Damage to Buildings by EF5 Tornado in Iowa, U.S. on May 25, 2008

by

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ABSTRACT

A major tornado struck the towns of Parkersburg and New Hartford, located in the north-central region of Iowa in United States, on May 25, 2008. This is the only EF5 tornado to occur in 2008. This paper summarizes the extent of the structural damage to buildings induced by this tornado. Results of field survey show the region where there were lots of seriously damaged buildings and typical modes of damage of these residential, public and commercial buildings. Further, based on the post disaster survey, rates of progress in recovery and replacement of damaged houses are shown.

KEYWORDS: Tornado, Damage Survey, Enhanced Fujita Scale

1. INTRODUCTION

A major tornado struck the towns of Parkersburg and New Hartford, located in the north-central region of Iowa in United States, on May 25, 2008 (Sunday) around 5 pm (CST). These towns are located slightly north of highway US-20 and east of Interstate I-35. Parkersburg, a town of 1,900, is about 80 miles northeast of Des Moines, the capital of Iowa. The counties that were affected by this natural disaster were Black Hawk, Buchanan, Butler and Delaware. The tornado touched down at 4:48 pm (CST) two miles south of Aplington near the Butler-Grundy county line, and moved 43 miles to the east until it lifted off at 5:58 pm (CST). The 43-mile damage path was 0.5 mile (800 m) wide near Parkersburg, ¼-mile wide east of New Hartford and 1.2 miles wide north of Dunkerton before the tornado dissipated.

As per the clarification on damage assessment by Iowa Homeland Security and FEMA released on May 30, 621 houses were estimated to be damaged of which 394 were destroyed, 65 had major damage and 162 had minor damage. There were eight casualties, six at Parkersburg and two at New Hartford. These casualties contributed to the rising national death toll from tornadoes in 2008 (111 to date) which has already proven to be the worst year in a decade in terms of number of tornado occurrences (605 total to date).

Of the 1,691 tornado occurrences in 2008 [1)], 207 or ~12% of the total were rated EF2 or higher - 148 EF2, 49 EF3, 9 EF4 and 1 EF5. The Parkersburg-New Hartford tornado is the only EF5 tornado to occur in the US this year and the only EF5 tornado to occur in Iowa in last 32 years; the last F5 tornado occurred in the Boone and Story counties of Iowa in 1976 in which 88 houses were destroyed but there were no serious injuries.

The co-authors of this paper carried out a field survey of the damaged area and buildings on May 26-27 and May 30 at Parkersburg and New Hartford. Assistance during the field survey from the office of National Weather Service at Johnston, Iowa is acknowledged.

2. TORNADO INTENSITY AND RELATED DAMAGE

Information on the tornado intensity and related damage as it appeared in the press releases of State of Iowa[2)], the local newspapers (*e.g.* the Des Moines Register[3)]), and US National Weather Service is summarized below.

The US National Weather Service has rated this tornado as EF5 on the newly adopted Enhanced Fujita Damage Scale or EF-Scale with an estimated wind speed of 205 mph (92 m/s). Although EF5 is the highest rating on the

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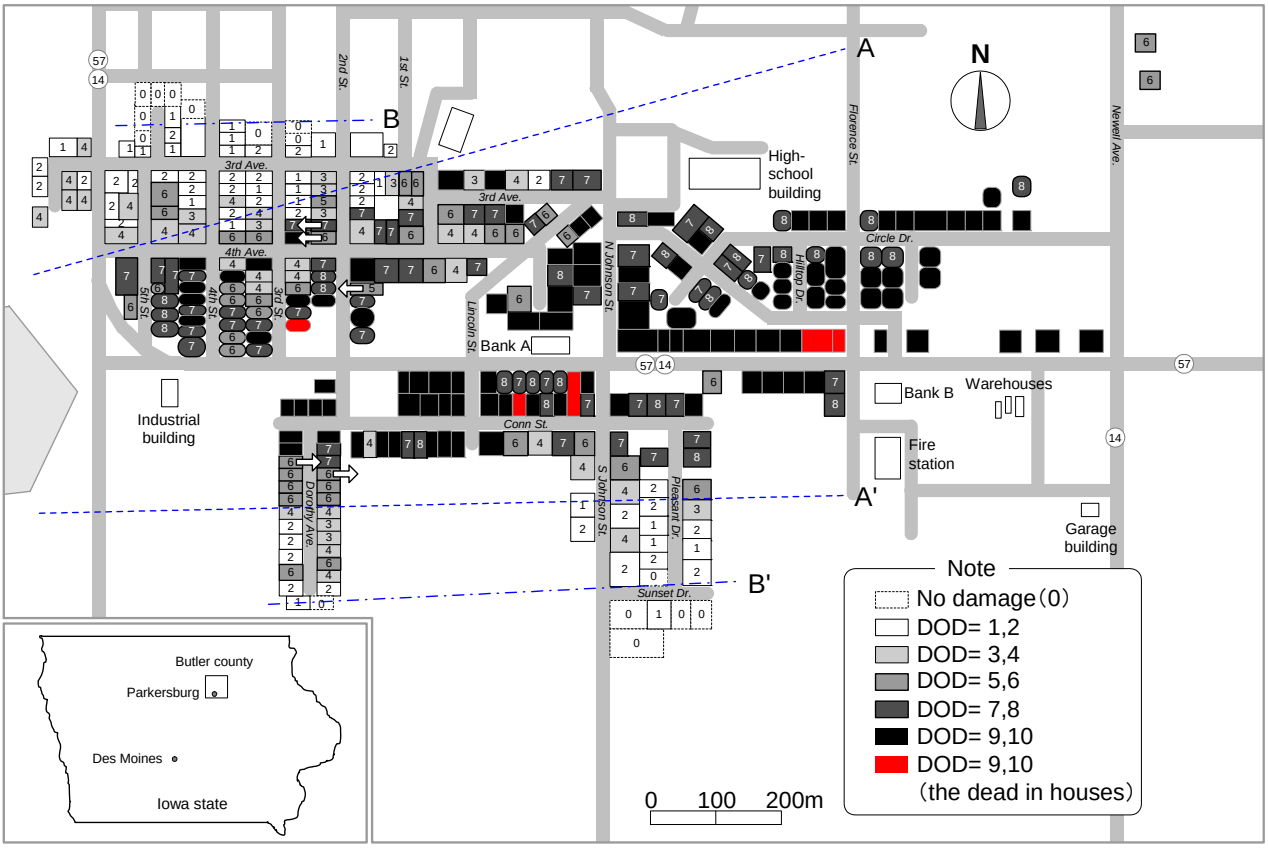


Figure 1 Distribution of damage to buildings in Parkersburg, IA

tornado intensity scale, the estimated wind speeds barely exceeded the range of wind speeds assigned to the EF4 scale (166-200 mph). In this regard, the tornado was at the low end of the EF5 scale.

Statistics of structural and other types of damages and fatalities are as follows:

- As of May 30, in Butler, Buchanan, Black Hawk, and Delaware counties, 621 houses were estimated to be damaged in the storm of which 394 were destroyed, 65 had major damage and 162 had minor damage. In addition, 21 businesses including 4 major ones and a high school were damaged. The City Hall in Parkersburg was also destroyed.
- As of May 28, 7 persons were dead because of the storm. The ages of the 5 persons who died in Parkersburg range from 71 to 80 years and the 2 persons who died in New Hartford were 48 and 71 years old. At least 50 persons were injured of which one was in critical condition.
- There were 1,002 electrical outages in Parkersburg. Of these, 320 were in homes or businesses that were destroyed.

3. TORNADO-INDUCED STRUCTURAL DAMAGE

3.1 Damage Distribution of Buildings in Parkersburg

A rough map of Parkersburg showing the locations of the damaged buildings is given in Figure 1. Damage state of each house correspond to the degree of damage or DOD regulated for one- or two-family residences as shown in Table 1[4]. The damage state is defined as DOD of 1 to 10 in EF scale. DOD of 1 to 4 indicate damage states in which non-structural components are mainly damaged, while DOD of 5 and more indicate damage states related to structural components including destruction of entire structure.

The most severe damage area, where almost all the houses were collapsed, is along highway 57th, Conn street, N Johnson street, and Circle street. Therefore, it can be estimated that the center of tornado vortex passed through highway 57th. According to the local newspaper, the casualties occurred in several

houses that were located along the estimated path.

Generally, it can be noted that the boundary between severely damaged area and quite less damaged one is more distinguishable in tornado-induced damage than in the case of typhoon-induced damage[5]. Based on that, line A – A' (Fig. 1) can be approximate boundary between structural components' related damage and non-structural components' related damage. Also line B – B' can be approximate threshold of visible damage to buildings. This result shows that houses suffering structural damage range in width of approximately 400 – 600m, and that houses suffering mostly non structural damage range in width of approximately 200m in both sides.

Table 1 Degree of damage for one- or two-family residences in EF scale [4]

DOD	Damage description
1	Threshold of visible damage
2	Loss of roof covering material (<20%); gutters and/or awning; loss of vinyl or metal siding
3	Broken glass in doors and windows
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward; failure of porch or carport
5	Entire house shifts off foundation
6	Large sections of roof structure removed; most walls remain standing
7	Exterior walls collapsed
8	Most walls collapsed, except small interior rooms
9	All walls
10	Destruction of engineered and/or well constructed residence; slab swept clean

3.2 Damage to Public and Commercial Buildings

Under this category of buildings is High-School, Bank, Car-Wash, Garage, Warehouse, Fire-Station and Industrial Buildings and Grain Bins or Tanks. Most of these were engineered buildings. Damage to each of these categories is described next.

(1) *High-school Building*

Damage to the high school building is shown below. The walls were made out of one external layer of brick and mortar and one internal layer of unreinforced concrete masonry unit (or CMU) and mortar, placed side by side while spanning between reinforced concrete columns. The roof was flat and it was supported by light steel truss spanning between the walls. It is observed that walls of the classrooms along the west side (Photos 1, 2) and those along the east side (Photos 3 – 4) were completely destroyed. Photo 5 shows the exposed steel reinforcement of the collapsed column that was part of a wall along the east side. Extensive roof damage of the school gymnasium can be seen in Photos 2, 3 and lots of broken glass were found scattered all around. The clock in Photo 1 shows the time of destruction when it stopped at 4:55 pm (CST).

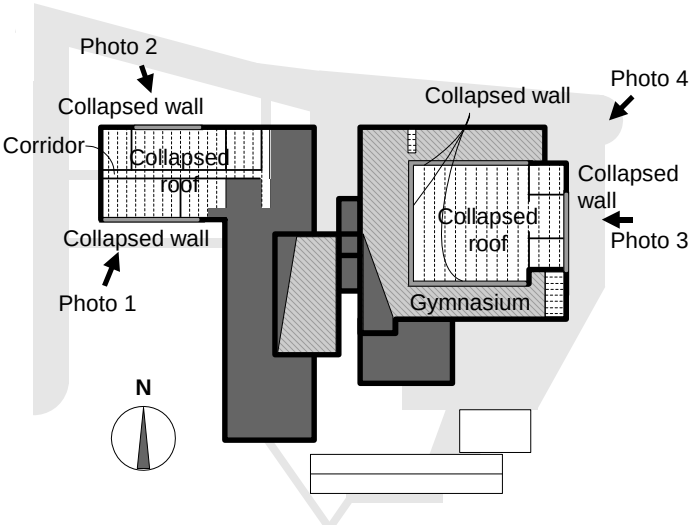


Figure 2 Damage to high-school building

Photo 1 Collapse of wall of classroom

Photo 2 Collapse of wall and roof of classroom

Photo 3 Collapse of wall and roof

Photo 4 View of collapsed wall

Photo 5 Failure of structural elements reinforced with bars

(2) *Bank Buildings*

Damage to Bank A and Bank B buildings is shown in Photos 6, 7, and Photo 8, respectively. These were regular timber constructions with a brick veneer. The structural damage to Bank A building such as collapse of a wall resulted in much more devastation than that of Bank B building. It is surprising to note that although Bank A building, in spite of its location right along the tornado path, was the only building that stood and was not completely demolished. It should be noted that this was a newer construction.

Photo 6 View of damage from the south (Bank A)

Photo 7 View of south west corner showing collapse of a portion of south wall (Bank A)

Photo 8 Damage to roof canopy (Bank B)

(3) *Fire Station*

Damage to a fire station is shown in Photos 9 – 10 below. The fire station sustained minor damage but all seven out of its eight overhead shutters on the western side were completely lost (Photo 9). This is a typical metal building structure with metal cladding and steel frame. This building was not in the direct tornado path and is located close to the water tank on the southern side of the tornado path.

Photo 9 West side of fire-station

Photo 10 North side of fire-station

(4) *Industrial Building*

An industrial steel framed building with gable roof and a large roof span took the first hit from the tornado as it was located at the south-western corner of the town where the tornado first approached Parkersburg. The entire building was destroyed and only the concrete slab remained. The twisted steel frame and corrugated sheet metal are seen in Photo 11 and failed steel components and sheared welded joints are seen in Photo 12. All the columns of the building were sheared from their base.

Photo 11 Destroyed structural elements

Photo 12 Failed steel component

(5) *Warehouses and Garage Building*

There were three warehouses (A, B and C) on Figure 1. Each of three warehouses has individual compartment rooms attached with shutters, which are arranged in line in both east and west sides. Damage to Warehouse A is shown in Photos 13 – 15. This one is located on the eastern-most end of the three warehouses that were built side by side and is the largest amongst the three warehouses. The end-most roof truss of this warehouse on the north side (Photo 15) and most of the roof on the east side are lost (Photo 13).

This warehouse sustained much more damage to its roof and shutters compared to the garage. This could be because it was closer to the path of the tornado than the garage. It is evident that a few of the shutters in the warehouse were pulled outward that is consistent with the loading produced by suction in the tornado vortex (Photo 14).

Figure 3 shows distribution of damage to roof cover, shutter and wall of all the three warehouses in plan view. This shows marked contrast of damage states between east and west sides in each warehouse: there are severe damage to roofing systems and not so much damage to shutters in east side of each warehouse, while there are severe damage to shutters in west side of each one. Moreover, with respect to damage to shutters, almost all the damaged shutters in east sides were pulled outward as shown in Photo 14, while all the damaged ones in west side were pushed inward.

Damage to a vehicle garage is shown in Photos 16 – 17. The roof cover on the west side of the vehicle garage is lost. This building has a gable roof with its ridge oriented along the east-west direction. It is observed in Photo 16 that the damage to the roof and its gable end occurred at the west end which was the leading edge of the rotating flow. The overhead shutters that were on the north side performed very well, as seen in the photo. Photo 17 shows flying debris impact on the west wall.

Photo 13 Damaged shutters and roof frames

Photo 14 Pulled-out shutters

Photo 15 Loss of roof truss and wall

Photo 16 Damage in west and north side

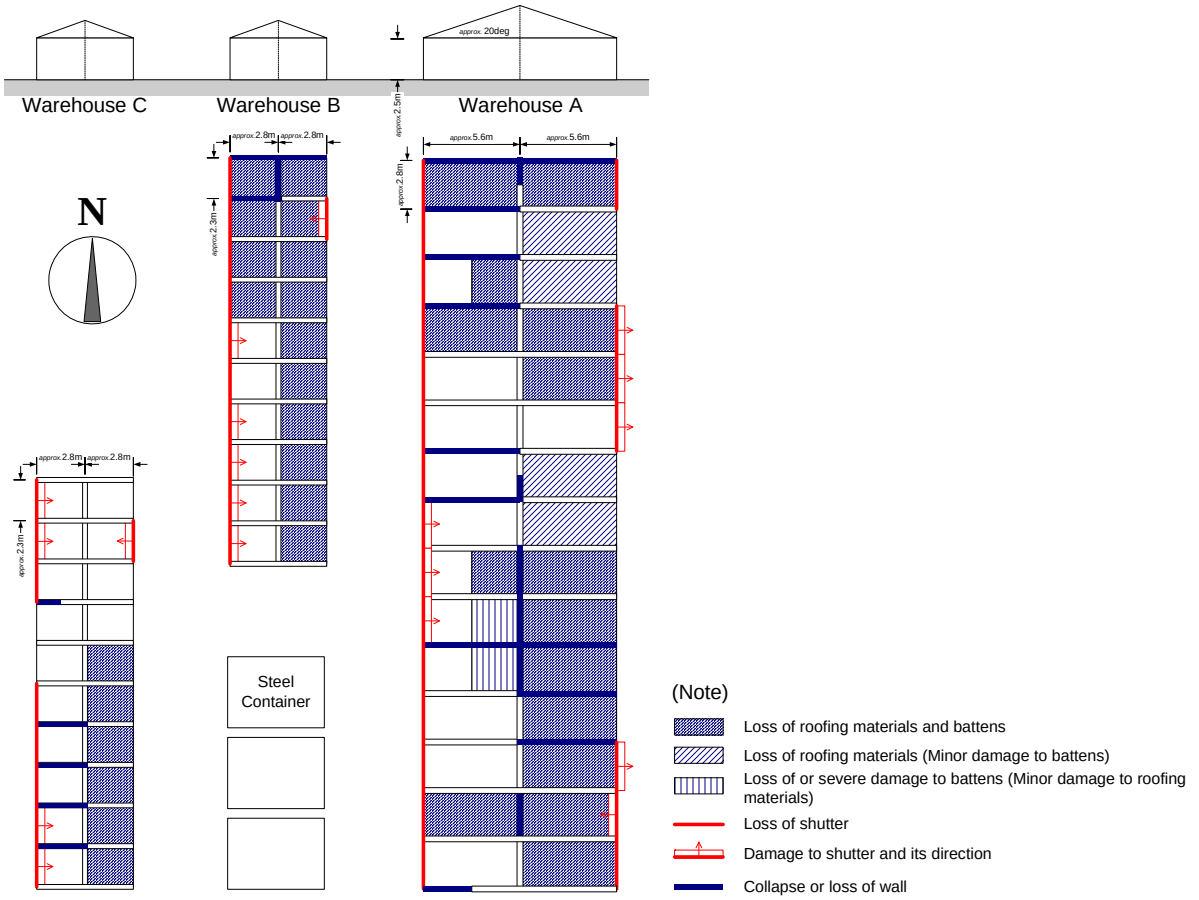


Figure 3 Plan view of damage to warehouses

Photo 17 Flying debris impact on the west wall

(6) *Grain Bins and Tanks*

Damage to grain bins and tanks is shown below. This grain bin complex is located approximately two miles east of the most damaged area of Parkersburg along the tornado path. All the grain bin structures lost its dome-shaped roof (Photo 18). Severe buckling of the cylindrical shell (Photo 19) and overturning of the smaller tanks (Photo 20) could be observed. The bucking of the shell usually occurred in the top third or in the upper half portion of the structure. It was unclear whether these grain bins or tanks were empty or full or partially full.

Photo 18 Loss of dome-shaped roof

Photo 19 Severe buckling of the cylindrical shells

Photo 20 Overturning of smaller tanks

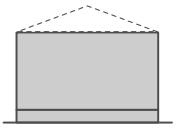
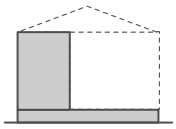
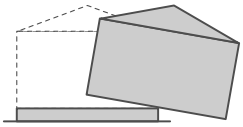
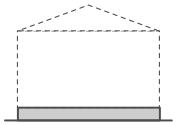
3.3 Damage to Residential Buildings

Severe damage was observed in residential buildings not only to non-structural elements such as roofing material and cladding but also to the structural elements. These buildings are typically timber houses. Damage to structural elements can be categorized under several modes as follows:

- Partial or complete loss of roofing system
- Partial loss or collapse of walls
- Lateral shifting of entire house from foundation
- Partial loss or collapse of the entire house with basement exposed

Examples of these damage modes, as observed in this tornado damage survey, are given below.

Table 2 Modes of structural damage to houses

(1)	(2)
 Partial or complete loss of roofing system	 Partial loss or collapse of walls
(3)	(4)
 Lateral shifting of entire house from foundation	 Partial loss or collapse of the entire house with basement exposed

(1) *Partial or complete loss of roofing system*

While most walls of buildings, as shown in Photos 21 – 23, are still intact, the roof is partially or completely lost. In addition, Photo 23 shows partial or complete collapse of one wall.

Photo 21 Complete loss of the roof

Photo 22 Complete loss of roof

Photo 23 Loss of roof and overturn of the wall

(2) *Partial loss or collapse of walls*

There were many damaged houses in which most walls (external or internal) had collapsed and the roof is completely destroyed. Photo 25 shows collapse of walls on three sides of the house resulting in the vertical collapse of the entire roof structure. In some cases, for example as seen in Photo 26, one room with interior walls remained intact.

Photo 24 Partial loss of walls

Photo 25 Collapse of walls

Photo 27 Lateral shifting of entire house

Photo 26 Intact small room

Photo 28 Collapse of continuous footing

(3) *Lateral shifting of entire house from foundation*

The entire house in Photo 27 is seen shifted off to the west direction. Another view of this house is shown in Photo 28. Entire house in Photo 29 is observed to be shifted in the east direction. This is consistent with the counterclockwise rotational direction of the wind where winds to the south of the path are in the east direction causing damage to buildings in Photo 29 and winds to the north of the path are in the west direction causing damage to building in Photo 27.

Photo 29 Lateral shifting of entire house

(4) *Partial loss or collapse of the entire house with basement exposed*

Loss of entire house can be categorized into two damage modes — one where the floor slab remains on the foundation (Photo 30) and the other where the floor slab is swept clean (Photo 31).

Photo 30 Loss of entire house

Photo 31 Loss of entire house and swept-clean floor slab

Moreover, in partially damaged houses, impact of flying debris on walls or glasses could be seen in Photo 32. Most of the debris is timber structural component from failed homes (Photo 33).

Photo 32 Damage of wall by wind-borne debris impact

Photo 33 Scattered timber components

4. COMMENTS RELATED TO THE DISASTER

Based on the press releases by State of Iowa and the news in the local newspaper (e.g. the Des Moines Register), comments related to the disaster are summarized as follows. CNN news related to this disaster is also shown in Photo 34.

- Gov. Chet Culver declared Butler, Buchanan, and Black Hawk counties on May 25 and Delaware County on May 26 to be state disaster areas, respectively. President Bush declared Butler County a federal disaster area on May 27, which will help bring federal assistance to residents of the Parkersburg area. He also declared Buchanan, Black Hawk, and Delaware counties federal disaster area on May 30.
- Casualties in this disaster contribute to the rising national death toll by tornadoes this year and this year is the worst in a decade.
- The weather service issued a tornado warning that specifically mentioned Parkersburg at 4:46pm. The Butler County sheriff's office said sirens wailed in the town for at least five minutes before the tornado struck at about 4.53 pm. In Parkersburg, an additional siren was installed a few days before the storm. This action reduced the number of fatalities.
- In New Hartford, the siren began 15 minutes before the tornado, but lasted only a few minutes before power was knocked out. Firefighters drove through the streets, using their truck sirens to alert residents.
- Wisconsin residents have been finding

debris from a tornado more than 100 miles away in Iowa. Most of them are lightweight materials such as photographs, personal papers and check stubs.

Photo 34 CNN News (Evening, May 25)

5. POST DISASTER SURVEY

The author carried out post disaster survey to obtain the status of residents' activities related to the recovery from the disaster. This survey was carried out on June 17, July 18, August 24, and September 19, approximately every one month after May 25.

Progress in recovery of houses damaged by the tornado is shown in Figure 4. Figure 5 shows the recovery progress of houses which suffered serious damage. Vertical axis in this figure indicates the ratio of recovery or completion, calculated as follows:

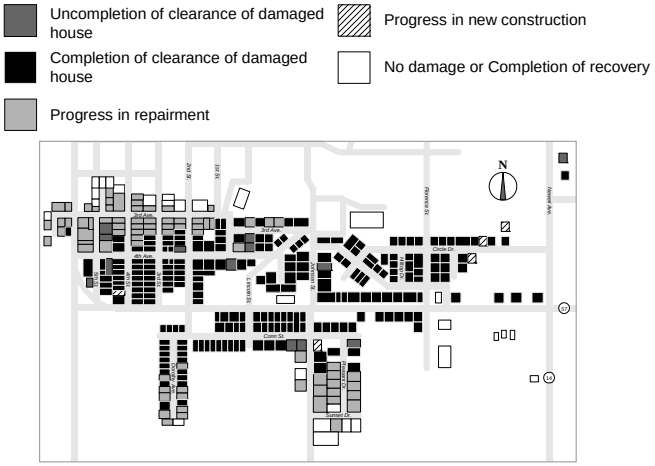
$$R_{rec}(t) = \frac{N_{rec}(DOD \geq 5, t)}{N(DOD \geq 5)} \quad (1)$$

$$R_{com}(t) = \frac{N_{com}(DOD \geq 5, t)}{N(DOD \geq 5)} \quad (2)$$

where $R_{rec}(t)$: ratio of recovery, $R_{com}(t)$: ratio of completion, t: elapsed time from the date of disaster, $N(DOD \geq 5)$: number of damaged houses with DOD of five or more, $N_{rec}(DOD \geq 5, t)$: number of damaged houses with DOD of five or more whose recovery has been already in progress at t, $N_{com}(DOD \geq 5, t)$: number of damaged houses with DOD of five or more which has been replaced by new construction at t, respectively.

These figures show that the recovery of damaged houses did not occur in the first month since the disaster struck, and that new construction has not started since two months after the disaster struck. At the elapsed time of four months, new construction of approximately half of the seriously damaged houses has been in progress, but construction of just only 10% of those has been completed.

This post disaster survey also revealed that new construction method in all the seriously damaged houses chose continuous footing made from reinforced concrete as shown in Photo 35, because continuous footing that were damage and exposed, as shown in Photo 28, showed inadequate reinforcement.



(*a*) June 17, 2008

(*b*) July 18, 2008

(*c*) August 24, 2008

(*d*) September 19, 2008

Figure 4 Progress in recovery of houses damaged by the tornado

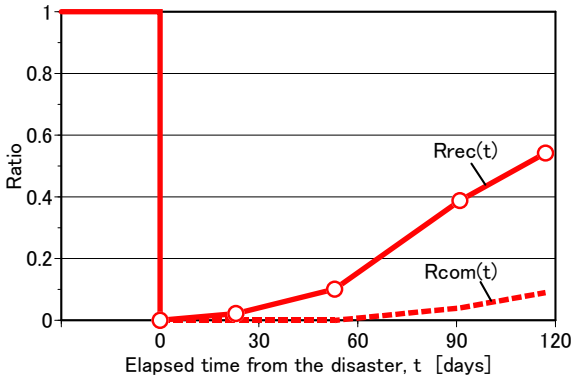


Figure 5 Ratio of recovery or completion of seriously damaged house *vs*. elapsed time

Photo 35 New construction of continuous footing and basement

6. CONCLUSION

This paper presents the outline of structural damage induced by EF-5 tornado in Iowa, U.S. on May 2008. This is the only EF5 tornado to occur in 2008. Results of field survey shows width of region where there were lots of seriously damaged houses and typical damage modes of residential, public and commercial buildings. Further, based on the post disaster survey, rates of progress in recovery of damaged houses and completion of newly constructed houses to replace the damaged houses are shown.

7. REFERENCES

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