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LUBBOCK TORNADO:
A Survey of Building Damage in an Urban Area

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Lubbock Tornado:
A Survey of Building Damage in an Urban Area

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Abstract

The Building Research Division of the National Bureau of Standards' Institute of Applied Technology sent a three-man team to investigate the damage to buildings and other structures caused by the tornado which struck Lubbock, Texas, on May 11, 1970. The team members—the authors of this report—carried out photographic surveys on the ground and from a helicopter on the days of May 14, 15, and 16, 1970. The report is based largely on data gathered during this period but includes some data provided by other agencies and individuals whose assistance is acknowledged in the report. The report concludes that current good practice in the design and construction of buildings and mobile homes would have greatly reduced the damage observed at Lubbock. It also notes that natural disasters provide full-scale tests of buildings and urges the development of performance criteria with respect to wind loads for certain building elements.

Key words: Anchorage; building performance; glazing; hailstones; masonry; mobile homes; roofs; structural engineering; wind load.

Contents

Introduction

On the late evening of May 11, 1970, Lubbock Texas, experienced the worst tornado storm in its history. The storm affected most of the northeast quarter of the city, leaving a trail of deaths, injuries, structural damage and a temporary disruption to normal life.

Lubbock lies on the South High Plains of west Texas. This region has a high incidence of tornadoes, being part of the broad tornado belt which extends from North Dakota to Texas and from the foothills of the Rocky Mountains to Ohio. Tornadoes are localized in their effects and because a very small percentage of the total area of this tornado belt is urbanized, the probability of what happened at Lubbock is low. Nevertheless, it did happen, and because it involved such a wide range of building structures, it served to offer one of the few large-scale lessons for engineers and architects on how buildings perform in these extreme storm conditions.

The Building Research Division of the National Bureau of Standards' Institute for Applied Technology sent a three-man team to investigate the damage to buildings and other structures. The team members—the authors of this report—carried out photographic surveys on the ground and from a helicopter on the days of May 14, 15 and 16. This report is based largely on data gathered during this period but includes some data provided by other agencies and individuals whose assistance is acknowledged in this report.

City of Lubbock

Lubbock is a city of approximately 150,000 persons and extends over an area roughly rectangular and measuring 10 miles in the east-west direction and 8½ miles in the north-south direction. It lies 115 miles due south of Amarillo, the nearest large city, at a meeting point of highways, railroads and airlines and is the major trade center for a large part of west Texas and eastern New Mexico; note figures 1 and 2. Lubbock Municipal Airport is located to the northeast of the city.

Lubbock's trade is concerned with cotton and grain and thus the city has a great many structures for the storage of these products. It also has a large plant for the production of earth-moving equipment. In recent years there has been increased construction of high-rise buildings in the center of the city; the tallest structure is the 20-story Great Plains Life Building which houses commercial and professional offices.

Most Federal Government buildings in the city are leased with the exception of the new Post Office Facility and the eight-story Federal Office Building which is under construction.

The great majority of houses in the city is of one-story construction, and because of a high water table, few have basements.

The building code currently enforced by the City of Lubbock is the 1964 Uniform Building Code [1].[1]

Frequency of Tornadoes

Thom [2] has given an account of the recorded frequency of tornadoes in the United States. For this purpose he divided the country into approximately square areas, the sides of which correspond to one degree of latitude and longitude respectively. At the latitude of Lubbock, this square corresponds to an area of approximately 59 miles by 67 miles with the longer side being north-south. Within the ten-year period from 1953 through 1962, approximately 23 tornadoes were reported for this area—a mean annual frequency of 2.3.

Direction of Tornado Rotation

Melarangno [3] points out that the direction of the tornado vortex is usually counterclockwise in

[1] Numbers in brackets indicate the literature references at the end of this report.

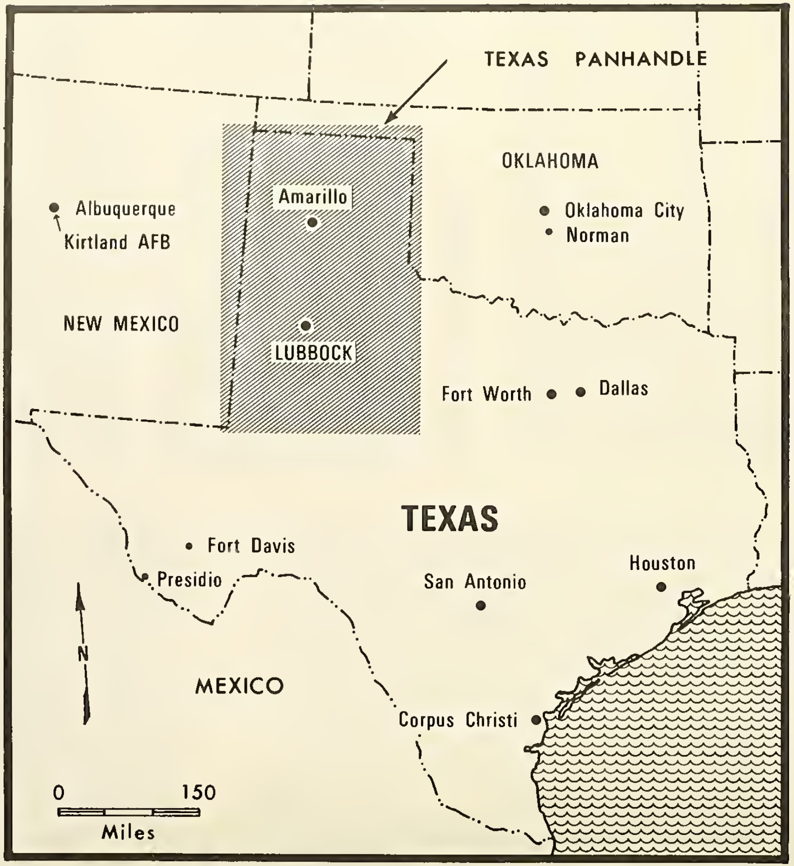


Figure 1 GENERAL LOCATION

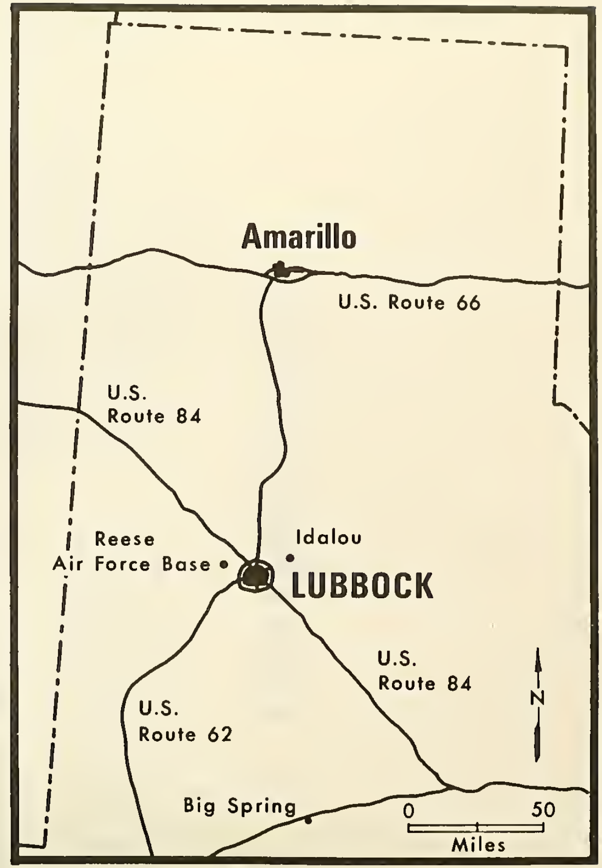


Figure 2 TEXAS PANHANDLE

plan in the northern hemisphere because of the deflection due to the Coriolis force. Tornadoes, however, have revolved in a clockwise direction in the northern hemisphere on a number of occasions. Flora [4] mentions a study by J. P. Finley that was published in the American Meteorological Journal in 1890. Finley reported that in a study made of 500 tornadoes that occurred in the United States, only 29 were found to have had a clockwise direction of rotation. Based on the damage observed in Lubbock, the tornado had a counter clockwise rotation.

Hailstones

Hailstorms are generally the outgrowth of thunderstorms and usually contain relatively small hailstones. Thus they inflict little if any damage on buildings. Large hailstones (exceeding 1 inch in diameter) are indeed damaging, however, and stones of such size have been reported in many parts of the world as well as in the United States.

A review of the literature on hail formation indicates that the formation mechanism is not completely understood. At the same time, it is generally accepted that the majority of the hailstorms in the United States result from warm moist tropical air from the Gulf area moving into the Midwestern States. Storms causing large hailstones occur mostly in the states located between the Appalachian and Rocky Mountains.

Surface temperatures are generally above freezing when hail occurs, and it occurs in Texas in the spring, early summer and late fall.

The conditions that produce thunderstorms with sufficient intensity to develop damaging hail are (1) air aloft cooler than normal, (2) warm and moist air near the surface of the earth, (3) strong winds aloft to assist in developing vertical motion, (4) means of lifting the warm air to cause updrafts such as frontal lifting, and (5) suitably cool air temperature below the cloud formation so that the hail does not melt before reaching the earth. These conditions cause a rising column of air or updraft chimney that is roughly cylindrical in shape and topped by a half spherical cap. The updraft velocities in thunderstorms have exceeded 100 feet per second and the distance these updrafts travel, or the height of the storm, affects the size of the hail that is discharged. This means that the longer the path length available for growth of hailstorms, the larger they may grow. The storm cloud formations reported in the area of Lubbock on the evening of May 11 reached a height of 55,000 feet.

Meteorological Events

■ The regional meteorology in west Texas on May 11 is detailed in Appendix A.

Lubbock Weather Watch

The following information was compiled from reports in the evening edition of the May 14 Lubbock Avalanche Journal. The Weather Bureau's usual 5:10 p.m.[2] forecast on Monday, May 11, contained no mention of the severe weather which was to follow. The sky was clear.

Two hours later thunderstorms developed around the South High Plains. The Weather Bureau issued a severe thunderstorm warning for Lubbock at 7:50 p.m. and followed up with the first tornado alert at 8:15 p.m. as rain and hail fell in the city.

At 8:41 p.m. another statement was issued warning of a severe thunderstorm located just west of the town of Idalou which lies 12 miles to the northeast of Lubbock.

At 8:59 p.m. the tornado warning was extended until 10 p.m. At 9:15 p.m. the Lubbock Weather Bureau picked up a "hook echo" on the radar screen indicating a tornado approximately 10 miles east of the city.

The next hook echo on the radar screen was sighted at 9:35 p.m. near the center of the city. At about the same time a policeman sighted the tornado funnel and reported it to the Civil Defense Unit. In the next few minutes the local radio system carried this message until the system was silenced by the tornado as it touched the ground.

With a loss of electric power in the area, the Lubbock Weather Bureau switched over to its emergency power system. However, all communications within Lubbock were cut off and remained so long after the storm had passed.

[2] Times quoted here and elsewhere in the report are based on Central Daylight Time.

Lubbock Weather Bureau Data

The following data were obtained from the Lubbock Weather Bureau located on the east side of Lubbock Municipal Airport. The data indicate that the tornado passed the Weather Bureau Office at approximately 10 p.m.

Wind Speeds (at 20 feet elevation)

Time (CDT)	*Wind Speed (knots)*	*Wind Speed (mph)*
9:30 p.m.	10	11.5
9:55 p.m.	40	46
10:00 p.m.	20	23
10:02 p.m.	77	89
10:15 p.m.	10	11.5

Rain

1.8 inches in one hour period. (Recording needle stuck when rain pail was lifted during storm.)

Air Pressure (times are approximate)

26.5 in. at 9:55 p.m. 26.2 in. at 9:59 p.m. 26.5 in. at 10:00 p.m.

Path of Tornado

Area of Severe Damage

Figure 3 shows the main features of the city. Figure 4 shows the area which sustained "severe damage." The term severe damage indicates destruction or damage which the building owner or occupant must seek specialist help in repairing.

Within this overall area there are areas in which all building structures were demolished as well as areas in which the damage was less severe. To avoid overcomplication, the latter areas are not delineated in figure 4.

The area of severe damage is some seven miles long, extending from a point roughly at the center of the city to the east side of Lubbock Municipal Airport. At its widest end the band of severe damage was approximately 1½ miles wide while at the narrow end it was approximately ½ mile.

Information used in the tracing of this severe damage area was obtained in the survey. It was supplemented by data gleaned from aerial photographs taken at 3,000 feet and provided by the Office of Emergency Preparedness. It was further supplemented by data furnished by Professors J. Neils Thompson and Franklin B. Johnson of the University of Texas at Austin.

The area of severe damage covered approximately nine square miles while the area sustaining at least slight damage covered about 15 square miles, which is almost one quarter of the city.

Estimated Route of Tornado

From a study of the aerial photographic data and from surface surveys it has been possible to estimate the probable direction of travel of the tornado. This route is indicated graphically in figure 4. Damage distribution indicates that two tornadoes touched the ground to the east of the Texas Technological University and made discontinuous contact with the ground over that part of the route shown by broken lines. From a point north of the center of the city, where the two tornadoes became one, the route was generally northeast and in the vicinity of U.S. Highway 87. It stayed in contact with the ground until shortly after it passed near the Weather Bureau Office which is situated at the eastern edge of Lubbock Municipal Airport.

Zoning of Tornado Path

The route of the tornado took it across three distinctly different areas running up to and just beyond the city limits. For the purposes of reporting the building damage that occurred, these areas will be referred to as zones:

Zone 1

Inner-city commercial and residential area

Zone 2

Light industrial area to the south of Loop Highway 289

Zone 3

Residential area to north of Loop Highway 289 and including the Municipal Airport

Zone 4

An area to the south of the city pelted by large hailstones

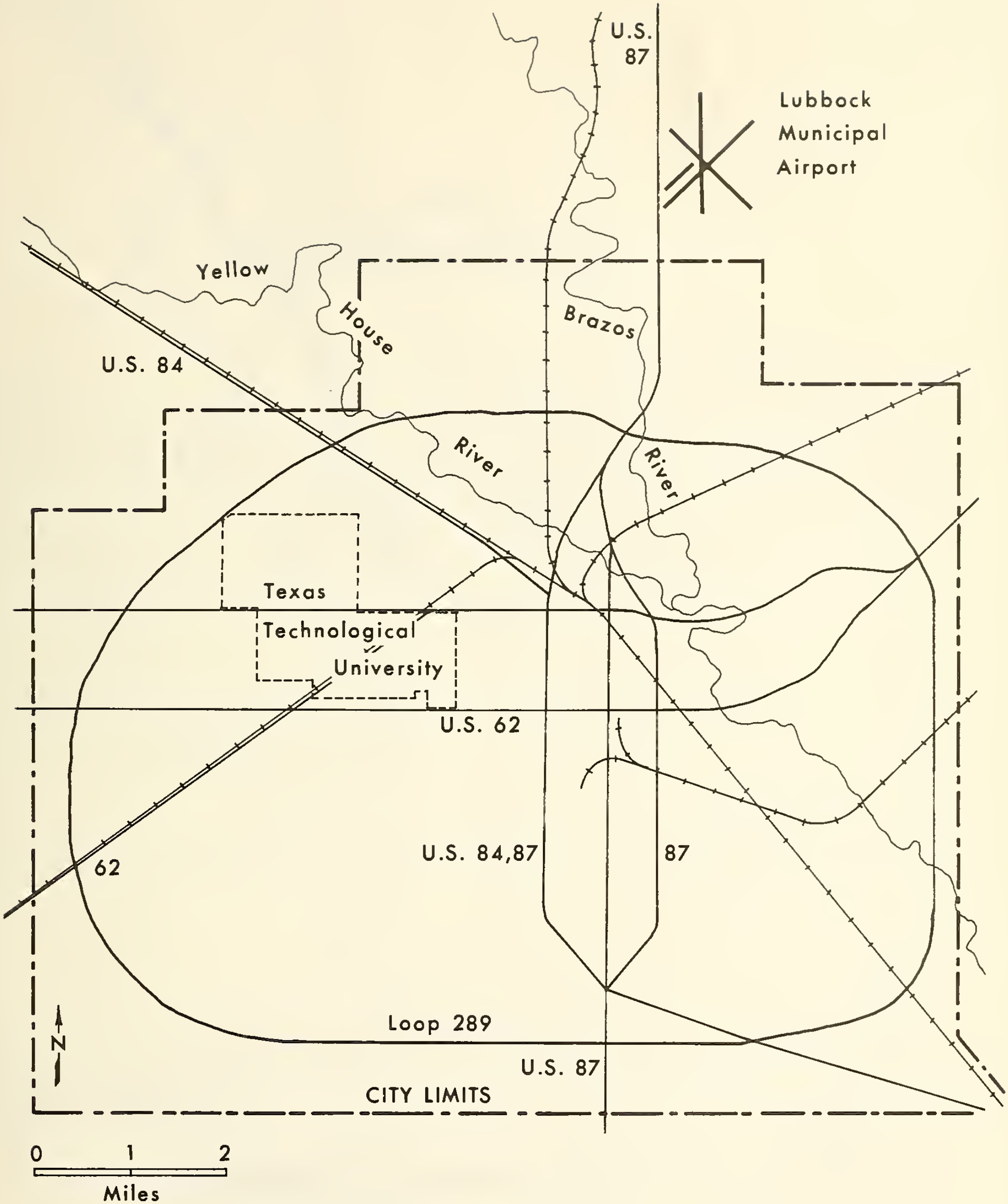


Figure 3 CITY OF LUBBOCK

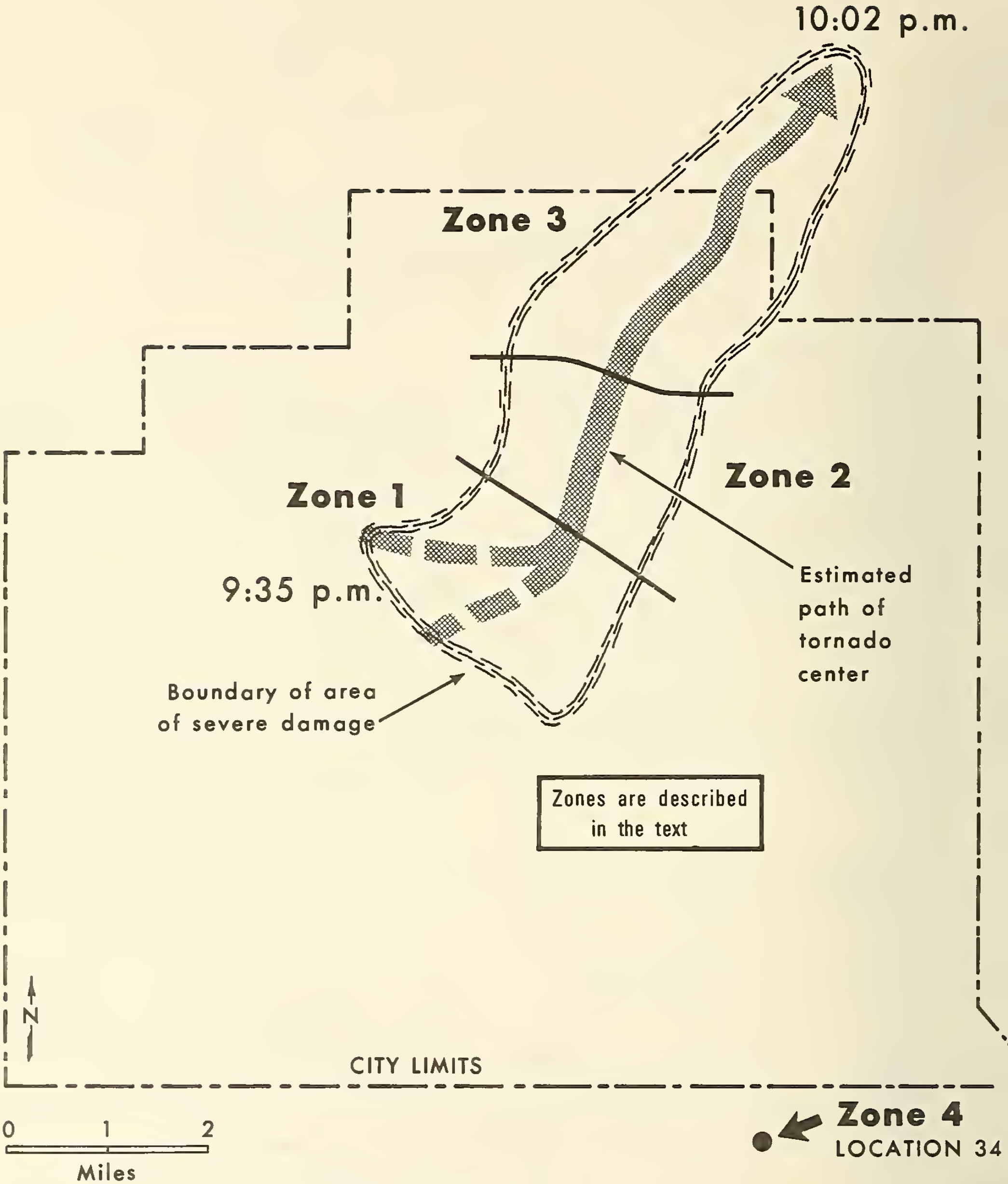


Figure 4 PATH OF TORNADO

Statistics

Deaths and Injuries

According to information supplied by the American Red Cross, the death toll was 26. Undoubtedly, this toll would have been much higher if the storm had struck earlier in the day when many of the downtown offices and stores were fully occupied. The estimated number of people who received medical treatment was 1,500 with 96 being hospitalized. Many of the injured, especially those in the downtown district, were struck by fragments of shattered windows.

Detailed information on the direct causes and locations of persons killed or injured was difficult to obtain at the time of writing although it was reported that four deaths occurred in houses in the vicinity of Lubbock Country Club at the north side of the city (Location 31).

Property Loss

The cost of property damage due to this tornado has been estimated at $200 million. Besides buildings, this figure includes damage to utilities, 119 small aircraft and 10,000 private automobiles.

It was learned that only 50 percent of the homes were covered with some insurance and that the average coverage of those insured was only 40 percent of the value. Statistics supplied by the American Red Cross on the number of homes affected are:

Single family detached houses

■ Destroyed	460
■ Severe damage [1]	489
■ Minor damage	764

Mobile homes

■ Destroyed	80
■ Severe damage [1]	30

[1] Beyond the ability of the average resident to make repairs.

It was also estimated that 250 small businesses were disrupted. A total of 600 apartment units were demolished. This included 9 apartment houses containing 240 dwelling units.

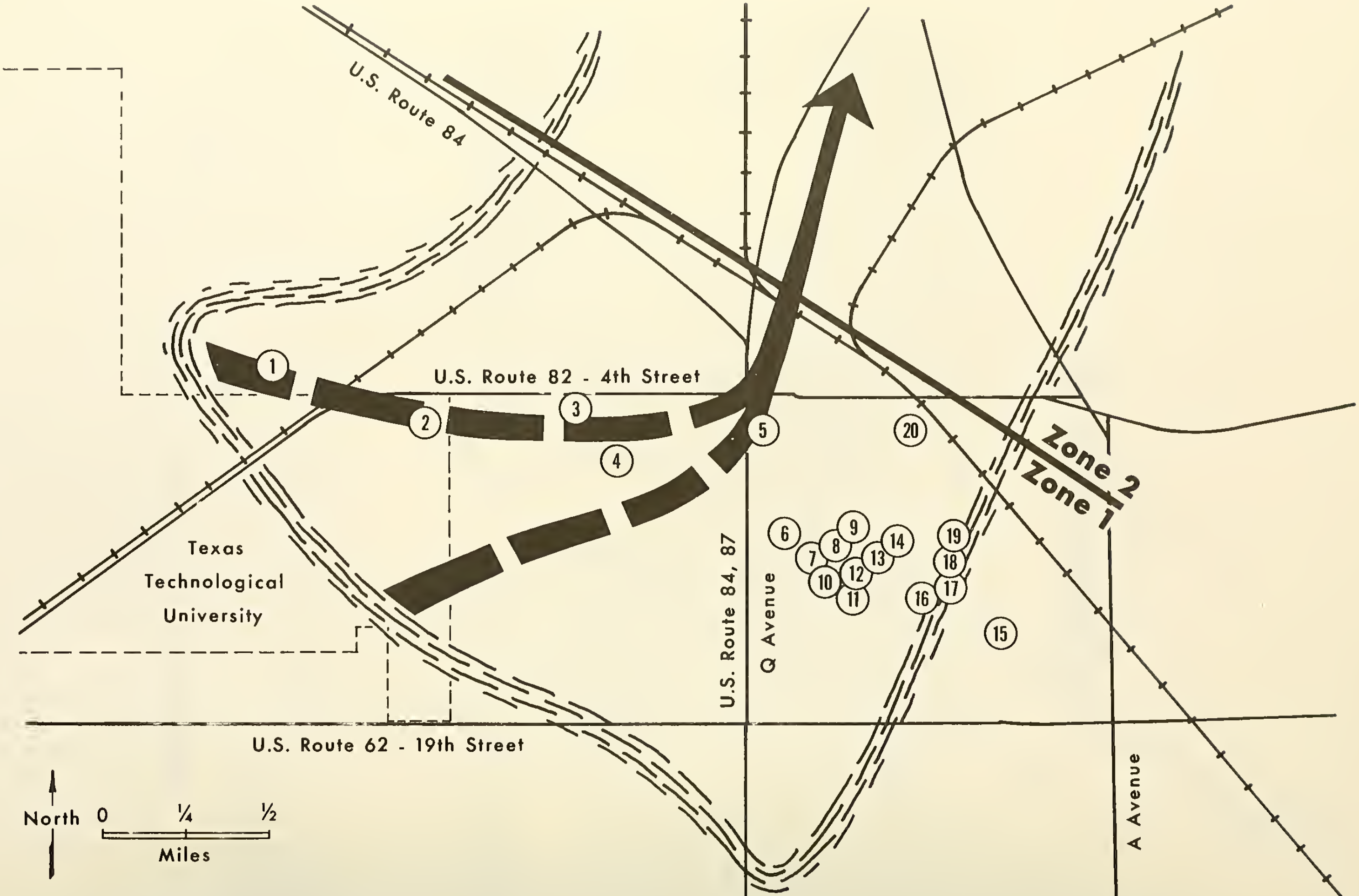


Figure 5 - Zone 1

INNER-CITY COMMERCIAL AND RESIDENTIAL AREA

Circled numbers are locations referred to in report

Damage in Zone 1

General Comments on Roofs

The damage observed at Lubbock on flat and low-slope builtup roofs, even in the heart of the storm path, varied from total destruction to easily repaired damage. Undoubtedly contributing to this variation were such factors as rigidity of deck, strength of mechanical and/or adhesive bond of the roof membrane and insulation, and bond strength of the edge flashing. It must be pointed out that the mere fact that one roof came through the storm unscathed while neighboring roofs were damaged is no basis for believing the undamaged roofs to be stronger. These undamaged roofs may not have encountered the same kinds of wind patterns that produced structural damage or loss of roof coverings elsewhere.

Apartment Complex

Photograph 1 shows roof decks completely ripped from low-rise apartment buildings. Photograph 2 shows how wind struck the corners of the buildings, attacked the edge flashing, ripped the flashing apart,

Photograph 1—Apartment complex with considerable loss of structural roof deck. View looking south. (Location 1)

Photograph 2—Apartment complex with "peel-back" of roof membrane and loss of roof overhanging a balcony. View looking east. (Location 2)

moved under the roof deck and by a combination of external and internal wind forces rolled up the roof deck, insulation and covering. The overhanging balcony roof along the west elevation in the center of photograph 2 was also destroyed by uplifting wind forces.

Jones Stadium

The stadium of the Texas Technological University lies at the eastern edge of the campus across which the tornado made a discontinuous contact with the ground. Just 200 yards east of the stadium, the tornado touched down and destroyed portions of two apartment buildings.

The effect of this touch-down on the floodlight standards to the stadium is shown in photograph 3. Three tubular steel standards collapsed while three surviving standards showed significant curvature and leaned to the east.

On that part of its path shown by the broken line in figure 5, the tornado traveled east-west, touching ground discontinuously. One touchdown point is shown in photograph 4. In the foreground, the west end of buildings of the Hygeia-Ozarka Water Com-

Photograph 3—Jones Stadium of Texas Technological University with bent and collapsed floodlight standards. View looking west. (Location 2)

Photograph 4—Roof and wall damage to building of Hygeia-Ozarka Water Company located in center foreground. View looking south. (Location 3)

Photograph 5—Random damage to gable roofs of wood framed houses. View looking south. (Location 4)

pany suffered damage to roofs and walls. In the center of the photograph, an apartment complex lost a considerable portion of its roof.

Various Building Types

The erratic distribution of damage to the gable frame roofs of in-city houses is illustrated in photograph 5. Some houses sustained complete destruction of the structural roof while others had only slight damage to the tabs of asphalt shingles. Such variations were discussed at the beginning of this chapter. Many non-reinforced masonry chimneys on older houses in this same area had toppled over causing considerable damage to the roofs.

Newson's Living Center is shown in the foreground of photograph 6 and comprises a circular one-story building and an adjoining two-story building, rectangular in plan. The tornado is believed to have passed directly over these structures before changing its direction of travel to the northeast. The one-story building was destroyed while the second floor of the two-story building was badly damaged. Considerable distortion of the steel frame occurred in both structures.

The all-timber superstructure of the First Cumberland Presbyterian Church was destroyed as shown in photograph 7. Damage to a nearby house is shown in photograph 8. Free-tab lightweight asphalt shingles were torn off the south slope of the house roof.

Photograph 6—View looking northeast from center of city. Note destruction of Newsom's Living Center and neighboring buildings in the foreground. (Location 5)

Photograph 7—Church of timber construction. View looking northwest. (Location 6)

Photograph 8—Partial loss of asphalt shingles on south slope of roof. *(Location 6)*

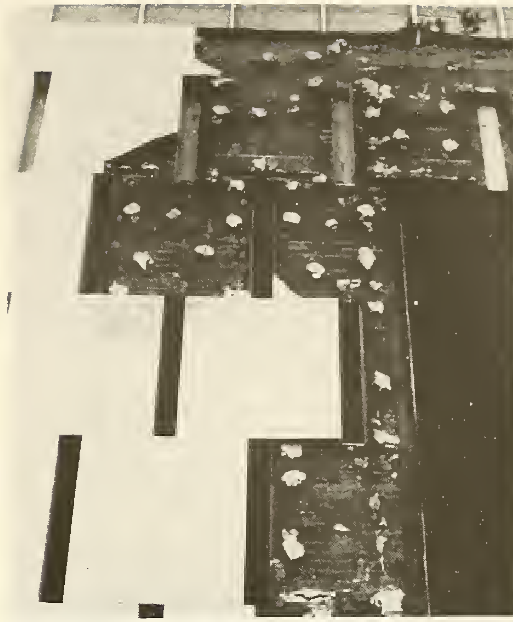
First National-Pioneer Building

Damage to the 15-story First National-Pioneer Building was estimated at $1 million.[3] This reinforced-concrete frame building was completed in January, 1969, and consists of a large two-story base and a 13-story tower. As shown in photograph 9, exterior marble veneer was stripped from portions of the two-story base. Some loss of marble veneer was observed on all four elevations of the building. Extensive damage to the glazing and the glass spandrels of the 13-story tower can also be seen in photograph 9. Interior building damage was reported to be severe and included damage to suspended ceilings.

Close-up views of the marble veneer damage on the east elevation of the building are provided by photographs 10 and 11. Typical pieces of marble veneer are approximately 8 sq. ft. (2 ft. by 4 ft.) in area and ⅞-in. thick. This veneer was tied by copper wire anchors to masonry or concrete backup. In most places the loss of marble veneer was due to the wire anchors pulling out of the holes in the edge of the veneer. Splitting of the marble veneer at the anchor holes was also observed; note photograph 11.

Based on a cursory examination, it appeared that the method of anchoring the marble veneer was in accordance with American National Standard Speci-

Photograph 9—View of First National-Pioneer Building looking southeast. Glazing, spandrel glass veneer and marble veneer severely damaged. *(Location 7)*



Photograph 10—Close-up of marble veneer on east elevation of First National-Pioneer Building. *(Location 7)*

Photograph 11—Marble veneer anchorage failure; First National-Pioneer Building. *(Location 7)*

[3] *Engineering News Record,* May 21, 1970, page 35, McGraw-Hill Inc., New York City.

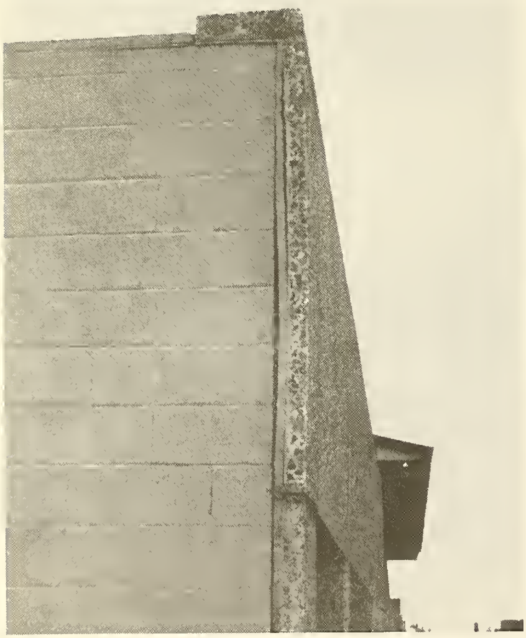
fications for Thin Exterior Marble Veneer (2-inch and less in thickness), A94.2-1961. (See Appendix B for excerpts)

At Locations 8 and 9

A dislodged precast concrete panel was noted at one exterior corner of the Sanders Funeral Home (photograph 12). In the front part of this building, the overhanging roof had been lifted and damaged. In the interior of the building, cracking along the wall/roof intersection was also noted.

Typical tree damage is shown in photograph 13. A few trees in this area had also been uprooted.

Cautionary Note—Because the time available to them was limited, the authors in conducting photographic ground surveys were unable to gather detailed documentation on some of the damage reported herein. It is possible, therefore, that some of the minor building damage shown in this report (for example, in photographs 12 and 34) occurred prior to the May 11 tornado.



Photograph 12—Dislodged precast concrete panel at northwest corner of Sanders Funeral Home. (Location 8)

Although heavily damaged, the steel sign in photograph 14 was anchored sufficiently to prevent it from being blown away; failures at the base of the steel posts occurred at weld locations (photograph 15).

Photograph 13—Typical tree damage. View looking west. (Location 8)

Photograph 14—Damage to sign with tubular steel posts. View looking north. (Location 9)

Photograph 15—Weld-fracture at base of sign posts shown in Figure 14. (Location 9)

A small building built with non-reinforced masonry walls was particularly vulnerable to the wind forces after it lost its roof structure (photograph 16).

The First Methodist Church shown in photograph 17 is constructed of brick masonry and has a steep gable roof covered with ½-inch thick flat clay tiles. Relatively few of these tiles were dislodged.

Photograph 18 shows the Texas, New Mexico and Oklahoma Coach Company maintenance shops and damage to the east wall and roof structure of this one-story building which is almost square in plan. At the south end of the west elevation, an 18-foot-wide overhead door was pushed into the building. The combination of wind pressure inside the building and wind force on the approximately four-foot-high parapet caused the outward collapse of the lightly-loaded masonry east wall shown in the photograph. The wood roof collapsed with the loss of support from the wall. The masonry wall was 12 inches thick and consisted of a 4-inch brick facing and 8-inch clay tile backup.

Photograph 16—Small office building for dealer in used automobiles. Roof structure completely removed and non-reinforced masonry walls badly damaged. (Location 9)

Photograph 17—View of First Methodist Church looking northwest. This masonry structure sustained only minor damage to clay roof tiles and to glazing. (Location 10)

Photograph 18—Maintenance shops of Texas, New Mexico and Oklahoma Coach Company. View looking southwest. (Location 11)

The west elevation of a store is shown in photograph 19. Near the south end of this elevation four panels of marble veneer were missing from the facade.

Photograph 19—West elevation of store with loss of marble veneer. (Location 12)

Great Plains Life Building

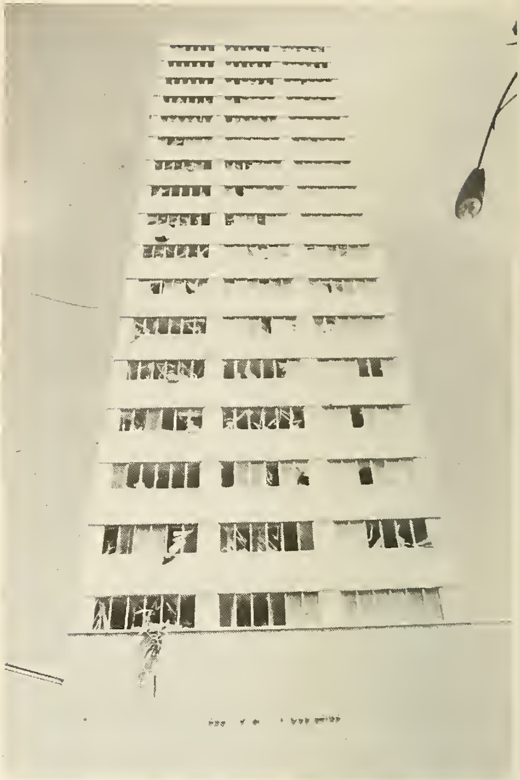
This building was completed in 1954 and it dominates the city skyline as can be seen from photograph 20. The authors carried out a survey from top to bottom of this structure on May 15. At this time there was still no electric power in the building and clocks showed the time at which they had stopped during the passage of the tornado—between 9:45 and 9:47 p.m.

At this time on Monday evening, May 11, there were only about 30 people in the building, a fortunate circumstance since damage observed by the authors leaves no doubt that, had the same tornado occurred between 8 a.m. and 5 p.m., casualties would have been many.

The Great Plains Life Building is approximately ½ mile southeast of the path of the center of the tornado as shown in figure 4. Thus, the building was subjected to winds along the peripheral path of the tornado and escaped contact with the core of the funnel. Indeed the damage observed in this building would have been more severe had the tornado path been closer. The assumption that the tornado rotated counter-clockwise in plan is consistent with the wind damage observed in the building and with the inclination of the radio antenna on the roof.

Approximately 50 percent of the glazing was pushed into the building on both the south and west elevations as shown in photograph 20. This effect is concentrated near the southwest corner as shown in photographs 20 and 21. On the east elevation, however, the probable combination of pressure buildup inside the building and suction outside the building caused glazing to be forced out and to fall in the street below. Some 20 percent of the glazing was lost from the east elevation.

Photograph 20—Center of City with 20-story Great Plains Life Building in foreground. View looking northeast. (Location 13)

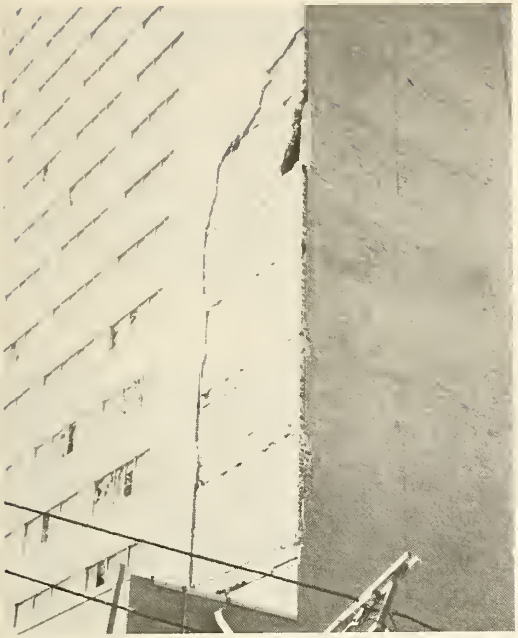


Photograph 21—South elevation of Great Plains Life Building. Glazing damage was particularly severe on southwest corner of building. (Location 13)

On the north edge of the east elevation the combination of the air flow around the building and the twisting of the building caused the loss of brick veneer over a clay tile infill wall panel enveloping the utility tower. This area extended vertically over seven stories with a maximum width of 20 feet; note photograph 22. From ground level it appeared that the brick was bonded by brick headers to the clay tile backup.

The Great Plains Life Building is a steel framed 20-story structure having its long axis in the north-south direction. The 3-story base is 75 feet by 125 feet in plan and from it rises a 17-story tower measuring 56 feet by 125 feet. Columns are spaced approximately 19 feet on center in the north-south direction and 18 feet on center in the east-west direction. Fire protection to the columns consists of gypsum tiles. Elevators, utilities, and the stairwell are located at the north end of the building in a utility tower in which the infill panels are structural clay tile with brick veneer. On the north elevation there is no glazing while on the other three elevations glazing begins at the fourth floor and continues to the 20th. On each floor—other than the first floor—there is a corridor centered on the long axis of the building.

The utility tower gives the structure considerable shear resistance due to the stiffening effect of the masonry infill panels; the tower has a high torsional stiffness being an almost complete rectangular box section. The contribution of the utility tower masonry in resisting the wind force was very apparent from the cracking observed in the masonry walls of the stairwell. Cracking of the mortar plaster on the clay tile infill panels on the three walls of the stairwell was particularly severe at the fourth, fifth and sixth levels but lessened progressively for the floors above. In some areas this cracking was sufficient to cause areas of plaster to fall. The angle of the cracks was either horizontal or between 30 to 50 degrees from the horizontal. The cracking sug-



Photograph 22—Northeast corner of Great Plains Life Building with loss of brick veneer over clay tile infill wall panels enveloping the utility tower. (Location 13)

Photograph 23—Disruption of gypsum-tile fire protection to steel column in the Great Plains Life Building. (Location 13)

gests that the stairwell, and hence the utility tower as a whole, was twisted in a counter-clockwise direction in plan. This is the deformation to be expected of this building which underwent high wind forces on its west elevation and which had its center of twist offset to the north from its centroidal axis because of the torsional stiffness of the utility tower.

Other evidence of this torsional rotation was provided by similar cracking of fire protection to steel columns adjacent to the utility tower. In these columns the cracks were at 45 degrees to the horizontal. Photograph 23 shows that the movement of one steel column on the sixth floor was large enough to cause disruption of gypsum tile.

When the wind pressure broke the glazing on the west and south elevations, pressure built up within the building and particularly in those rooms located in the southwest corner. Photograph 24 shows that the interior nonloadbearing walls were unable to withstand these pressures and were shattered. These walls were 3-inch gypsum tile with ¾-inch mortar plaster on both sides. The high forces imposed on the masonry spandrel below the windows on the south wall resulted in a loss of plaster.

There was considerable evidence to show that the pressure buildup in these offices caused ceilings

Photograph 24—Southwest corner on the sixth floor of Great Plains Life Building. The 3-inch gypsum tile non-loadbearing walls were shattered by wind pressure. (Location 13)

to lift from the walls in several locations. Various paper items were swept through the gap by the air as it rushed through the building. Much of this paper was trapped when the ceiling settled back on to the walls.

Photograph 25 shows a one-inch vertical movement of the gypsum tile partition at the southeast corner of the sixth floor. In this case the ceiling and wall remained in contact and the resulting movement racked a door frame.

Photograph 25—One inch vertical movement of gypsum tile partition at southeast corner of sixth floor of Great Plains Life Building. Note racking of door frame. (Location 13)

Photograph 26—Eight-foot lengths of stainless steel coping were completely stripped from east parapet wall on the roof of the Great Plains Life Building. (Location 13)

There was considerable damage at both the roof level and at the top of the utility tower which rises 40 feet higher. In one area where an exhaust vent passed through the roof, a 4 foot square area of built-up roofing around the vent was lifted. The brick parapet wall on each side of the roof was capped by stainless steel coping in 8-foot lengths. The end of each length was fastened down by a strap. Wind forces stripped coping from the entire east parapet wall, adding to the debris falling on the city; note photograph 26.

On the roof of the utility tower, a 34-foot-high steel radio antenna was bent approximately 10 degrees out of the vertical towards the northeast. A smaller antenna approximately 20 feet high and some 10 feet away was bent in the same direction. On this roof, coping was lost from the entire south side, and from about half of the west side.

A Personal Account

There were some revealing accounts of experiences by people who were in the building at the time of the tornado. Mr. John D. Zahn reported to the Dallas Times-Herald that he was conducting a class on the top floor when what he thought was a typical west Texas thunderstorm started. As the hailstone pelting against the windows increased, he began to feel dizzy. After falling over his lectern, Zahn decided it was time to close the class! When the class members stood up he noted that they, too, were staggering. The lights went out as they left the room; in the corridor they were tossed from one wall to the other by the swaying of the building. Zahn reported that it was impossible to stand up, that the experience was like walking on a ship during a storm.

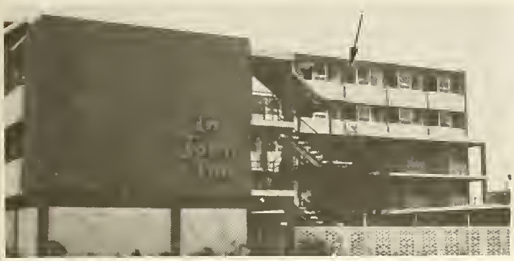
The group made for the stairs and started down; the lights came on momentarily and then there was total darkness again. Zahn reported that as they started down the stairs, the building began to rock and at the half-way point, the plaster debris from the stairwell walls fell thickly. With the swaying of the building, one step forward would cause the group to be thrown forward, while the next step resulted in their being thrown back into a sitting position. Zahn kept telling everyone to keep hold of the rails to prevent a fall. At the second floor they were warned by another man not to go down because electrical wires were popping and they might step on one. It took about 15 minutes for Zahn and his group to reach the bottom. He reported that when his group was joined by other people the number of people totaled 30.

When they reached the building lobby, everything became calm for a minute and then the winds started again and this time the glass in the lobby windows and doors blew out, Zahn reported.

Zahn's final comment is interesting. He said that his group heard no warning of the impending tornado but that this is probably what saved the life of everyone in the building and kept them from being injured; had they heard a warning, he points out, they would have rushed out into the street to be hit by flying debris. They were safer inside the building.

The In Town Inn

Glazing damage in the upper stories of the In Town Inn motel is shown in photograph 27. No structural damage to this reinforced concrete building was observed. The perforated 8-inch brick fence (approximately 6 feet 6 inches in height) shown at the right of the photograph also escaped damage. However, a similar brick wall, which was in line and to the east of this wall, overturned at midheight; note photograph 28.

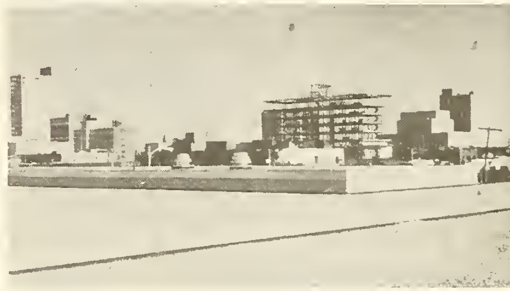


Photograph 27—South elevation of five-story motel with damage to glazing in upper floors. (Location 14)

Photograph 28—East-west brick wall with the upper 40-inch height overturned. (Location 14)

The wall contained vertical reinforcement but unfortunately this reinforcement terminated at midheight; note photograph 29. Based on the wall dimensions and an assumed bond strength of 20 psi, the minimum wind speed was calculated as 83 miles per hour. Although the type of mortar is not known, the value assumed for the bond strength is conservative and hence the wind speed derived from this calculation is conservative.

Photograph 29—Overturning of wall occurred at level at which vertical reinforcement was terminated. (Location 14)



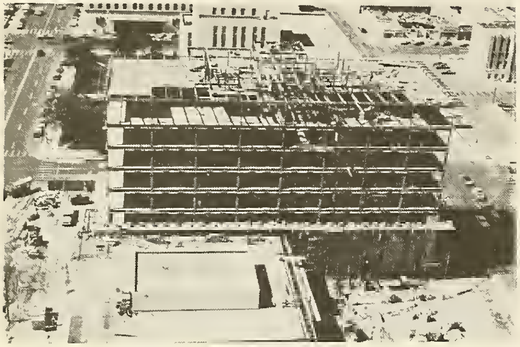
Photograph 30—Lubbock skyline from roof of Post Office building which was just outside the area of severe damage. View looking northwest. (Location 15)

Photograph 31—View looking northeast showing roof of Recruiting Station for U.S. Military Services. Note punctured roof in foreground and overturned parapet wall to the rear. (Location 16)

Government Buildings

The new Post Office Building is located outside the boundary of the severe damage area in downtown Lubbock. This one-story building sustained only minor window damage on the west elevation. As illustrated in photograph 30, the gravel-surfaced roofing, metal flashing, and roof ventilators were not damaged. The Great Plains Life Building, five blocks to the northwest, can be seen on the left side of this photograph.

As shown in photograph 31, the damage to the one-story U.S. Military Recruiting Station was a large puncture through the roof membrane and deck. It is believed that this damage was caused by flying debris from another building.



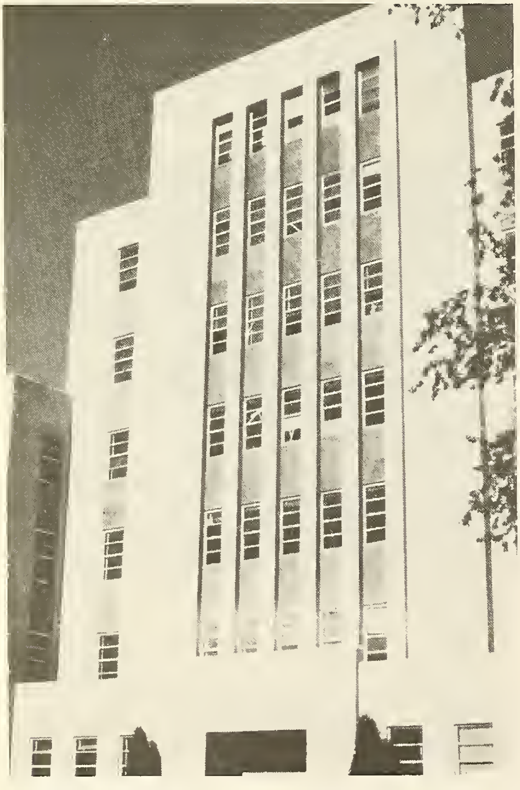
Photograph 32—Federal Office Building under construction. View looking north. (Location 17)

The estimate of the total cost to repair the damage to all *occupied* Federal Government buildings was low—$2,000.

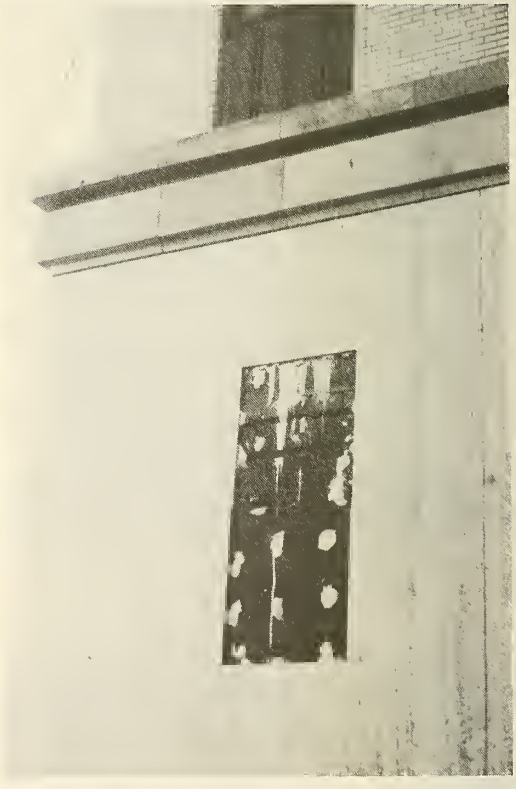
The eight-story Federal Office Building is located about ½ mile southeast of the estimated path of the tornado center and as photograph 32 shows, it was under construction at the time of the tornado. Very costly damage was caused to building materials stacked both at the site and on the structure. An early estimate of the cost of this damage was reported as $150,000 by the building manager for the General Services Administration. The steel framing for the building was reported to be sound and work was to continue on its construction.

The seven-story County Courthouse building is situated just east of the area of severe damage and experienced only minor glass breakage as shown in photograph 33.

The 13-story Lubbock National Bank building is on the fringe of the severe damage area. Metal signs were ripped from its roof and there was light dam-



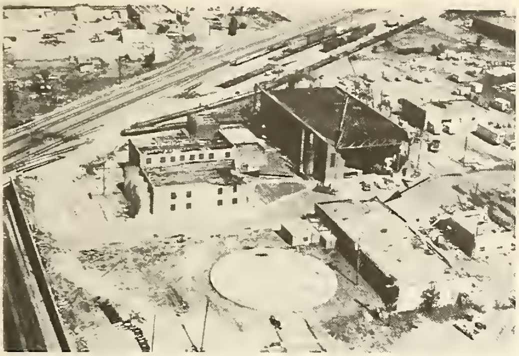
Photograph 33—West elevation of County Court Building suffered only slight glazing damage. (Location 18)



Photograph 34—Marble veneer dislodged from east elevation near southeast corner of Lubbock National Bank. (Location 19)

age to glazing. On the east elevation near the south corner of the building, and approximately 12 feet above the ground, two panels of marble veneer were missing as shown in photograph 34.

Aerial photographs 35 and 36 show damage typical of many light industrial buildings. Photograph 35 illustrates major damage to a high nonloadbearing masonry end wall of one of these buildings. Damage to built-up roofing on other buildings is shown in the foreground of photograph 36.



Photograph 35—Wall and roof damage to light industrial buildings. View looking east. (Location 20)

Photograph 36—Roof damage to light industrial buildings. View looking north. (Location 20)

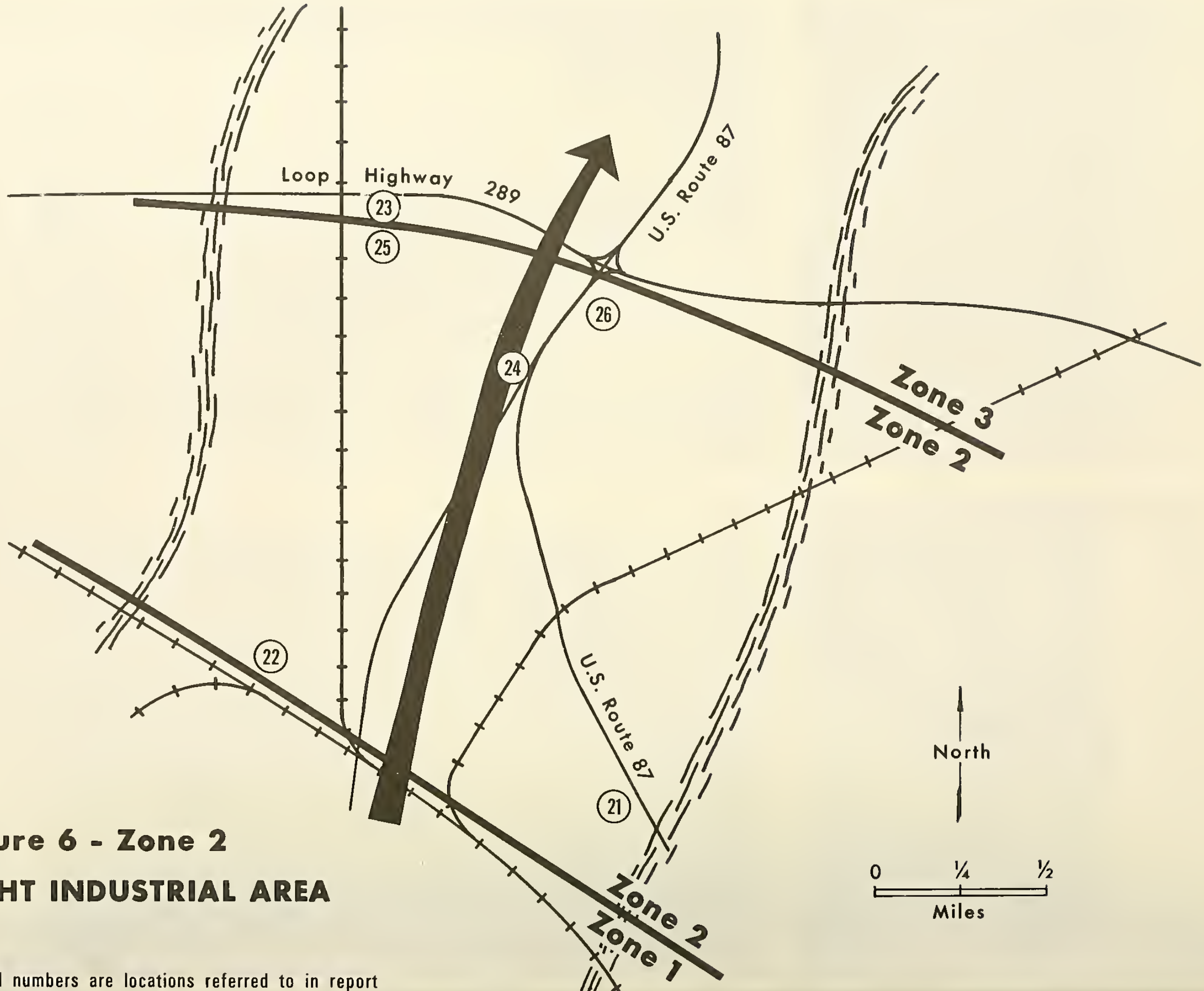


Figure 6 - Zone 2

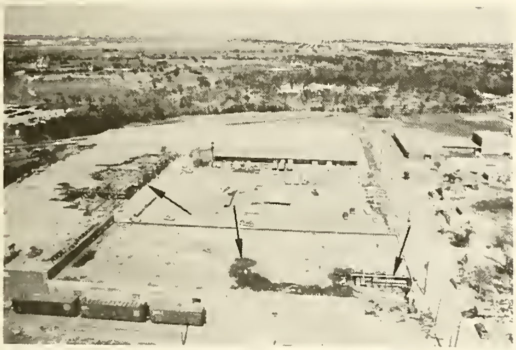
LIGHT INDUSTRIAL AREA

Circled numbers are locations referred to in report

Damage in Zone 2

Photographs 37 and 38 show typical wind damage along the leading edges of flat roof decks at the K. T. Ibell Warehouse. The separation of wind flow at such edges causes a negative pressure resulting in an uplift force on the roof.

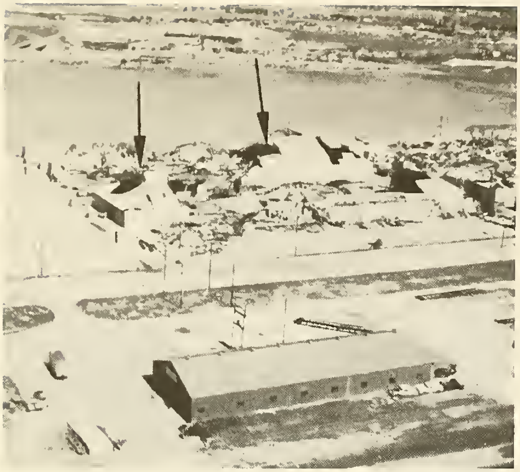
Substantial damage to roofing and to light roof panels has exposed the structural steel frame of the large industrial building shown in photograph 39, the Hancock Division—Clark Equipment Company.



Photograph 37—K. T. Ibell Wholesale Grocery Warehouse with roof and wall damage. View looking west. (Location 21)

Photograph 38—K. T. Ibell Wholesale Grocery Warehouse with damage at edge of roof. View looking west. (Location 21)

Photograph 39—Damage to roofs of light industrial buildings of the Hancock Division of Clark Equipment Company. View looking west. (Location 22)



Photograph 40—Destruction of cotton process buildings. View looking east. (Location 23)

Photograph 42—Damage to roof structure of light industrial building. View looking east. (Location 25)

Structural roof damage was caused to several light steel frame buildings in an area covering approximately one acre as illustrated in the background of photograph 40. Similar buildings to the left and in the foreground were relatively untouched.

Photograph 41 shows the destruction of a soft-drink warehouse adjacent to US Route 87. The steel frame of this building collapsed sideways in the northerly direction. Non-loadbearing block walls also collapsed, but it is not known whether this was due to wind or the tumbled cartons, or a combination of the two.

The corner of photograph 42 shows severe structural damage to the hip roof of a metal-clad steel-framed building.

Reinforced concrete covers on the grain silos shown in the left of the photograph were lifted and damaged by tornado suction forces. No damage was observed to the silos themselves which were of reinforced concrete construction.

The Clark Equipment Company building shown in photograph 43 is located on the east side of US Route 87. The metal roof panels were almost completely stripped off this building. Lightweight wall panels were also lost and the structural steel frame was severely buckled.

Photograph 41—Destruction of a soft-drink warehouse. View looking west. (Location 24)

Photograph 43—Clark Equipment Company workshop with stripping of corrugated metal roofing and distortion of the structural steel frame. View looking south. (Location 26)

Damage in Zone 3

The two-story Ramada Inn is located on US Route 87 near the estimated path of the tornado center. It was learned that, just before the tornado passed, the occupants of the second story were urged to descend to the first story, a factor that probably contributed to the absence of deaths in this motel.

Photographs 44 and 45 show the severe extent of the destruction. This brick veneer, wood frame structure was hit by a considerable amount of flying debris. The damage is particularly evident on the southwest elevation shown in photograph 45. Flying debris may have also contributed to the loss of brick veneer which was attached with conventional corrugated metal ties to the wood frame backing. The roof of the motel entrance carport was lifted completely from its supports and set down intact approximately 40 feet to the north. This roof is shown in photograph 46 and its location may be identified in photograph 44.

In approximately the same location a one-story motel shown in photograph 47 sustained a complete loss of roof structure on the south, west and north wings, and a loss of some roof covering on the west wing.

Photograph 44—View looking south over the destroyed two-story Ramada Inn Motel. (Location 27)

Photograph 45—Southwest elevation of Ramada Inn with effect of intense bombardment by debris. (Location 27)

Photograph 46—Complete wood frame roof sucked from the forecourt building of the Ramada Inn Motel and transported 40 feet. (Location 27)

Within the city, large numbers of street and highway lighting standards were blown down or severely bent. Failure was generally observed to have occurred in the standard and not in the foundation as shown in photographs 48 and 49.

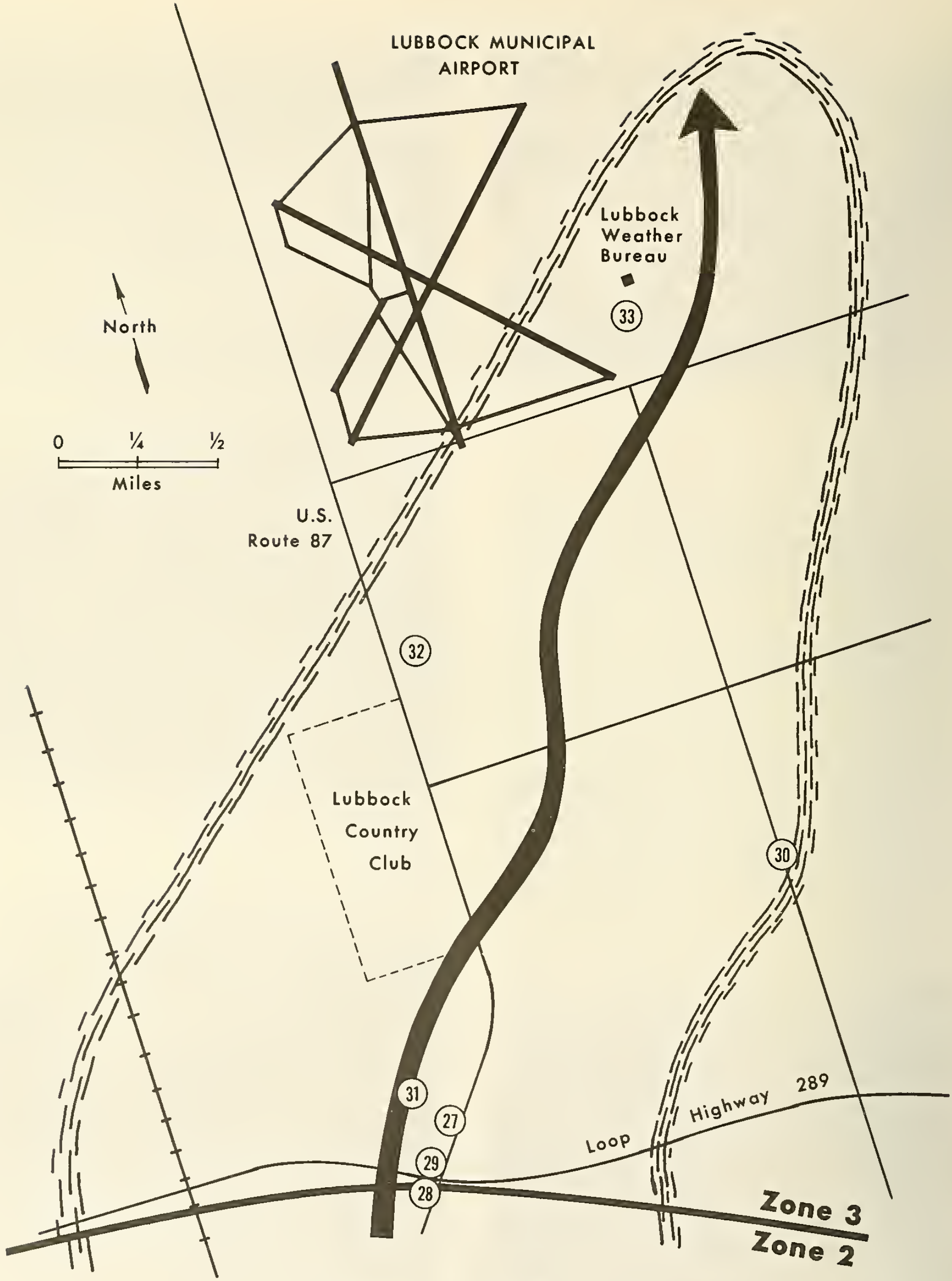
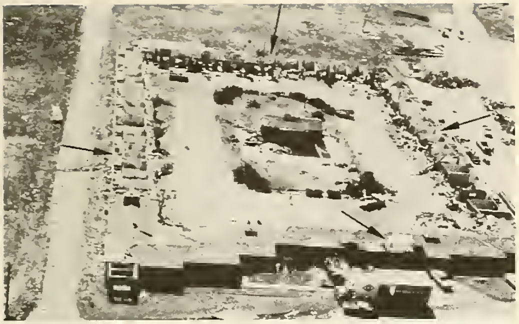


Figure 7 - Zone 3
OUTER RESIDENTIAL AREA

Circled numbers are locations referred to in report



Photograph 47—Motel with loss of complete roof structure on south, west and north sides and loss of some roof covering on east side. View looking west. (Location 27)

Photograph 48—Collapsed steel lighting standard on U.S. Route 87. View looking north. (Location 28)

Photograph 49—Median strip lighting standards leaning to the north on U.S. Route 87. (Location 29)

Mobile Home Park

The mobile home park at location 30 is a very exposed site bordering arable land and having very

Photograph 50—Mobile home park at Quirt Road, looking east. (Location 30)

Photograph 51—Typical damage to light aluminum skins of mobile homes at Quirt Road. (Location 30)

Photograph 52—Several unanchored mobile homes overturned. (Location 30)

few natural windbreaks. Aerial photograph 50 shows the general disruption to the site. Some homes suffered glass breakage and a stripping of their light-guage aluminum skins; note photograph 51. Others were overturned (photograph 52) and several of these were crushed under this action. Photograph 53 shows the base of a moblie home from which the complete superstructure was stripped.

An interview with one of the residents revealed that the great majority of the park's residents had sought early shelter in the basement of the neighboring house of the park owner. Several people who chose to remain in their mobile homes suffered broken fingers and toes and multiple bruising, but no lives were lost on this site which had experienced a tornado only a year earlier. It is believed that the overturning shown in photograph 52 could have been prevented by anchoring the unit to the ground by the use of ties as suggested in American National Standard Specification for Mobile Homes, ANSI A119.1 dated 1969 (see Appendix B).

Photograph 53—Base of mobile home from which complete superstructure has been stripped. (Location 30)

Expensive Housing Area

The row of expensive houses shown in photograph 54 lies just south and southwest of Lubbock Country Club. It is believed to be almost coincident with the route of the center of the tornado. Several houses appear to have exploded while others lost their complete roof structure. A considerable amount of debris covered the area; most of this being structural lumber but occasionally it included pieces of timber telephone poles. Trees in the area were frequently seen to have been completely stripped of leaves and small limbs.

One house in this row escaped damage by some strange chance and is located in the upper part of the photograph 54. This house is shown close up in photograph 55 beyond the wreckage of the neighboring house.

Flying debris adds significantly to the effect of the tornado and the magnitude of the effect can be gauged from photograph 56. This stucco-wood frame house withstood bombardment well; however, the rounded clay tiles in the roof were completely dislodged.

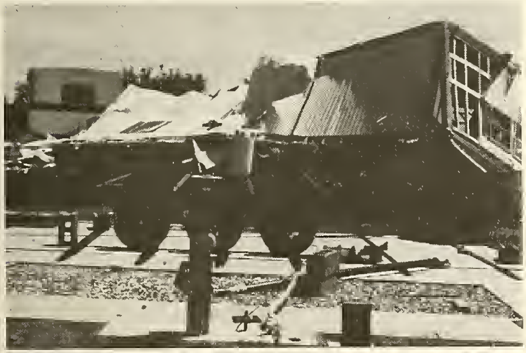
It was observed that very few of the residents in Lubbock had basements or storm shelters in which to take refuge. Many people attempted to protect

Photograph 54—View looking north on destruction of expensive housing which was in the direct path of the tornado. Note that one house (upper left) in this line escaped damage. (Location 31)

Photograph 55—While houses immediately north and south of this house were severely damaged, this home remained unscathed. (Location 31)

Photograph 56—Damage to a house constructed with stucco-wood frame and roofed with rounded clay tiles. Note bombardment of walls by debris. (Location 31)

Photograph 57—A loss of everything but a sense of humor. (Location 31)



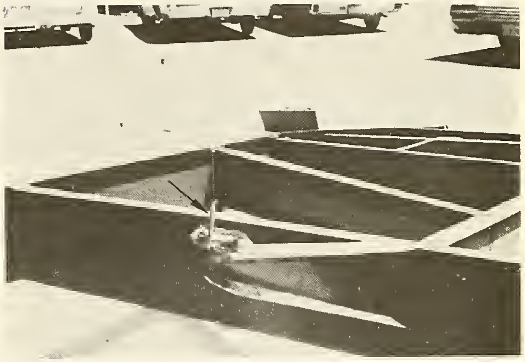
Photograph 58—Mobile home park at Purdue Street with one unit dislodged from its chassis and partly overturned. (Location 32)

themselves with mattresses. It was noted that walls of bathrooms and closets were still standing in many of the otherwise completely destroyed homes presumably because of the small dimensions of these rooms giving a closer spacing of cross walls; note photograph 57. Some reinforcement of bathrooms is possibly provided by the presence of plumbing, vent stacks and bathroom fixtures.

More Mobile Homes

The second mobile home park to be visited was located in an area with natural windbreaks and in addition this park was surrounded by a fence consisting of 6-foot high concrete panels. This wall undoubtedly protected most mobile homes from damage. In the center of the site however, six mobile homes were damaged.

Photograph 58 shows one partly overturned unit which had separated from its chasis. Photograph 59 shows one of the 3-inch screws which failed to hold the unit in its place. Other units collided during the storm with the results typified by photograph 60.



Photograph 59—Typical holdingdown screw which failed to prevent separation of mobile home from its chassis. (Location 32)

Photograph 60—This mobile home probably collided with a neighboring unit. (Location 32)

Photograph 61—An overturned steel column is all that remains of several private airplane hangars on the east side of Lubbock Municipal Airport. (Location 33)

Photograph 62—Considerable damage was caused to private planes both inside and outside hangars. (Location 33)

Estimates of the damage to mobile homes at Lubbock have been given at 80 destroyed and 30 with severe damage.

Hangar Complex

A large number of hangars serve the private aircraft facility at the east side of Lubbock Municipal Airport. The tornado passed through this area destroying approximately 100 private planes both inside and outside the hangars. In addition, 19 small military aircraft were damaged beyond repair.

The foreground of photograph 61 previously contained a row of steel framed hangars similar to those in the background. Those originally in the foreground were either broken down into their component parts and blown away by the wind or were shifted and rolled over to the rear of this area.

Much of this disassembled material was piled against the adjacent row of hangars. The nose of an aircraft is just visible in the left of photograph 62.

Damage in Zone 4

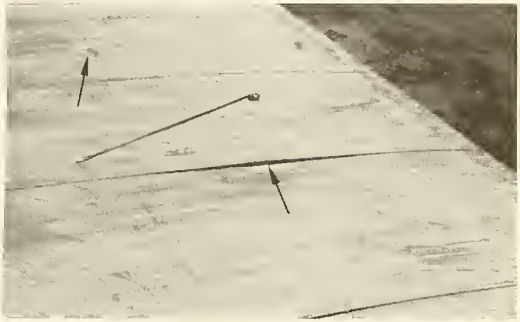
It was reported that damaging hail fell in Lubbock just before and at the time of the tornado. At the time of the survey, however, it was difficult to distinguish such damage from that caused by wind-blown debris.

Town and Country Airport

The Town and Country Airport, five miles south of Lubbock, was subjected to hailstones known to have exceeded 3 inches in diameter and reported by others to have reached 6 inches; note photograph 63.

These hailstones damaged steel roofing panels on the hangar buildings and dented aluminum roofs and the roof seams on a nearby mobile home as shown in photograph 64. Hailstones also damaged light aircraft as shown in photograph 65. This hailstorm occurred approximately ½ hour before the tornado hit downtown Lubbock.

Photograph 63—View of three-inch hailstone preserved by local resident in area five miles south of Lubbock. (Location 34)



Photograph 64—Mobile home aluminum roof shows denting and spliting of seams caused by hailstone impact. (Location 34)

Photograph 65—Hailstone damage to the wing of a light aircraft at the Town and Country Airport, five miles south of Lubbock. (Location 34)

Discussion

The predominant type of building damage observed in Lubbock was the loss of roof coverings and roof structures.

■ Roofs

Roof damage was observed on many types of structures—single-family residences, motels, apartments, light industrial and commercial buildings. It is believed that in the majority of such buildings the damage began along the windward edges of the roofs where high uplift pressures occurred.

General observations with respect to different roof coverings are as follows:

Asphalt Shingles—Generally, the heavier asphalt shingles had a greater resistance to wind than lightweight shingles. This survey confirmed previous findings, i.e. tabs of both lightweight and heavyweight asphalt shingles which are fastened down by adhesive have greater resistance to wind damage than shingles not fastened in this way.

Clay Tile—Flat clay roof tiles demonstrated a greater resistance to wind damage than rounded clay tiles.

Metal—Inadequate fastening resulted in large areas of this roofing being stripped from the structural frames. In part this was due to the fact that metal panels have the necessary tensile strength to break away in one piece. In addition a fastening serves to anchor one or more panels and this naturally leads to progressive stripping.

On the night of the storm, the combination of wind and rain caused much damage to the building interiors and their contents when either the roof covering or roof structure was lost.

The loss of the complete roof structure observed on many buildings indicated that insufficient attention had been given to wind uplift forces and the anchorage required to resist these forces. The neglect of these uplift forces in the design of fastenings was also evident in the case of copings.

■ Glazing

The loss of glazing was generally severe, particularly in the high-rise buildings, and this led to considerable wind and rain damage to partitions, ceilings and building contents. Shattered glazing also proved to be one of the major causes of injury.

■ Masonry Veneer

Although there was evidence of considerable damage to masonry veneer, the attachment of this veneer appeared to be in accordance with current design standards and codes. It must be noted, however, that these design requirements generally relate to details of attachment and not to the wind forces which these attachments must resist.

■ Flying Debris

Much of the debris in Lubbock originated from buildings. This debris consisted of broken glass, masonry veneer, wood cladding, copings, clay roofing tiles, and metal roof and wall panels. This in turn caused damage and generated additional debris as it struck buildings in its path. Obviously one way to reduce the loss of life, limb and property is to pay more attention to the design of these elements.

■ Mobile Homes

The major portion of the mobile home damage could have been greatly minimized by the use of over-the-roof ties as specified in the current standard for mobile homes excerpted in Appendix B.

■ Hailstone Damage

Although the magnitude of hailstone damage observed in Lubbock was low, it provided evidence of the destructive forces caused by 3-inch hailstones which reach the ground at a terminal velocity of approximately 88 miles per hour [9].

General Conclusions

Based on the type and scope of building damage observed in Lubbock, the following general conclusions were reached:

(1) Currently accepted good practice for the design and construction of buildings and mobile homes against wind loads to be expected during their useful life would, if used, have greatly reduced the damage observed at Lubbock.

(2) Natural disasters provide full-scale tests of buildings. Information gained from systematic study of building performance in these disasters will, if implemented, lead to improved building design and construction practice that will save lives and reduce property losses.

(3) Research is needed to develop performance criteria with respect to wind loads for certain building elements, in particular roofs, cladding, masonry veneer, and glazing.

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Professor C. C. Chang, Head, Department of Space Science and Applied Physics, Catholic University, Washington, D.C.

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[5] American National Standard Specifications for Thin Exterior Marble Veneer (Two Inches and less in thickness), A 94.2—1961, American National Standards Institute.

[6] American National Standard for Mobile Homes—Body and Frame Design and Construction Requirements and the Installation of Plumbing, Heating and Electrical Systems, A 119.1—1969, American National Standards Institute (1969).

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Appendices

APPENDIX A

Regional Meteorology

The following meteorological data was assembled by the Earth Resources Aircraft Program at the request of the National Resources Analysis Center, Washington, D.C.

The meteorological situation in west Texas on May 11 was a classical one for the occurrence of severe storms. Moisture inflow at low levels from the Gulf of Mexico had been occurring over a long enough time period (several days) to build up ample moisture. A dry front (a line separating moist and dry areas) was located from Fort Davis to Lubbock, and the upper level flow (500 mb) was from the southwest such as to give divergence over the area of west Texas, thus assisting any cloud buildup. Extremely unstable conditions existed through the area with warm moist air lying in the lower levels and dry, cold air aloft.

In the afternoon, possible severe storms were forecast for areas of west Texas. Solar heating during the afternoon, together with other perturbations, were probably the triggers that initiated the release of this high potential energy situation, with a line of thunderstorms first forming near Presidio at 5:45 p.m. This line, which was oriented north-south, moved to the northeast, with individual cells propagating to the northeast, dying and reforming on the back side much like a wave crest coming ashore at the beach.

At 7:32 p.m. a weather advisory was issued for Lubbock and Big Spring, Texas, for a few thunderstorms with ½-inch hail and gusts of up to 35 knots (40.5 mph) for the 9 p.m. to 1 a.m. period. At 8:05 p.m. Reese Air Force Base (eight miles west of Lubbock) reported a hook echo at 105 degrees at 5 nautical miles. The hook echo is a radar signature indicative of rapid rotation of the updraft portion of the storm and usually signifies a tornado. Also reported at 8:05 p.m. was 2-inch hail three miles south of Lubbock. At 8:10 p.m. 4-inch hail was reported five miles south of Lubbock. At about 9 p.m., an RB-57F aircraft from the 58th weather squadron at Kirtland AFB, flying a Roughrider mission for the National Severe Storms Laboratory, Norman, Oklahoma, reported severe storms with cloud tops of 54,000 to 55,000 feet near the Lubbock area. At 9 p.m. a severe weather watch for 9 p.m. to 1 a.m. was given for southwestern Texas, along and on either side of a line from Big Spring to 120 miles south-southwest of Big Spring, (also going 120 miles to the north-northeast). The forecast was for scattered to widely scattered thunderstorms occasionally forming in short broken lines with a few severe thunderstorms with tops to 60,000 feet, large hail and extreme turbulence. Radar reported cloud tops of 55,000 feet near Lubbock at that time.

At 9:13 p.m. the Lubbock Weather Bureau office reported 1-inch hail, a 2,000 feet ceiling, overcast skies, three-mile visibility, heavy thunderstorms, moderate hail, wind—150 degrees at 8 knots (9.3 mph), thunder, lightning in clouds and cloud-to-ground all quadrants. At 9:31 p.m. they reported 2-inch hail, a 1,000-foot ceiling-overcast, ¾ mile visibility, moderate hail, heavy thunderstorms, wind—60 degrees at 7 knots (8 mph) and thunder, lightning in clouds and cloud-to-ground all quadrants.

APPENDIX B

(1) Excerpts from ANSI Specification A 94.2—1961

This specification deals with the installation of thin marble veneer (2-inch and less in thickness).

Anchorage

a. "A minimum of 2 anchors shall be required on all pieces up to 2 sq. ft. in area"
b. "A minimum of 4 anchors shall be required on all pieces up to 20 sq. ft. in area"
c. "A minimum of 2 additional anchors shall be required on each additional 10 sq. ft."

Setting Materials and Methods (for veneer setting against pre-built masonry wall)

"Wire anchors shall be of stainless steel, brass, medium hard-drawn cooper or other non-corrodable metal at least ⅛-in. in diameter. "Anchors shall be attached to the marble by being hooked or embedded in holes ¾-in. deep in the edges of the piece, parallel to the face and equidistant from front and back faces. The hole shall then be filled with non-staining cement mortar mixed in the following proportions: one (1) part non-staining Portland Cement, three (3) parts clean sharp sand, one fifth (1/5) part hydrated lime based on cement volume, all dry mixed. Water shall be added until a plastic mix has been obtained. Attachment to the wall shall be made by inserting the anchor into a hole in the backing, shaped to receive and retain it, and filled with non-staining accelerated cement mortar."

"Allow at least 1-in., but not more than 1½-in., clearance back of veneer and set each piece rigidly against spots of non-staining cement mortar with accelerator, located at or near the anchors and spaced not further than 18-in. apart over the back of each face."

(2) Excerpts from American National Standards Institute A 119.1—1969, Standard for Mobile Homes.

6.5 *Fastening of Structural Systems.* Roof framing shall be securely fastened to wall framing, walls to floor structure, and floor structure to frame to secure and maintain continuity between the floor and frame (if provided) so as to resist wind overturning and sliding as imposed by design loads in 6.3.1 of this part (directions for anchorage shall accompany all mobile homes)

6.5.1 *Hurricane and Windstorm Resistive Mobile Homes* shall have over-the-roof ties with provisions for distributing the load of these ties, and provisions for the attachment of anchors so as to resist wind overturning and sliding as imposed by the design loads in 6.3.2. of this part.

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