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USE OF TORNADO PATH LENGTHS AND GRADATIONS OF DAMAGE TO ASSESS TORNADO INTENSITY PROBABILITIES

Robert F. Abbey, Jr.

U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

T. Theodore Fujita

The University of Chicago
Chicago, Illinois 60637

1. INTRODUCTION

Until recently, previous attempts to calculate tornado risk probability have dealt with the determination of tornado incidence or touch-down frequency. Tornado incidence in the United States cannot be determined or mapped with complete accuracy, but it can be represented more realistically and with less confusion than has been done in the past. Court (1970) analyzed tornado occurrence climatologies prepared through 1969 and categorized the approaches as being listings, enumerations, graphs, or maps. Annual occurrences and distribution of tornadoes are now being routinely tabulated by utilizing the rating system introduced by Fujita (1971). In addition, the FPP scale classifies the relative strength and size of tornadoes based on general damage surveys. Despite its shortcomings, this approach has the advantage that all tornadoes can be ranked according to the degree and extent of damage produced.

Several difficulties arise when one attempts to translate tornado incidence into a realistic assessment of risk. Thom (1963) and Howe (1974) have stressed the importance of the area covered by a tornado, rather than its point of origin, in the determination of realistic tornado risks. As described by Court (1970), few efforts have been made since the studies by Brown and Roberts (1935;1937) to determine such figures. The FPP scale is certainly a progressive step in determining the characteristic lengths and widths of tornado paths in different seasons and different regions.

A detailed map of past tornado tracks since 1950 is being prepared by Fujita which takes into account the classification of tornadoes according to their relative intensity. This map will be similar to the one prepared by Fujita (1975a) of the April 3-4, 1974 tornado outbreak.

More realistic attempts to assess probabilities of intense tornadoes have appeared as a result of the introduction and use of the FPP rating system (Wen and Chu, 1973; Singh, et al., 1973; Markee, et al., 1974; Garson, et al., 1974; McDonald, et al., 1975). Fujita (1970b; 1972) categorized the maximum tornadic windspeeds in the northwestern United States and the southernmost Rockies. In general these approaches failed to take into account the distribution of degrees of damage within a tornado path or accounted for gradations of damage by assuming a windspeed profile through the vortex. Only McDonald, et al. (1975) analyzed the length and width of tornado paths in their methodology. The elimination of population bias in reporting of tornado occurrences remains a significant problem in all analyses of this type.

An approach has been developed which determines tornado intensity probabilities by accounting for total path length, path width, relative intensity as classified by Fujita (1971), and gradations of damage within the tornado path. Utilizing the distribution of actual damage from detailed surveys of the April 3-4, 1974 tornado outbreak, the actual areas of damage per F-scale intensity unit per tornado are calculated. Thus, gradations of F-scale damage within each tornado path are determined without the necessity to assume a windspeed profile through the tornado vortex.

Based on an analysis of the damage associated with the April 3-4, 1974 tornadoes, an index is created to account for gradations of damage along the tornado path. The total path lengths for all tornadoes per intensity classification per 1° square for the years 1950-1972 are tabulated. Probabilities of a particular F-scale damage can then be computed for any given region. The representativeness of the 147 tornadoes which comprised the April 3-4, 1974 outbreak needs to be examined in more detail.

2. DATA BASE

Using occurrences and descriptions of tornadoes recorded in a tornado data bank built up by Fujita over the past 20 years from all types of records, an intensity classification and path length were assigned to each tornado which was reported from 1950-1974. In addition, each tornado path (length and direction) was plotted per 1° square for the contiguous United States. Figure 1 illustrates this procedure for F2 or greater tornadoes since 1950 (Fujita, et al., 1975). Two examples of this detailed mapping procedure are shown in Figure 2; the wider lines indicate F4-5 tornadoes.

The path length for all tornadoes per 1° square per F-scale classification were summed. For tornadoes reported as having no definable ground path or "skipping," the path length used was one-fourth of the recorded path length. When the path length was not mentioned or when only "touch-down" was reported, a conservative path length of one mile was assumed. For ease in computation and to account for uncertainty in F-scale assignments, the F4-5 (violent) tornado path lengths were added as were the F2-3 (strong) and F0-1 (weak) paths. The result is the total path lengths for violent, strong, and weak tornadoes for each 1° square for the years 1950-1972. The tornado path lengths for the 1973-1974 tornadoes have not been processed as of this writing.

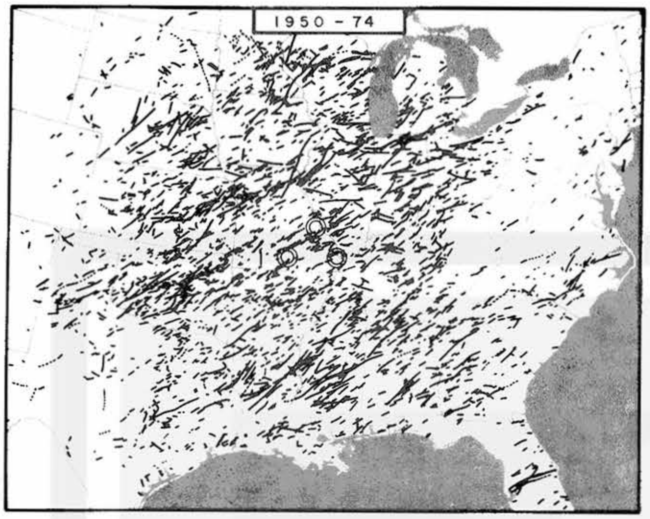

Figure 1. Tracks of F2 or greater tornadoes, 1950-1974 (after, Fujita, et al., 1975).

Table 1 shows the unadjusted and adjusted total path lengths for the violent, strong and weak tornadoes for the two regions depicted in Fig. 2. The adjusted total path length is the sum of the violent tornado path lengths plus one-tenth of the strong tornado path lengths. Similarly, the adjusted strong tornado path length is the sum of nine-tenths of the actual strong tornado path lengths plus one-tenth of the weak tornado path lengths. The adjusted path length of the weak tornados is nine-tenths of the actual weak tornado path lengths. This adjustment probably leads to overestimating violent tornado damage probabilities, but does take into account the possibility that a violent tornado could have been classified as a strong tornado, i.e., one strong tornado out of ten could have been a violent tornado.

Detailed damage surveys were performed for the 148 tornadoes which occurred April 3-4, 1974. The Leonard Town tornado, No. 135 on "Superoutbreak Map" compiled by Fujita (1975a), was excluded because it was a tornado cyclone (FPP of 0,3,5). Table 2 shows the number of tornadoes per F-scale and their path lengths and widths for this outbreak. In general, the F5 damage within an F5 tornado was concentrated in narrow swaths, usually no greater than about 20 m (Fujita, 1975b). Since it is impossible to determine gradations of F-scale damage within each past tornado path, the assumption is made that such gradations would tend to be the same for all tornadoes per F-scale intensity classification. Fujita (1974) described these paths.

3. DAPPLE INDEX

In order to apply the analysis of gradations of damage to all tornadoes, an index was created to utilize past tornado path lengths. The assumption is made that the total damage area as well as the gradations of damage per F-scale rating for the April 3-4, 1974 tornado outbreak is representative of tornadoes in general. Since path lengths are usually the most accurately recorded tornado characteristic, the total damage area per F-scale intensity was normalized with respect to the path length per tornado. This approach is believed to permit a more realistic assessment of tornado risk than those techniques which assume an average area per tornado or velocity profile within the vortex or rely on tornado incidence statistics.

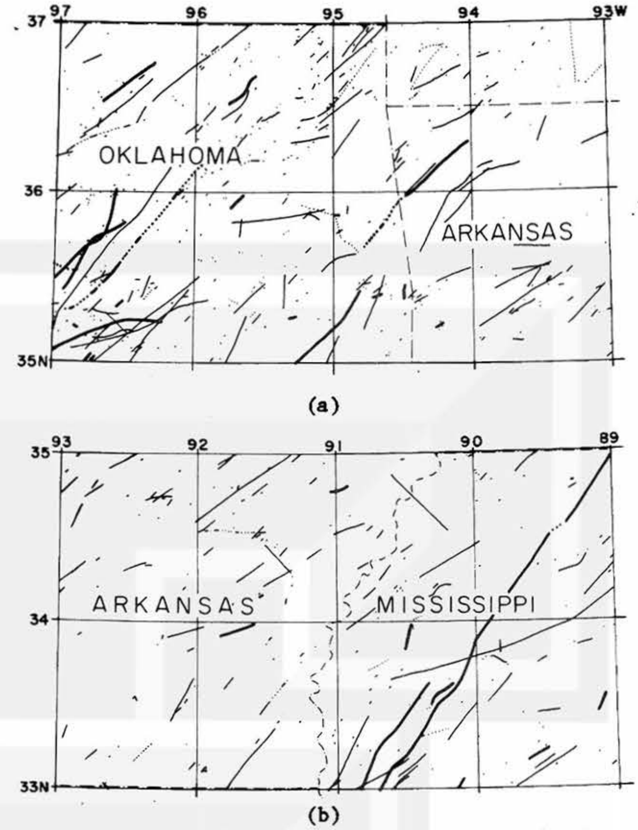

Figure 2. Detailed mapping of tornado paths for two selected regions. Wider lines depict paths of violent (F4-5) tornadoes.

Figure 3 presents the variation of Damage Area Per Path Length (DAPPLE) versus F-scale classification. No windspeeds are associated with the F-scale at this time, except in the comparison with other risk models (Section 6). The DAPPLE curves for each F-scale designation were derived from an analysis of the tornado paths and damage gradations of the April 3-4, 1974 outbreak. Table 3 summarizes the path length, path width, area and DAPPLE index for each F-scale tornado classification for the April 3-4, 1974 tornadoes. The total path lengths per F-scale were multiplied by the mean width for that F-scale tornado to give the mean area of F-scale damage per F-scale tornado.

Table 1

TOTAL TORNADO PATH LENGTHS [mi] FOR SELECTED REGIONS

Latitude		97°W–96° unadj	adj	96°–95° unadj	adj	95°–94° unadj	adj	94°–93°W unadj	adj
37°N–36°	V	40	48.2	18	30.9	47	64.3	0	7.4
	S	82	81.1	129	125.5	173	163.4	74	69.4
	W	73	65.7	94	84.6	77	69.3	28	25.2
36°–35°N	V	209	245.8	28	43.8	40	51.3	1	14.9
	S	368	335.5	158	145.9	113	104.9	139	129.3
	W	43	38.7	37	33.3	32	28.8	42	37.8

Latitude		93°W–92° unadj	adj	92°–91° unadj	adj	91°–90° unadj	adj	90°–89°W unadj	adj
35°N–34°	V	0	11.5	3	13.8	9	22.1	84	90.3
	S	115	104.5	108	105.3	131	120.5	63	60.8
	W	10	9	81	72.9	26	23.4	41	36.9
34°–33°N	V	1	5.8	16	23.1	165	174.9	29	39.3
	S	48	46.7	71	65.3	99	98.9	103	97.5
	W	35	31.5	14	12.6	98	88.2	48	43.2

Table 2

F-SCALE CLASSIFICATION STATISTICS OF APRIL 3-4, 1974 TORNADO OUTBREAK

	Frequency	L - total length [mi]	A - total area [mi^2]	W - mean width [mi]
F5	6	302	147.1	.487
F4	24	858	392.1	.457
F3	35	710	259.9	.366
F2	30	360	66.5	.185
F1	31	295	18.3	.062
F0	21	46	1.3	.028
	147	2572	885.3	

An empirical equation was derived for the width of each F-scale damage rating,

$$W_F = W_0 \ (2.4)^{-F} \tag{1}$$

where F is the appropriate F-scale of interest (F0-F5), W_F is the width of the Fth-scale or greater damage, and W_0 is the mean width of the tornado which is assumed to be the width of F0 or greater tornado damage. A best-fit DAPPLE curve was then drawn for F4-5, F2-3, and F0-1 to correspond to the categorization of F-scale path lengths, i.e., violent, strong, and weak, respectively. This approximation overestimates the F4 damage and underestimates the F5 damage, for example; but, since more tornadoes are classified F4 than F5, the overall result tends to overestimate the area of violent tornado damage.

4. TORNADO RISK PROBABILITIES

Probabilities per year of violent tornado damage were calculated for each 1^o square by multiplying the adjusted total path lengths of violent tornadoes in a 1^o_A square by the appropriate DAPPLE index (6.0×10^{-4}) and dividing by the number of years of data, y, and the area of each 1^o square, A,:

$$P = \frac{(P_L)\ (D)}{(A)\ (y)} \tag{2}$$

where P_L is the adjusted total path lengths and D is the corresponding DAPPLE index. This agrees with Thom's (1963) formulation

$$P = \frac{(N)\ (a)}{(y)\ (A)} \tag{3}$$

where N is the number of tornadoes occurring in y years in area A; a is the mean area per tornado. Eq. 3 is an approximation to the more elaborate point strike probability relation

$$P = 1 - (1 - \frac{a}{A})^{Ny} \tag{4}$$

where the notation is as defined previously.

Since the current position of the U.S. Nuclear Regulatory Commission (NRC) assumes a risk level of one tornado event of a given magnitude per ten million per the lifetime of the plant (Markee, et al., 1974), areas in the eastern United States where the probability of violent tornado damage is greater than 10^{-7} were determined and are shown in Figure 4. Only two small areas of the country, central Oklahoma and west-central Mississippi, have a probability of violent tornado damage of 10^{-6} or greater (denoted by the darkest shading). Isolated regions where the probability of violent tornado damage is 5×10^{-7} or greater are also shown. Pockets where the probabilities are less than 10^{-7} appear within the major 10^{-7} region; these are not thought to be "tornado-free" locations in the sense that these areas are not meteorologically nor orographically different from the surrounding areas.

As developed, the proposed method indicates that when the violent tornado path lengths total 15 miles, the associated risk probability is 10^{-7}; it follows that if the total path length is 75 miles, the probability is 5×10^{-7} and for 150 miles, 10^{-6} probability results. It should be noted that a small contribution to the violent tornado damage area comes from the strong tornadoes. There is a DAPPLE index which accounts for the possibility that a strong tornado could have violent (F4 or F5) damage imbedded within its path which went unnoticed when assigning the F-scale rating.

5. ANALYSIS OF TORNADO RISK MODELS

The remarks of C. R. Allen, past president of the Geological Society of America, are pertinent when one attempts to predict upper bounds of natural phenomena. Allen (1974) emphasizes that no amount of sophisticated statistics or extreme value theory can throw much light on the nature and frequency of large events based on a time sample that is too short to include any such events, unless a specific physical model is also assumed.

The windspeeds associated with given probabilities resulting from the method outlined in Sec. 4 are compared with four other approaches to assess

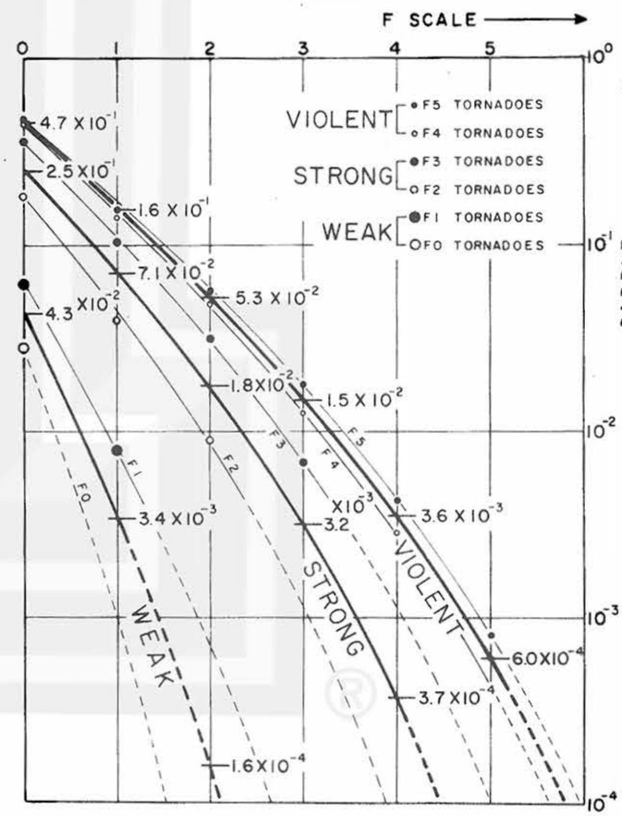

Figure 3. Damage area per path length (DAPPLE) as a function of F-scale rating.

Table 3

DETERMINATION OF DAMAGE GRADATIONS WITHIN EACH F-SCALE TORNADO CLASSIFICATION FOR THE APRIL 3-4, 1974 OUTBREAK

	F5	F4	F3	F2	F1	F0
$L_0 \le$	302	858	710	360	295	46
$W_0 \le$	.487	.457	.366	.185	.062	.028
$A_0 \le$	147.1	392.1	259.9	66.6	18.3	1.3
$D_0 \le$	.487	.457	.366	.185	.062	.028
$L_1 \le$	233	643	486	187	91	---
$W_1 \le$	.203	.190	.153	.077	.026	---
$A_1 \le$	47.3	122.7	74.4	14.4	2.4	---
$D_1 \le$	.157	.142	.105	.040	.0080	---
$L_2 \le$	203	526	356	103	---	---
$W_2 \le$	.085	.079	.064	.032	---	---
$A_2 \le$	17.3	41.6	22.8	3.3	---	---
$D_2 \le$	.057	.048	.032	.0092	---	---
$L_3 \le$	155	331	187	---	---	---
$W_3 \le$	.035	.033	.026	---	---	---
$A_3 \le$	5.4	10.9	4.9	---	---	---
$D_3 \le$	.018	.013	.0068	---	---	---
$L_4 \le$	86	175	---	---	---	---
$W_4 \le$	.015	.014	---	---	---	---
$A_4 \le$	1.3	2.5	---	---	---	---
$D_4 \le$	.0043	.0029	---	---	---	---
$L_5 \le$	39	---	---	---	---	---
$W_5 \le$	.006	---	---	---	---	---
$A_5 \le$	.23	---	---	---	---	---
$D_5 \le$	.0008	---	---	---	---	---

tornado probability and/or risk (Wen and Chu, 1973; Garson, et al., 1974; Markee, et al., 1974; and McDonald, et al., 1975).

A tornado risk model gives the probability that the windspeed in a tornado will exceed a particular value in one year. All of the aforementioned tornado risk models are based on the F-scale intensity ratings (Fujita, 1971); consequently, the resultant windspeed will be the fastest one-quarter-mile windspeed. The windspeed is generally considered to be the vector sum of the rotational and translational wind velocity component.

5.1 Tornado Risk Model by Wen and Chu (1973)

This model makes use of data accumulated by Fujita to construct a joint probability distribution for average tornado damage path area and peak windspeed. The probability of a tornado striking a given point with a maximum windspeed exceeding the design windspeed, V, during a period of t years is

$$P_t(V) = \frac{N\ t\ R'(V)}{y\ A} \qquad (5)$$

N is the number of tornado occurrences in area A in y number of years. N/yA varies from location to location. A contour map of N/yA can be prepared from tornado records; Wen and Chu (1973) utilize

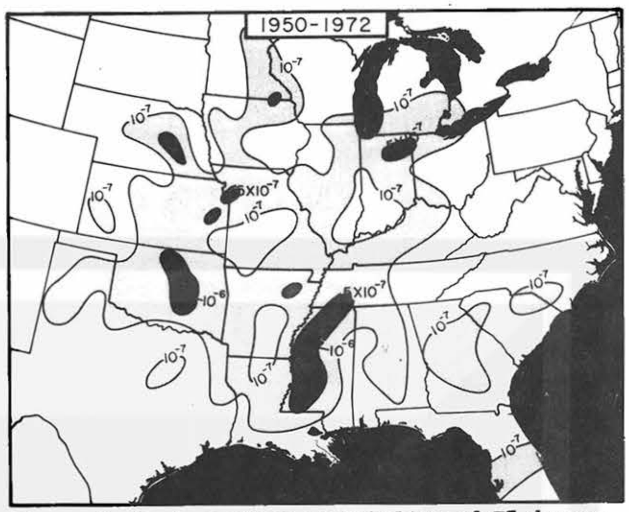

Figure 4. Regions where probability of F5 damage is 10^{-7} or greater.

such a map prepared by Fujita (1970a). R'(V) represents the effective area exposed to the wind with a speed higher than V and is referred to by Wen and Chu (1973) as the tornado speed-area function. This function is assumed to be insensitive to change in location. R'(V) is given for V < 290 mph as

$$R'(V) = \frac{1.65}{(1 + 0.4 \times 10^{-11}\ V^5)^{.75}} \qquad (6)$$

and for V > 290 mph

$$R'(V) = 17.4 \exp(-0.014\ V) \qquad (7)$$

Using Eqs. (6) and (7), a continuous probability density function of V can be obtained.

The path area of a tornado is defined as the area bounded by gale intensity tornado damage (74 mph). Although peak wind intensity occurs only over a small portion of this area, the Wen and Chu (1973) model assumes that the peak wind velocity extends over the entire area. McDonald, et al. (1973) and Garson, et al., (1974) have suggested that a windspeed decay from peak velocity out to the gale intensity boundary be introduced. This concept may be combined with the Wen and Chu (1973) model to provide a procedure for estimating the likelihoods of damaging tornado winds based on an assumed windspeed profile.

5.2 Tornado Risk Model by Garson, et al., (1974)

Garson, et al., (1974) propose a correction to the Wen and Chu (1973) model by incorporating a windspeed profile. The tornado windspeed profile is based on the work by Hoecker (1960) in his analysis of the Dallas, Texas tornado of April 2, 1957. In the range between peak velocity, V, and gale intensity velocity, V_b, the form of the profile is assumed to be

$$V\ R^k = C \qquad (8)$$

in which V is the windspeed, R is the radial distance from the tornado center, k and C are parameters selected to fit a given storm. Hoecker (1960) found k to be 1.6 near the ground and 1.0 at higher elevations. The value of 1.6 is used here since it is the more conservative value. The constant, C, is found for each tornado from the gale intensity damage path width

$$C = V_b R_b^k \quad (9)$$

in which V_b is the gale velocity and R_b is one-half the damage path width. Substituting Eq. (9) into (8) and solving for R,

$$R = \left(\frac{V_b}{V}\right)^{1/k} R_b \quad (10)$$

The width of damage of intensity V is

$$W_V = \left(\frac{V_b}{V}\right)^{1/k} W_b \quad (11)$$

where W_b is the average width of gale intensity damage.

Garson, et al., (1974) show that accounting for the wind velocity profile, Eq. (5) becomes

$$P_t(V) = \frac{N\ t\ R'(V)}{y\ A} \left(\frac{V_b}{V}\right)^{1/k} \quad (12)$$

5.3 Tornado Risk Model by Markee, et al., (1974)

In this approach, the assumption is made that if the probability of tornado risk is P, and if the tornado strike probability is P_s, then the probability of intensity can be obtained from the relationship

$$P_i = \frac{P}{P_s} \quad (13)$$

This relationship is based on the assumption that tornado strike occurrence and intensity occurrence are independent events. The probability of a strike can be obtained from Eq. (3) or (4). The probability of intensity, P_i, is obtained from Eq. (13) for any value of P. Using two years of tornado classification by F-scale rating, 1971-1972, for the contiguous United States, it was found that the probability of exceeding ordinate values of windspeed approximately followed a log-normal distribution as shown in Figure 5.

Although not performed by Markee, et al., (1974) a least-squares linear regression can be applied to the log-normal probability distribution of tornado windspeeds (Figure 5); as determined by Abbey (1975b), the resulting equation is

$$\log V = sz + m \quad (14)$$

where log V (the random variable) is normally distributed with a standard deviation, s, of 0.1445 and a mean, m, of 1.999, based on the data presented by Markee, et al., (1974); z is the value of the random variable having the standard normal distribution. The correlation coefficient is 0.997.

Abbey (1975b) further extended this approach by incorporating the 4528 tornadoes classified by F-scale for 1965 and 1971-1974 and by dividing the cumulative probability by (N + 1) tornado occurrences to achieve greater statistical confidence. The linear regression equation thus determined is

$$\log V = 0.1314\ z + 2.024 \quad (15)$$

with a correlation coefficient of 0.992.

Tornado strike probabilities within 5° squares in the contiguous United States were determined using 13 years of tornado occurrence records, 1955-1967, based on Pautz, ed., (1969). The probabilities of intensity from Eq. (13) were computed assuming P equal to 10^{-7}; the corresponding windspeeds were then obtained by using Figure 5 or Eq. (14).

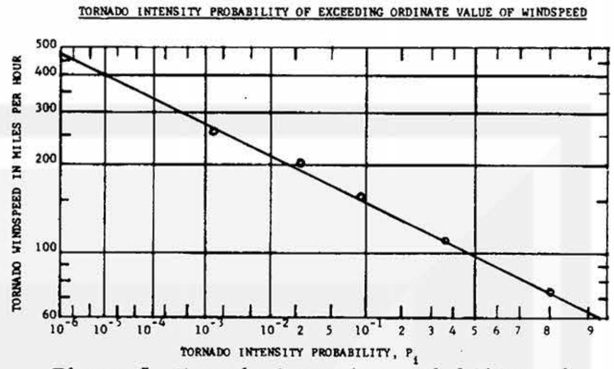

Figure 5. Tornado intensity probability of exceeding ordinate value of windspeed (after Abbey, 1975b).

5.4 Tornado Risk Model by McDonald, et al., (1975)

A region surrounding the site of interest is defined, which may range in area from a 1° to a 5° square. The tornado records for the defined region are then assembled. Since the tornado intensities are expressed in terms of the FPP scale (Fujita, 1971), a risk model is developed on this basis. Four basic steps are involved:

(1) Determination of a damage area-intensity relationship in a global region surrounding the plant site.

(2) Determination of an occurrence-intensity relationship in a local region surrounding the plant site.

(3) Calculation of the probability of a point within the local region experiencing windspeeds, the magnitude of which fall into any arbitrary interval.

(4) Determination of the probability of winds exceeding any threshold value within the local region.

A plot of the results of Step 4 is the tornado risk model. Each of the four steps is described in detail in the paragraphs below.

Damage Area-Intensity Relationship. A global region surrounding the plant site of sufficient area to permit the determination of a mean damage area-intensity relationship is defined. The global region usually consists of one or more states. Meteorological and topographical factors should be considered in selecting the region. The NSSFC tape gives Fujita Scale (F), Pearson path length (P_L) and Pearson path width (P_W) scales for most tornadoes in the three-year period 1971-1973. From the P_L and P_W ratings, the damage area in square miles for each tornado is determined using the median length and width in each classification. The mean damage area for each F scale classification is determined and an appropriate curve is fitted through the points to obtain a continuous relationship between mean damage area and windspeed. A semi-log or log-log plot is normally used. The curve thus obtained is the required damage area-intensity relationship.

Occurrence-Intensity Relationship. A local region within the global region is defined to permit the determination of an occurrence-intensity relationship. The size of this local region may range from a 1° to a 5° square, depending on the number of tornado occurrences in the vicinity of the plant site. The degree-square is used for convenience because tornado touchdown points are given in terms of latitude and longitude. The number of tornadoes exceeding each F-scale classification for the 15-year period 1959-1974 is obtained from the master list of tornadoes that have occurred in the local region. This relationship is fitted to an appropriate curve to give a continuous relationship. From this curve, the number of tornadoes occurring in arbitrary, but equal, class intervals is obtained. The number of tornadoes per year in each class interval is denoted λ_i. The set of λ's for all class intervals represents the occurrence-intensity relationship.

Probability of Windspeeds in any Arbitrary Interval. The probability of a point in the local region experiencing a windspeed in any class interval V_j, from tornadoes with maximum windspeeds greater than or equal to the class interval windspeeds is given by the expression

$$P_j = \frac{1}{A}\sum_{i=i}^{n} \lambda_i a_{ij} \qquad (16)$$

where

A is the geographical area of the local region (sq mi)

λ_i is the occurrence-intensity relationship (tornadoes per year)

a_{ij} is the area within the damage path that experiences windspeeds V_j in a tornado whose maximum windspeed is in the class interval V_i, $(i \leq j)$ (sq mi)

n identifies the class interval containing the largest tornado windspeed considered

The a_{ij} term requires some further discussion. The magnitude of a_{ij} depends on the maximum intensity of the tornado and its mean damage path area, which is defined as the extent of damage from winds greater than or equal to 75 mph. The windspeed model is assumed to be a Rankine type vortex. Thus,

$$a_{ij} = \frac{75\,(a_i)(V_{j+1} - V_j)}{(V_j)(V_{j+1})} \qquad j < i \qquad (17)$$

The a_i term is the mean damage path area defined by 75 mph winds for a tornado of intensity i. The i and j terms refer to windspeeds in class intervals V_i and V_j.

Probability of Exceeding Any Threshold Value. The probability that a point within the local region will experience windspeeds greater than V_j is

$$P_{Ej} = \sum_{j=j}^{n} P_j \qquad (18)$$

A plot of P_{Ej} versus threshold windspeed V_j is the tornado risk model.

6. COMPARISON OF TORNADO RISK MODELS

The risk probability versus windspeed relationship for each of the above models was compared utilizing a 3° square. Figure 6 shows this comparison for the sample being considered. At the 10^{-7} probability level, the windspeeds predicted by each of the above models are listed in Table 4. The 10^{-7} windspeeds vary by a factor of three which means that the dynamic wind loads vary by an order of magnitude, depending on which model is being considered. Analysis of another region yielded differences between the McDonald and Markee methods of greater than 100 mph at the 10^{-6} and 10^{-7} risk levels, whereas the differences between the proposed model and the McDonald approach were less than 50 mph. McDonald, et al., (1975) found one of the most sensitive parameters in tornado risk probability calculations to be the area, A, selected for consideration as the representative region for a particular site. Another significant parameter is the proportion of F4-5 rated tornadoes to the total number of tornadoes observed in the region of interest.

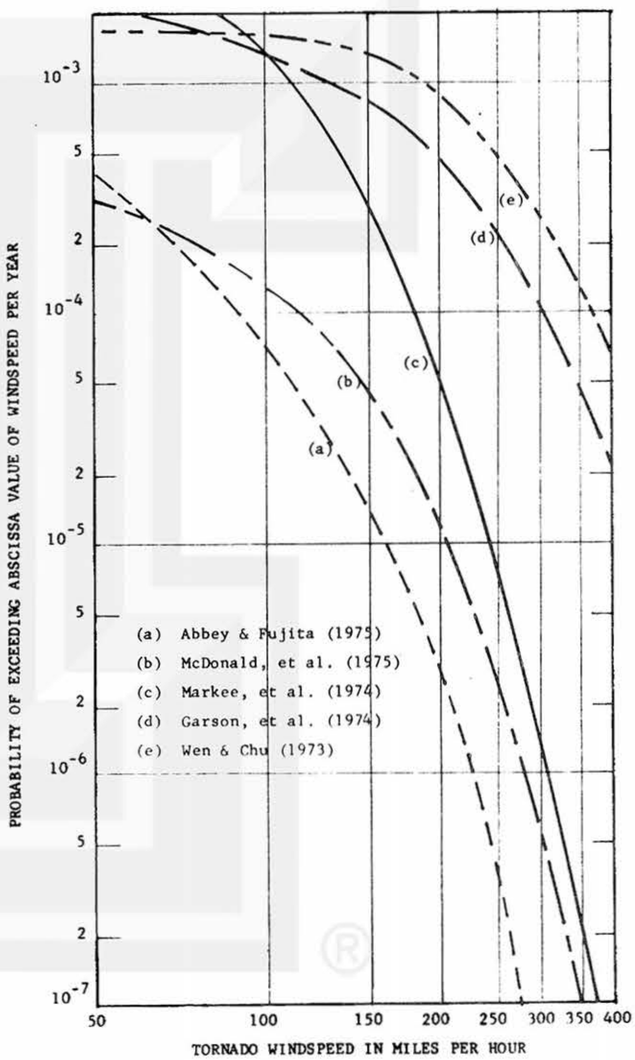

Figure 6. Comparison of five tornado risk models where the windspeed is a function of risk level.

Table 4

EXAMPLE OF 10^{-7} WINDSPEEDS PREDICTED BY SELECTED TORNADO RISK MODELS FOR A GIVEN 3^{o} SQUARE

Investigator	Windspeed [mph]
Abbey & Fujita (1975)	280
McDonald, et al. (1975)	355
Markee, et al. (1974)	375
Garson, et al. (1974)	755
Wen & Chu (1973)	860

7. CONCLUSIONS

A new approach in determining tornado intensity probabilities has been developed which takes into account total path length, path width, relative intensity of tornadoes as classified by the Fujita scale, and gradation of damage within the tornado path. Elimination of some of the deficiences inherent in previous approaches has been achieved, but at the risk of introducing some new concepts and assumptions which need to be investigated as more data become available. Past attempts to calculate tornado risk probability have assumed, for example, that all tornadoes classified as F5 produced F5 damage along their entire path, or assumed as average area per tornado regardless of intensity or region of occurrence, or assumed a windspeed profile through the vortex. These approaches may lead to misconceptions when attempting to determine geographic areas of high tornado intensity, or when defining the maximum tolerable tornado windspeed for design purposes.

When compared with previous techniques, the proposed methodology provides a realistic assessment of tornado risk based on actual damage areas of 147 tornadoes and path length-intensity history for each 1^{o} square. The risk estimates based on this method indicate a lower probability of high intensity damage than those estimates derived by the more conventional tornado incidence techniques. By utilizing the tornado data record since 1950, the path lengths for all tornadoes per intensity classification per 1^{o} square are believed to more realistically depict regions of high, moderate and low tornado risks. As discussed by Abbey (1975a), one of the objectives of the Office of Nuclear Regulatory Research's program in severe storms is to quantify and regionalize maximum tornado parameters. As part of this effort, probabilistic and statistical investigations are underway to evaluate the assumptions and the methodologies outlined in the approaches presented in this paper.

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