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AN ENGINEERING ANALYSIS OF THE GRAND ISLAND, NE TORNADOES

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1. INTRODUCTION

On the evening of June 3, 1980, an isolated thunderstorm developed just north of Grand Island, Nebraska. The thunderstorm produced multiple tornadoes that had both cyclonic and anticyclonic rotation. The unusual tornado paths were the result of a very slow moving and well-organized storm system. Shortly after the storm, the Institute for Disaster Research at Texas Tech University sent a storm study team to the disaster scene. The purpose of the investigation was to document the damage and debris patterns left in the wake of the storm, to evaluate the performance of engineering structures and to establish a sequence of events during the passage of the complex storm system. This paper summarizes our findings from the survey and subsequent engineering analyses. Four unique tornado paths were identified within the city. Other tornadoes occurred outside the city, but were not extensively documented by the IDR team since they essentially occurred in open country.

2. VETERANS HOME

The first tornado entered the city shortly after 9 p.m. CDT (Fig. 1). Debris patterns, as well as radar images, showed that the tornado rotation was anticyclonic. The tornado traveled southward through relatively open farmland until it reached Capital Avenue, where it made a sharp left turn toward the east. Residential damage along Capital Avenue was heavy, having the appearance of F3 damage on the F-scale classification system. The width of the tornado damage path was approximately 1000 feet.

The Nebraska Veterans Home complex is located on the periphery of the tornado damage path (Fig. 2). The building complex consists of several three-story institutional-type buildings, several old buildings which are currently used for mechanical equipment and maintenance operations, and two, single-story

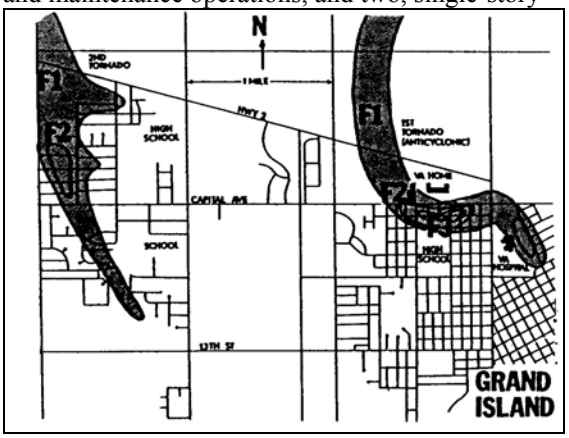

Figure 1. Tornado paths in northwest Grand Island as determined by extensive ground and aerial damage surveys. Gradations of damage are based on the F-scale.

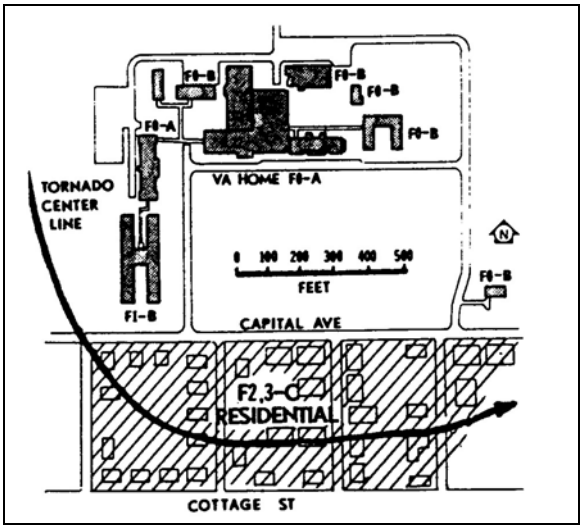

Figure 2. Plot plan of the Nebraska Veterans home complex and residential area to the south. building damages are classified according to the

F-scale and type of building. (A-engineered, B-marginally-engineered, C-non-engineered)

living quarters (Annex buildings). The three-story buildings had received obvious engineering attention in the design. Damage was confined to broken windows, loss of roofing material, and the loss of fascia and decorative materials. The older buildings were in need of renovation prior to the storm. Nails that anchored the timber decking to the roof trusses had no doubt loosened with age making the roof more susceptible to uplift forces. The one-story building, that housed the physical therapy facility, had a relatively new synthetic rubber membrane roof that was covered with large gravel. Instead of the usual 1/4 to 1/2-inch diameter aggregate size, the aggregate averaged one inch in diameter. The pressure deficit under the membrane, either due to the atmospheric pressure change or the aerodynamic pressure, gave an initial acceleration to the roof gravel that allowed the larger gravel to travel longer distances than the smaller gravel on the three-story buildings built-up roofs. As a result, the impact of the larger size roof gravel did considerably more damage to window and exterior finishes. Evidence of roof gravel was found on several window sills and in the interior of several buildings throughout the complex.

The annex buildings suffered loss of roof material and partial loss of plywood roof decking in the vicinity of the eaves, ridges, and corners where localized pressures are larger than overall pressures. The roof system consisted of gabled timber trusses which span 45 feet between the loadbearing walls. Most of the trusses remained in place after the tornado, despite the fact that they were only toe-nailed in place. This weak anchorage to the walls suggests that winds were not very strong on the northern periphery of the tornado.

3. VETERANS HOSPITAL

The tornado continued eastward for five blocks before striking the VA Hospital (Fig. 3). The tornado appeared to have weakened since the residential damage northwest of the hospital was lighter in magnitude than near the VA home. The hospital is a seven-story, steel reinforced concrete frame with brick masonry for exterior cladding. The damage was limited to broken windows and loss of some lightweight concrete canopies over two sun porches on the fifth floor. Again, roof gravel became airborne and impacted several windows (Fig. 4). Breach of the building containment resulted in wind and water penetrating into the interior of the building. Though the building didn't sustain structural damage, the wind and water damage was typical to similar hospital buildings studied by McDonald and Lea (1978).

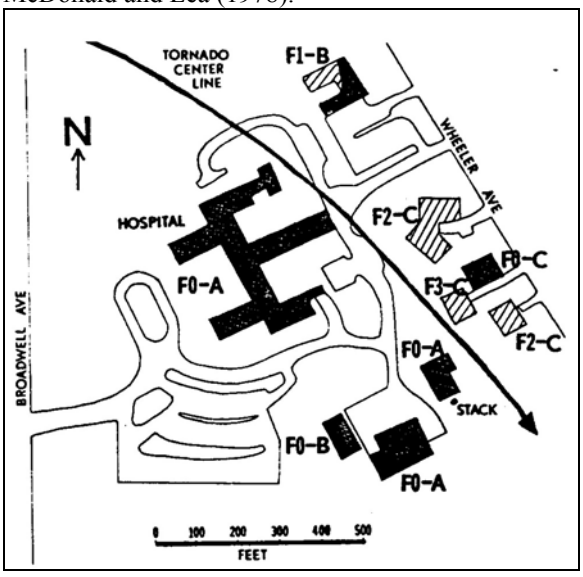

Figure 3. Plot plan of the Nebraska Veterans Hospital (dark shaded). Buildings with structural damage are hatched and classified according to F-scale and type (A-engineered, B-marginally-engineered, and C-non-engineered.)

Figure 4. Damaged safety glass and window frame from roof gravel impacts at Veterans Hospital.

Residences located east of the hospital building sustained heavy structural damage and uprooted trees circumvented the hospital grounds.

4. CAPITAL HEIGHTS SUBDIVISION

The second tornado was cyclonic and entered the Capital Heights subdivision at approximately 9:20 p.m. local time (Fig. 1). From aerial and ground

damage surveys, it was discovered that the residential damage was widespread and that a clear tornado path was not easily discernible even though most of the homes in the area were homogeneously constructed. These homes were young in age, of the ranch-style construction along with attached garages. Upon investigation of several residences, we found a variety of construction practices were still apparent.

In a few instances, residences that were not anchored to their foundations had slid causing the floor to collapse into the basement. These residences appeared to be totally destroyed among other anchored residences. In addition, various degrees of roof damage were found depending on the direction and speed of the oncoming wind (Fig. 5). Nearly half of the residences with roof damage experienced windward failure of the garage door that led to total garage failure and partial loss of the roof. Other types of roof failure that were less common initiated at the eave, corner, or ridgeline of the residence. Minor et al (1977) has summarized the performance of residential structures in tornadic wind loads from several years of damage investigations. The study concluded that varying construction practices and orientation of the residence to the wind were crucial in relation to the damage intensity.

5. MODES OF BUILDING CONSTRUCTION

The F-scale damage rating is primarily based on the appearance of damage and should be used with caution when trying to estimate wind speeds (see Minor, 1977). In the vicinity of the Veterans Home and hospital, the F-scale varied dramatically according to the type of building construction. Mehta et al (1981) has correlated the intensity of wind damage resulting from Hurricane Frederick to the various types of construction practices. The study concludes that building performance was related to the amount of attention given in the engineering design phase. Therefore, in a similar attempt for Grand Island, buildings were categorized into three types:

TYPE A- Engineered buildings - Structures which are entirely designed by engineers. These include the main complexes of the Nebraska Veterans Homes and Hospital where under a tornadic wind load (F3), the buildings had breach of containment from window breakage but otherwise remained structurally sound.

TYPE B - Marginally engineered buildings - Structures in which there is some evidence of engineering design such as frame reinforcement. These buildings consist of the annex buildings of both complexes, the Regal 8 Motel, and the Meves Bowling Alley. Under a similar wind load (F3), breach of containment as well as minor structural

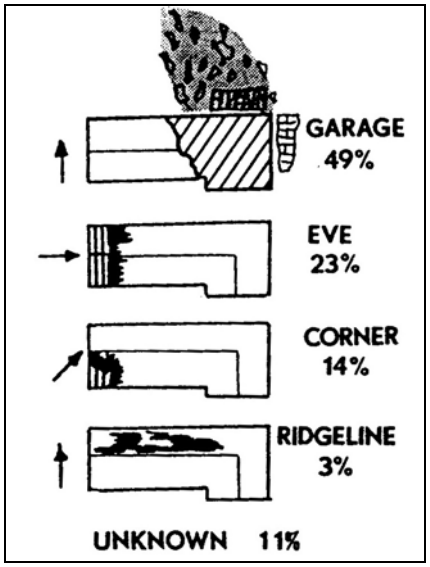

Figure 5. Percentage of roof damage initiation in the Capital Heights subdivision from a total of 104 damaged residences. Wind vectors show the direction of the oncoming wind.

damage occurred to the engineered portions. Non-loadbearing walls sustained considerable damage.

TYPE C - Non-engineered buildings - Structures that have no engineering design such as residential buildings. Under a similar wind load (F3), these buildings offer little resistance to the wind and suffered substantial roof and wall damage along with considerable damage to the interior.

6. MEVES BOWLING ALLEY

The storm system redeveloped about 10 p.m. CDT and produced a third tornado which was cyclonic (Fig. 6). The tornado developed over an open field and moved westward into the Kuesters Lake subdivision causing F2 damage and uprooting many trees. The tornado continued westward and impacted the Meves Bowling Alley from the northeast (Fig. 7).

The non-loadbearing north wall blew into the bowling alley and the resulting wind pressures caused the south wall to collapse outward. The classic case of windward and leeward wall failure suggest the same behavior under a tornadic wind load as it would under a straight-line wind load. Most of

the metal roof decking was stripped off and considerable wind damage was done to the interior. However, even though the bowling alley sustained heavy damage, the steel frame remained relatively intact. Based on the surrounding residential damage as well as the damage

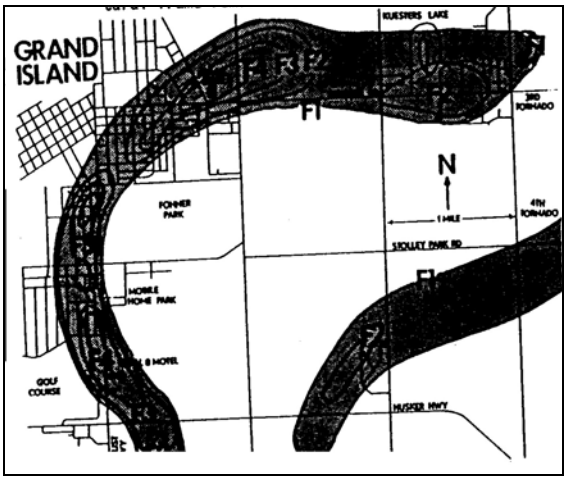

Figure 6. Tornado paths in southeastern Grand Island after extensive ground and aerial surveys. Gradations in damage were rated by F-scale.

Figure 7. Aerial view of Meves Bowling Alley looking toward the southwest illustrating windward and leeward end wall failures.

to the bowling alley, it was determined that this area saw the strongest winds in our damage survey.

7. REGAL 8 MOTEL

The tornado continued and turned southward traveling along Locust Street for one mile and impacted the Regal 8 Motel. It was at this site that we discovered unusual tornado-generated missiles. The roof system of the motel consisted of several hundred precast concrete planks measuring 24 feet long by 12 inches wide by 8 inches thick and weighing about 600 pounds each (Fig. 8). As the tornado approached the motel from the north, the windward windows failed and the resulting wind pressures inside had lifted the planks. Approximately 200 planks were uplifted of which nearly half became airborne (Fig. 9). Some of the planks traveled more than 100 meters and one struck a residence, passed through an exterior wall, the floor and was found

Figure 8. Concrete plank missile embedded into the ground. The plank originated from the roof of the Regal 8 motel in the background.

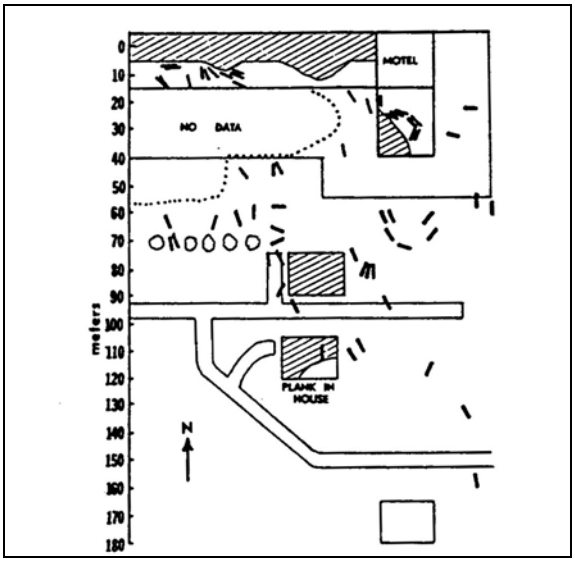

Figure 9. Locations of concrete roof planks with respect to the Regal 8 Motel. The tornado traveled from northwest to southeast. Hatched areas indicate the locations of missing roof planks.

embedded nearly three feet in the crawlspace. The plank landed just a few feet away from where two persons were seeking shelter from the storm. Most of the planks shattered into small pieces and missile impacts were evident on the ground and road surfaces downwind from the motel. It appeared that the planks were not anchored to the tops of the walls.

8. CONCLUSIONS

The results of our damage survey shows that engineered structures, such as the Nebraska Veterans Home and Hospital performed well on the periphery of the tornadic winds with superficial damage to windows from airborne roof gravel impacts. The importance of roof gravel as a potential missile can't be stressed enough. Meves Bowling Alley and the surrounding residential area experienced the strongest winds with the structural frame of the bowling alley still remaining intact. The Regal 8 Motel damage illustrates the magnitude of potential tornado-generated missiles as nearly 200 concrete planks were displaced, some over 100 meters downwind from the motel. Current research is being done by IDR to simulate the concrete plank missile trajectories and the results will be presented at the conference. Mitigation of the missile hazard along with proper inspection of residential construction practices must be addressed further in order to insure adequate safety and occupant protection.

9. ACKNOWLEDGEMENTS

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10. REFERENCES

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