MITIGATION ASSESSMENT TEAM REPORT

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HURRICANE **IKE** IN TEXAS & LOUISIANA

5 Performance of Buildings in Houston's Central Business District

Although Hurricane Ike's winds were not as high as the current design wind speed, some buildings received extensive exterior envelope damage.

The MAT observed various types of building envelope damage at several buildings in downtown Houston. According to ASCE 7-05, the basic wind speed for downtown Houston is approximately 108 mph. The estimated maximum speed during Hurricane Ike was approximately 94 mph. Although Hurricane Ike's winds were not as high as the current design wind speed, some buildings received extensive exterior envelope damage. Most of the damage was to glazing and roof coverings. Sections 5.1 to 5.3 describe the types of buildings and building damage observed by the MAT. Vegetative roofs are discussed in Section 5.4.

HURRICANE ALICIA (1983)

Downtown Houston is infamous for glazing damage during Hurricane Alicia. More downtown glazing was broken during that hurricane than during or since any other U.S. hurricane. Extensive glass breakage was documented at six high-rise buildings (Savage et al., 1984 and Kareem, 1986). The number of broken windows and glass spandrel panels was reported on three buildings as follows: 1,100 to 1,200 units, 630 units, and 80 to 100 units. More than 80 percent of the glazing damage in the central business district was attributed to windborne debris impact. Aggregate from BURs was identified as a major contributor of the debris.

Good structural system performance is critical to avoid injury to occupants and minimize damage to a building and its contents; however, good structural system performance alone does not ensure occupant or building protection. Good performance of the building envelope is also critical. Glazing can be very expensive to replace, as is replacing a roof system. In addition, once a building envelope is breached, costs are incurred due to wind and/or water damage to interiors and contents (Section 5.2.1). Interruption of businesses when businesses are forced to vacate because of damaged buildings can result in even greater costs. The costs associated with interruption and temporary relocation often exceed the direct costs of repairing the damaged buildings and their contents.

Following Hurricane Alicia in 1983, a committee of the Houston Construction Industry Council—with participation from the City's building department—recommended a code change to the City of Houston Building Code that prohibited the use of aggregate on roof surfaces over 55 feet above grade (Smith, 1997). However, the City Council did not accept the recommendation and local code continued to allow aggregate surfacing on BURs. In January 2006, the City of Houston adopted the 2003 edition of the IBC (with local amendments). One of the local amendments (1504.8) was a response to changes in the 2006 edition of the IBC prohibiting aggregate (referred to as "gravel or crushed stone") roof surfaces. Although the 2006 IBC prohibits all roof aggregate (regardless of size) in hurricane-prone regions, Houston's building department does not interpret the local amendment as applicable to 1 ½-inch or larger aggregate (which is used on aggregate ballasted single-ply roof membranes). As a result, after nearly 23 years, the local code prohibits installation of aggregate-surfaced BURs, but continues to allow installation of aggregate-ballasted roof systems and does not require abatement of existing aggregate-surfaced roofs.

The MAT observed commercial high-, mid-, and low-rise buildings in downtown Houston. The building ages ranged from several decades to just a few years old. Figure 5-1 shows an aerial photograph of a portion of downtown Houston. There was significant building envelope damage in areas indicated by the blue and red circles on Figure 5-1; the red circle denotes buildings that are discussed as cluster A (Section 5.2), and the blue circle denotes buildings discussed as cluster B (Section 5.3). Random isolated envelope damage was observed in the areas outside the clusters, as described in Section 5.1.

5.1 Areas Outside Clusters A and B

Several of the buildings outside of the clusters had limited glazing damage, ranging from one or a few broken windows to several broken windows as shown in Figure 5-2. At the building shown

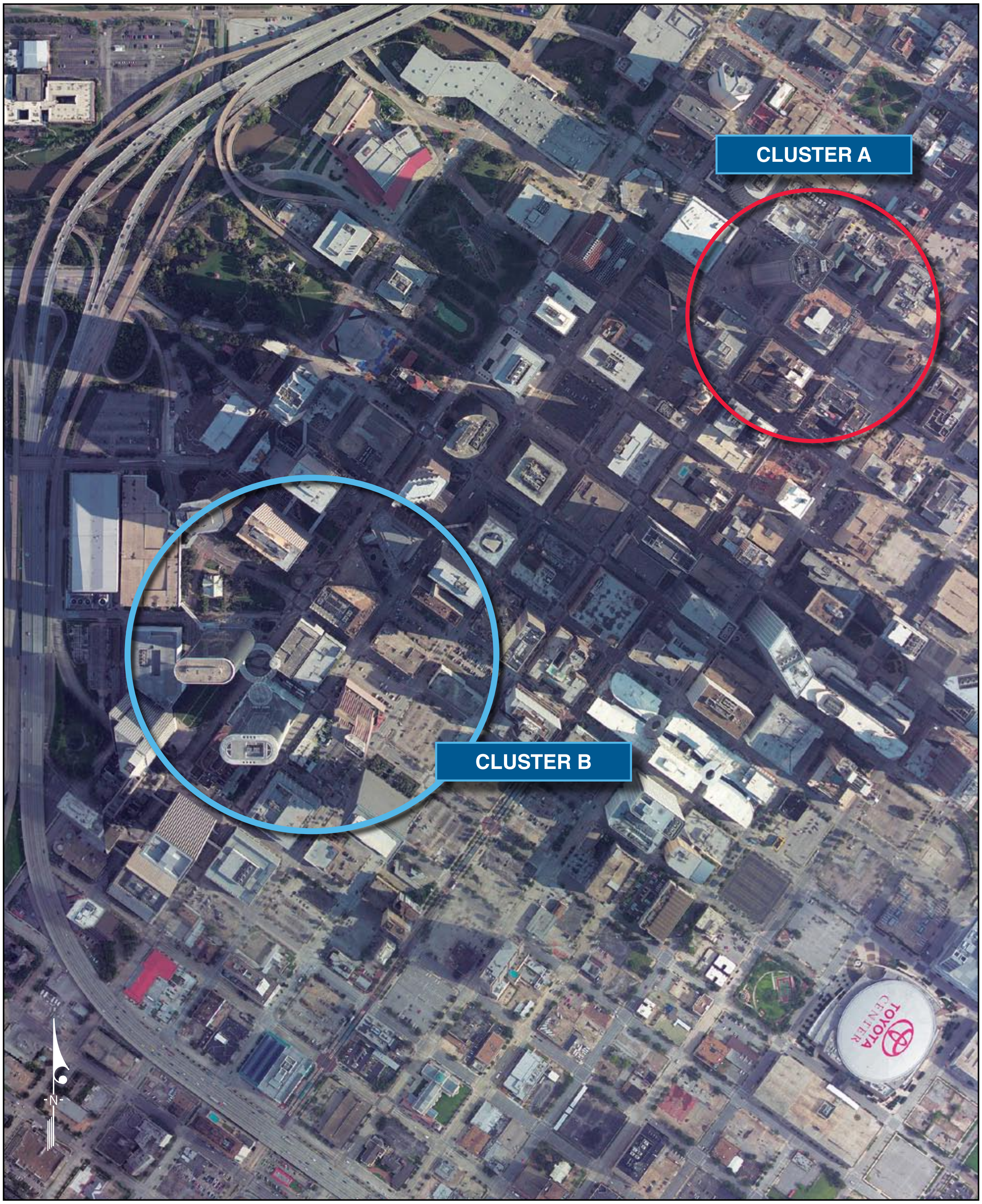


Figure 5-1.
View of a portion of downtown Houston. The red circle denotes cluster A and the blue circle denotes cluster B.
SOURCE: NOAA, SEPTEMBER 17, 2008

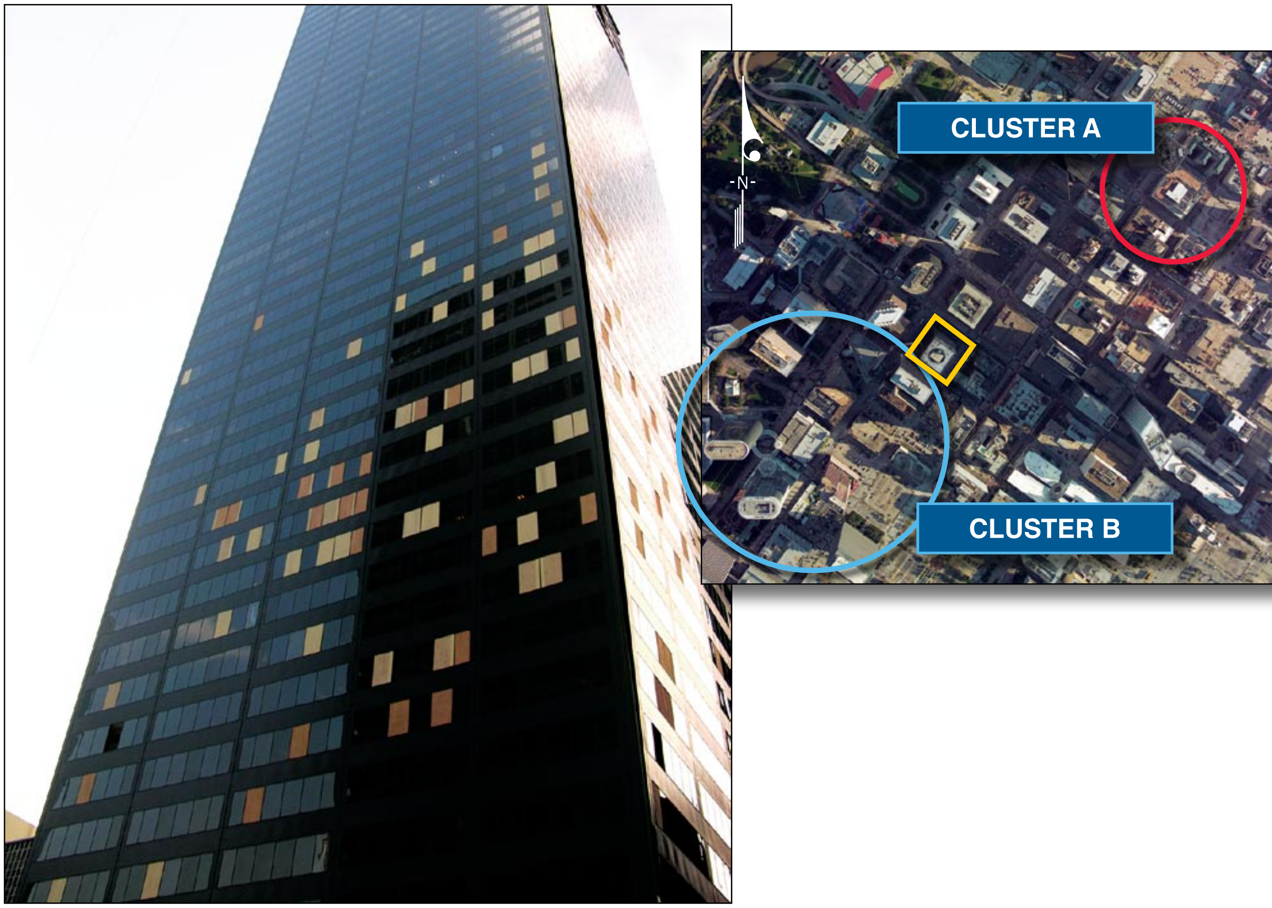


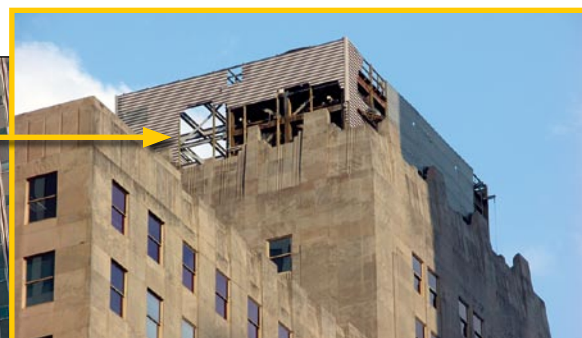
Figure 5-2.
Building with glazing damage; location shown by yellow square in inset

in Figure 5-2, 79 windows on one face were boarded up (presumably both the inner and outer panes were broken). For at least five other windows, the outer pane was also broken on this façade (these windows were not boarded).

Glazing breakage also occurred several floors above grade at other buildings. There was also random breakage at or near street level at some buildings, as shown in Figure 5-3. Exterior glazing is very susceptible to windborne debris breakage unless it is impact resistant (via use of laminated glass or shutters). Since Houston is not in a windborne debris region, protected glazing is not commonplace. The probability that any one window will be struck by windborne debris is typically small (unless the glazing is downstream from an aggregate-surfaced roof). The probability of impact depends upon local wind characteristics and the amount of natural and manmade windborne debris in the vicinity. The greater the wind speed, the greater the amount of windborne debris that is likely to become airborne. Glazing can also be broken by overpressurization via either high negative or positive wind loads, but this damage is not as common as debris-induced damage. Older glazing is more susceptible to wind-load damage because it is often weakened by scratches. In addition, much of the older glazing on low-rise buildings was installed when little attention was given to wind resistance.

Figure 5-3.
Random breakage of first floor glazing

Windborne debris in the downtown area included glass shards, rooftop mechanical equipment, roof aggregate, wall coverings (Figure 5-4), building signage, and tree limbs. Some of the debris was of relatively high momentum (Figure 5-5).



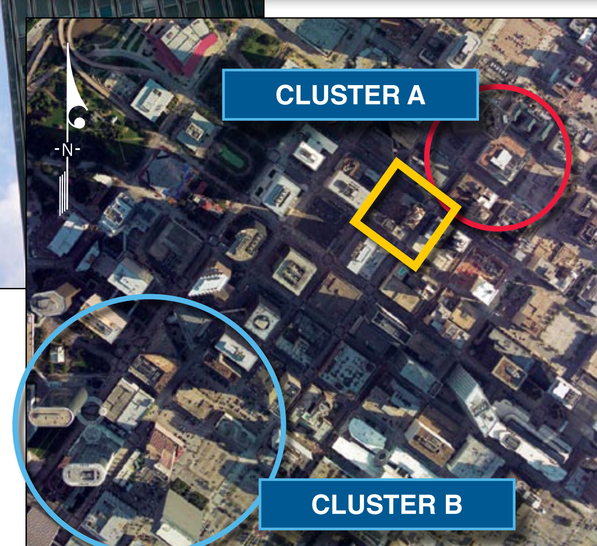


Figure 5-4.
Portions of the mechanical equipment screen wall blew away. Location shown by yellow box in bottom inset.

Figure 5-5.
The wire mesh of this stucco wall was penetrated by windborne debris. The impact location is about 5 feet above the sidewalk.

5.2 Cluster A – JP Morgan Chase Area

An enlarged view of cluster A is shown in Figure 5-6. The JP Morgan Chase Tower and Center are part of cluster A.

- **JP Morgan Chase Tower.** Built in 1982 and standing 75 stories (1,000 feet), this is the tallest building in Houston. The building never lost power during the event, as power is fed from two vaults from two different substations. This building sustained significant glazing damage (Section 5.2.1).
- **JP Morgan Chase Center.** Built in 1982, this is a 20-story (240-foot) building. Floors 1 through 13 are a parking garage. Floors 14 through 20 are offices. Virtually all of the glazing on one façade was damaged (Section 5.2.1) and the main roof covering was blown off (Section 5.2.4).

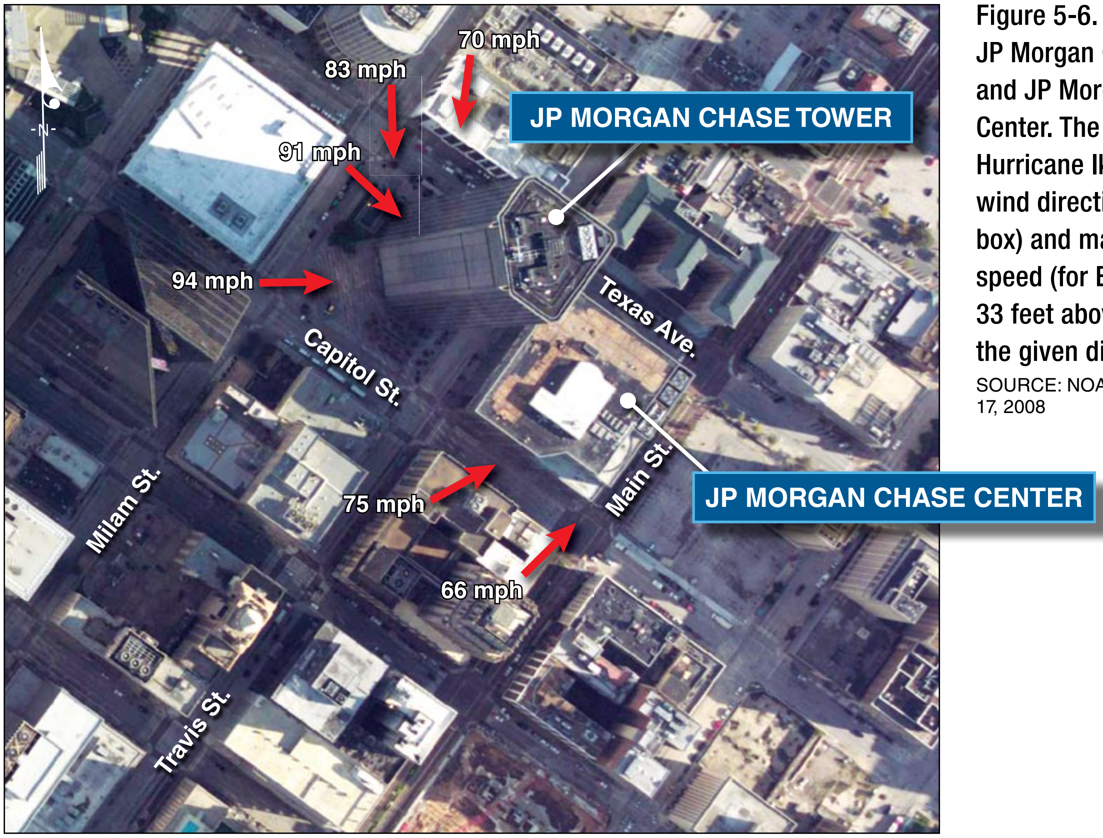


Figure 5-6.
JP Morgan Chase Tower and JP Morgan Chase Center. The arrows show Hurricane Ike's primary wind directions (see text box) and maximum gust speed (for Exposure C at 33 feet above grade) for the given direction.[1]
SOURCE: NOAA, SEPTEMBER 17, 2008

WIND DIRECTIONS AND SPEEDS IN DOWNTOWN HOUSTON

The variation in wind speeds and wind directions shown in Figures 5-6 and 5-16 were derived from measurements obtained from a Florida Coastal Monitoring Program 10-meter tower located on the University of Houston Campus. The magnitudes of the wind speeds were adjusted in two ways, as follows:

(1) Since the measurements were taken in an area with a terrain exposure best described as suburban, the wind speeds were converted to equivalent open country exposure conditions to facilitate comparison with basic design wind speeds specified in the 2006 IBC / ASCE 7-05. The terrain conversion resulted in an increase of 17 percent in the gust wind speeds over the actual measurements.

(2) The tower data represent measurements at a single point. However, the wind field model developed by ARA (2008) considers data from many sources and represents a smoothed estimate of wind speeds throughout the area. Therefore, the open terrain wind speed estimates computed from the actual tower measurements were increased by an additional 7 percent to be consistent with the ARA wind field estimates for downtown Houston.

1 All estimated speeds in this Chapter are peak gust, Exposure C at 33 feet taken from *Estimates of Maximum Wind Speed Produced by Hurricane Ike in Texas and Louisiana* (ARA, 2008)

5.2.1 Glazing

JP Morgan Chase Tower

The glazing panes of the JP Morgan Chase Tower are ¼-inch thick each, inner and outer, with a ½-inch air space between the panes. The glazing units are tinted and annealed. There was significant damage on the southeast façade, which was on the leeward side of the building during the time of the strongest winds (yellow circled area in Figure 5-7 and yellow arrow in inset), where both the inner and outer panes of approximately 463 windows were broken. On that façade, all windows in the first 22 floors were broken. The highest broken window was on the 47th floor. The southwest façade had 23 windows with broken inner and outer panes, and the northeast façade had two. The temporary protection and glazing replacement costs were significant.

For most of the southeast façade, very little wind and rain was driven into the offices. However, because of localized wind effects, some offices had significant amounts of rain and wind infiltration, which blew out ceiling boards and toppled office partitions. The MAT was advised that some furniture blew out of offices in this building and landed on the roof of the JP Morgan Chase Center across Travis Street. Because few of the broken windows were on windward façades, there was relatively little interior damage (Note: an explanation of the observed damage pattern is provided later in this section).

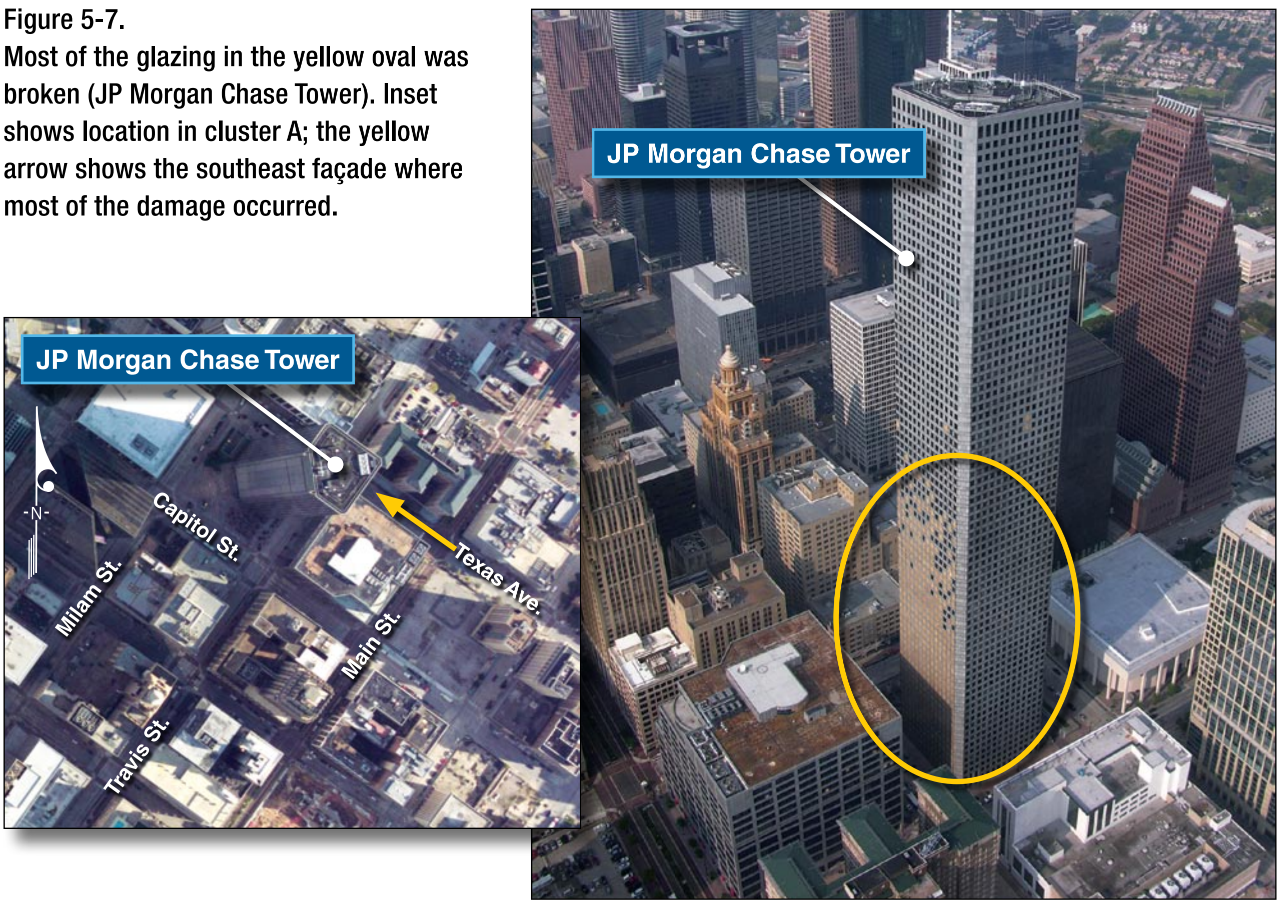
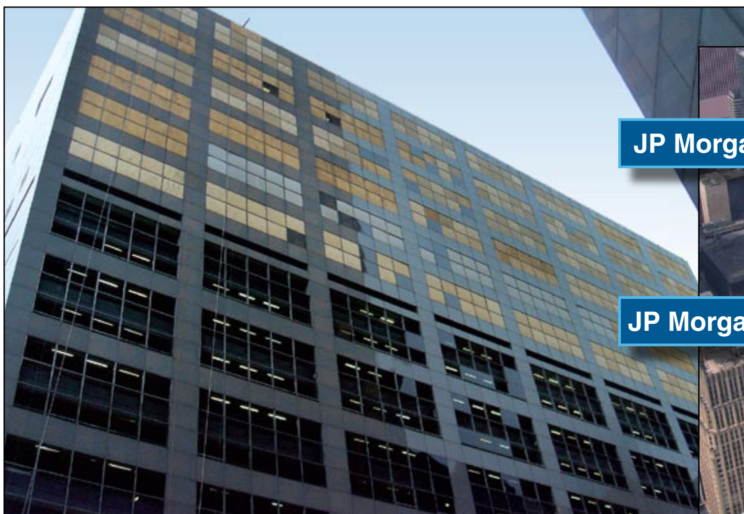


Figure 5-7.
Most of the glazing in the yellow oval was broken (JP Morgan Chase Tower). Inset shows location in cluster A; the yellow arrow shows the southeast façade where most of the damage occurred.

JP Morgan Chase Center

The JP Morgan Chase Center utilizes single-pane, heat-strengthened glazing. Virtually all of the penthouse glazing and the glazing on the northwest façade, which was the windward side of the building during the time of the strongest winds (Figure 5-8), was broken. At least 16 windows were broken on the façade with the yellow arrow in Figure 5-8 inset. Only a few windows were broken in the opposite façade. There was no damage in the southeast façade.

The broken glazing on the northwest façade blew approximately 50 feet into the interior of the building. Once the exterior glazing was breached, wind-driven rain penetrated into the building, causing extensive interior damage.



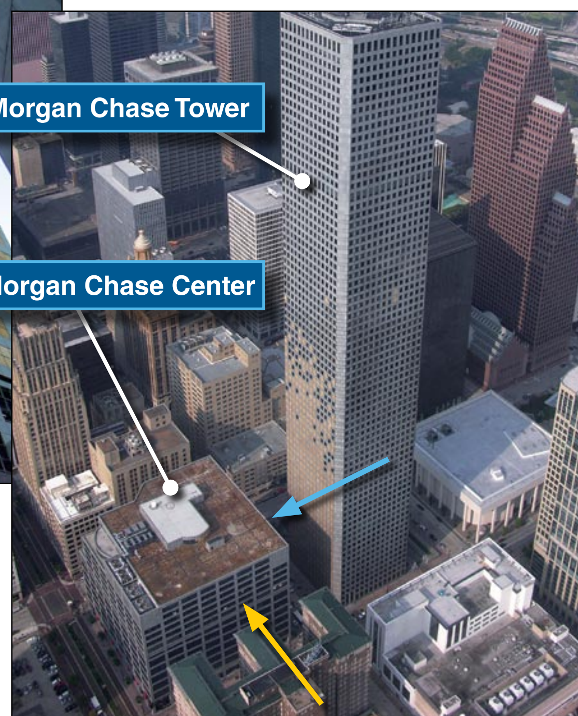


Figure 5-8.
Northwest façade glazing damage on JP Morgan Chase Center. The broken windows at the office level are boarded up, but broken windows at the parking level are not. The blue arrow in the inset indicates the northwest façade; the yellow arrow indicates a façade that also received some damage.

The extensive glazing damage at the JP Morgan Chase Center, possibly in combination with some contribution from roof damage, allowed water penetration into the offices on Floors 14 through 20, resulting in significant damage and loss of office space (Figure 5-9). On one of the floors, the MAT observed water damage that extended about 250 feet into the interior of the building. The water damaged interior walls and ceilings; some of the interior corridor walls toward the exterior fell over and touched the far wall. A computer lab, located along the exterior wall, received extensive water damage. Water damaged approximately 150 desktop computers.

Floors 18 and 19 sustained extensive damage. Water-damaged carpet and ceiling boards were removed from approximately 50 percent of the floor area that was observed by the MAT. At the time of the MAT observation, new materials were being installed, including new wiring, new data cables, and extensive HVAC work. Approximately 25 percent of the floor area on Floors 14 through 17 sustained similar damage.

Figure 5-9.
View of repairs to an office damaged in the JP Morgan Chase Center

Cause of Glazing Damage in JP Morgan Chase Tower and Center

Although the glazing damage shown in Figures 5-7 and 5-8 is indicative of damage caused by windborne roof aggregate, the MAT conclusion is that aggregate did not, in fact, cause the damage based on the following observations:

Although aggregate-surfaced BURs were present on the buildings shown in the yellow and orange circles in Figure 5-10, it is unlikely that debris from these roofs caused the glazing damage observed at the JP Morgan Tower and Center. The wind direction and relatively low speed precluded aggregate from the roofs in the orange circle from being a debris source. The speed and direction may have been sufficient to cause aggregate to be blown from the penthouse of the building shown in the yellow circle of Figure 5-10 (and discussed in Section 5.2.4), but if that occurred, the aggregate would likely only have struck the JP Morgan Center façade, which had very little damage. MAT observations from a helicopter and the roofs of the Tower and Center did not reveal any other aggregate-surfaced roofs in the vicinity.

OVERPRESSURIZATION

Wind speeds in downtown Houston during Hurricane Ike were below the ASCE 7-05 design wind speed. Hence, glazing failure due to overpressurization via negative (suction) or positive loading would not be expected, unless the glazing was weakened by scratches, was inadequately designed for wind loads, or glazing or frame-capture of the glazing was inadequate to meet the wind loads.

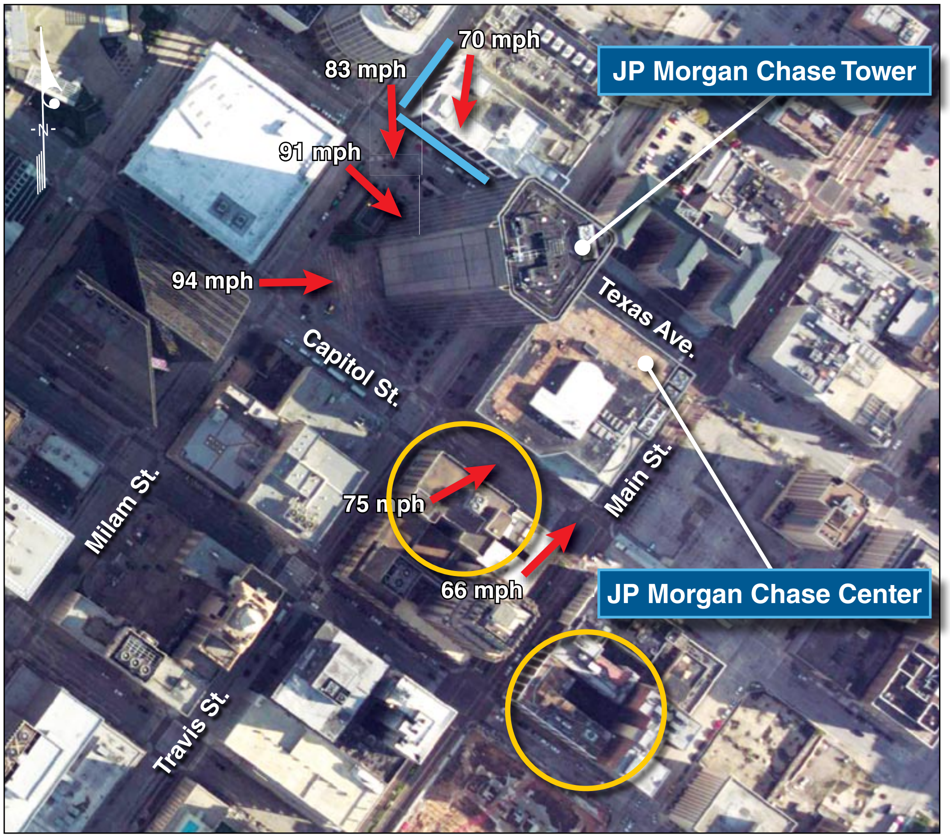


Figure 5-10. Locations of possible debris sources that impacted the JP Morgan Tower and Center. Aggregate-surfaced roofs within cluster A area shown by yellow circles. Blue lines show location of failed metal panel veneer.
SOURCE: NOAA, SEPTEMBER 17, 2008

The MAT postulates that the glazing damage occurred as a result of the following: some glazing in the Tower or the Center failed, either due to windborne debris or overpressurization, and the resulting glass shards became enveloped in vortices that developed between the two buildings. As the shards impacted the opposing façades, additional shards were injected into the vortices. It is believed that the vortices lifted the shards upwards, thereby causing damage at the upper floors (shown in Figure 5-11). Potential initial debris sources include trees along the sidewalks and metal wall panels from a nearby building (blue lines shown in Figure 5-10; refer also to Section 5.2.4).

The MAT's postulate is consistent with initial research work on the observed glazing damage conducted by the University of Notre Dame in a paper titled *Saga of Glass Damage in Urban Environments Continues: Consequences of Aerodynamics and Debris Impact During Hurricane Ike* (Kareem, 2008).[2] A model of the JP Morgan Tower and surrounding buildings was constructed and flow visualization experiments were conducted in a wind tunnel. In addition, flow visualization was analyzed by computational fluid dynamics (CFD). The wind tunnel and CFD studies both demonstrated that a series of vortical flow structures formed between the two façades that were heavily damaged (Figure 5-11).

2 Available at www.nd.edu/~nathaz/doc/NATHAZ_Ike_Glass_Dmg.pdf

Figure 5-11.
The Tower is on the left and the Center is on the right. It is believed that vortices developed between these façades, and that glass shards entrapped within the vortices were slammed against and broke glazing in the opposing façades.

5.2.2 Granite Veneer

At least two granite veneer panels on the southeast façade of JP Morgan Chase Tower were blown off. Stone fragments reportedly punctured the roof membrane on the JP Morgan Chase Center. The MAT observed a veneer panel on the southwest façade that remained in place, but had a notable debris impact scar. The cause of failure of the two panels may have either been a result of overpressurization (influenced by panel weakness or an installation deficiency) or they may have been broken by windborne debris.

5.2.3 Roof Systems and Rooftop Equipment

According to project records, the original roof on the JP Morgan Chase Tower was a smooth-surface built-up roof over a concrete deck (Figure 5-12). It was reroofed in 1990 by fully adhering an EPDM[3] membrane directly to the BUR. The MAT did not observe any areas of membrane debonding or any damage to rooftop equipment. Some lightning protection conductors were

3 Ethylene propylene diene monomer

no longer held by some of the connectors, but it was not clear if the attachment was lost prior to or during the hurricane.

A portion of the window washing equipment on the JP Morgan Chase Tower broke loose and slammed around, damaging the equipment (Figure 5-12 inset).

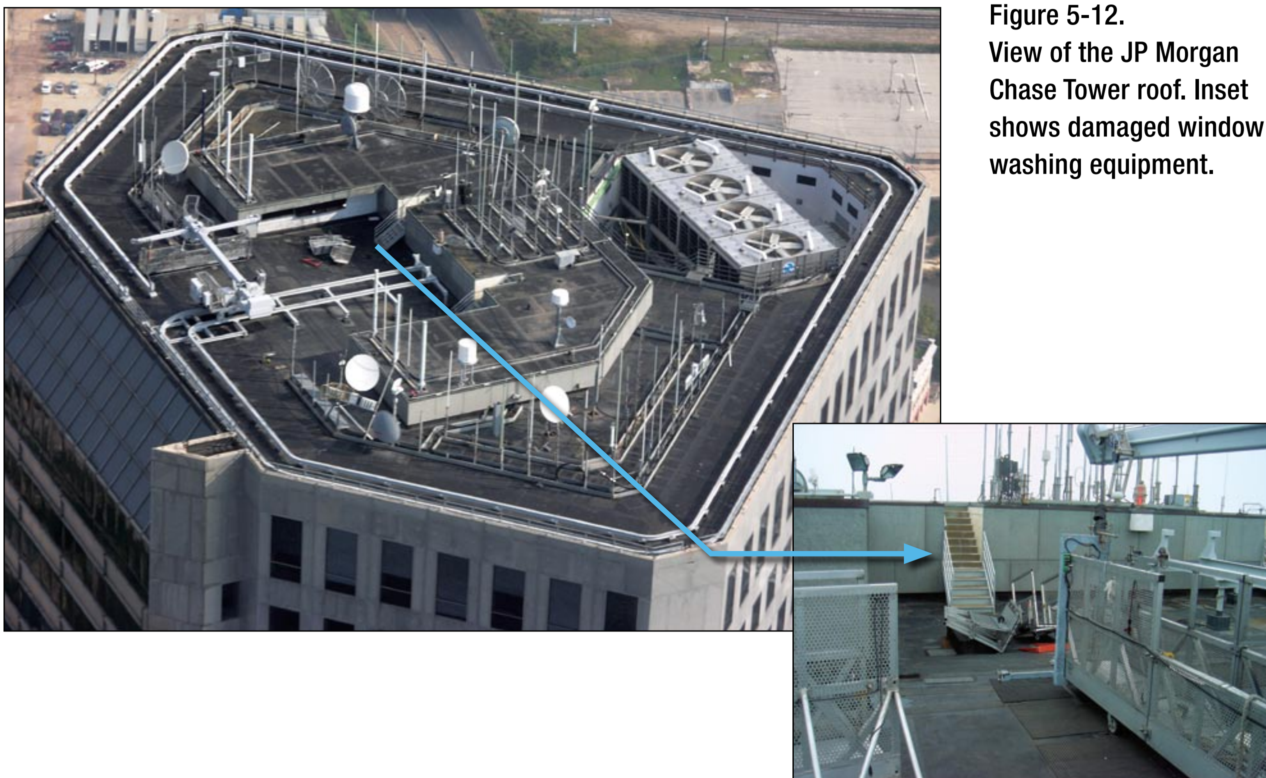


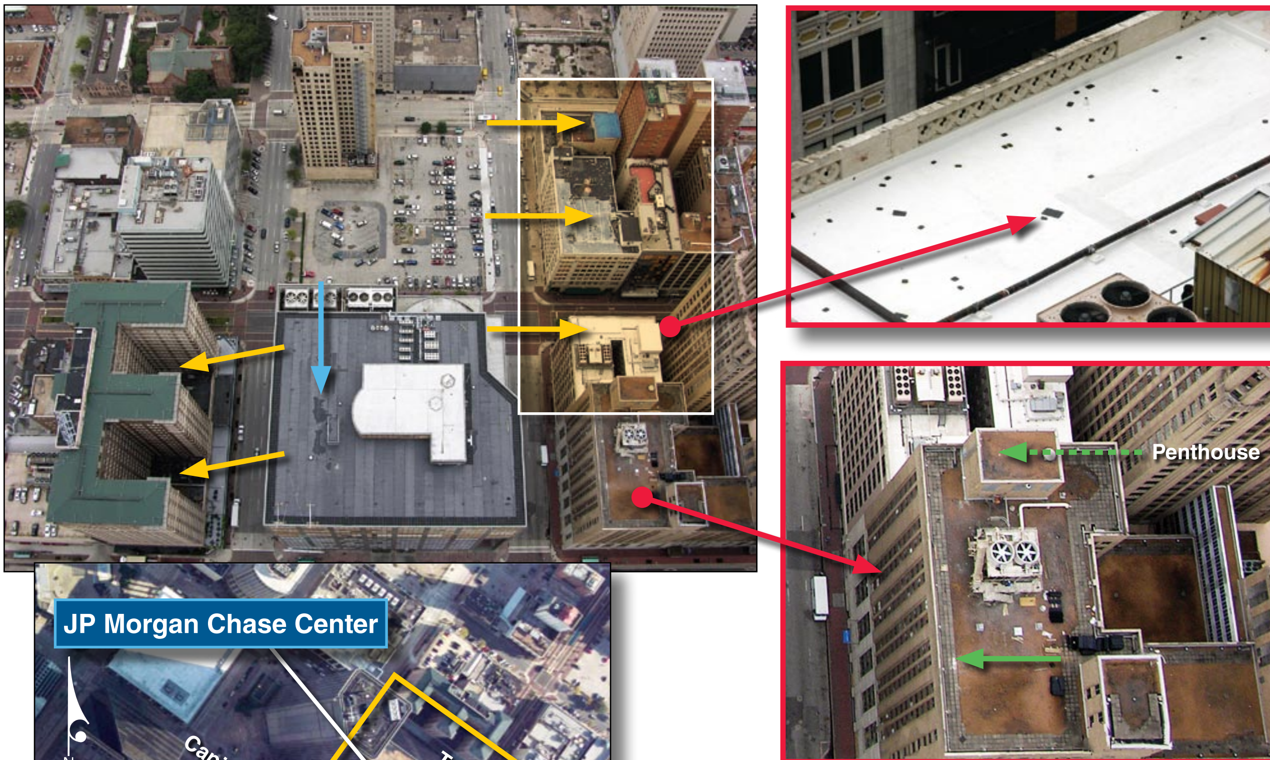
Figure 5-12.
View of the JP Morgan Chase Tower roof. Inset shows damaged window washing equipment.

5.2.4 Nearby Building Performance

There was variable performance of glazing and roof coverings at the surrounding buildings. Although some buildings were undamaged, several low-rise buildings had glazing and/or roof covering damage and one building had signage and wall covering damage.

The roofs shown by the yellow arrows in Figure 5-13 had either been blown off (i.e., the tarped roofs) or punctured by windborne debris. Much of the roof puncture and glazing damage was likely caused by windborne glass shards.

At the building shown in the bottom inset at Figure 5-13, concrete pavers had been installed around the perimeter of the main roof (solid green arrow at the inset) and at a portion of one of the penthouses as part of the original roof surfacing. However, the penthouse roof indicated with the dashed green arrow did not have pavers; its roof had a raised curb at the roof edge. Aggregate from this penthouse roof may have struck the side of JP Morgan Chase Center that had very little glazing damage.



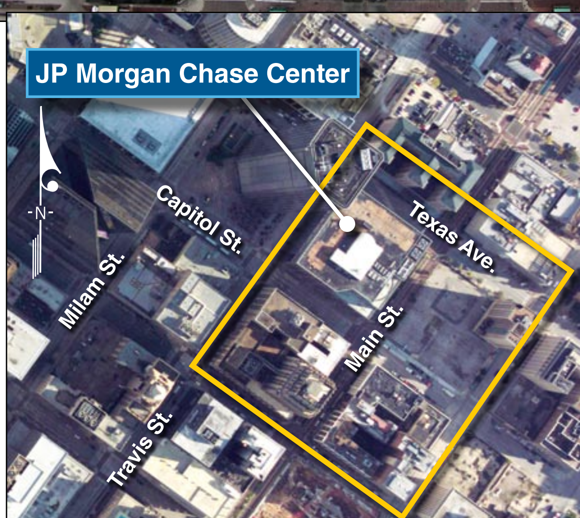


Figure 5-13.
The main roof of the JP Morgan Chase Center (blue arrow) and several other roofs (indicated by yellow arrows) were blown off or damaged by debris. Black areas at the top inset are patches. The bottom inset shows a building with built-up aggregate-surfaced roofs. The location inset shows the buildings in this figure (yellow box). See Figure 5-14 for the buildings in the white rectangle.

Figure 5-14 is a view of the roofs in the white rectangle at Figure 5-13. Blue and clear plastic tarps cover two roof areas. The green arrows show where an aggregate-surfaced built-up membrane lifted and peeled back. It is doubtful that aggregate from these roofs struck the JP Morgan Chase Tower or Center buildings. The punctured roof with the black arrow is the same as shown at the top inset of Figure 5-13. Several windows were broken in the buildings shown by the yellow arrows.

Figure 5-15 shows a building that lost several metal wall panels and a wall-mounted sign; the inset shows the building location and the façade that lost the panels (blue lines). It appears that the wall panel debris had the potential to strike either the JP Morgan Tower or Center.

In addition to the damage described above, the MAT observed a mid-rise building that had a protected membrane roof system that used extruded polystyrene insulation boards with a cementitious coating for the ballast. On-the-roof observation was not made, but analysis of high resolution photographs did not reveal any wind uplift problems.

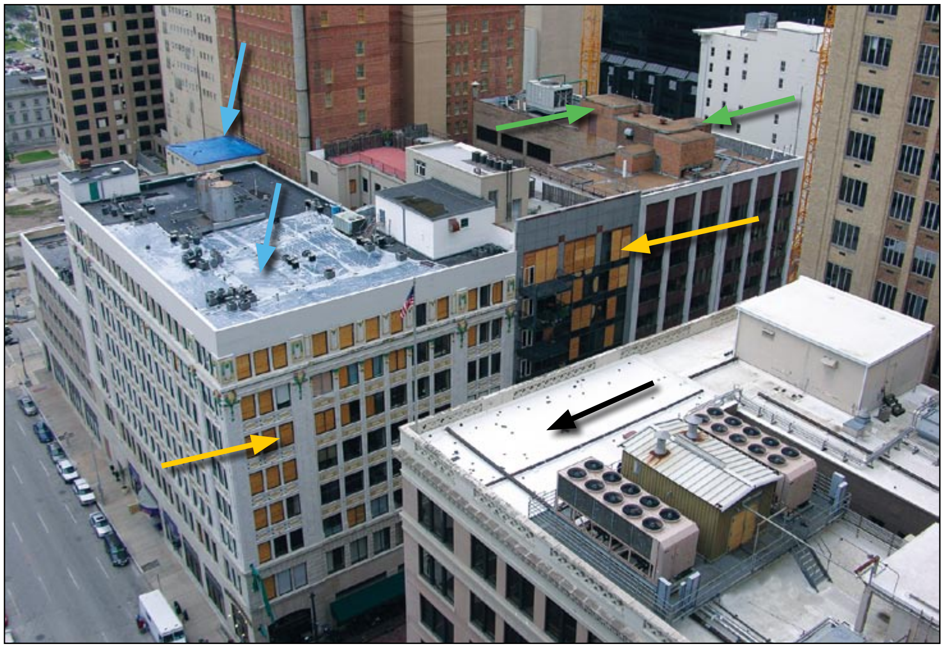
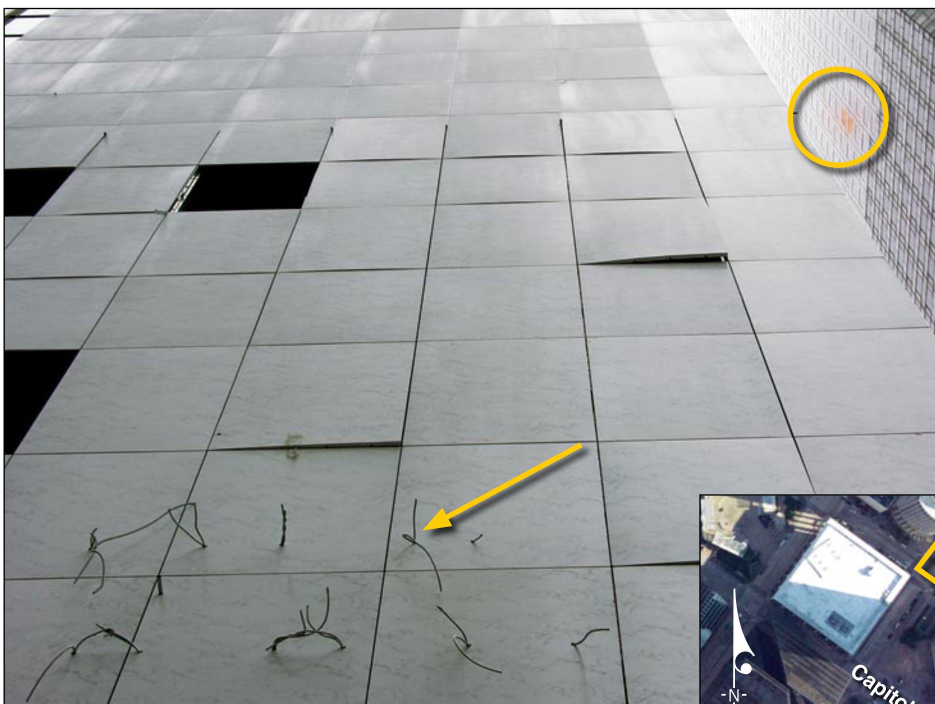


Figure 5-14.
Glazing damage (yellow arrows) at two of the buildings shown in the white rectangle in Figure 5-13. The blue, green, and black arrows indicate damaged roofs.



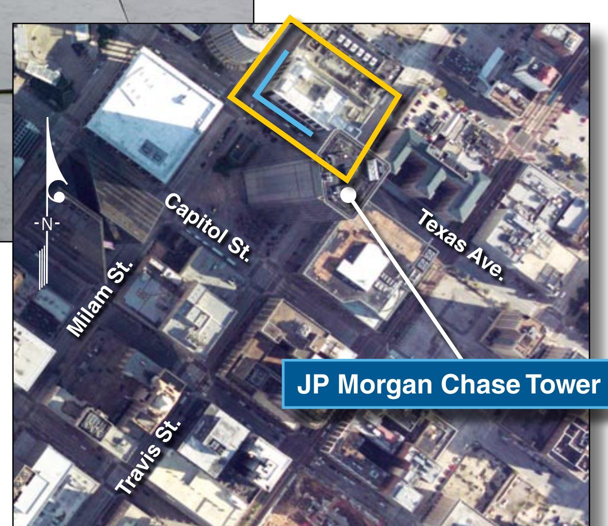


Figure 5-15.
Several metal panels blew off of two façades of this building, along with a wall-mounted sign (yellow arrow). Two broken windows can be seen in the yellow circle at the JP Morgan Chase Tower. Inset shows location of building (yellow box); blue lines indicate façades where metal panels blew off.

Loss of Function

The upper floors of JP Morgan Chase Center, Floors 14 through 20, were not operational for a substantial amount of time. The cost of the repairs is expected to be around $3.1 million. At the time of the MAT observation, the cleanup and repair crews had been at the building for about 2 months. In addition to cleanup costs, costs were incurred by the resulting loss of function of the offices. Some of the office functions were moved out of the State.

5.3 Cluster B – Chevron Center Area

An enlarged view of cluster B from Figure 5-1 is shown in Figure 5-16. The Chevron Center is part of cluster B. This 40-story building was built in 1999–2002. A large number of windows were broken on the side indicated by the yellow arrow in Figure 5-16 (refer also to Section 5.3.1). The roof membrane was blown off the end of the building indicated by the green arrow (refer also to Section 5.3.2). The building lost power during Hurricane Ike and for 2 days afterward.

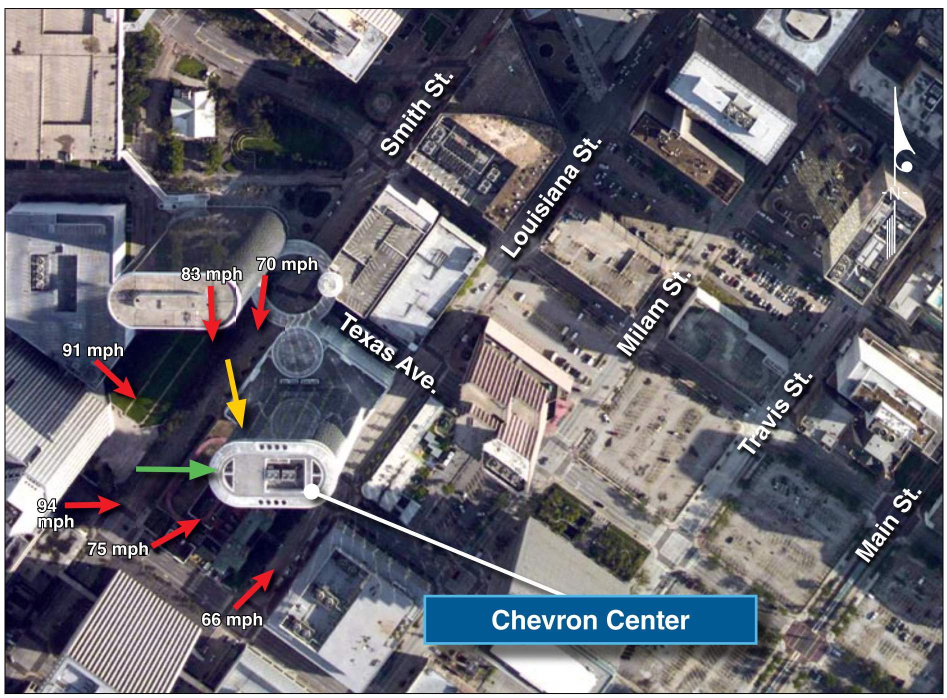


Figure 5-16.
A substantial amount of glazing damage occurred to the façade of the Chevron Center, indicated by the yellow arrow. The roof membrane blew off from the end of the building (green arrow). The red arrows show Hurricane Ike's primary wind directions and maximum gust speed for the given direction.
SOURCE: NOAA, SEPTEMBER 17, 2008

5.3.1 Glazing

The area of the Chevron Center that received most of the glazing damage is shown in Figure 5-17. The outer panes of about 700 heat-strengthened windows were broken. At seven windows, both the inner and outer lites were broken.

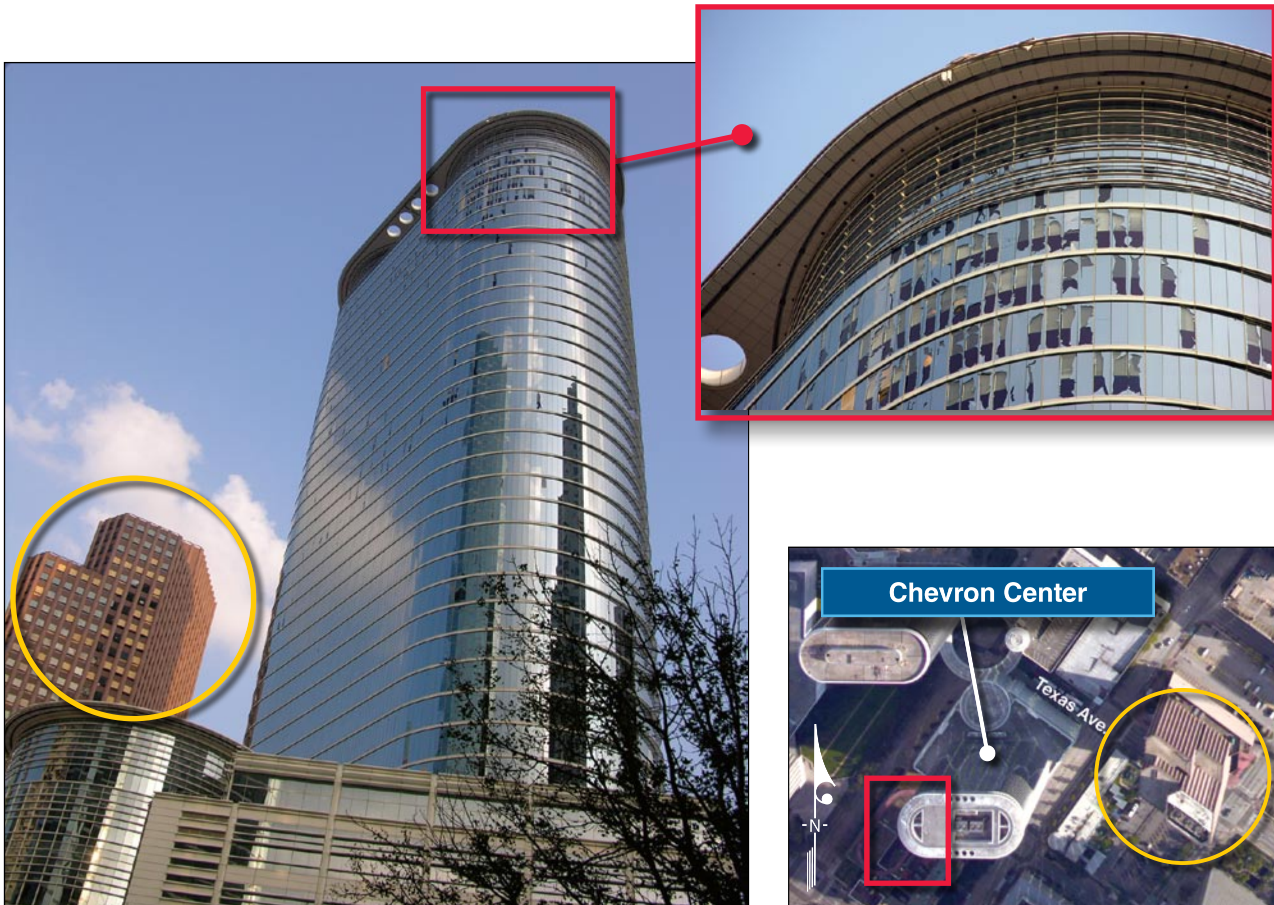


Figure 5-17.
Chevron Center glazing damage. At the building beyond (yellow circle), at least 35 windows were boarded up. Bottom inset shows location.

Shortly after the storm, the building owner retained a company to quickly install a temporary film over all of the broken glazing as a safety precaution to avoid falling shards of glass (Figure 5-18). Once the protective film was in place, work commenced on removing the broken glass that was still in place. Glass removal took considerable time, hence the initial installation of the protective film was prudent to protect pedestrians.

Figure 5-18.
Broken glazing held in place with temporary film

Cause of glazing damage: Prior to and during the MAT helicopter observations, the glazing damage at the Chevron Center had not been detected. Therefore, the high-rise roofs near the Chevron Center were not observed during the flight for potential debris sources. Subsequent analysis of the NOAA high-resolution photographs did not reveal an obvious debris source. Roof debris from the building designated as B-1 in Figure 5-19 (close up view shown in Figure 5-28) appears to have had the potential to strike the center area of the Chevron Center. Although some glazing damage occurred in the center area, the damage was primarily near the end of the Chevron Center. Also, when the wind was blowing in the direction conducive for roof debris from building B-1 to strike the Chevron Center, the wind speed was relatively low. Therefore, roof debris from building B-1 is not believed to be the primary cause of the Chevron Center glazing damage.

Two mid-rise buildings with aggregate-surfaced BURs occur to the south of the Chevron Center (yellow arrows at the inset of Figure 5-19). These buildings are shown in Figure 6-4. The closest building is approximately 250 feet from the Chevron Center, which is well within the flight capability of windborne aggregate. However, wind direction during Hurricane Ike precluded aggregate from these buildings as being potential debris sources for the glazing damage at the Chevron Center (refer to red arrows indicating wind directions shown on Figure 5-19).

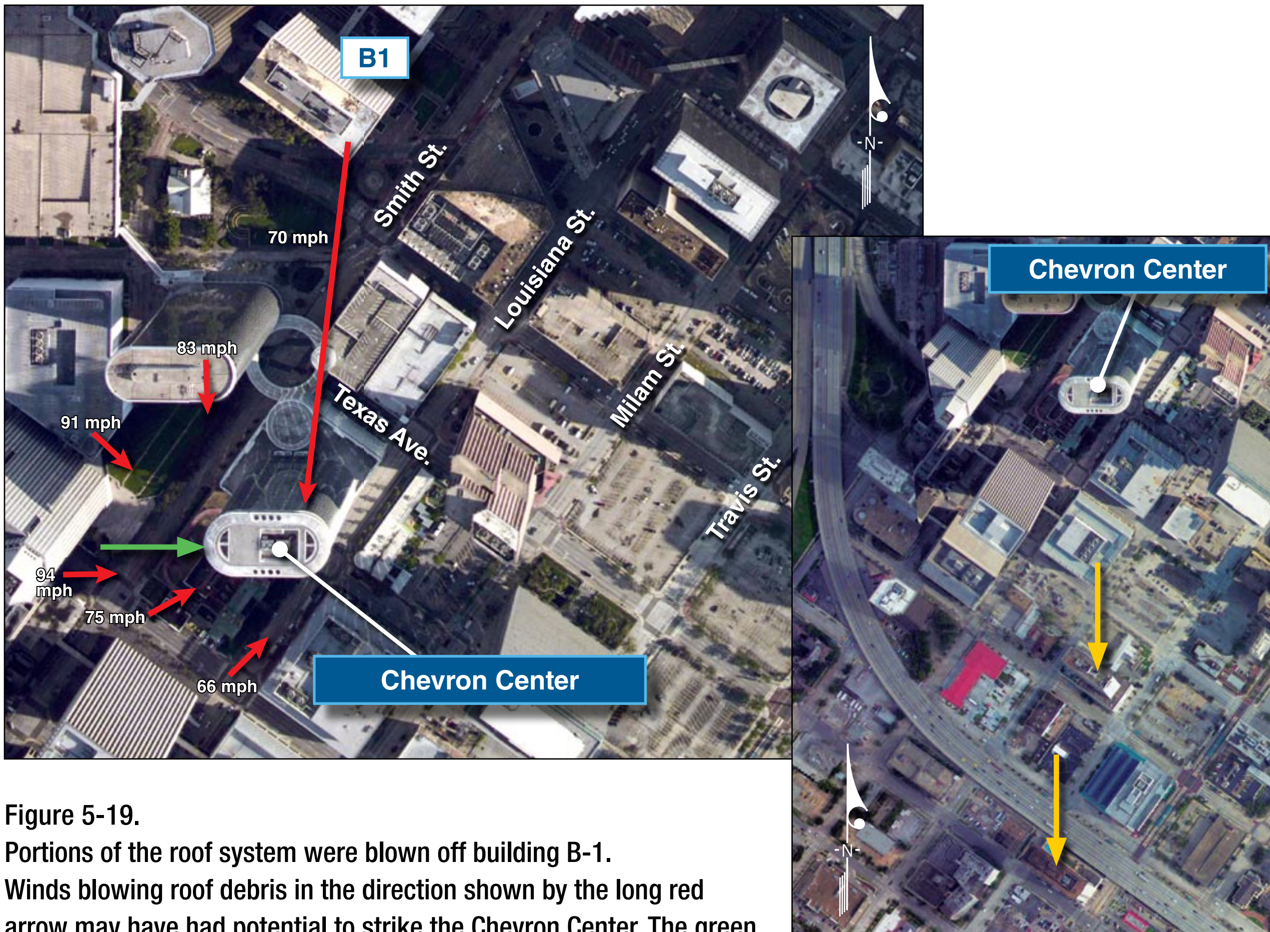


Figure 5-19.
Portions of the roof system were blown off building B-1. Winds blowing roof debris in the direction shown by the long red arrow may have had potential to strike the Chevron Center. The green arrow indicates where a portion of the roof membrane blew off the Chevron Center. The yellow arrows at the inset show locations of buildings that had aggregate-surfaced roofs.
SOURCE: NOAA, SEPTEMBER 17, 2008

The LPS conductor around the perimeter of the Chevron Center detached from the conductor connectors. It is conceivable that the conductor dangled over the side of the building (similar to that shown in Figure 4-40) and caused some glazing damage. Also, as discussed in Section 5.3.2, some of the lightweight insulating concrete roof deck blew off and landed on a roof area that was just a few floors below the main roof. It is conceivable that some of the deck debris caused some glazing damage.

Additional study, which is beyond the scope of the MAT, is needed to more definitively assess the primary cause of glazing damage on this building.

5.3.2 Roof Systems and Rooftop Equipment

The perimeter of the Chevron Center roof had a PVC membrane fully adhered to lightweight insulating concrete. The main roof is surfaced with 16-inch by 16-inch lightweight interlocking concrete pavers.

A portion of the PVC roof membrane was blown off in the vicinity shown by the green arrow in Figure 5-19 and as shown in Figure 5-20. The concrete deck was gouged in many locations (Figure 5-20). The gouging may have been due to roof membrane flutter, or it may have been caused by the detached lightning protection conductor.

Figure 5-20.
The lightweight insulating concrete deck was gouged in many locations

As a result of the roof membrane damage, the window washing track (Figure 5-21) was damaged. Apparently, membrane fluttering caused the nuts on the ½-inch stainless steel bolts to loosen. The galvanized T-shaped window washing track is 4 inches high and 5 ½ inches wide, with a ¼-inch thick head and a ⅜-inch stem.

Figure 5-21.
View of the damaged window washing track (green arrow). The concrete pavers (blue arrow) were not damaged.

5.3.3 Damage at Nearby Buildings

In addition to the glazing and roof covering damage at the Chevron Center, several other low-, mid-, and high-rise buildings shown in Figures 5-22 and 5-23 had various types of building envelope damage as described below.

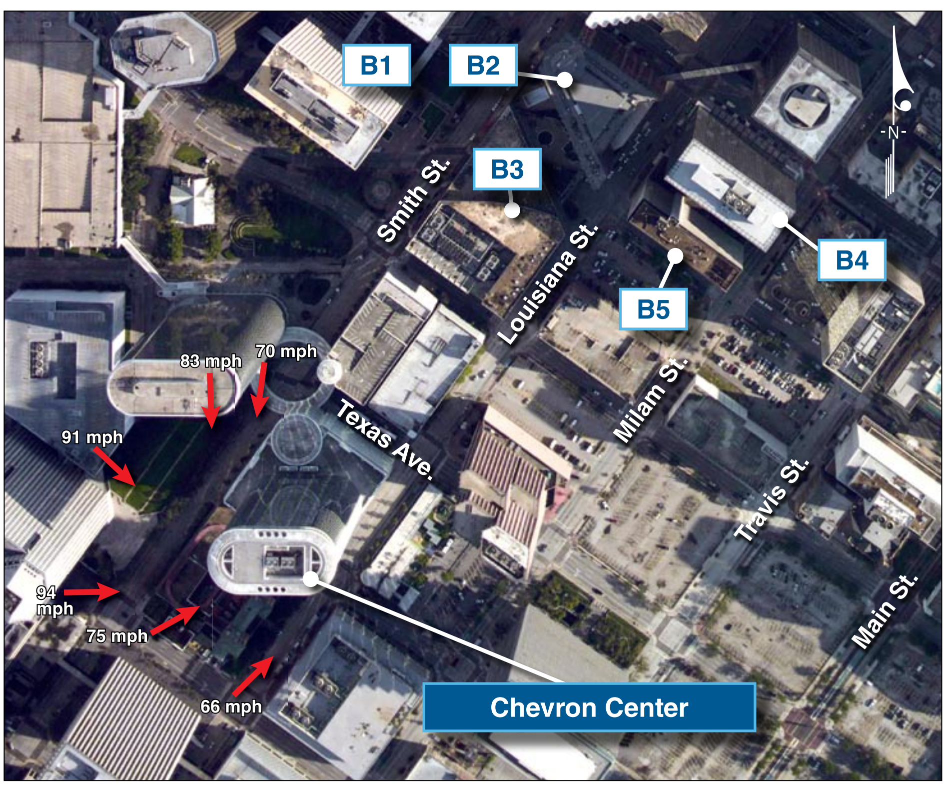


Figure 5-22.
Locations of nearby damaged buildings
SOURCE: NOAA, SEPTEMBER 17, 2008

The view in Figure 5-23 is looking northeast from the roof of the Chevron Center. Yellow arrows indicate two broken windows in the high-rise beyond. There was extensive roof covering damage at building B-3, including exterior wall collapse (green arrow).

Figure 5-23.
View of buildings with glazing, roof and wall covering, and rooftop equipment damage

At building B-2, as shown in Figure 5-24, there was roof puncture damage at the three roof areas shown by the blue arrows, metal wall panels were blown off (yellow arrow), skylights were damaged (green arrow), and a fan cowling was blown off the upper round roof. According to a Hurricane Alicia investigator, this building experienced similar damage during that hurricane.

Building B-5 had an aggregate-surfaced BUR with low parapets (likely less than 12 inches high). The aggregate from this roof was a debris source for the building B-4 glass damage (Figure 5-25; close-up shown in Figure 5-26). The red arrow in Figure 5-25 indicates the generalized likely flight path of the aggregate debris. At least two fan cowlings blew off the building B-5 roof. On the back side of building B-5, a few stone veneer panels were damaged (Figure 5-27). According

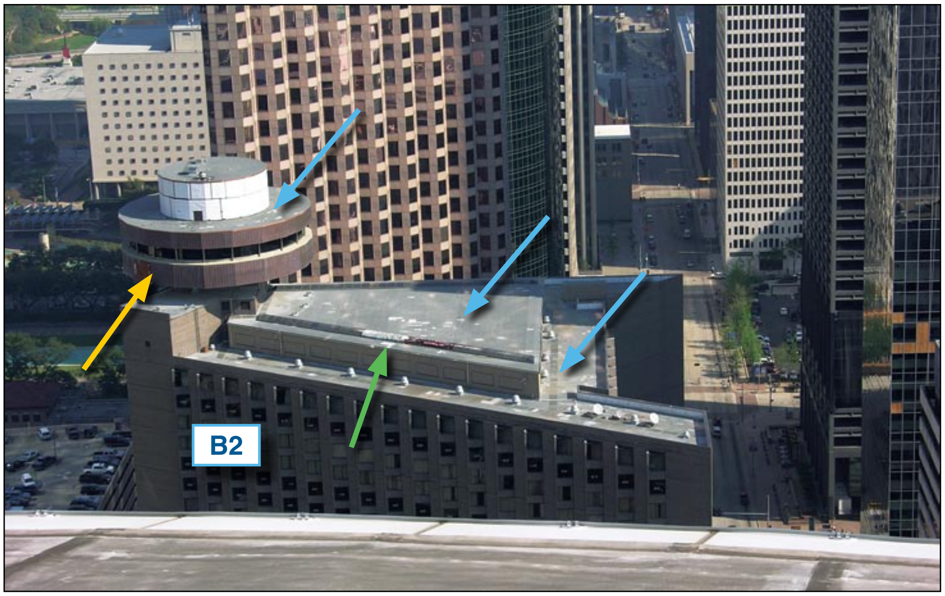


Figure 5-24.
Roof and wall covering, skylight, and roof-top equipment damage at building B-2

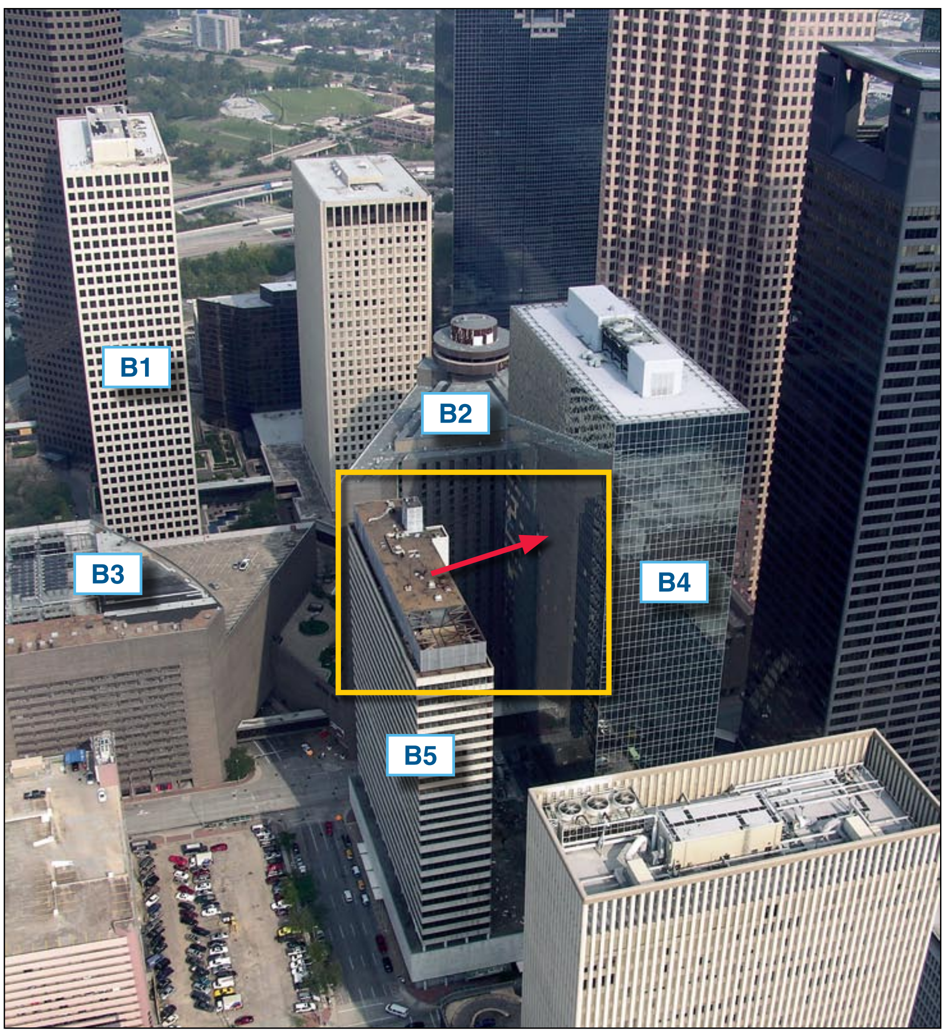


Figure 5-25.
Roof aggregate from building B-5 was the likely cause of the majority of the building B-4 glass damage. The area in the yellow box is shown in Figure 5-26.

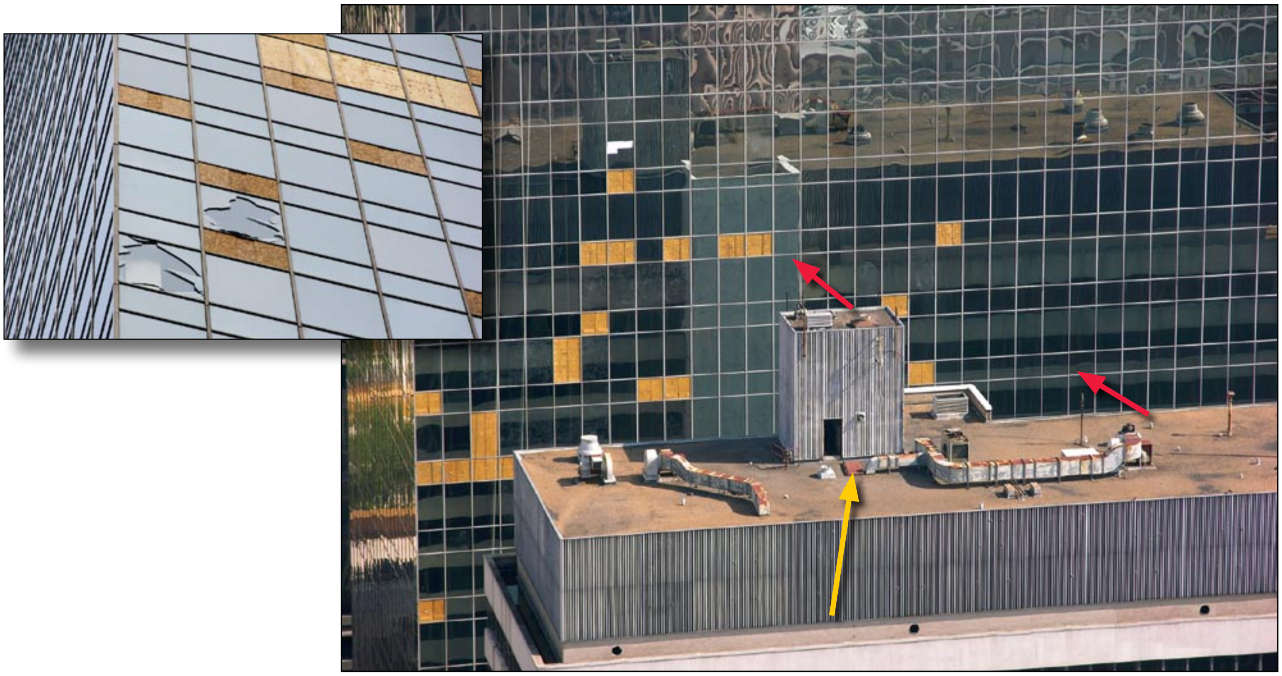
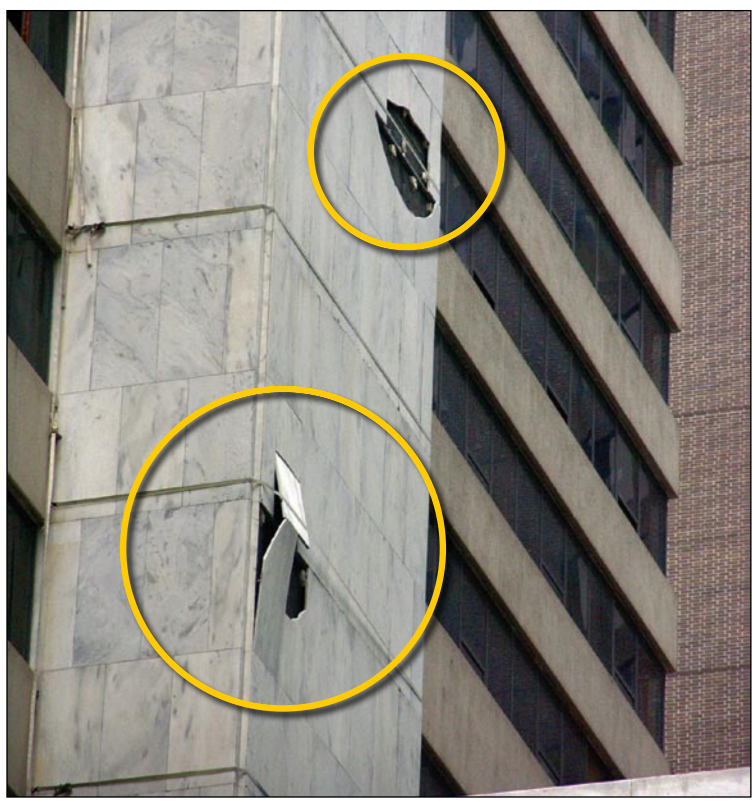


Figure 5-26.
View of the aggregate-surfaced roofs on building B-5 and broken glazing on building B-4 beyond. Red arrows indicate generalized aggregate flight path. The yellow arrow shows a penthouse door that blew off. Inset shows damage on a portion of building B-4 below the area shown in the main photograph.

Figure 5-27.
Stone veneer damage on backside of building B-5 (side facing B-4)



to a Hurricane Alicia investigator, buildings B-4 and B-5 had somewhat similar damage during that hurricane. However, the rooftop penthouse performance on building B-5 was better during Hurricane Ike.

Figure 5-28 shows roof covering damage to building B-1, which was a possible debris source for some of the glazing damage to Chevron Center, as discussed in Section 5.3.1. This building is one of the oldest high-rise buildings in the downtown area.

Figure 5-28.
Roof covering damage on the main and penthouse roofs of building B-1

5.4 Vegetative Roofs

In the downtown area, the MAT observed three vegetative roofs (also known as garden roofs and green roofs). Vegetative roofs had not been observed by previous MATs. The MAT is not aware of previous documentation of wind performance of vegetative roofs. Currently, there are no consensus wind design guides or wind-related code requirements for this type of roof.

Vegetative roofs can either be “extensive” (with very low plants) or “intensive” (which allows for the planting of shrubs and trees). All three of the vegetative roofs observed by the MAT had trees, as shown in Figure 5-29. The MAT did not perform on-the-roof observations at any of the vegetative roofs, but it was apparent that few, if any, tree limbs were blown away. Lack of limb damage may have been prevented by sheltering from nearby buildings. Also, the low-level wind speeds in the downtown area were not sufficiently high to cause substantial loss of limbs. The concern with limbs is their potential to damage glazing if they are blown away, particularly when trees are placed many floors above grade.

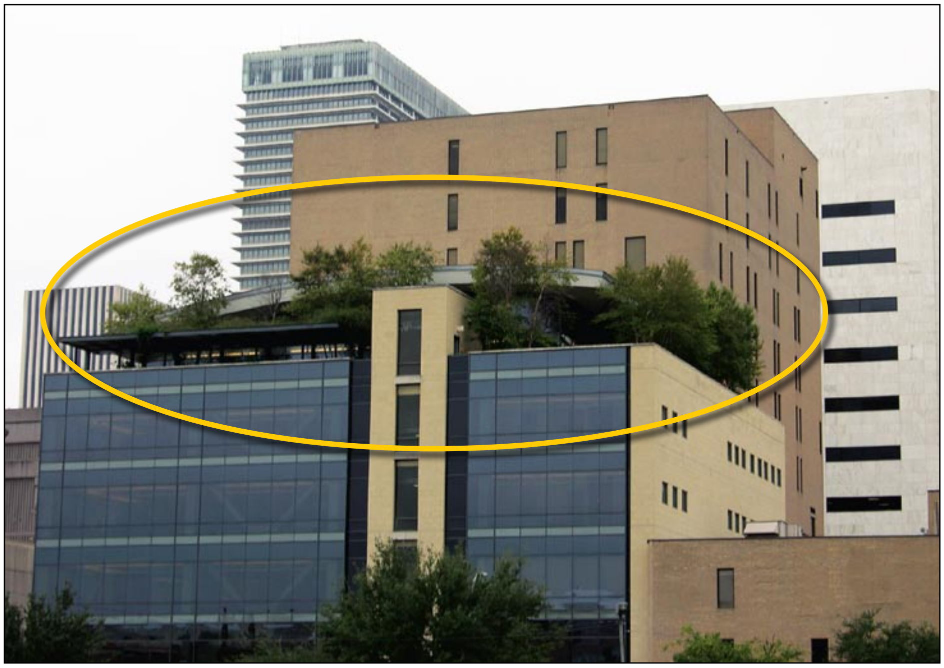


Figure 5-29.
View of a vegetative roof in the downtown area