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THE LUBBOCK STORM

MAY 11, 1970

RESPONSE OF STRUCTURAL SYSTEMS TO THE LUBBOCK STORM

TEXAS TECH UNIVERSITY

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TEXAS TECH UNIVERSITY opened in 1925 as a coeducational college. Today it is a complete university comprised of six colleges: Agricultural Sciences, Arts & Sciences, Business Administration, Education, Engineering, and Home Economics; and three schools: Law, Medicine, and the Graduate School. As one of four State supported universities offering full graduate programs in Texas, Texas Tech University offers curricula leading to doctoral degrees in a wide range of disciplines. Enrollment in the fall of 1970 was approximately 20,000 students.

Texas Tech University is located in Lubbock, Texas, a city with a population of approximately 180,000. The campus occupies 1, 839 acres of land in one contiguous tract, in addition to several agricultural tracts. The University is governed by a Board of Regents whose nine members are appointed by the Governor of the State of Texas. The Board is legally responsible for the establishment and control of the University's policies.

THE INTERNATIONAL CENTER FOR ARID AND SEMI-ARID LAND STUDIES (ICASALS) was established at the University in 1966 to implement and coordinate research activities pertaining to arid and semi-arid lands. Such lands comprise approximately half of the exposed surface of the earth. The development of a world-wide center of multidisciplinary knowledge of these lands is the ultimate goal of ICASALS.

STORM RESEARCH has existed as a multidisciplinary entity on the campus of Texas Tech University since the May 11 storm. Departments throughout the University injected themselves into studies of the effects of the storm on the sociology of the community, the regional economy, structures, city government, civil defense planning, and regional development. Expertise gained through these experiences has permitted engineers, scientists, economists, and sociologists to extend their research activities in storm research as a general topic. Investigations of the impact of Hurricane Celia on the Corpus Christi, Texas area are direct outgrowths of this program.

RESPONSE OF STRUCTURAL SYSTEMS
TO THE LUBBOCK STORM

by

Kishor C. Mehta
James R. McDonald
Joseph E. Minor
Albert J. Sanger

FINAL REPORT

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TEXAS TECH UNIVERSITY STORM RESEARCH REPORT 03
(TTU SRR 03)

Department of Civil Engineering
Texas Tech University
Lubbock, Texas 79409

October 1971

APPROVED:

Ernst W. Kiesling

Ernst W. Kiesling
Professor and Chairman
Department of Civil Engineering

FOREWORD

This report is the third of a series of documentary research reports on the Lubbock Tornado of May 11, 1970. The report series will record pertinent facts and evaluations related to the effects of the storm on the Lubbock region. Reports are planned in several disciplines, including engineering, economics, sociology, management, history, meteorology, and industrial operations. These reports will be published as work is completed in each specific research area; the objective of this procedure is to make available to the respective professions data and research results as soon as they become available.

Research activities involved with inspecting, photographing, documenting, and evaluating damage to structures in Lubbock, Texas, following the May 11, 1970, storm were sponsored by the National Science Foundation and Texas Tech University. The report was developed as a comprehensive documentation of wind induced structural damage with the objective of advancing the understanding of the behavior of structures under the action of wind forces.

ACKNOWLEDGMENTS

The work done in producing this report was supported by the National Science Foundation and Texas Tech University. National Science Foundation Grant No. GK-26366 was administered by Dr. Michael P. Gaus, Director of the Engineering Mechanics Program in the Division of Engineering. Administrative support provided by Texas Tech University through Dr. Orlo E. Childs, Vice President for Research and Special Programs, and through Dr. Ernst W. Kiesling, Chairman of the Department of Civil Engineering, is gratefully acknowledged.

The authors wish to thank our colleagues in the Department of Civil Engineering who gave generously of their time during the days immediately following the storm to assure the accuracy and completeness of the documentations. Appreciation is also expressed to officials of the City of Lubbock who supported the idea of a thorough documentation of damage even during the early hours of the disaster. Assistance provided by other governmental agencies is gratefully acknowledged; the Texas Highway Department was particularly helpful in providing information and data. Photographic contributions by the staff of the Lubbock Avalanche Journal and by free lance photographers are acknowledged. Data provided by the Amarillo office of the AT&SF Railroad is acknowledged. Finally, the assistance and cooperativeness of the many building owners, building managers, leasees, and building occupants contributed immeasurably to the accuracy and completeness of the report. These contributions are gratefully acknowledged.

ABSTRACT

The investigation described in this report involved examination and documentation of structural damage that was caused by the tornadic winds of May 11, 1970, in Lubbock, Texas. Damaged structures at 93 locations and objects moved by the wind at four locations were inspected in detail immediately following the storm. Data documented at each location have been synthesized for presentation in this report. Information presented on each structure includes structural description, type and degree of damage, destruction zone in which the structure was located, wind direction, structural response, and supporting photographs. In cases where the structure was "clean" enough to permit a rational determination of wind forces, damaging wind velocities are calculated and presented.

The 93 locations are divided into five groups according to a broad structure usage classification. The groupings are: (1) multistory buildings, (2) industrial and commercial buildings, (3) apartments and motels, (4) residences and mobile homes, and (5) non-occupied structures. The relatively large industrial and commercial building group is subdivided into subgroups: steel frame buildings, metal building system structures, buildings with loadbearing walls, and wood frame buildings. Pertinent information regarding structural behavior associated with specific types of buildings in each group and subgroup is extracted and presented as introductory material for each grouping. Observations regarding the nature of the storm, behavior of structures, typical weaknesses in construction, and estimated maximum wind velocities are also presented.

SUMMARY

This report compiles documentations of damage to structural systems incurred by the tornadic winds of May 11, 1970 in Lubbock, Texas. The storm destroyed or severely damaged structures in a 9 sq mi area of the City which included the downtown area, an industrial section, and medium and low density residential areas. Property damage was estimated to be $135 million.

Immediately following the storm several teams made up of Civil Engineering faculty members and students from Texas Tech University were dispatched to the field to document the structural damage. These documentations included information regarding type of structure, degree and type of damage, wind direction, and structural response. Damage to structures at 93 locations and evidence of four incidents involving large windborne objects were recorded. Photographs, records, sketches, taped interviews, and drawings were collected and placed in a file for each individual location. The findings presented in this report are based on the documented evidence collected in these files.

Extensive studies of the storm-affected areas and detailed examinations of damaged structures produced the following general observations:

(1) The Lubbock storm was intense but disorganized as it formed over the downtown area. It became increasingly better organized and more intense as it moved northeastward from the downtown area.

(2) The best estimate of the highest wind velocity generated near ground level by the Lubbock Storm is 200 mph. No evidence was observed that would indicate a value of wind velocity at ground level greater than 200 mph.

(3) Most of the damage sustained by structures in Lubbock was caused by winds in the range of 75 to 125 mph.

(4) The disorganized pattern of structural damage observed in the storm-affected areas can be more satisfactorily explained by noting the variations in the abilities of structures to resist wind forces, than by relying on complex meteorological theories which assume dramatically different wind velocities within short distances.

(5) Severe damage or total destruction of many structures could be traced to failure of a structural component which constituted a weak link in the structural system. Failures of this type led to progressive damage to the structures.

The documentations of structural damage are divided into groups and subgroups according to building usage and structural type classifications. Pertinent conclusions regarding structural behavior identified with specific types of buildings are as follows:

(1) Multistory Buildings:

Damage to the interior and to the structural frame of the Great Plains Life Building was caused by large deformations associated with dynamic racking of the structure. The First National Bank-Pioneer Gas Company Building sustained severe interior damage through breakage of window glass by windborne debris, as well as severe exterior damage to the simulated marble facia.

(2) Industrial and Commercial Buildings:

- Steel Frame Buildings - Many structures of this type exhibited limited resistance to lateral loads. Furthermore, the loss of inadequate anchored sheet metal and the failure of windows and overhead doors led to progressive failures in many of these structures.
- Metal Building System Structures - Sheet metal panels were stripped from the sides and roof of these structures because sheet metal around the fastening holes was torn leaving the fasteners in place. Purlins spanning between end frames and first interior frames buckled under the action of axial forces induced by winds acting directly on the ends of the buildings. Purlins and girts spanning between interior frames experienced buckling in lower flanges and webs under the action of upward and outward forces induced by winds flowing over and around the buildings. End frames which were made of lighter material than interior frames were unable to resist wind loads acting directly on the ends of the buildings. The collapse of overhead doors lead to progressive failures in a few structures of this type. Metal building system structures were also susceptible to damage from windborne debris.
- Buildings with Loadbearing Walls - Walls collapsed from direct outside wind pressure, as well as from internal pressures created subsequent to failure of doors or windows. Bond beams along the tops of masonry walls were ineffective unless they were tied to pilasters.

Wood Frame Buildings - Failures in this type of structure were initiated by inadequate connections between structural members, and by inadequate anchorages between roofs and walls.

(3) Apartments and Motels:

Many two story structures of this type lost roofs but sustained relatively little damage to first floors. Poor roof to wall anchorages and lightness of roof construction permitted the wind to act along the underside of overhangs and covered walkways to peel the roofs back.

(4) Residences and Mobile Homes:

There was often a closet, a bathroom, or a small room left intact in severely damaged residences. These areas provided places for residents to take refuge, if a storm cellar was not available. In many residences the walls remained standing eventhough entire roofs were uplifted and destroyed. Exterior doors and picture windows were particularly susceptible to failure from high wind forces. Mobile homes that were not securely anchored suffered severe damage through overturning and translation.

(5) Non-occupied Structures:

A large number of free standing sign structures and street light standards were damaged by direct winds, as well as by impacts from windborne debris. Unanchored objects such as automobiles and equipment were tossed and tumbled during the storm.

The background information and documentations pertaining to the Lubbock Storm should prove valuable to meteorologists and engineers who are concerned with the tornado as a destructive natural phenomenon. Hopefully, understandings gained through examination and study of the information contained in this report will produce improved building designs which are both safe and economical with respect to the resisting of tornadic winds.

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I. INTRODUCTION

Urban sprawl associated with the growth of our cities has increased the frequency of impacts of windstorms on populated areas. This increasing frequency of occurrence of damage due to windstorms has produced concern by engineers regarding the effects of wind forces on structures. This concern has resulted in the development of a specialty area known as "wind engineering" which promises to develop much in the same manner as the well known "earthquake engineering" specialty which originated approximately ten years ago.

The Lubbock Storm of May 11, 1970, provided engineers with a unique opportunity to view the effects of winds on a variety of structures within a relatively small area and, through these observations, to advance their understandings of the response of structures to wind forces. The extensive documentations contained in this report were developed with this objective: to contribute to the understanding of structural response to wind loads.

Because certain unknowns regarding the nature of violent storms remain, an introductory portion of the report concerns background information on the Lubbock Storm (Section II). This portion of the report summarizes meteorologists' and engineers' viewpoints regarding the storm, and establishes a perspective which gives the detailed documentations relevancy. Detailed documentations of structural damage comprise the main protion of the report (Section III). Windborne objects and missiles are treated in a separate section because of the increasing incidence of damage caused by these means (Section IV).

II. BACKGROUND INFORMATION

For the information presented in this report to be useful to researchers and practicing engineers, it is necessary to document certain background information concerning the configuration of the storm and the general nature of its effects. This background information will provide researchers and practicing engineers with proper frames of reference for making interpretations of the detailed documentations of damage contained in Section III.

The Lubbock Storm event was unique in several ways: the meteorological conditions which spawned the turbulence, the wide-spread severity of the winds, the disorganized patterns of structural damage, and the magnitude of the impact of the storm on the economic, sociological, and political systems comprising the Lubbock region. Much has been written about the many aspects of this particular storm, and additional publications describing effects of the Lubbock Storm are planned. References are made in the following discussions to specific publications relating to the Lubbock Storm which are available at this writing.

A. Meteorology

The most comprehensive documentation of the meteorological events leading up to the Lubbock Storm has been provided by Fujita [1].* The moist air which engulfed Lubbock in the late afternoon on May 11 was moving north-northeastward. A dry-moist line extended from western Texas and central Kansas to Iowa. A marked moisture gradient existed along this dry-moist line. This line had retreated southeastward through the Lubbock area earlier in the day on May 11. The return of the moist air to the Lubbock area at about 6:00 p.m. represented a departure from the usual sequence of meteorological events for this time of year in the South Plains area.

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* Numbers in brackets refer to List of References, Section V.

Photographic documentation of the meteorological events is very thorough up to 8:00 p.m. on May 11 when the last Tiros Satellite (ATS-III) picture was taken [1]. This picture showed a cloud (which had formed at about 6:00 p.m. 25 miles to the south of Lubbock) 15 to 20 mi behind the clearly distinguishable dry-moist line. This storm cloud did not form, as in many cases, in a region where warm moist air is being plowed by advancing cold air. Instead, it originated just behind an advancing dry-moist line which exhibited only a small temperature difference between the two air masses.

Tracing of the meteorological events beyond 8:00 p.m. must shift to data provided by the WSR-1 Radar screen located at the Lubbock Weather Bureau Station (8 mi north of the City), the WSR-57 Radar screen at Amarillo, Texas (120 mi north of Lubbock), the AN/FPS-77 Radar Scope at Reese Air Force Base (11 mi west of Lubbock), and observations from the ground. The radar screens at the Lubbock Weather Bureau Station and at Reese AFB do not have photographic capabilities, hence, there are no photographic records of hook patterns observed during the evening on these two radar screens. An echo which formed to the south of Lubbock at 6:30 p.m. had grown and divided into three echo pairs which were located near the southern edge of Lubbock by 8:00 p.m. Between 9:00 p.m. and 10:30 p.m. a significant echo convergence took place over the city; this convergence is documented by the Amarillo radar screen pictures. These times bracket the times of the devastation in Lubbock. Fujita [1] notes that during this time frame "the Lubbock storm echo swallowed all small echoes to the southwest." The photographic evidence of the echoes and convergence, as shown on the Amarillo radar, does not reflect the hook pattern characteristic of tornadoes because of the great distance of the storm from Amarillo.

B. Storm Configuration and Path

Three independent theories have been advanced regarding the configuration and path of the Lubbock Storm. Fujita [1] develops and substantiates a "two tornado theory" by interpreting meteorological data and by examining damage patterns on the ground. Specific paths of the two tornadoes are mapped in his article on the Lubbock Storm and in Figure 1. According to Fujita, a "first" tornado originated at about 8:10 p.m. at a point 3 mi east of the downtown area; he reports that this tornado moved northeastward to the city limits. According to a documentary report prepared by the Office of Civil Defense [2] there were no reports of a tornado at this time to the Emergency Operations Center (EOC) in City Hall. A communication from the Lubbock Weather Bureau to the EOC reflected a hook echo at approximately this location at about 9:03 p.m., although there was no visible confirmation of a tornado in this area from the police reporting system or from the public. The existence of this first tornado on the ground is questioned by the authors on the basis of analysis of damaged structures in this area (Section III, Structure 87). Fujita describes the path of the "second" tornado as originating south of Texas Tech University, making a loop between a point just west of 4th Street and Avenue Q and a point at the northeast corner of the University campus, and then travelling northeastward to the Lubbock Weather Bureau Station. This storm path is shown in Figure 1.

An interesting facet of Fujita's theory on the configuration of the storm concerns tornado "suction spots" [1]. These "suction spots" are three to five concentrations of intense wind velocity, resembling convective towers found around the eye of a hurricane, which revolve slowly around the fringe of a tornado core. Fujita uses the probable existence of these concentrations of wind velocity to explain streaks of very severe damage that could be observed on the ground along the storm path. The possible existence of these "suction spots" has implications in the analysis of damaged structures along the tornado path.

Goldman [3] describes the configuration of the storm by outlining a sequence of events that occurred between 9:35 p.m. and 10:06 p.m. on May 11. His theory includes the possible existence of three tornadoes (Ref. Fig. 1). He suggests a tornado "aloft" moving north-northeastward across the center of the downtown area "damaging tall buildings extensively but leaving shorter ones relatively untouched." A "second" tornado is described as originating northeast of the Texas

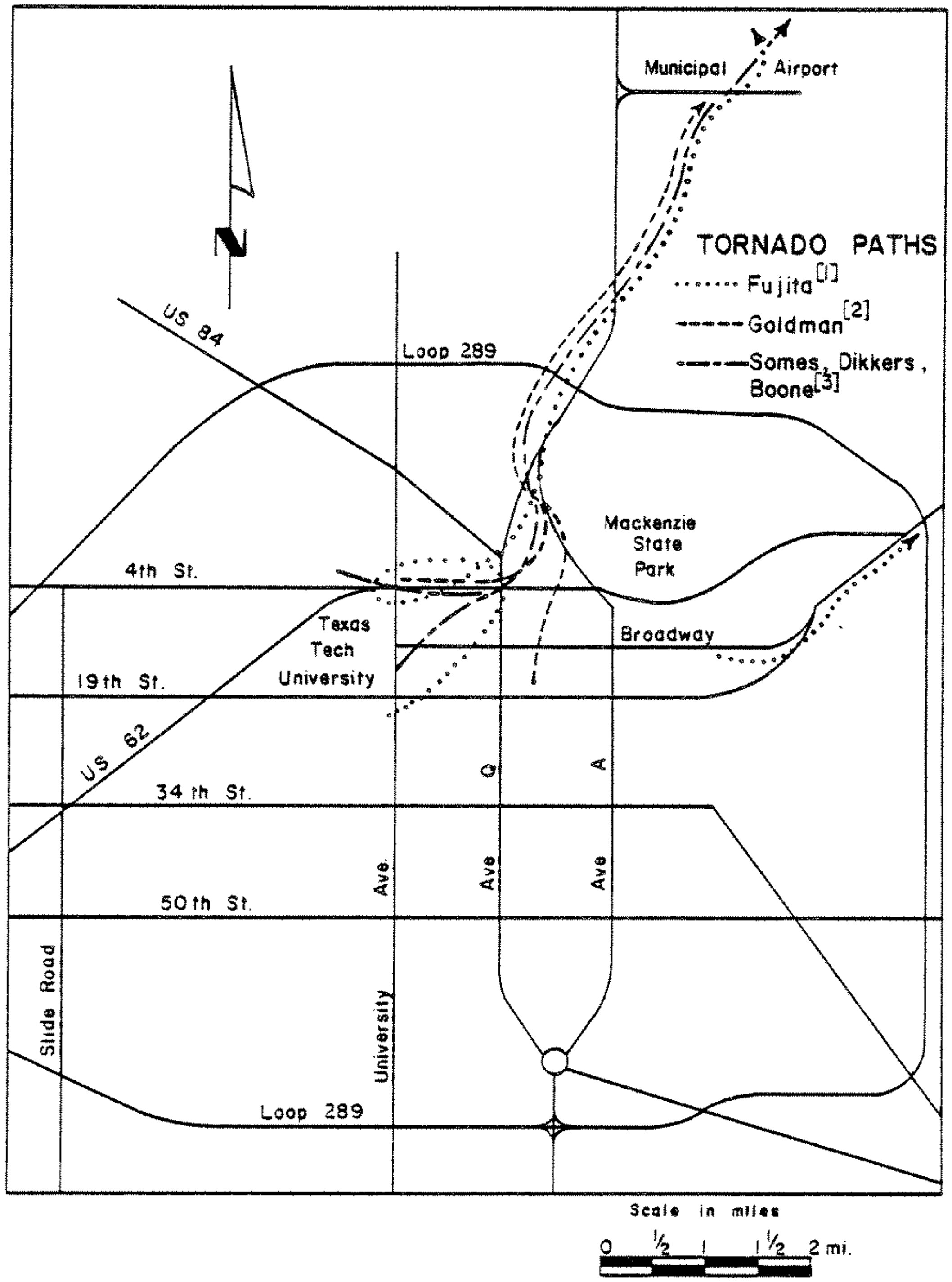

FIGURE 1. SUMMARY OF THREE THEORIES REGARDING THE CONFIGURATION AND PATH OF THE LUBBOCK STORM

Tech University at Jones Stadium (4th Street and University Avenue) and moving eastward to merge with the first tornado just north of the downtown area. This larger tornado then moved into the Country Club area north of the City. Goldman notes, however, that damage in this area may have been caused by a "third" tornado. Goldman's conjecture concerning the paths of the tornadoes is based upon observations of damage patterns on the ground and the times of arrival of severe winds at various locations.

A third report on the path of the storm is advanced by Somes, Dikkers, and Boone [4]. They report that a hook echo approximately 10 mi east of the city was seen on the radar at the Lubbock Weather Bureau at 9:15 p.m. They report that a second hook echo located over the city at 9:35 p.m. was seen on the same radar screen, and was confirmed as a tornado by a policeman and by the ensuing damage in the downtown area. Examination of the damage from the ground and air, and examination of aeiral photographs, led these authors to advance a "two tornado theory" which is different from Fujita's and Goldman's ideas of the configuration of the storm. They suggest that two tornadoes touched the ground simultaneously east of Texas Tech University, one in the vicinity of Jones Stadium and one near Broadway and University Avenue. These tornadoes moved eastward, respectively, to a point north of the downtown area (4th Street and Avenue Q). At this point the two tornadoes "merged" and the subsequent single route was generally northeast (Ref. Fig. 1). The authors report that this "merged" tornado stayed in contact with the ground until after it passed the Lubbock Regional Airport.

The authors of the present report have taken note of the various theories concerning the configuration of the storm and its path across the city. The available meteorological and damage data can be made to support each of these relatively complex theories. In the opinion of the authors, however, the relatively complex ideas of tornadoes aloft, looping tornadoes with suction spots, and merging tornadoes are not necessary to explain the disorganized damage patterns and the events which occurred on the ground. Detailed examinations of structures in the damage areas revealed that the outward appearance of a damaged structure had only a loose relationship to the velocity of winds causing the damage. Many cases of severely damaged structures of one type which were located adjacent to relatively undamaged structures of the same or another type were observed. The differences in degree of damage in such situations could be more rationally resolved by noting basic differences in structural design, construction practices, anchorage details, and orientation of the structure rather than by assuming dramatically different magnitudes of wind velocities across short distances.

Thus, detailed examinations of damage situations along the storm path tend to dispell theories which assume the existence of dramatically different wind velocities within short distances. Furthermore, overall examination of damage patterns does not support theories which assume that the storm was a "clean", axis symmetric "funnel" in the classic sense often associated with a tornado. The generally disorganized damage patterns suggest the presence of a certain amount of locally varying turbulence within the storm cell, rather than the presence of a tornado core of uniform circular winds. This view is also supported by Reed in a report on glass damage [5]. Although the local turbulence that was present could have been caused by the "suction spots" described by Fujita, a less complex explanation is that the storm cell was in its formative stages over the downtown area and became increasingly better organized as it moved northward. A single storm cell forming over the city and moving north-northeastward as it intensified could have caused the increasingly distinct damage path evident on the ground. Highly disorganized at first, the turbulence associated with the storm cell during its formative stages would have been sufficient to cause the scattered and moderate damage patterns in the downtown area, in the area between downtown and Texas Tech University, and in the area adjacent to the campus on the north. Near the intersection of 4th Street and Avenue Q the storm had progressively intensified into a concentrated storm cell with a large diameter structure of circulating winds that were in contact with the ground. Although the damage in this area (and areas along a path to the northeast) clearly suggests tornadic (severe) winds, the damage patterns indicate that these turbulent winds still were not extremely well organized in the classic sense that is commonly associated with a tornado.

C. Damage Patterns

The patterns of damage observed in Lubbock subsequent to the storm on May 11, 1970, have been recorded in several research oriented manuscripts, [1, 3, 4, 5, and 6] by the news media, [7, 8, and 9] in professional files,* in local free lance publications,[10 and 11] and in aerial photographs taken for the City of Lubbock on May 13.* Figure 2 summarizes the general pattern of damage by dividing the storm affected area into destruction "zones." The destruction zone designations (scattered, moderate, and extensive) refer to the general nature of damage incurred within zones. The "extensive" designation signifies that a high percentage of structures present in this area were affected and that a majority of the structures were destroyed or severely damaged (collapse of loadbearing walls, collapse of frames, removal of entire roofs, collapse of utility poles and sign structures, etc.). The "extensive" destruction zone is approximately 3/4 mi wide beginning near the intersection of 7th Street and Avenue Q. The zone reduces to about 1/2 mi wide near the intersection of Loop 289 and U.S. 87 and extends northeastward to the Lubbock Regional Airport. The "moderate" designation signifies that approximately one half of the structures in the zone were significantly damaged. The extent of damage in the "moderate" zone was in the form of major damage to roof structures, toppling of signs, breakage of windows, loss of siding, etc. The "moderate" zone extends along 4th Street between the Texas Tech University campus and Avenue Q, and in the general area south of the 7th Street and Avenue Q intersection. A large "scattered" zone encircles the downtown area on the east, west, and south. The "scattered" designation signifies that only a small percentage of structures were significantly damaged. The

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* Approximately 1200 photographs (black and white prints, color prints, aerial photographs, and color slides) are on file in the Department of Civil Engineering, Texas Tech University.

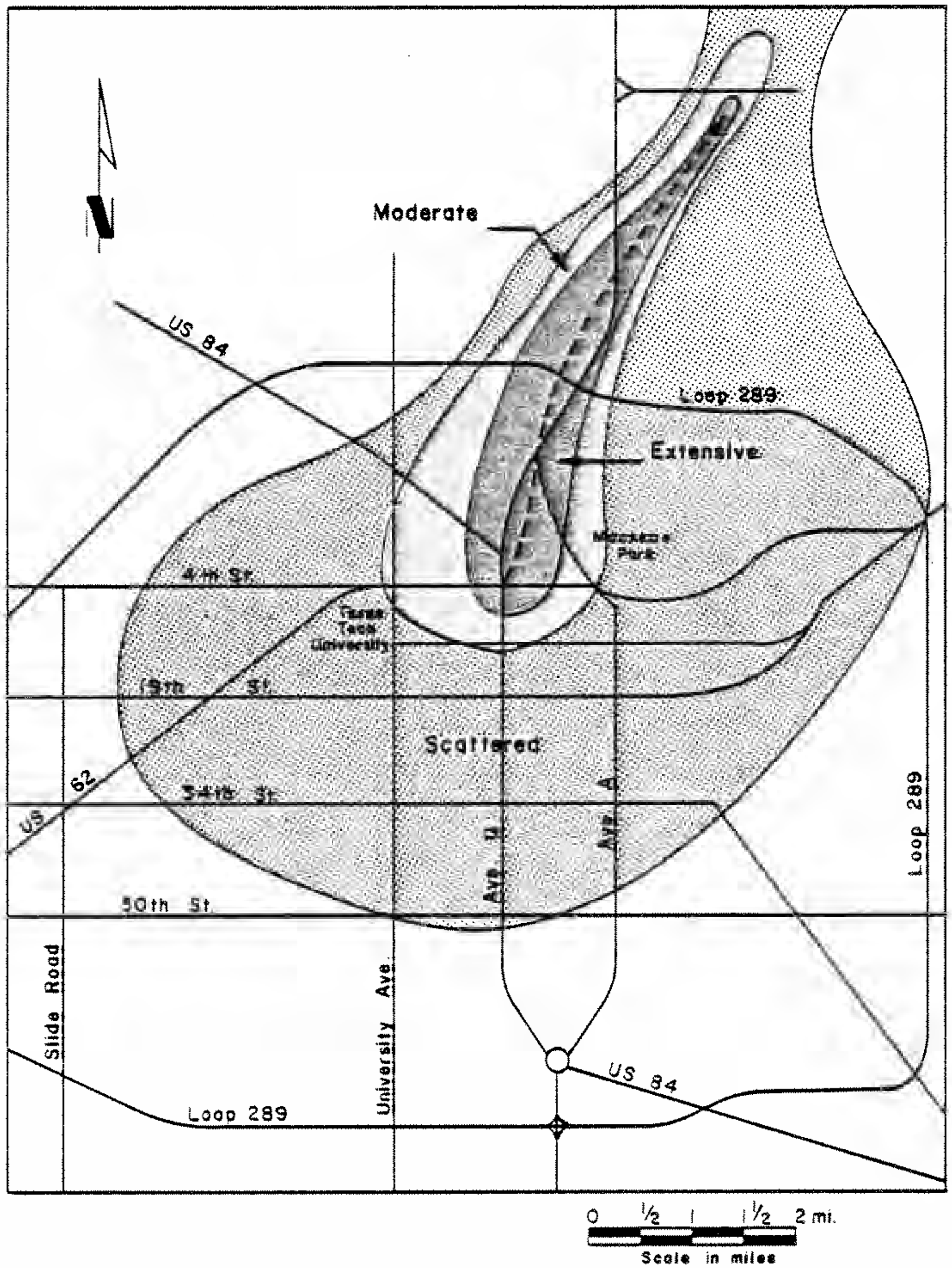

FIGURE 2. PATTERN OF DAMAGE CAUSED BY THE LUBBOCK STORM

damage to the structures was relatively light (damage to carport roofs, fences, shingles, metal roofing, and siding). It is important to note, that individual structures in each of the three destruction "zones" may have received degrees of damage different from that implied by the zone designation; specific structure damage designations are treated in Section III.

A color photograph of a map of the damaged areas which was developed by the City of Lubbock is contained in a Lubbock Chamber of Commerce publication [11]. This photograph also provides a graphic description of the damage pattern. A significant observation that can be made concerning the general damage patterns reflected in Figure 2 and in the color photograph contained in Reference 11 is the progressive narrowing of the affected zones of destruction as the storm moved northward and then northeastward out of the City. This observation, coupled with the more extensive destruction in the northernmost portion of the path, supports the general hypothesis that a progressively intensifying storm cell moved across the City, with an actual "tornado" existing only from the general vicinity of 4th Street and Avenue Q.

D. Wind Directions and Wind Speeds

Ninety-three individual structures were examined in detail by teams of structural engineers and students assembled from the Department of Civil Engineering. Detailed documentations of damage to these structures comprise the major portion of this report. Each structure has been numbered for identification purposes and located on a map of the Lubbock area (see Section III). As additional background data, the wind directions determined by examining damage at each structure location have been noted by arrows on a map of the Lubbock region; this wind direction information is presented in Figure 3. In several specific damage situations, the nature of the structure and its orientation with respect to the wind (e.g. a sign or a light pole) permitted quantitative computations of wind velocities. The locations of these structures and the computed wind velocities are also noted in Figure 3. Except for these specific examples related to failures of relatively "clean"

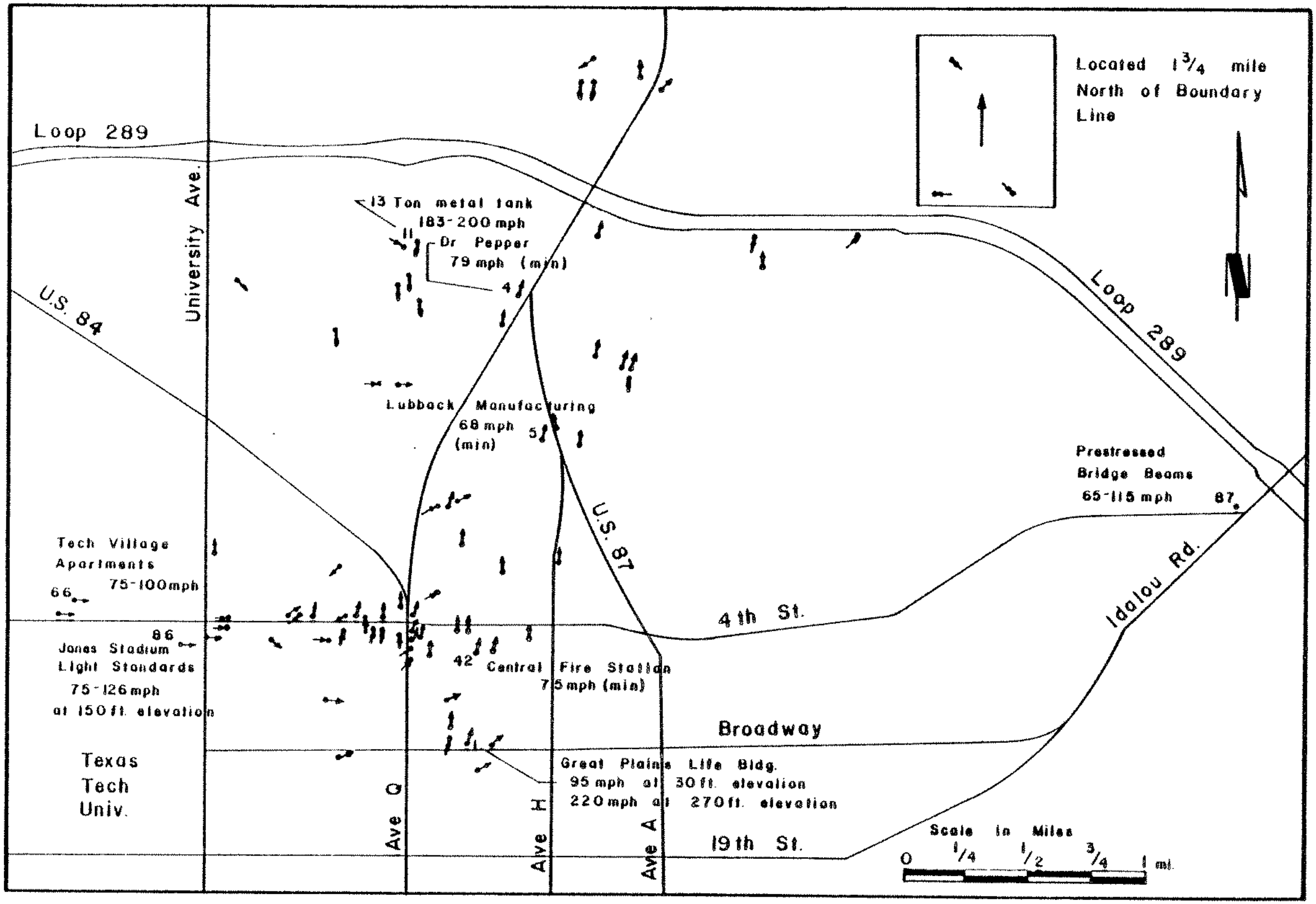

FIGURE 3. WIND DIRECTIONS AT NINETY THREE LOCATIONS WITHIN THE DAMAGED AREA

structures and Reed's report on glass breakage [5], no other rational estimates of wind velocity in the Lubbock Storm have been published.

E. Related Studies

The impact of the Lubbock Storm is the subject of a variety of studies in several disciplines. The tornado path crossed a low income, predominantly Mexican-American community on the near north side of the city. Damage to the homes was so extensive that many of the residents had to be relocated in a housing area (owned principally by the federal government) in the northeast portion of the city. Sociological problems involving integration of Mexican-American families from the storm damaged neighborhood with Negro and Anglo families in the northeast neighborhood are treated in a report by Minnis and McWilliams[12].

The response of governmental and service oriented organizations to the disaster is the subject of a report prepared in the College of Business Administration at Texas Tech University. "A City's Response to Disaster" [13] summarizes the actions and decisions of organizations directly affected by the storm. Organizational response of the fire department, the police department, the City Emergency Operations Center, utilities (both private and city owned), and selected private businesses are included in this presentation.

Civil defense oriented reports were prepared by Region 5 of the Office of Civil Defense [2] and by the Civil Defense Director for the City of Lubbock [14]. These documents present a chornology of events leading up to the storm and describe information received and actions taken in the Emergency Operations Center of the City in the time periods immediately after the storm.

The impact of the storm on the economy of the region is the subject of an Office of Civil Defense report prepared by Texas Tech University [15]. Governmental response to the disaster is treated in a Texas Tech University Report prepared in the Department of Government [16]. A detailed analysis of structural damage to the 20-story Great Plains Life Building in downtown Lubbock is contained in a Texas Tech University report by McDonald [17].