

## Part 1 World Trade Center Building Performance Study Data Collection, Preliminary Observations, and Recommendations

Federal Emergency Management Agency Federal Insurance and Mitigation Administration Washington, D.C.

FEMA Region II New York, New York



Data Collection, Preliminary Observations, and Recommendations



Federal Emergency Management Agency Federal Insurance and Mitigation Administration, Washington, DC FEMA Region II, New York, New York

## Purpose of the Study

- Examine the damage caused by these events, including the immediate effects of the aircraft impacts on each tower, the spread of fires following the crashes, the fire-induced reduction of structural strength, and the mechanism that led to the collapse of each tower
- Identify additional studies that should be performed
- Collect data
- Develop an understanding of the response of each affected building
- Determine the effects of damage to buildings in the immediate vicinity of the towers from falling debris and fires
- Identify the causes of observed behavior
- Identify additional studies that should be performed





























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**North Elevation (Developed)** 

#### West Elevation (Developed)



**South Elevation (Developed)** 

**East Elevation (Developed)** 













### Part 2 World Trade Center Building Performance Study Data Collection, Preliminary Observations, and Recommendations

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# Recommendation

 Conduct further studies to understand how WTC 3 resisted progressive collapse.















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#### Outline of Original Building

ALL DAY

22

40































# Recommendations

- Conduct further studies to determine the performance of connections and their adequacy under real fire exposures.
- Determine the combined structural and fire properties of the critical structural connections so that predictions of their behavior under overload conditions can be made. This can be accomplished with a combination of thermal transfer modeling, structural finite element modeling (FEM), and full-scale physical testing.
































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## Recommendations

- Collect additional data to confirm the extent of the damage to the south face of WTC 7 caused by falling debris.
- Determine the specific fuel loads, especially at the lower levels, to identify possible fuel supplied to sustain the fires for a substantial duration. Areas of interest include storage rooms, file rooms, spaces with high-density combustible materials, and locations of fuel lines. The control and operation of the emergency power system, including generators and storage tanks, needs to be thoroughly understood. Confirm the ability of the diesel fuel pumps to continue to operate and send fuel to the upper floors after a fuel line is severed.
- Examine the anticipated temperatures and duration of the fires and the effects of the fires on the structure, with an emphasis on the behavior of transfer systems and their connections.
- Study and confirm suggested mechanisms for a progressive collapse. Determine how the collapse of an unknown number of gravity columns brought down the whole building.
- Explain the role that the axial capacity between the beam-column connection and the relatively strong structural diaphragms may have had in the progressive collapse.
- Study the level of fire resistance and the ratio of capacity-to-demand required for structural members and connections deemed to be critical to the performance of WTC 7. The collapse of some structural members and connections may be more detrimental to the overall performance of the building than other structural members. Also study the adequacy of current design provisions for members whose failure could result in large-scale collapse.























## Recommendations

- Determine whether the observed damage in the column flange, and not at the beam flange, of the moment frames top connection plates is due to high restraint in the welds.
- Conduct further studies as to why the bottom flange welded connection has typically failed at the fillet weld to beam interface and not at the fillet weld to seat plate interface.
- Examine the impact response of various moment-connected details.
- Determine if composite construction would reduce local collapse zones. (There were no shear connectors to provide composite action between the floor beams and slab. Composite construction would have increased the capacity of the members and may have dissipated more of the impact energy; however, it may have also pulled a greater extent of the adjoining regions into the collapse zone.)
- Conduct further studies as to whether perimeter rebar in the slabs could improve the structural response by providing catenary action and tensile force resistance in the slabs to reduce local collapse zones.
- Determine whether the partial-strength connections permitted members to break away from the structure, thereby limiting the extent of damage. (If the moment connections had been designed for the capacity of the sections, as opposed to fully rigid partial strength based on design load and stiffness requirements, the building performance is likely to have been different.)
- Determine whether the collapse zone would have been limited if the spandrels on the 16th, 17th, and 18th floors had not been so grossly distorted through twisting.


No.	Block	Lot	Address	Name	Building Color Code <sup>2</sup>	Building Rating
1	16	100	395 South End Ave.	Gateway	Yellow	Moderate Damage
2	16	120	120 West St.	1 WFC Tower A	Yellow	Moderate Damage
3	16	120	120 West St.	South Bridge	Yellow	Moderate Damage
4	16	120	120 West St	1-2 WFC Link Bridge	Yellow	Moderate Damage
5	16	125	125 West St.	2 WFC Tower B	Blue	Major Damage
6	16	140	200 Vesev St	3 WFC Tower C - Annex	Blue	Major Damage
7	16	140	201 Vesev St.	Winter Garden Building	Blue	Major Damage
8	48	1	2 Wall St.	Thinker Buildenig	Yellow	Moderate Damage
9	49	2	111 Broadway		Yellow	Moderate Damage
10	51	14	125 Greenwich St		Yellow	Moderate Damage
11	51	15	90 Trinity Pl		Yellow	Moderate Damage
12	52	10	120 Cedar St		Blue	Major Damage
13	52	15	110 Trinity Pl		Yellow	Moderate Damage
14	52	21	120 Liberty St	0	Yellow	Moderate Damage
15	52	22	124 Liberty St.	Fire Station	Yellow	Moderate Damage
16	52	30	106 Liberty St	The olation	Yellow	Moderate Damage
17	52	7501	110 Liberty St		Yellow	Moderate Damage
18	52	7502	114 Liberty St	Engineering Building	Blue	Major Damage
19	53	23	5 Carlielo	Engineering Duilding	Yellow	Moderate Damage
20	53	20	1 Carlisle	<u>.</u>	Yellow	Moderate Damage
21	53	20	110 Greenwich St		Yellow	Moderate Damage
22	54	1	120 Liborty St	Backers Truct	Blue	Major Damaga
23	56		130 Coder St.	Dankers must	Blue	Major Damage
23	56	20	150 Gedar St.	Creek Orthodox Church	Black	Colleges
24	50	20	155 Gedar St.	Greek Orthodox Church	Blue	Collapse Major Domono
20	50	4	90 West St.	No ath Tanana	Block	Major Damage
20	50		WICI	North Tower	Black	Collapse
21	50	-	WIC2	South lower	Black	Collapse
20	50		WIC3	Marriott International Hotel	Black	Collapse
29	50	1	WIC4	South East Plaza	Red	Partial Collapse
30	50	1	WIC5	North East Plaza	Ped	Partial Collapse
31	00	1	WIC6	Custom House	Plack	Partial Collapse
32	04		WIC7		Black	Collapse
33	62		1 Liberty Plaza	0	Yellow	Moderate Damage
34	63	1	10 Cortland St.		Yellow	Moderate Damage
35	63	3	22 Cortland St.		Yellow	Moderate Damage
30	63	6	27 Church St.	Century 21	Yellow	Moderate Damage
37	63	13	189 Broadway		Yellow	Moderate Damage
38	63	15	187 Broadway		Yellow	Moderate Damage
39	65	10	9 Maiden Ln.	Jeweler's Building	Yellow	Moderate Damage
40	65	16	1/4 Broadway		Yellow	Moderate Damage
41	80	4	47 Church St.	Millennium Hotel	Tellow	Moderate Damage
42	84	1	140 West St.	Verizon	Blue	Major Damage
43	86	1	90 Church St.	Post Office	Yellow	Moderate Damage
44	88	2	12 Vesey St.		Yellow	Moderate Damage
45	88	8	26 Vesey St.		Yellow	Moderate Damage
46	88	10	28 Vesey St.		Yellow	Moderate Damage
47	88	13	14 Barclay St.		Yellow	Moderate Damage
48	125	20	100 Church St.		Yellow	Moderate Damage
49	126	2	110 Church St.		Yellow	Moderate Damage
50	126	9	45 Park Pl.		Blue	Major Damage
51	126	27	120 Church St.		Yellow	Moderate Damage
52	127	1	30 West Broadway		Blue	Major Damage
53	127	18	75 Park Pl.	1	Yellow	Moderate Damage
54	128	2	224 Greenwich St.		Yellow	Moderate Damage
55	136	15	60 Warren St.		Yellow	Moderate Damage
56	136	16	128 Chambers St.		Yellow	Moderate Damage

































## Recommendations

 Utilize the known data and conditions of the perimeter structures after the impact damage as a basis for calibration, comparison, and verification of existing software intended to predict such behavior, and for the development of new software for the prediction of the ability of structures to sustain localized and global overload conditions.

## **Overall Recommendations**

- Conduct detailed modeling of the aircraft impacts into WTC 1 and WTC 2 to provide understanding of the probable damage state immediately following the impacts.
- Conduct detailed modeling of the fires and combine with structural modeling to develop specific failure modes likely to have occurred.
- Conduct detailed modeling of the floor framing systems and their connections to understand the effects of localized overloads and failures to determine ultimate failure modes. Other types of common building framing should also be examined for these effects.
- Conduct studies of the fire-performance of steel trusses with spray-applied fire protection, and with end restraint conditions similar to those present in the two towers.
- Conduct tests of spray-applied fireproofing materials to understand how well they withstand mechanical damage and to determine whether it is appropriate and feasible to improve their resistance to such damage.
- Conduct studies to determine, given the great size and weight of the two towers, whether there are feasible design and construction features that would permit such buildings to arrest or limit a collapse, once it began.