(Bottom)

Image 5.W.07 with columns and floor levels overlaid

Image 5.W.08 Southwest corner, approximately 2:00PM–3:30PM

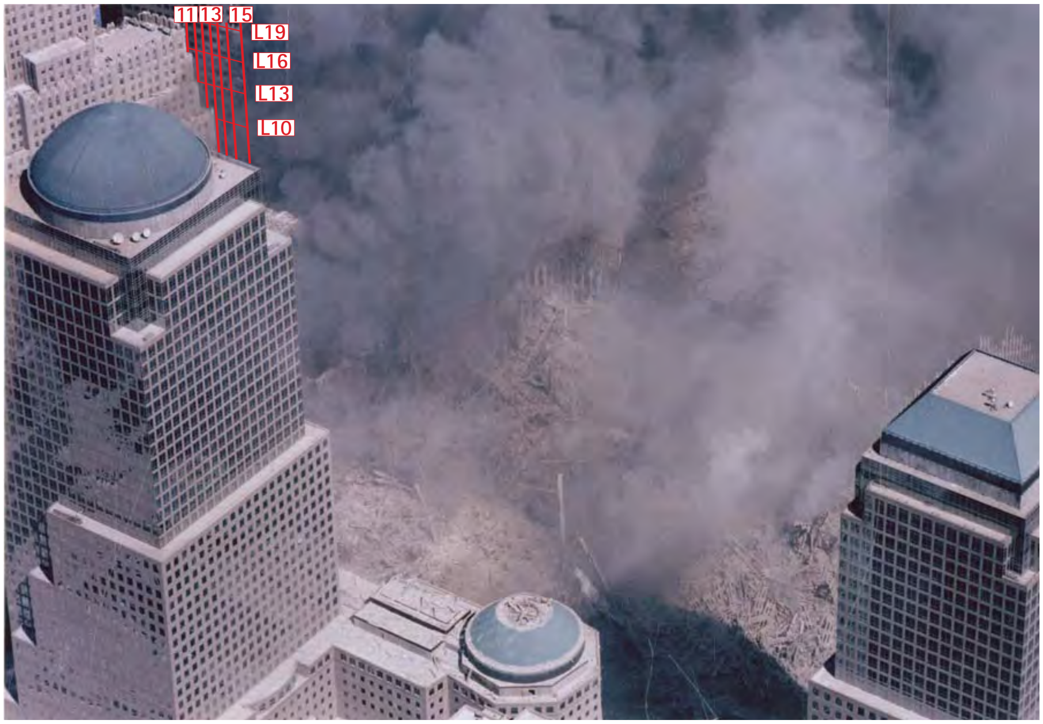


Image 5.W.08 with columns and floor levels overlaid

Image 5.W.09 Southwest corner, approximately 2:00PM-3:30PM

Image 5.W.09 with columns and floor levels overlaid

Image 5.W.10 Northwest corner, 2:30PM-3:00PM

Image 5.W.10 with columns and floor levels overlaid

Image 5.S.01 Southwest corner, approximately after 2:00PM

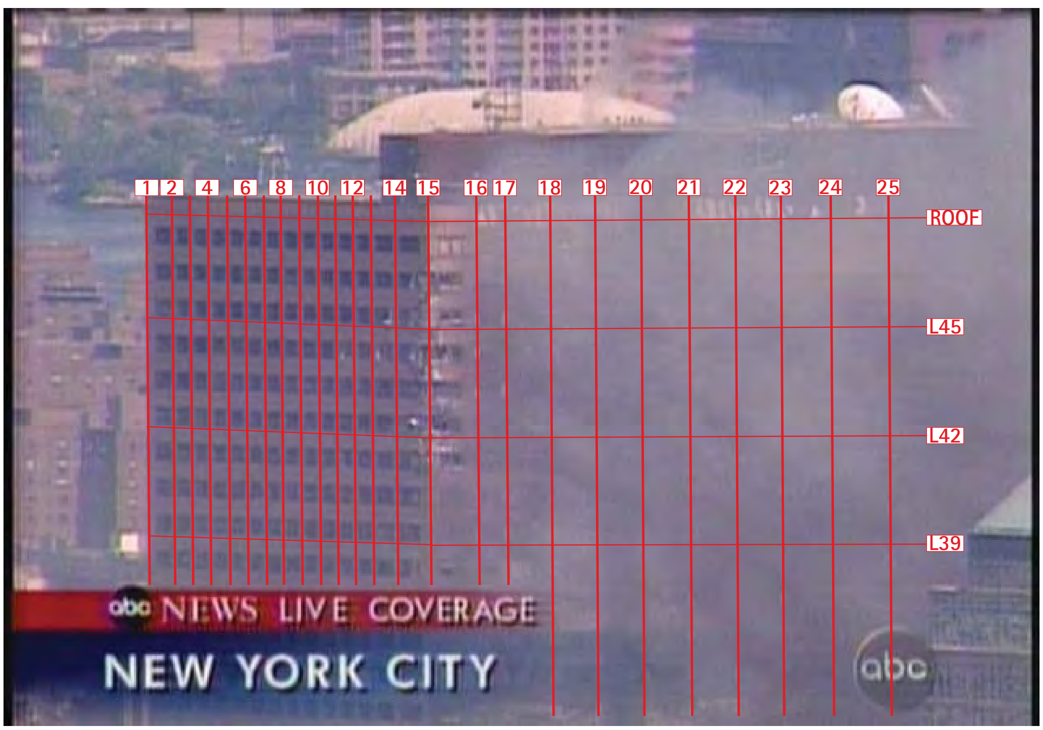


Image 5.S.01 with columns and floor levels overlaid

Image 5.S.02 Southwest corner, approximately after 2:00PM

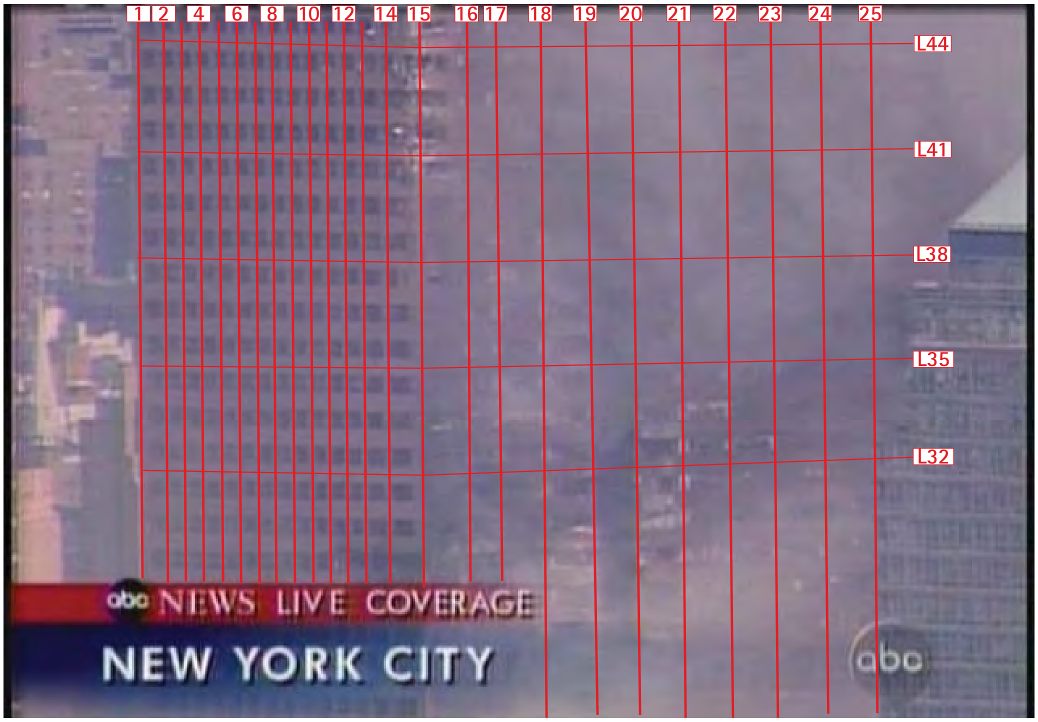


Image 5.S.02with columns and floor levels overlaid

A.6 FIRE PROGRESSION - 3PM TO 4PM

East Facade - The available visual evidence during this time period shows that fire has reached the northeast corner on levels 8, 12, and 13, though at different times throughout the hour; floor 12 at the very beginning, 13 around the middle, and 8 at the very end of the hour. The fire on floor 8 came from the north facade while the fires on levels 12 and 13 were moving towards the north face. In addition, an image indicates that smoke may have been emitted on floor 6 close to 4:00pm.

North Facade - A large succession of images show that fires burned on levels 7, 8, 9, 12, and 13 during this time period. The fires on floors 7 and 8 moved to the east while the fires on levels 12 and 13 moved west. Photographs showed fires burning on level 7 for the first half of the hour; 8, 9, and 13 didn't begin until the second half; 12 showed flames for almost the entire hour; and 9 only appeared at the very end.

West Facade - During this time period, visual evidence shows both fire and smoke at level 8 on the north side of the facade. Levels 17, 18, and 22 once again emitted smoke. In addition, an area at the center of the facade on level 17 appears to have released smoke and subsequently burned-out.

South Facade - No new visual evidence of fire-related damage during this time period.

A.6.1 Fire Damage Diagrams

Figures 6.E.01, 6.N.01, 6.W.01, and 6.S.01 on pages 204 to 210 depict the condition of each elevation at the end of this time period as evidenced in the available images. These diagrams are cumulative and contain the fire-related damage timed up until 4:00pm as well as the debris damage from WTC1's collapse. Fire damage types include smoke, broken window with internal fire, broken window with external fire, and burned-out. The fire-related damage on these figures represents a compilation of the last available visual evidence for each area within hour; therefore, these diagrams are only an approximation of what the elevation might have looked like at 4:00pm.

Figures 6.N.02 6.N.03, 6.W.02, 6.W.03, and 6.W.04 on pages 205 to 209 depict a series of sequential images showing the progression of fire in particular areas of the north and west façades during this time increment. While the full elevation diagrams represent the condition of each facade at the end of the time period, the detail elevation mappings illustrate how fire traveled or altered throughout the hour in a specific area. Debris damage has been omitted from these diagrams for clarity.

A.6.2 Photographs of Damage

The images found on pages 211 to 271 are all the images that show fire-related damage and are attributed to the time period from 3:00pm until 4:00pm. Each image is presented twice on one page; the top image is the untouched version while columns and level markers have been added to the lower image for reference. In some instances an untouched version of the photograph was not available and in its place an image that NIST has notated is used instead. These images are also shown twice with additional column and level markers added for full clarity.

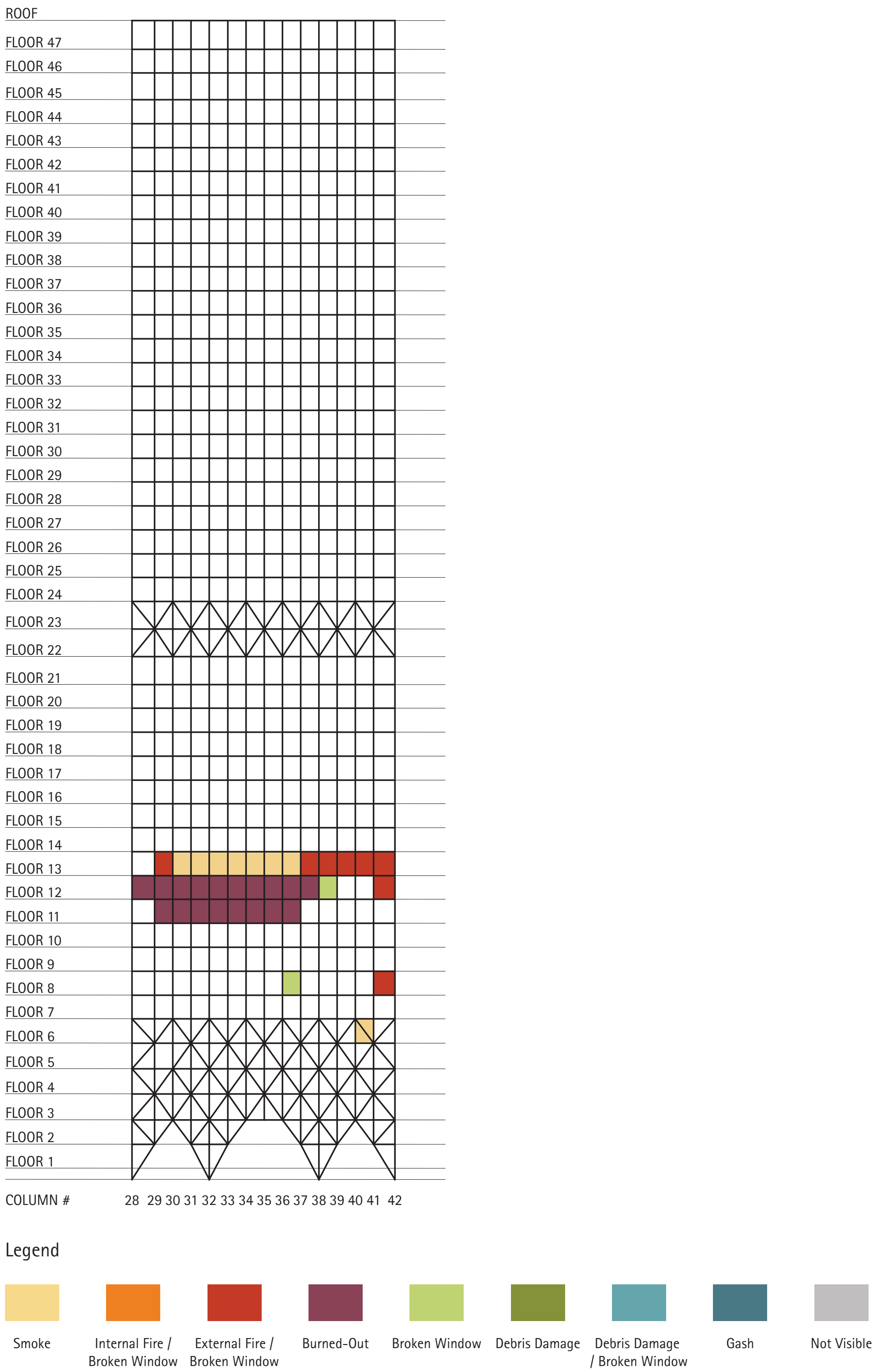


Figure 6.E.01 WTC7 East facade – Debris and Fire Damage at approximately 4PM

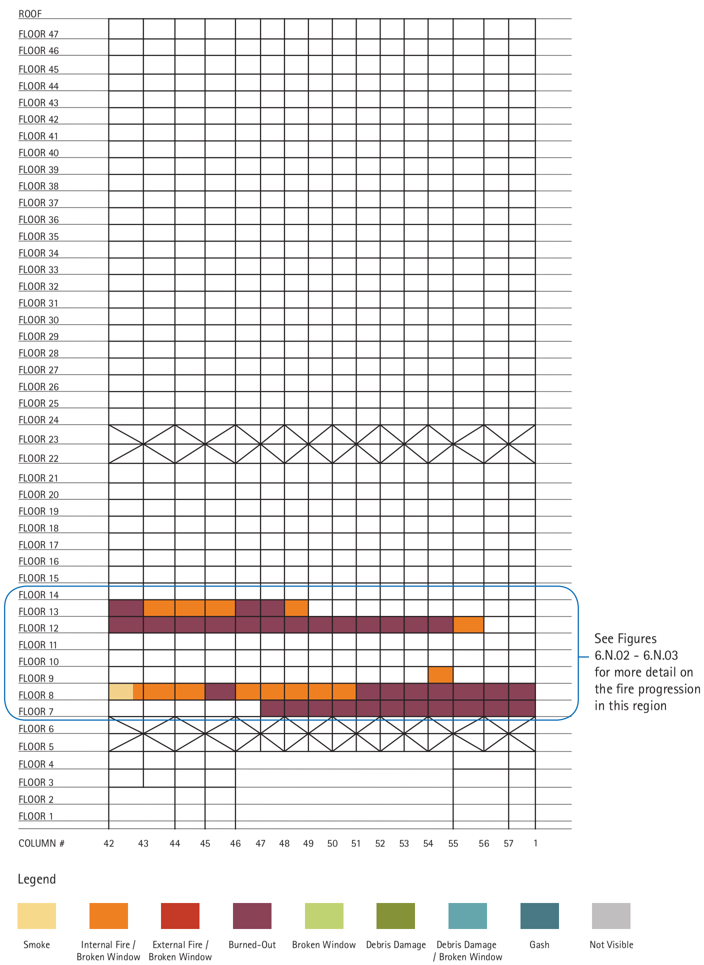


Figure 6.N.01 WTC7 North Facade - Debris and Fire Damage at approximately 4PM

ESTIMATED TIME 3:05PM TO 3:10PM

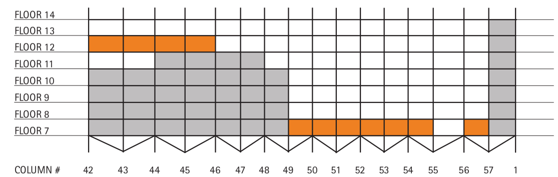


Diagram of Image 6.N.02

Image 6.N.02

ESTIMATED TIME 3:12:50PM +/-300s

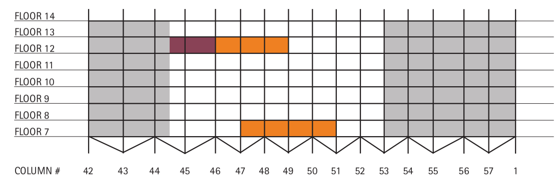


Diagram of Image 6.N.09

Image 6.N.09

ESTIMATED TIME 3:42:30PM +/-120s

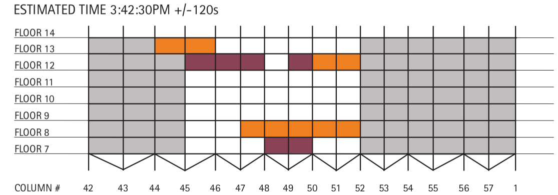


Diagram of Image 6.N.13

Image 6.N.13

ESTIMATED TIME 3:44PM +/-240s

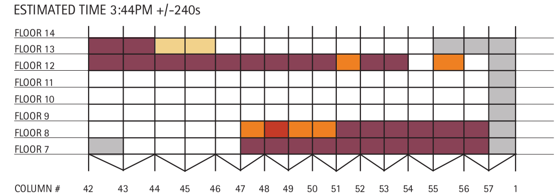


Diagram of Image 6.N.15

Image 6.N.15

Figure 6.N.02 WTC7 North Facade - Detailed Fire Progression from 3PM to 4PM

ESTIMATED TIME 3:51PM TO 3:58PM

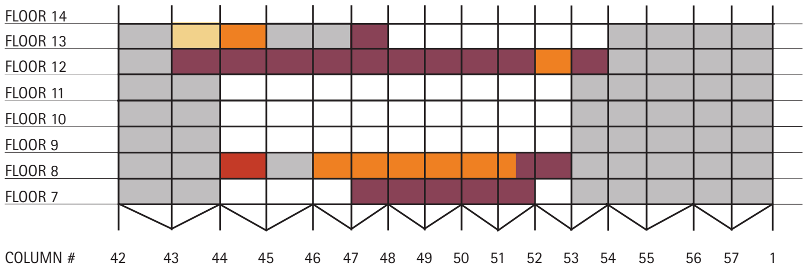


Diagram of Image 6.N.19

Image 6.N.19

ESTIMATED TIME NEAR 3:55PM

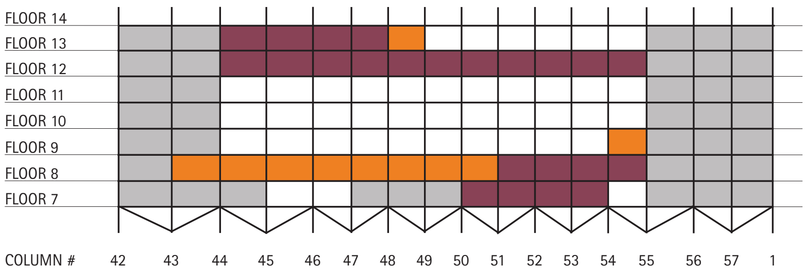


Diagram of Image 6.N.21

Image 6.N.21

ESTIMATED TIME 3:53PM TO 4:02PM

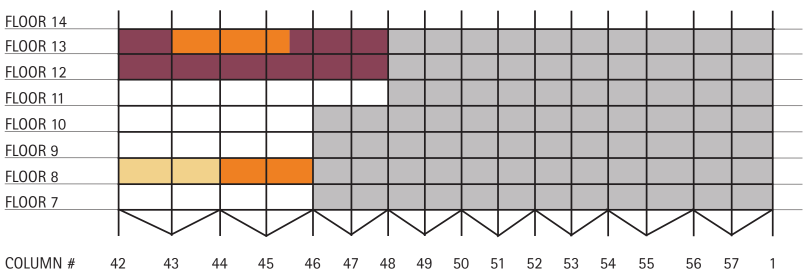


Diagram of Image 6.N.22

Image 6.N.22

Legend

Figure 6.N.03 WTC7 North Facade - Detailed Fire Progression from 3PM to 4PM

Guy Nordenson and Associates

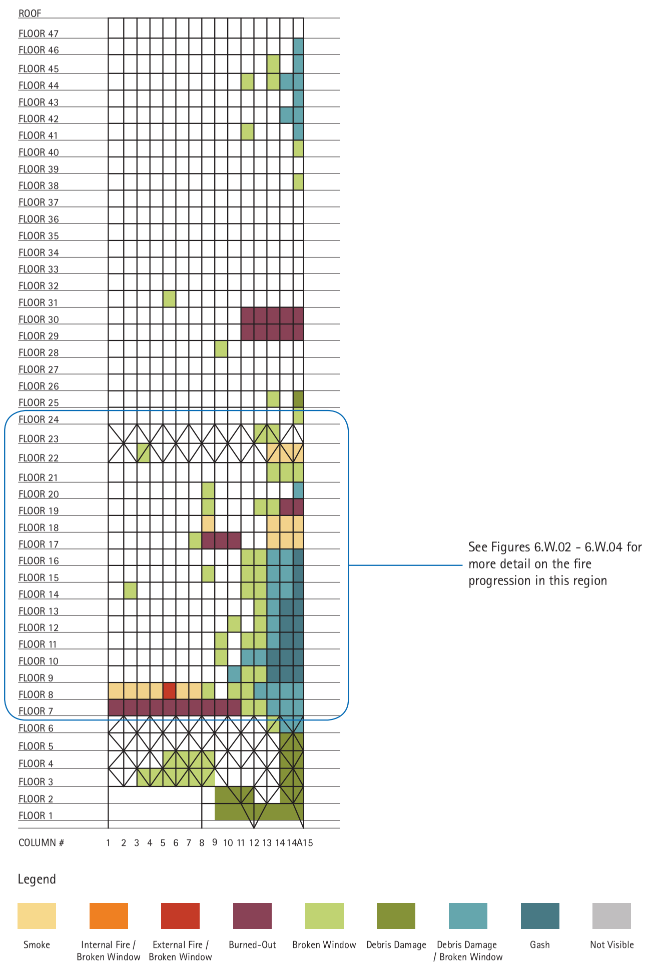


Figure 6.W.01 WTC7 West Facade- Debris and Fire Damage at approximately 4PM

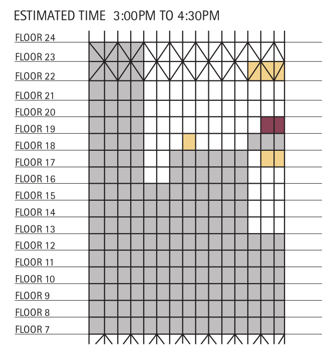


Diagram of Image 6.W.06

Image 6.W.06

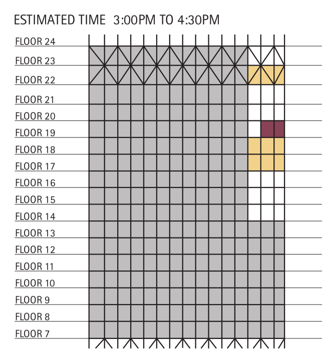


Diagram of Image 6.W.16

Image 6.W.16

Figure 6.W.02 WTC7 West Facade - Detailed Fire Progression from 3PM to 4PM

ESTIMATED TIME 3:00PM TO 4:30PM

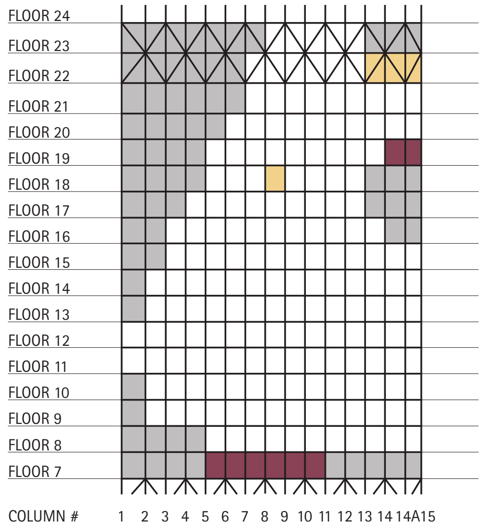


Diagram of Image 6.W.17

Image 6.W.17

ESTIMATED TIME 3:00PM TO 4:30PM

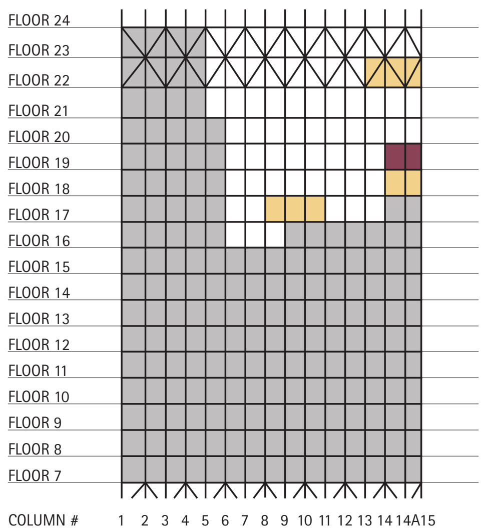


Diagram of Image 6.W.21

Image 6.W.21

Legend

Smoke | Internal Fire / Broken Window | External Fire / Broken Window | Burned-Out | Broken Window | Debris Damage | Debris Damage / Broken Window | Gash | Not Visible

Figure 6.W.03 WTC7 West Facade - Detailed Fire Progression from 3PM to 4PM

ESTIMATED TIME 3:41:30PM +/-300s

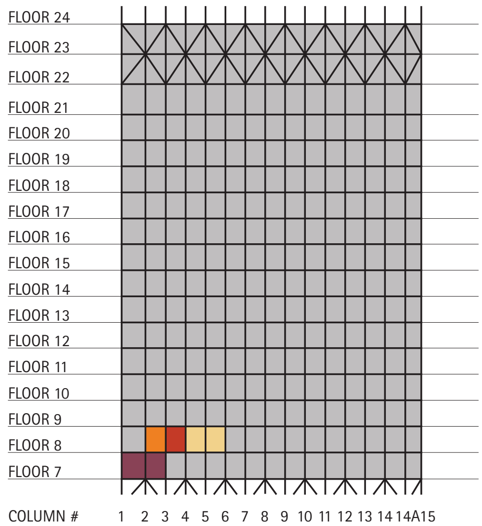


Diagram of Image 6.W.32

Image 6.W.32

ESTIMATED TIME 3:42PM +/-300s

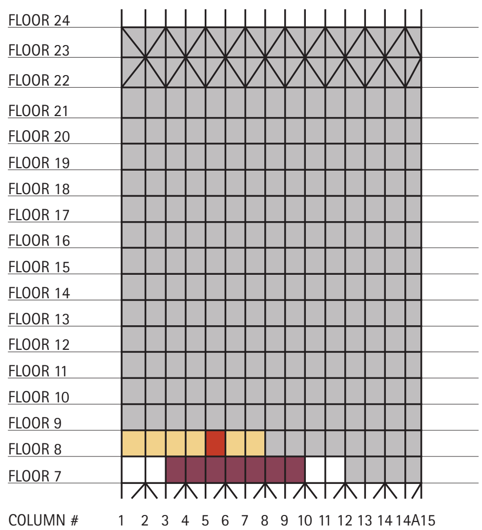


Diagram of Image 6.N.14

Image 6.N.14

Legend

Figure 6.W.04 WTC7 West Facade – Detailed Fire Progression from 3PM to 4PM

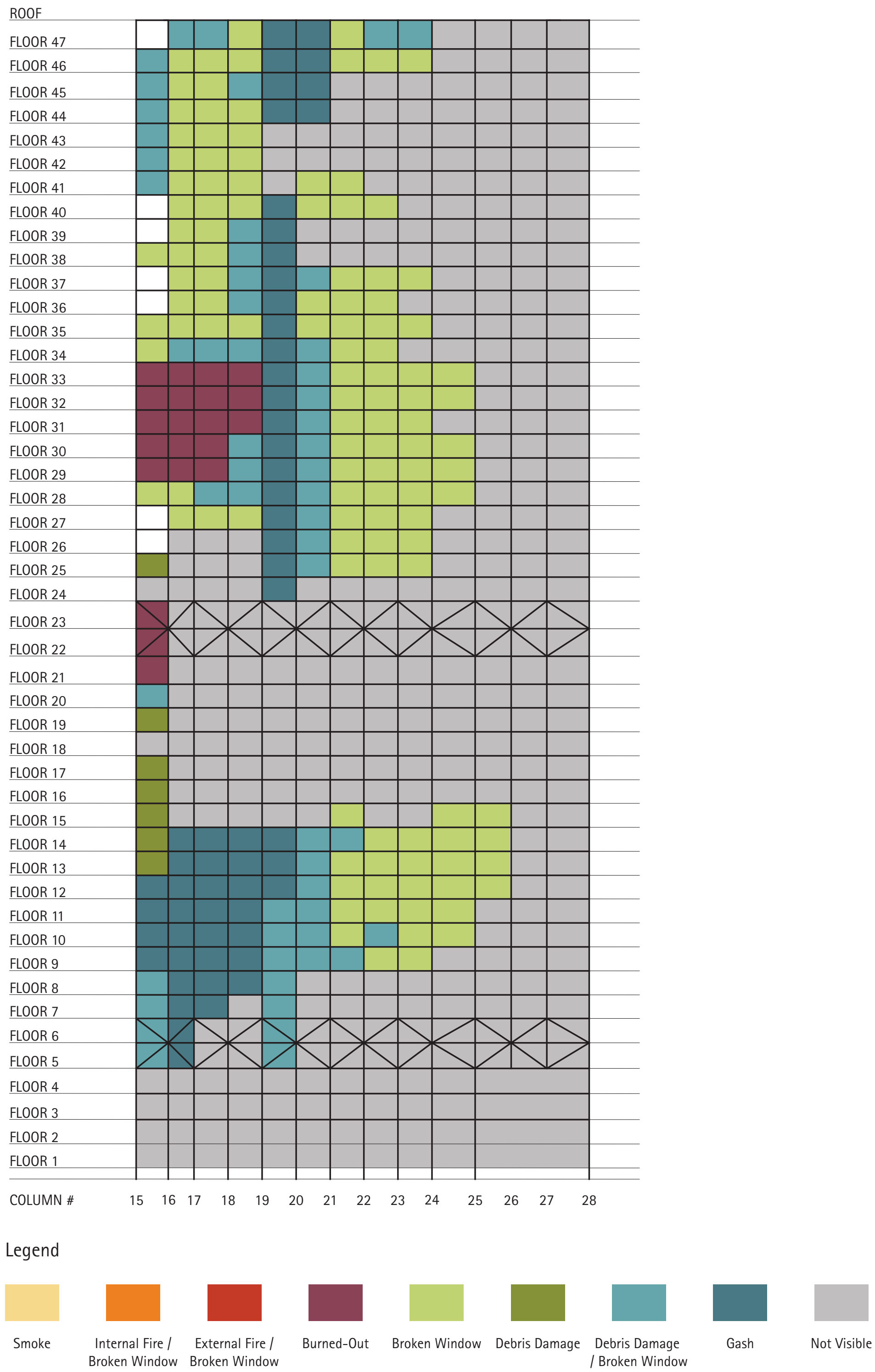
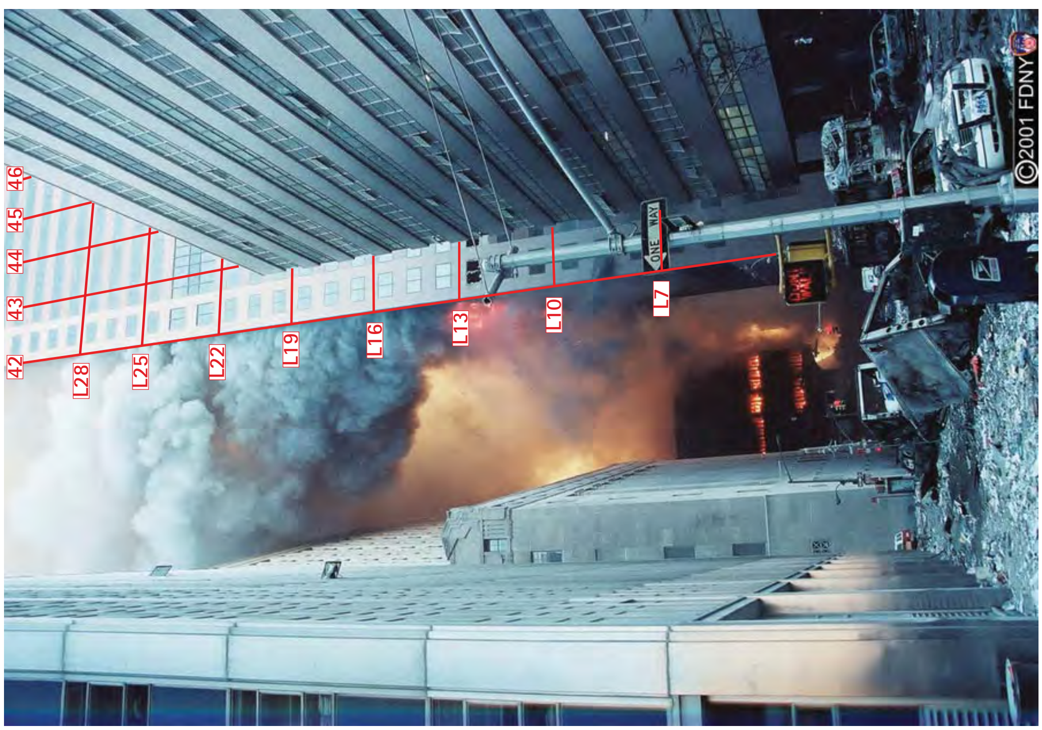


Figure 6.S.01 WTC7 South facade - Debris and Fire Damage at approximately 4PM

(Bottom)

Image 6.E.01 Northeast corner, approximately 3:20PM-3:40PM

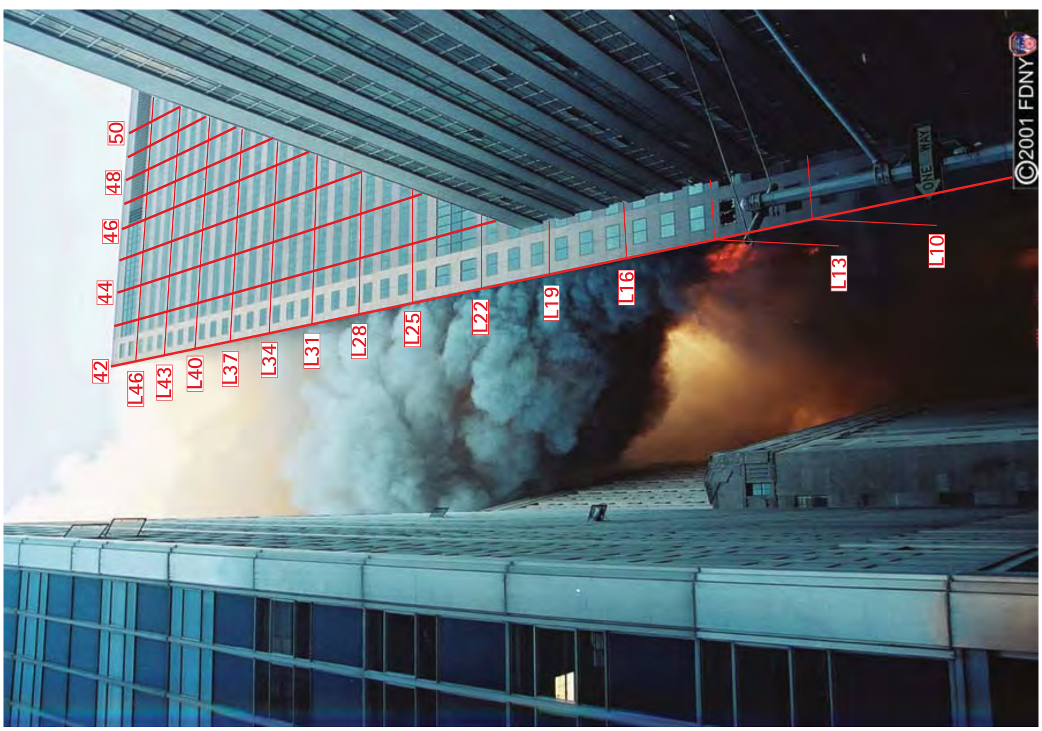


(Bottom)

Image 6.E.01 with columns and floor levels overlaid

(Bottom)

Image 6.E.02 Northeast corner, likely 3:20PM–3:40PM



(Bottom)

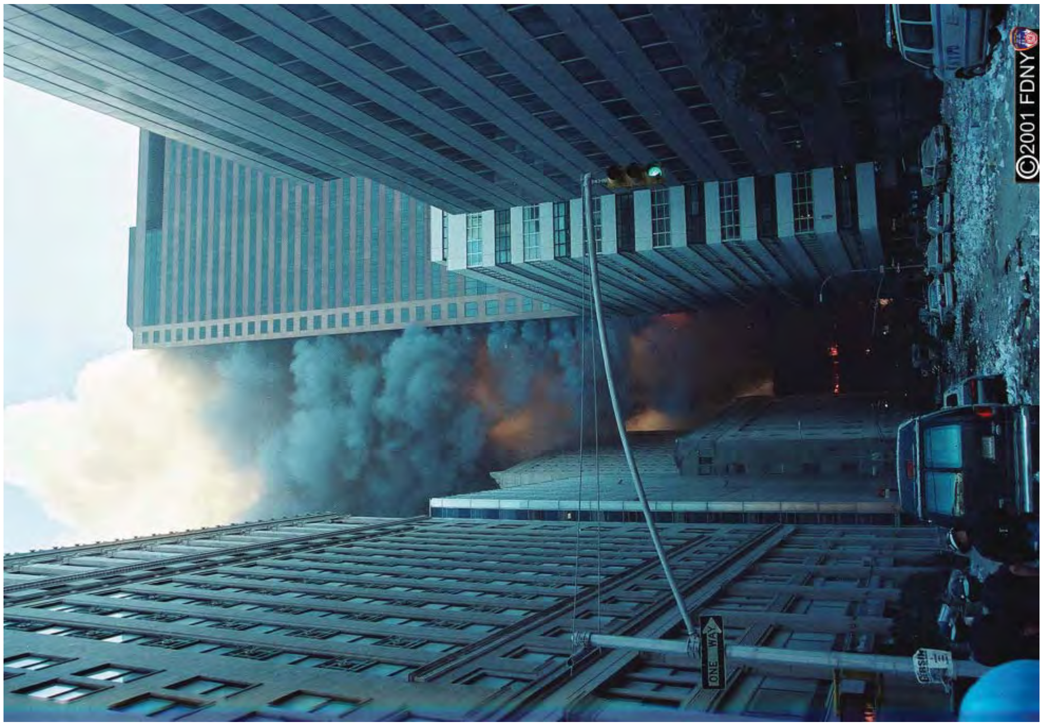
Image 6.E.02 with columns and floor levels overlaid

(Bottom)

Image 6.E.03 Northeast corner, approximately 3:20PM-3:40PM

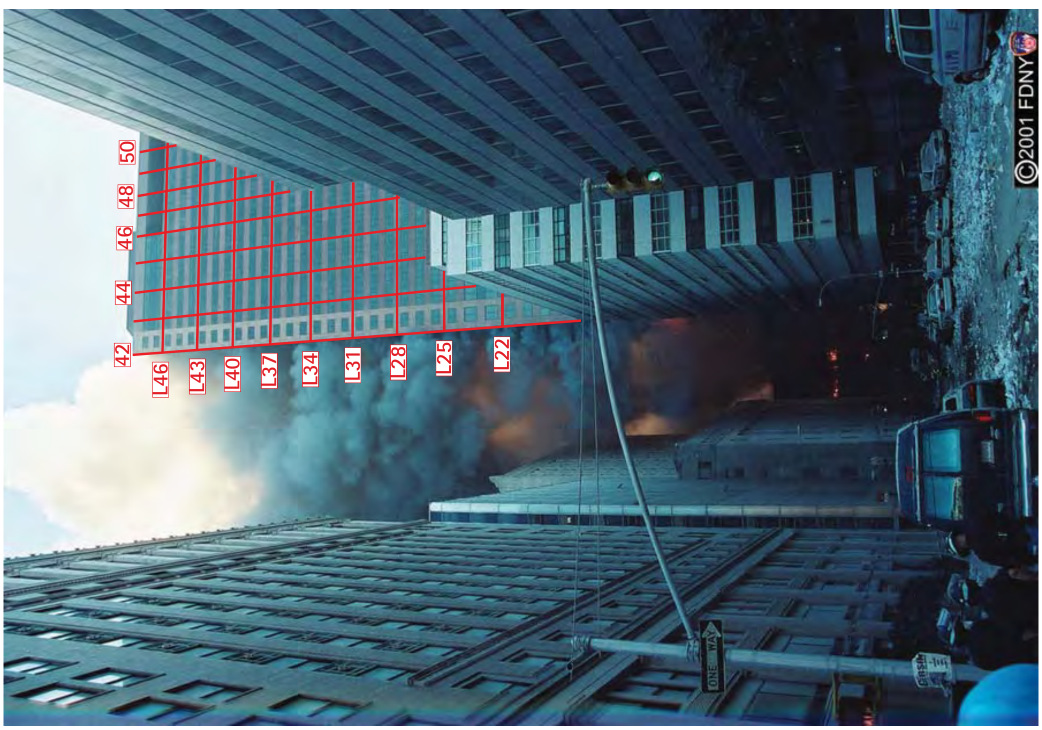
(Bottom)

Image 6.E.03 with columns and floor levels overlaid



(Bottom)

Image 6.E.04 Northeast corner, approximately 3:20PM–3:40PM



(Bottom)

Image 6.E.04 with columns and floor levels overlaid

Image 6.N.01 North facade, 3:05PM +/-300S

Image 6.N.01 with columns and floor levels overlaid

Image 6.N.02 North facade, approximately 3:05PM-3:10PM

Image 6.N.02 with columns and floor levels overlaid

Image 6.N.03 North facade, approximately 3:05PM–3:10PM

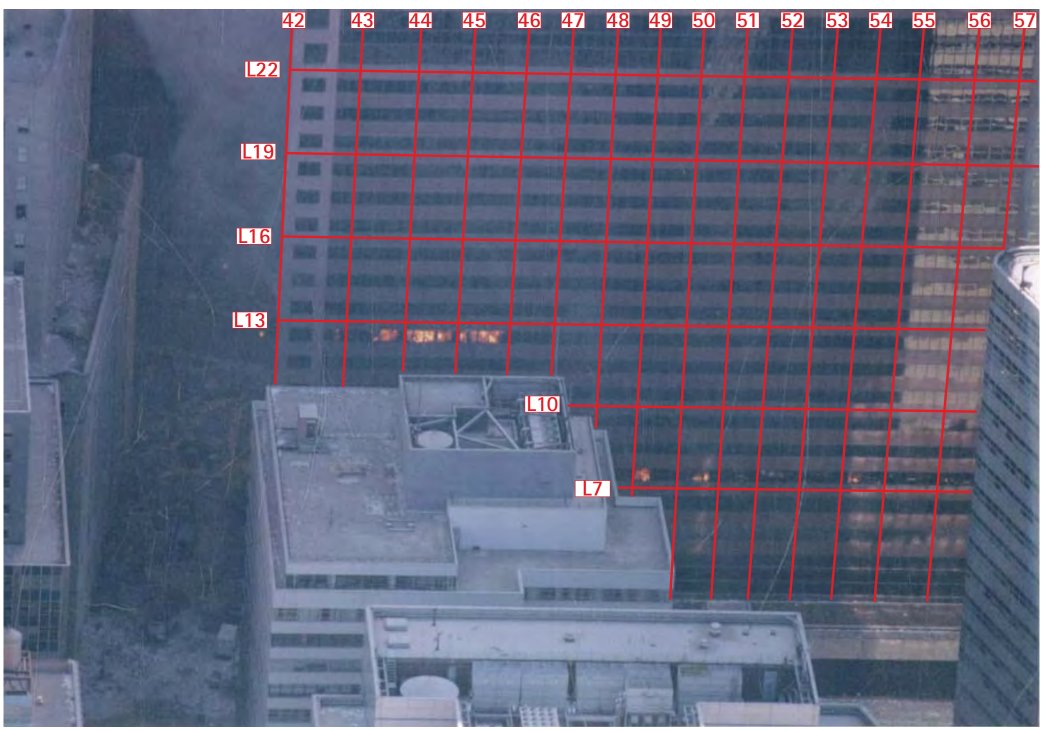


Image 6.N.03 with columns and floor levels overlaid

Image 6.N.04 Northeast corner, 3:10PM +/-300S

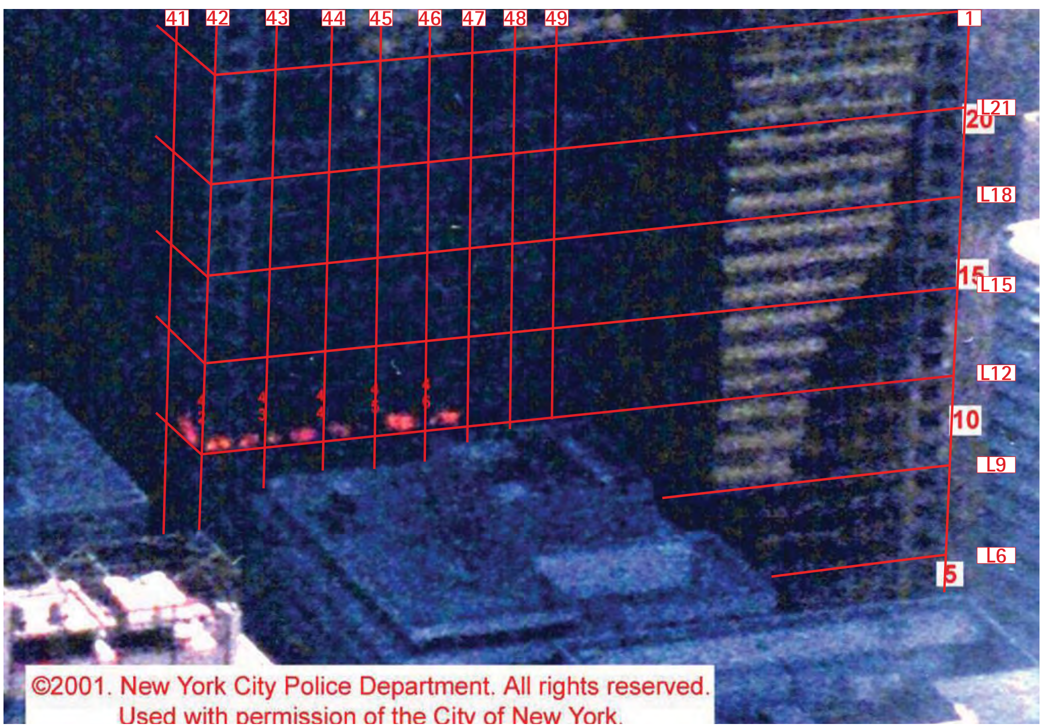


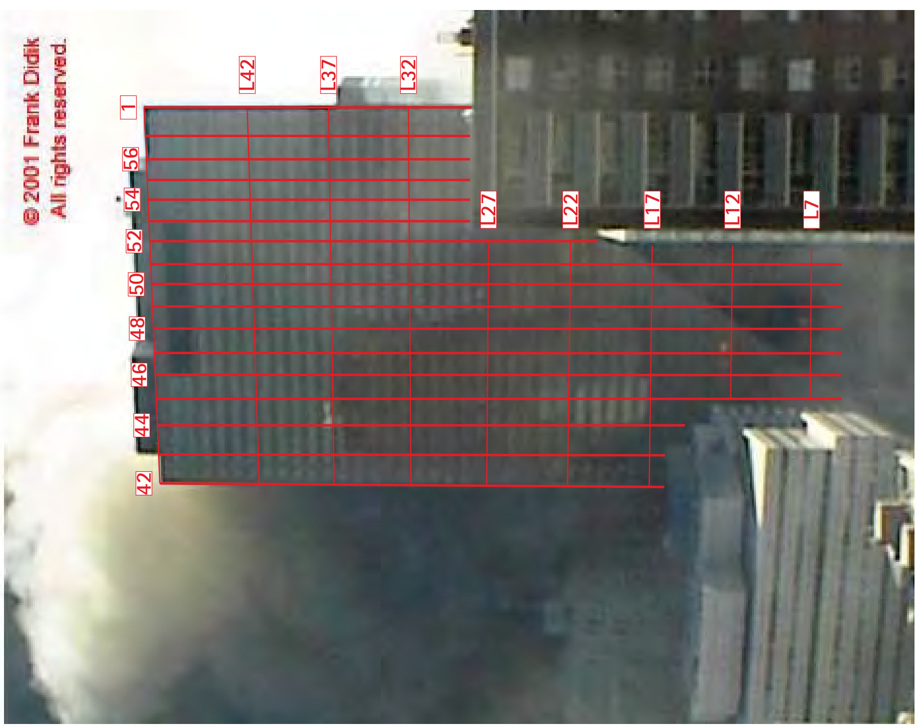
Image 6.N.04 with columns and floor levels overlaid

Image 6.N.05 North facade, approximately 3:05PM-3:10PM

Image 6.N.05 with columns and floor levels overlaid

(Bottom)

Image 6.N.06 North facade, 3:10:46PM +/-3S



(Bottom)

Image 6.N.06 with columns and floor levels overlaid