US-ASIA CONFERENCE ON

ENGINEERING FOR MITIGATING NATURAL HAZARDS DAMAGE

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MITIGATION OF WIND RELATED DAMAGES DUE TO SEVERE WIND STORMS AND HURRICANES

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ABSTRACT Wind storms, cyclones and tornadoes are estimated to cause average total annual building losses in the United States exceeding earthquakes, expansive soils, landslides, or floods. Since 72% of wind losses result from severe damage or collapse situations, whereas, on the average, tsuanmi, earthquake and storm surge cause only 6% of the losses in the severe or collapse category, the severity of losses from wind is greater than the severity of losses from all other natural disaster situations combined. Nonetheless, by effective use of land zoning, planning procedures, building to codes, and incorporation of modern design information into new structures some estimates suggest projected damages could be reduced by 35%.

INTRODUCTION

The ancients had a great deal of respect for the wind. It moved their ships and wrecked them. It pumped water, ground corn, but sometimes destroyed their crops and homes. Ehecatohatiuh, ancient god of the wind for the Aztecs of Mexico, was believed to have created man in the form of apes in order that they might cling to the earth better and not be carried away by the hurricanes; thus originating the similarity between the human race and monkeys. The word hurricane comes from the Caribbean Indian word 'huracan' for 'big wind'. Similarly the Japanese immortalized the god of the wind 'Fujin' in the mountain of wind - 'Fujiyama'. In modern times man retains his respect for the impact of extreme winds. The Bangaladesh cyclone of 1970 is estimated to have caused a death toll between 300,000 to 500,000, and Wiggins, 1987, estimates that a $40 billion dollar annual loss in the United States due to hurricanes is as likely as a similar loss due to the maximum severity earthquake.

This paper reviews the costs and type of damage associated with wind storms, examines the value of computational and physical models in estimating and alleviating potential losses, and discusses various mitigation schemes and design techniques to mitigate damage due to wind.

TYPES OF WIND STORMS

Wind storms can be classified into four categories based on severity and physical origins. The types include tornadoes, hurricanes (cyclones or typhoons), and severe winds (thunderstorms, downbursts, and downslope winds). Table 1 summarizes data concerning the average characteristics of such storms, their impact and the potential for mitigation (Gray, 1986; Walker, 1985b; Changery et al., 1984; Batts et al., 1980; Hart, 1976).

Tornadoes are one of nature's most violent and frightening natural hazards. They appear suddenly, often with little warning and contain the most powerful of all winds. They form during synoptic situations involving thunderstorm squall lines along a cold front, when cool dry air overruns warm moist air, and aloft when cold moist air masses exist from the surface to great altitudes. Fully developed tornadoes can have a variety of shapes varying from an ordinary funnel, wide at the top and narrow at the bottom, to cylinders whose diameter is constant between the cloud base and the ground. The tornado funnel one sees is a cloud of water droplets mixed with dust and other debris. The funnel translates along the ground with an average speed of 45 mph (5 to 65 mph), produces a maximum pressure drop of about 2 1/2 in. of Hg (1.2 psi.), contains a maximum wind speed somewhat below 300 mph, and cuts a swath a few meters to kilometers width over a path length from a fraction of a kilometer to hundreds of kilometers long. The maximum mean annual observed number of tornadoes per year in the United States per 10,000 sq miles is 10.4. About 10% of these will have wind speeds exceeding 158 mph, and only 2.3% will exceed 207 mph. Although tornadoes can occur almost anywhere in the world, over 90% of observed tornadoes occur on the North American continent.

Hurricanes are typically longer lasting (average of nine days), less intense (maximum wind speeds of 200 mph), and impact a larger surface area than tornadoes. A tropical cyclone is considered a hurricane if maximum wind speeds exceed 73 mph. Although tornadoes may occur almost anywhere, hurricanes originate between the 5 and 20 degree latitudes and impact islands and coastal regions. Cyclones are characterized by three main features: a) strong winds circulating around a calm eye in an anticlockwise manner in the Northern hemisphere (vice versa in Southern hemisphere), b) high tides caused by the storm surge, and c) heavy rains. Typical cyclones have a diameter of 400 miles, a depth of 9 to 12 miles, and move along the storm track at 5 to 32 mph. Winds spiral into the center at sea level and spiral out at upper levels. A cyclone has an eye diameter from 5 to 25 miles, hurricane force winds out to a diameter of 100 miles, and gales over a 400 mile diameter. Hurricane-spawned tornadoes are much more common than was once thought. Recent studies indicate that virtually all storms of hurricane intensity along the coast of the U.S., and half the storms of tropical storm intensity, spawned tornadoes (Gray, 1986). Latent heat released by condensation of water vapor from the warm ocean provides the energy source which intensifies and maintains the cyclone. The intensity of a cyclone is measured in terms of central pressure at the core, i.e.. less than 29.0 in. of Hg (982 millibars) when winds exceed 73 mph. Cyclones occur along the coasts of Australia and all the continents except South America.

Severe Winds can occur in all locations. Data associated with high variability storms such as hurricanes and tornadoes must be removed from an extreme wind time series to evaluate severe wind effects. They are usually associated with storm fronts, winter gales, or downslope winds. Severe wind statistics are generally well behaved, have reasonably low annual variability and are well predicted by Fischer Type I or Weibell probability distributions. Often called "straight line" winds, they are not expected to swirl like tornadoes or cyclones, and may show a strong directional dependence. These are the winds typically considered in building codes (UBC, SBC, ANSI in United States).

DAMAGE TYPES AND COSTS

Insurance companies evaluate the relative cost to a community of the various types of storms in terms of the mean annual losses, the variability of annual losses and the maximum possible loss (Walker, 1985a; Friedman, 1980, 1983). Insurance works best when the annual variability of incidents is small. This enables insurance companies to determine premiums with confidence. Information about the maximum possible loss is used to estimate necessary reinsurance.

Mean Annual Losses

In the United States (U.S.) wind related natural hazards caused about 400 deaths/year or 35% of all natural disaster related deaths (or about 1/250 the death rate of man-made accidents), and annual wind related dollar losses ($5 billion) equal building losses due to fire or more than one-half of the annual dollar losses from automobile accidents. These annualized wind losses are distributed between hurricanes, tornadoes, and severe winds as 55, 40, and 5 percent, respectively. Storm surges account for about 40% of total hurricane damage.

Wiggins (1978) predicted that by the year 2000 annual average U.S. hurricane and tornado related losses would be $11 billion in 1987 dollars. Such increases are due to increase in population, concentration of people and property in cities, settlement in exposed coastal areas, higher construction and repair costs, and more hazardous technologies. Indeed the usefulness of past loss experience data decays rapidly with time because of changes in the number, geographical distribution and density of the elements-at-risk in hazard prone areas. Vulnerability to damage also changes with time due to inflationary trends.

Annual Variability

Annual fire losses have a coefficient of variation (c.o.v.) of about 10%, whereas hurricane wind losses have a c.o.v. of nearly 200%, and non-hurricane wind losses (tornadoes, thunderstorms and winter gales) have a c.o.v of 70%. Thus randomness and spread of risk are <u>not</u> characteristics of wind losses (Friedman, 1983; Walker, 1985a). Since in the past wind losses have been only a fraction of fire losses, most insurance companies offer wind damage coverage as an extension of fire policies even in hurricane prone areas. More recent statistics suggest wind losses now equal fire losses in the U.S.. When risk and variability become large, insurance companies are reluctant to insure a peril at all! (In the U.S. today flood losses are not included in most policies.)

Maximum Possible Loss

Munchener Ruck (1982) has noted that the causes of some 400 great natural disasters which have already occurred in this century are grouped by 52% inundation, 17% earthquake, 15% wind storm, 7% drought, 3% volcanic, and 6% other. At the beginning of the century there were about three disasters per year based on the existence of an extreme impact on the economies concerned due to the extent of bodily injury or property damage; whereas, currently there are about 15 per year. Between 1960 and 1980, Berz and Smolka (1987) found that 49 of the 89 major natural disasters were attributable to windstorms. In terms of property damage the worst natural disaster during this period was Hurricane Agnes which caused a $3.1 billion loss in the U.S..

Today Wiggins (1987) estimates that a single probable earthquake in the U.S. could cause $63 billion in damage; one hurricane, $10.5 billion; one tornado, $4.8 billion; one storm surge, $2.4 billion; one riverine flood, $3 billion; and one tsunami, $1 billion. Since it is much more likely that multiple hurricanes hit a populated coastline than multiple maximum critical earthquakes occur in one year, he calculated that it is not unlikely that hurricanes cause losses within a one year time of $40 billion due to wind only. Indeed, Gray (1986, 1987), notes that the past ten years have been an unusually quiet time for hurricanes along the U.S. coastline; a large portion of the U.S. coastline population has entered the region since the last major storms hit; hence, the next major storm might easily cause damage exceeding $5 billion.

A considerable difference exists between the damage, type, and magnitude caused by different natural hazards. An earthquake is expected to cause structural collapse or severe damage to less than 0.5% of the buildings exposed, but structural collapse or severe damage is experienced by 93% of the exposed buildings damaged by tornadoes and by 51% of those damaged by hurricanes (Petak and Hart, 1980). Loss of life is generally expected to correlate directly with such extreme damage.

NUMERICAL AND PHYSICAL MODELING OF EXTREME WINDS AND WIND LOADS

There are three critical questions which arise when one considers the developments and trends in designing for extreme winds: a) Just how much better are we doing now than say 100 years ago? b) Does a consensus exist about the validity of the methodologies? and c) Is the information available useful to the design engineer or planner?

State of Computational Modeling

Computer models may be used to forcast storms, generate probable wind fields of extreme winds, evaluate property and lives at risk in a wind storm, and predict loads and motions of specific structural configurations. These models are generally heavily dependent on the reliability of local climatological information, population and property inventories, and empirical accommodation factors. Indeed, Kareem (1987) suggests ranges of confidence and reliability should be incorporated into any decision matrix for design decisions in extreme wind situations.

Forecasting of lows, fronts, squall lines, and thunderstorms is a normal part of what we consider the meteorologists responsibility. Hence, an extensive computational effort has been made to predict the incidence, strength and track of tornadoes, hurricanes and severe winds (Kitade, 1986; Southern, 1986). Present day cyclone models are able to simulate a) tropical cyclogenesis from synoptic scale waves; b) organization of cloud elements into vortex shaped convective system; c) regional topographic effects; and d) the evolution of some real tropical cyclones. In most cases the spatial resolution has not been sufficient for all scales of motion. Operational models are predicting tropical cyclone tracks, but most do not simulate the tropical cyclone with much realism.

The predictability of atmospheric motions are expected to be no greater than the Lagrangian lifetime of the pattern, T, ie. 'you can't predict something longer than it lasts'. Thus the useful duration of a perfect-model forecast is about 2.5T. Stull (1985) conjectures that predictability curves normalized by their lifetime are independent of their spatial scales; thus, small mesoscale pheonomena, such as detailed tornadoes, hailstorms and wind damage forecasts, are anticipated to have usefully accurate model-produced predictabilities of less than one hour. Larger mesoscale activity such as fronts and huricanes may be predictable from one to seven days in advance. Alternatively, "nowcasting" can be performed once phenomena such as thunderstorms or hurricanes are discovered by radar or satellite. Since these models constantly update boundary and dynamic conditions nowcasting may be reliable for longer times.

Hart (1976) combined programs for storm physics, occurrence, exposure and vulnerability, and damage matrices into a risk model to predict the economic impact of tornadoes, hurricanes, and severe winds in the U.S.. Adjustments were made for the growth of property and population and the effect of various mitigation alternatives, and calculations predicted storm losses from 1970 to the year 2000. Because of limited data concerning the range of possible damage for different wind speeds, his model is highly dependent on the informed judgment of an expert wind effects panel. Different authors' estimates of the overall wind impact on buildings using a common base extend from about $900 million to $3.6 billion under 1980 conditions (Friedman, 1980). Leicester et al (1980) used a Monte Carlo version of this approach to assess potential cyclone damage along the coasts of Australia. These calculations provide valuable information for insurance, engineering and planning decisions.

Statistical techniques to predict extreme wind speeds and associated loads needs at least 10 years of continuous daily surface and upper-air observations and up to 50 years of monthly and annual extreme wind observations. Rarely do such data exist. An alternative approach is to use a "Monte Carlo" approach to computer simulate a large number of time histories of tropical cyclone passages past a given locality (Batts et al, 1980). Characteristics of the individual computer hurricane use probability distribution functions and inter-dependent relationships to predict wind speeds based on limited historical data statistics.

Batts et al used a log-normal distribution to describe hurricane pressure differences, a landfall retardation factor based on surface roughness, and a storm pressure decay adjusted for time after landfall. Later, Georgiou et al (1983) used a Weibell distribution to describe pressure difference and an improved filling parameter which adjusted the hurricane speeds and pressures for distance traveled inland. The authors claim their algorithms produce more reasonable long-term records and reproduce data along the 3000 mile coast between Texas and Maine. Recently, Delaunay (1987) used a similar technique to predict extreme winds in Guadeloupe, Martinique (Lesser Antilles), Reunion (Indian Ocean), New Caledonia and Tahiti (South Pacific Ocean). No adjustment is made in any of these computations for local terrain variation or the effects of vegetation or structural sheltering.

In most countries estimates of extreme winds have been incorporated into national codes which are used to design "engineered' structures. In most cases such engineered structures are limited to tall buildings, bridges, or towers which represent a significant financial investment. Recently, however, a simplified code approach has been advanced in Australia to include small buildings in cyclone prone areas (Walker, 1985b, 1987).

State of Physical Modeling

Although the science of theoretical fluid and solid mechanics is well developed and computational modeling is experiencing rapid growth, it remains necessary to perform physical experiments to gain needed insights into many complex effects associated with extreme wind and structure interaction. Indeed most procedures and algorithms to calculate wind loads found in codes today are dependent upon wind-tunnel data (ANSI 58.1-1982, Uniform Building Code, etc.). Even factors proposed to adjust wind speed estimates for changes in surface roughness and terrain are the result of physical model measurements (Cook, 1985).

There is not always uniform agreement in the wind-engineering community about simulation and wind-tunnel test procedures. As noted by Robertson (1985), often apparently identical investigations on the same building by different laboratories give different results. It is surprising how few full-scale tests have produced results in a form that can be used for the validation of wind-tunnel tests. In 1982 six papers in a conference on Wind Tunnel Modeling for Civil Engineering Applications (Sparks, 1982) examined full scale/wind tunnel model comparisons of data for wind forces and movements of buildings, towers, bridges and chimneys. Duplication of realistic mean pressures and forces is often possible, but accurate replication of pressure fluctuations seem to depend upon the appropriate selection of reference static pressure during the full scale measurements and adequate approach wind information in the field. Sparks cynically observes that the "highest correlation one is likely to encounter is that between storm conditions and malfunction of measuring or recording equipment."

Elaborate aeroelastic models are probably of limited use for initial wind-tunnel studies because of the inherent difficulties in the stipulation of the dynamic characteristics of the building before it is built. Currently rigid models are widely used to produce base-moment, drag and lift information which can be applied easily to a wide range of structural characteristics which the designer may consider likely to exist in his building. Halvorson and Isyumov (1986) concluded, based on a comparison of the measured full-scale response of the Allied Bank Plaza building in Houston during Hurricane Alicia, that wind-tunnel procedures for predicting acceleration response are "well developed and accurate". They found that wind tunnel predictions of structural loads based on estimates of a tower's dynamics properties can be "extremely accurate". In the case of chimneys and towers of circular crosssection, Melbourne (1982) observes that Reynolds number effects are very large, and very little faith can be placed on wind-tunnel results.

Were a wind-tunnel study a cost-free endeavor, then Dobryn et al (1982) suggests that all structure should be tested. Logically, however, one must balance design assurance against test costs. For a large 40 story building one can expect an aeroelastic study to cost 0.25% of the cost of the structure and 0.06% of the cost of the building. A cladding pressure test typically costs 1.0% of the cladding cost and 0.08% of the cost of the building. Often aeroelastic and cladding tests predict lower loads than those of current codes. Lower loads have very appealing economic implications, whereas higher ones can be accepted in the context of protection against risk. Wind tunnel experiments provide a) better estimates of approach winds, b) direct evaluation of extreme pressures, and c) selection of improved building orientations or architectural shape (eg. Hart and Ellingwood, 1982; Melbourne and Cheung, 1987). Confidence in the wind-tunnel predictions are of course necessary for economic justification, but wind-tunnel results should not be expected to be any less accurate than other design variables.

MITIGATION METHODOLOGIES

There is increased desirability of mitigation as opposed to relief and reconstrucition. In general, mitigations which result in reduced losses in human lives and property may be applied to all three driving factors: hazard, exposure and vulnerability. Use of mitigation devices could be coupled to an insurance programme as incentives to reduce premium rate increase. Consequential losses can also be mitigated by fast post event response, which can reduce "second" loss levels substantially.

Mitigation of the Hazard

Preventing, reducing, or halting an extreme wind event is normally presumed to be beyond the control of mankind. The very scale and intensity of a hurricane or tornado tend to make any conceivable response of man irrelevant. Surface level kinetic energy production magnitudes associated with a mature hurricane or a tornado are estimated to be 200,000,000 and 100,000,000 Megawatts, respectively. This compares to 200,000 Megawatts for a volcano or 500,000 Megawatts for the typical thunderstorm (Koenig and Bhumralkar, 1974).

Nonetheless, cloud seeding experiments on thunderstorms in Florida suggest that cloud development can be modified or enhanced by selective seeding with aerosols (Simpson and Woodley, 1971). Furthermore, hurricane damage in the U.S. has been found to correlate with the maximum sustained surface wind speed raised to a power of 4.3. If this is an accurate representation, then a 20% to 25% reduction in maximum surface winds on the right side of the storm might reduce storm damage by as much as 50% . Seeding the inner eye-wall of hurricanes with silver iodide was proposed by

R.H. Simpson in 1961, and Gentry (1970) described silver iodide treatment of the inner eye-wall of hurricane Debbie (1969) which was associated with a reported reduction of the peak wind of 31 and 15 percent. Gray et al (1976) have proposed weather modification by carbon dust seeding in hurricanes. Computer models suggested a wind speed reduction of 30 mph could occur, and a 20% reduction in wind speed would have a ratio of yearly average of damage reduction to modification cost of 33 to 1, even if only one-fourth of the storms with speeds greater than 90 mph along the U.S. are included. On a global basis the ratio is closer to 57 to 1. Unfortunately, even though environmental impact of such carbon dust seeding appears negligible, the idea does not appear socially or politically timely. Perhaps the idea will be given further consideration in the future.

Mitigation of Exposure

Since tornadoes and severe winds are possible over the entire continental U.S. the entire population and its property are at risk ($4000 billion and 250 million people). Hurricane damage is limited to coastal states; hence, wealth at risk is about 1/3 that of tornadoes and severe storms, and people at risk is about 1/3 also. Exposure can be reduced by limiting population growth in large cities and coastal regions, warning and evacuation, land-use planning through microzonation, and better public information.

Elimination of all population growth in a hurricane-prone states and high tornado risk counties after 1980 would reduce average annual property losses by about 8% or $900 million in 1987 dollars during the year 2000 (See Table 2). Societal and political factors suggest that no-growth concepts will be difficult to implement.

Advance storm warning to permit boarding of all windows would save 0.5% of all wind related losses or $50 million in 1987 dollars during the year 2000 (See Table 2). Major evacuation is presumed by many people to be difficult to justify since storm tracking is an inexact science. Indeed, Southern (1986) estimates that even given a potentially 100% accurate correct cyclone prediction the value of the prediction is degraded to 16% by various deficiencies in skill or usefulness of warnings, public authority dissemination and community utilization of the time provided.

Mitigation of Vulnerability

Mitigation of the effects of severe winds can be accomplished, at least in theory, by improving building codes and their enforcement, modifying methods of construction, using different building materials, protective devices, and residential shelters. Absolutely storm-proof construction methods cannot be attained at economically justifiable costs; nonetheless, stricter or more precise design procedures tend to be popular with engineers, who are oriented toward the construction of specific structures and buildings. Insurance companies, on the other hand, are more interested in the cost of an entire overall loss including contents.

The analysis by Hart (1976) suggests that simply strengthening existing building codes by a factor of 3 or 1.5 would result in the reduction of wind losses by 22% and 13% or $2.5 and $1.4 billion 1987 dollars by the year 2000, respectively (See Table 2). But building codes tend to be a combination of engineering data, informed opinion, and economic compromise. For example, current U.S. codes disregard tornado level winds as producing impractically expensive construction.

More conservative design procedures are often used for community sensitive structures, eg. nuclear power stations, schools, hospitals, and warehouses for the storage of critical materials. Designing for a tornado is similar to designing for the effect of a blast wave; hence, information from nuclear explosions are often used to specify wind loads (McDonald et al, 1973).

Walker (1983, 1984, 1987) has examined the characteristics of wind loading on residential housing. He has recently proposed an international simplified code with wind loads expressed directly in terms of pressure enabling much wider application of wind engineering to small buildings. Small buildings are those not over 15 m tall and not over 1000 square meters in area. Eaton (1980, 1985) describes research on low-cost housing for areas in the Caribbean and South Pacific. He observes that supposedly low cost construction, say $12/sq ft, is not cheap in underdeveloped countries; yet it is the loss of such structures which dominates individual loss and suffering.

CONCLUSIONS

Mitigation of the effects of severe winds on lives and property loss is in its infancy. The very magnitude of the losses involved makes significant improvements difficult. Mitigation of the severe winds directly appears hopeless to most observers; although, some storm seeding concepts should be examined further. Mitigation of the exposure of property and populace requires massive dislocation of people and a change in the trend for population growth along the world's coastlines. Mitigation of the vulnerability of the property and people exposed can conceivably reduce losses by 25%. Improved forecasting techniques will undoubtedly reduce lives lost, but warning and evacuation is not likely to make much of an impact on property losses.

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TABLE 2: UNITED STATES WIND LOSSES AND MITIGATION EFFECTS
(Revised from Hart, 1976)

EXPECTED LOSSES IN $ MILLIONS (1987)

MITIGATION	TORNADOES 1980	TORNADOES 1990	TORNADOES 2000	HURRICANES 1980	HURRICANES 1990	HURRICANES 2000	SEVERE WINDS 1980	SEVERE WINDS 1990	SEVERE WINDS 2000	TOTAL LOSSES 1980	TOTAL LOSSES 1990	TOTAL LOSSES 2000
Baseline: No mitigation activities	$3,401	$4,632	$6,039	$2,756	$3,811	$4,984	$44	$59	$73	$6,200	$8,501	$11,096
(1) All new structures newly built after 1980 must be built to comply with Uniform Building Code times 3.0	$3,401 0%	$4,045 -13%	$4,778 -21%	$2,756 0%	$3,225 -15%	$3,811 -24%	$44 0%	$50 -15%	$56 -24%	$6,200 0%	$7,320 -14%	$8,645 -22%
(2) All new structures newly built after 1980 must be built to comply with Uniform Building Code times 1.5	$3,401 0%	$4,280 -8%	$5,541 -8%	$2,756 0%	$3,518 -8%	$4,104 -18%	$44 0%	$53 -10%	$62 -16%	$6,200 0%	$7,851 -8%	$9,706 -13%
(3) After 1980 all structures are strengthened so that light damage losses are zero	$3,401 0%	$4,632 0%	$6,039 0%	$2,756 0%	$3,697 -3%	$4,834 -3%	$44 0%	$53 -10%	$67 -8%	$6,200 0%	$8,381 -1%	$10,940 -1%
(4) After 1980, glazing requirements and warnings result in no window damage	$3,401 0%	$4,573 -1%	$6,039 0%	$2,756 0%	$3,773 -1%	$4,934 -1%	$44 0%	$59 0%	$73 0%	$6,200 0%	$8,405 -1%	$11,046 0%
(5) Population growth is stopped in all counties where tornado strike probability is greater than 10-4 per year per square mile	$3,401 0%	$4,251 -8%	$5,541 -8%									
(6) Population growth in hurricane-prone states ceases after 1980				$2,756 0%	$3,659 -4%	$4,585 -8%						

HURRICANES: Losses due to winds > 73 mph
Does not include storm surge losses

SEVERE WINDS: Structurally related losses only
Does not include roofing shingles or contents

TABLE 1: CHARACTERISTICS OF SEVERE WIND STORMS AND HURRICANES (Extracted from Hart, 1976, Petak and Hart, 1980, and Georgiou et al, 1983)

STORM TYPE	CLASS *	MAXIMUM WIND SPEED (mph)	MAXIMUM AVG SPEED (mph)	MEAN AREA (sq miles)	PERCENT OBSERVED	STRIKE** PROBABILITY (x 10^5)	WEALTH-AT-RISK ($ 1970) (billions)	(% Total)	PEOPLE-AT-RISK (1970) (millions)	(% Total)	TOTAL LOSSES ($ 1970) (millions)	(% Total)
TORNADO	F0	40-72	56	0.02	19.9%	0.5	$1,798	89.1%	181	89.1%	$880	56.0%
	F1	73-112	93	0.27	44.0%	6.4						
	F2	113-157	135	1.72	26.6%	13.0						
	F3	158-206	182	8.00	7.2%	10.8						
	F4	207-260	234	28.36	2.1%	11.9						
	F5	261-318	290	83.90	0.2%	0.9						
HURRICANE	NWS1	73-95	84	125000	38.0%	--	$682	30.9%	63	30.9%	$680	43.3%
	NWS2	96-110	103		38.0%							
	NWS3	111-130	121		12.0%							
	NWS4	131-155	143		10.0%							
	NWS5	>155	200		2.0%							
SEVERE WINDS	-	50-200	--	--	--	--	$2,065	100.0%	203	100.0%	$11	0.7%

* F - Fujita Tornado Classification
NWS - U.S. National Weater Service Hurricane Classification

** Strike likelihood in a 3997 square mile area when the mean number of tornadoes in area is 5