

A WHITE PAPER ON HURRICANE LOSS CALCULATIONS FOR THE CARIBBEAN
REGION

PREPARED FOR

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PREPARED BY

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ABSTRACT

The objective of this work is to produce a short working paper that would assist insurance companies in the Caribbean Region in (1) identifying their PML calculation consulting needs, (2) determining what a PML calculation should contain, and (3) evaluating offerers of consulting services for assistance with PML calculations. As an additional constraint, the OAS specified that the paper concentrate on hurricanes and the methodology discussed be applicable to seismic events.

In Section 2.0, the concept of PML is discussed and a definition of PML and the calculation procedures used to represent the state-of-the-art in earthquake PML calculations are selected. The applicability of the PML methodology in estimating hurricane-related losses in the Caribbean Region is next examined. On the basis of the analysis, it is concluded that the traditional PML approach may not be the best methodology to estimate hurricane-related losses in the region. Beginning with the definition of an ideal state of hurricane-related loss estimation knowledge in the Caribbean, a list of capabilities that consultants should provide is developed.

Since the earthquake PML methodology is not being rigidly followed, the more general term of "loss estimation" is used instead of PML. In Section 3.0, what a loss estimation calculation should contain is identified. The general calculation procedure is based on the risk analysis approach is outlined. The desired output of any loss calculation methodology is determined along with the input needed for such a methodology. The algorithms needed to complete such a methodology are also defined. In addition, sources of information (e.g., meteorological records, post-disaster studies, building codes, field

inspections, insurance payout records, and local design/construction professionals) for the required input into the methodology are identified.

To further familiarize insurers with hurricane-related loss methodologies, the problem of developing classification schemes for buildings is reviewed and several examples of classifications schemes are provided. In the next several sections, a specific methodology for loss estimation of structural damage and contents damage is summarized and how the results can be presented in a format that is useful to insurance companies in the comprehensive evaluation of hurricane-related losses is provided. An extended example of a loss calculation for a portfolio along the Gulf Coast, using the method as a basis, is also provided. Finally, on the basis of the materials presented in the eleven sections, a list containing twenty criteria that can be used to evaluate offerers of loss estimation in the Caribbean is developed and how these criteria may be quantified and combined into a single indicator for rating purposes is discussed.

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1.0 INTRODUCTION

1.1 Background and Charge

In November 1994, the OAS-USAID/Caribbean Disaster Mitigation Project (CDMP) co-sponsored a seminar for senior insurance sector management personnel on overcoming obstacles to reinsurance in the region. One of the major outcomes of the seminar was the need to define the concept of Probable Maximum Loss (PML) and PML calculation methodologies. One working group, the Aggregated Value and PML Development Working Group, formed at the seminar specifically recommended that a generic PML development paper covering such topics as site vulnerability, construction vulnerabilities, and hazard characteristics be developed. In response to this recommendation, the OAS commissioned a white paper on PML calculations for the Caribbean Region. More specifically, the OAS requested "a short working paper that would assist insurance companies in the Caribbean in identifying their PML calculation consulting needs, determining what should a PML calculation contain, and evaluating offers of consulting services for assistance with PML calculations." As an additional constraint, the OAS specified that the paper concentrate on hurricanes and that the methodology to be discussed be applicable to seismic events.

1.2 Objective and Approach

The objective of this paper is to satisfy the latter requirements specified by the OAS. To meet this objective, the paper addresses such issues as the definition and concept of PML; the hurricane-related loss consulting needs in the Caribbean; the classification of loss calculations; the variables needed to make each type of loss calculation; the sources of data for loss calculations; the various equations, algorithms, and rules needed to complete the

loss calculations; and finally, internally consistent methodologies with which the insurance industry can rationally evaluate offerers of hurricane-related loss consulting services.

1.3 Scope of Paper

The intended audience and the specified hazard determines the scope of this paper. Firstly, the intended audience for this paper is the middle to high level insurance executive population with no formal background in Civil Engineering, Structural Engineering or Wind Engineering. Therefore, unless it becomes absolutely necessary for clarification purposes, technical explanations and the use of mathematical equations will be kept to a minimum. Secondly, the examples and discussions will be limited to the wind and missile components of the hurricane hazard. In most cases, extension of the ideas to other aspects of the hurricane hazard will be obvious.

After reading this document, the reader should:

1. Be aware of the various types of PML calculations,
2. Be more aware of components of PML calculations,
3. Be able to identify sources of information for loss calculations,
4. Be able to propose classification schemes for buildings in his or her organization's portfolio,
5. Be capable of effectively discussing insurance industry needs with the engineering community,
6. Be able to better analyze their organization's current methods of performing loss calculations,
7. Be capable of participating more fully in developing their organization's loss models,
8. Be better able to evaluate vendors of loss calculations, and

9. Be able to more objectively evaluate their organization's existing loss procedures.

2.0 IDENTIFICATION OF HURRICANE-RELATED LOSS CONSULTING NEEDS IN THE CARIBBEAN

2.1 Background and Objectives

In general, a hurricane loss estimate is a prediction of the effects of future or hypothetical hurricanes on a specific structure, a collection of structures, or an entire region. Here the term "loss" denotes such items as deaths and injuries; costs to repair damaged buildings; damage to a community's infrastructure, such as loss of communications internally as well as externally; disruption of transportation, and impairment of lifelines; damage to critical facilities, such as power plants and hospitals; an increase in the homeless population; and the negative impact on the economy of a region due to the business interruption caused by the hurricane. Hurricane losses may be estimated for many reasons which may include, but not be limited to, the following situations:

1. To identify especially vulnerable geographical areas,
2. To identify highly vulnerable buildings or other structures,
3. To provide additional input into emergency response plans,
4. To evaluate the overall impact of the hurricane event on the economy,
5. To identify potential hurricane shelters,
6. To evaluate the impact of such hazard reduction strategies as improved building codes or alternative land-use plans,
7. To estimate the expected consequences of a predicted hurricane, and
8. To estimate property losses to assess property insurers' risks.

This paper focuses on the estimation of hurricane-related losses in order to improve the accuracy of the assessment of property insurers' risks in the Caribbean Region.

Traditionally, losses in hazardous situations have been computed using the so-called PML approach. We have two objectives in this section: firstly, we will examine the concept of PML and its relationship to the hurricane hazard in the Caribbean, secondly we will identify loss calculation consulting needs in the Caribbean. To meet these objectives we adopt the following approach: firstly, we discuss the definition and concept of PML; secondly, we evaluate the applicability of the traditional PML approach to the hurricane hazard in the Caribbean; thirdly, we postulate an ideal state of loss estimation knowledge in the Caribbean; and finally, on comparing the traditional approach with this ideal state, we identify the hurricane-related loss estimation consulting needs in the Caribbean. Note that in the last sentence we have used the more general terminology of "loss estimation" instead of PML. As will be pointed out below, a PML is a number arrived at using a specific methodology and that methodology may not represent the best approach for estimating hurricane-related losses in the Caribbean region.

2.2 Definition and Concept of PML

The denotation of the term PML depends upon who is using the term or where the term is being used. At one extreme, the *Dictionary of Insurance* (Davids, 1983) defines PML as the "maximum amount of loss that can be expected under normal circumstances". According to the same source, extraordinary circumstances, such as delayed alarm, insufficient water supply etc., can result in a loss exceeding the PML. At the other extreme, the California Department of Insurance (California Department of Insurance, 1981) defines PML as follows:

The probable maximum loss for an individual building is that monetary loss expressed in dollars (or as a percentage of insured value) under the following conditions:

- (a) Located on firm alluvial ground or on equivalent compacted man-made fills in a probable maximum loss zone, and
- (b) Subjected only to vibratory motion from the maximum probable earthquake, that is, not astride a fault or in a resulting landslide.

The building class probable maximum loss (class PML) is defined as the expected maximum percentage monetary loss which will not be exceeded by 9 out of 10 buildings in a given earthquake building class under the conditions stated in the previous paragraph.

In the State of California's definition of PML, which we can assign here as representing the state-of-the-art in the field of PML calculations for earthquakes, the probable maximum loss zones are determined from geologic models of the regions of interest. Numerical values for PML for various building classes are determined from values obtained from data generated from so-called "maximum credible earthquake".

PML estimates can be used in the decision making process by utilizing such equations as

$$(\text{percent PML}) - (\text{percent deductible}) = (\text{percent loss over deductible})$$

Note that this formulation takes into consideration a single hazard, no mention is made of the time value of money and neither is there any mention of the probabilistic nature of earthquake strikes.

According to Steinbrugge and Algermissen (1990), PML loss-estimation methods were developed over a period of years by the structural engineers of the Pacific Fire Rating Bureau. Initially applications were limited to commercial and industrial buildings. Dwellings

were subsequently included in the classification system of the Pacific Fire Rating Bureau and its successor Insurance Services Office. Currently the PML method encompasses virtually all hazards and types of structures.

In brief, using the California model as a paradigm, the PML method utilizes the following steps:

1. Define the underwriting territory,
2. Divide the territory into zones,
3. Define a set of maximum credible events for which actuarial data are available,
3. Subject each zone to an appropriate maximum credible event, and
4. Estimate the PML for the territory.

A typical PML calculation for an earthquake scenario in California is shown in Table 2.1.

While we do not wish to downplay the extremely valuable role that the PML method performs in the insurance industry, with regard to the hurricane hazard, we can make several observations regarding the shortcomings of the PML methodology:

1. PML calculations ignore the stochastic nature of hurricanes,
2. PML calculations ignore environmental differences between the site at which the actuarial data were collected and the site at which the PML estimate is being made,
3. PML calculations ignore differences in construction practices for similar classes of buildings in the two areas,
4. PML calculations make limited usage of existing knowledge from engineering, meteorological, and economic analysis,
5. It is questionable that enough data has been gathered on rare events for a sufficiently long time such as earthquakes and hurricanes to define a maximum probable event,

6. PML calculations ignore improvements in building practices,
7. PML calculations ignore changes in building practices over time, and
8. PML calculations ignore the time value of money.

2.3 Applicability of Traditional PML Approaches to the Caribbean

Given the shortcomings listed above and other concerns to be discussed below, it would be unwise to apply the PML method as described in Section 2.2 to estimate losses in a hurricane environment. Firstly, it is highly unlikely that post-hurricane monetary losses for building classes of interest in this paper have been systematically collected and analyzed for any part or all of the Caribbean Region. In other words, actuarial data needed to form the basis of a traditional PML study does not exist. Secondly, in many parts of the Caribbean, most of the existing building stock has been put in place during the last thirty to forty years. Much of this stock has not experienced a hurricane and, therefore, there exist no data to provide the basis for a traditional PML study. Thirdly, a variety of codes and building practices are to be found in the Caribbean Region. Thus it becomes mandatory to examine each jurisdiction independently, since codes and building practices greatly impact the performance of structures.

2.4 Ideal State of Hurricane-Related Loss Estimation Knowledge

The ideal state of hurricane-related loss estimation knowledge in the Caribbean, or anywhere else for that matter, should be such that insurance companies can rationally evaluate the risks for a single structure, classes of structures, and zones. The evaluation should account for the stochastic nature of the hurricane, incorporate the unique behavior of a building or building class, be sufficiently flexible to include many financial alternatives,

and include the time value of money. For any given location, the resulting models should also be able to incorporate such variables as the profile and trajectories of past, and hypothetical hurricanes. A more detailed listing of what might comprise the ideal knowledge state is listed below for the single structure, the class of structures, and the zone.

For a single structure, the ideal state of hurricane-related loss estimation knowledge might include the following items:

1. An accurate model to estimate the monetary loss to a single structure subjected to a single hurricane,
2. An accurate model to estimate the monetary loss on an annual basis to a single structure subjected to all hurricanes,
3. An accurate model to estimate the monetary loss to a single structure for the period of the useful life of the structure or some predetermined time period, and
4. Means by which the uncertainty in each of the models above can be quantified.

Similarly, for a class of structures, the ideal state of hurricane-related loss estimation knowledge might include the following items:

1. An accurate model to estimate the monetary loss to a class of structures subjected to a single hurricane,
2. A accurate model to estimate the monetary loss on an annual basis to a class of structures subjected to all hurricanes,
3. An accurate model to estimate the monetary loss to a class of structures for the period of the useful life of the structures or some predetermined time period, and
4. Means by which the uncertainty in each of the models above can be quantified.

Finally for a zone or portfolio, the ideal state of hurricane-related loss estimation knowledge might include the following items:

1. An accurate model to estimate the monetary loss to the zone subjected to a single hurricane;
2. An accurate model to estimate the monetary loss on an annual basis to the zone subjected to all hurricanes;
3. An accurate model to estimate the monetary loss to the zone for some predetermined time period; and
4. Means by which the uncertainty in each of the models above can be quantified.

2.5 Loss Estimation Consulting Needs in the Caribbean

On the basis of the information presented in Section 2.3 and Section 2.4, we can begin to identify areas of hurricane loss estimation consulting needs in the Caribbean. The consulting services needed would be those that are necessary to operationalize the models listed in Section 2.4. To build the models, consultation will be needed on at least three levels:

1. Definition of losses to be estimated,
2. Development of algorithms to estimate the losses, and
3. Development of data bases to provide input into the algorithms.

Definition of losses might include losses due to structural and content damage in the single structure, the structural class, and the zone. Development of algorithms to estimate the losses might include algorithms for structural and content damage in single structures, a structural class, and the zone. These models should contain modules that explicitly consider the hazard to the structure (and its contents) or classes of structures (contents), the exposure

of the structure or class of structures, and the vulnerability of the structure or class of structure. The form and details of the models would dictate the input data needed to initialize the models.

Table 2.1: Probable Maximum Loss of Wood-Frame Dwellings in Magnitude 6.5 Earthquakes (From Steinbrugge and Algermissen, 1990)

Building Characteristics	Probable Maximum Loss (PML) At Zero Deductible			
	Author's Data		Ins. Co. A	
	1971 San Fernando ***Value (Table 8)	1983 Coalinga Market Val. (Table 13)	1983 Coalinga Insured Val. (Table 20)	Judgment PML
Wood floors:				
Age Group:				
Pre-1940	26%	19%	..	28%
1940-1949	10%	17%	..	14%
Post-1949	11%	16%	..	12%
All ages	11%	17%	13% to 16%	13%
Concrete floors:				
Age Group:				
Pre-1940	14%	.	..	18%
1940-1949	13%	.	..	14%
Post-1949	11%	.	7%	12%
All ages	11%	12%	8%	13%
Wood or concrete floors:				
Age Group:				
Pre-1940	22%	19%	..	22%
1940-1949	11%	16%	..	14%
Post-1949	11%	14%	8%	12%
All ages	11%	15%	10%	13%

*Not meaningful.

**Less than 50 dwellings.

***Authors' data are market values, but are same as insured values for new construction.

3.0 DETERMINATION OF WHAT A LOSS CALCULATION SHOULD CONTAIN

3.1 Background and Objective

Note that since we will not be using the PML methodology discussed in Section 2.0, we will not be referring to the calculations in this section as PML calculations. Instead, to reduce confusion, we will refer to the procedures as loss calculations. The objective of this section is to identify in more detail what a loss calculation should contain. We accomplish this objective by: (1) listing which loss calculations are to be performed, (2) discussing a general scheme for estimating cost of damage, then, (3) listing what is required based on the general scheme.

3.2 Listing of Types of Loss Calculations

The types of loss calculations that need to be performed follow directly from Section 2.4. From the detailed listing of what might comprise the ideal state of hurricane related loss estimation knowledge, we can identify the following nine types of loss calculations:

1. Estimate loss for a single structure subjected to a single hurricane,
2. Estimate loss for a class of structures subjected to a single hurricane,
3. Estimate loss for a zone subjected to a single hurricane,
4. Estimate annual loss for a single structure subjected to all hurricanes,
5. Estimate annual loss for a class of structures subjected to all hurricanes,
6. Estimate annual loss for a zone subjected to all hurricanes,
7. Estimate loss to a single structure over specified period of time,
8. Estimate loss to a class of structures over specified period of time, and
9. Estimate loss to a zone over specified period of time.

Most studies to date are of the type described in Item 3 above. However, a knowledge of all nine types of calculations will greatly increase the insurer's capability to consider other financial options.

3.3 General Scheme for Estimating Losses

The general scheme for estimating losses is summarized in Figure 3.1. The figure holds for evaluations of both the single structure and a class of structures; however, inputs such as vulnerability and exposure will vary for the two cases. In the figure, the expected cost of damage resulting from the hurricane is a function of the probability of occurrence of the hurricane, here referred to as the risk of the hurricane, and the cost of the damage. The expected cost is determined via the use of Algorithm A1. The cost of damage is a combination of the cost of structural damage, the cost of damage to the nonstructural elements, and the cost of damage to the contents. By structural damage we mean damage to the main load resisting portions of a structure, such as the frame and foundation. By nonstructural damage, we mean such items as ceilings and interior partitions. These costs are combined to give the total cost via the Algorithm A2. The schema for computing the constituent costs is the same in all cases. For example, the cost of structural damage is a function of the modified hazard to the structure and the vulnerability of the structure. By hazard, we mean the demand imposed on the structure; by vulnerability, we mean the capacity of the structure to resist the demand. The hazard and the vulnerability are combined to yield the cost of structural damage via Algorithm A3. The nominal hazard is modified at the site (i.e., magnified or diminished) by the exposure of the structure. Hazard modification is accomplished via Algorithm A4. Similar algorithms are utilized to obtain the

cost of nonstructural and content damage. Note that the methodology utilized here is the basic approach in any loss estimation; essentially the hazard and the vulnerability of the structure are first defined then brought together in a risk analysis to form the loss estimate (see FEMA, 1989 and Chiu, 1994).

3.4 Required Variables and Algorithms for Loss Estimation

From Figure 3.1, we can identify the following eight input elements that are needed to estimate the cost of damage to a single structure or a class of structures:

1. The risk of the hurricane,
2. The hurricane magnitude,
3. The exposure of the structure,
4. The vulnerability of the structure,
5. The exposure of the nonstructural elements,
6. The vulnerability of the nonstructural elements,
7. The exposure of the contents, and
9. The vulnerability of the contents.

In addition to these nine items, two other inputs have to be mentioned, although they may be implied by the hazard. The two items are:

1. The hurricane profile, and
2. The hurricane trajectory.

How these eleven elements are described will depend upon the details of the particular loss estimation model. For example, the hurricane magnitude may be expressed as a wind speed

or as a pressure and the vulnerability of the structure may also be expressed in terms of wind speed or load.

In addition, in order to generate an expected cost of damage, the following eight algorithms must be present:

1. An algorithm to compute expected cost as a function of risk of hurricane and total cost of damage;
2. An algorithm to compute total cost of damage as a function of costs of structural damage, nonstructural damage, and damage to contents;
3. An algorithm to compute the cost of structural damage as a function of the modified hazard to the structure and the vulnerability of the structure;
4. An algorithm to compute the modified hazard to the structure as a function of the exposure of the structure and the hurricane magnitude;
5. An algorithm to compute the cost of nonstructural damage as a function of the hazard to the nonstructural elements and the vulnerability of the nonstructural elements;
6. An algorithm to compute hazard to the nonstructural elements as a function of the exposure of the nonstructural elements and the hurricane magnitude;
7. An algorithm to compute the cost of content damage as a function of the hazard to the contents and the vulnerability of the contents; and
8. An algorithm to compute the hazard to the contents as a function of the exposure of the contents and the magnitude of the hurricane.

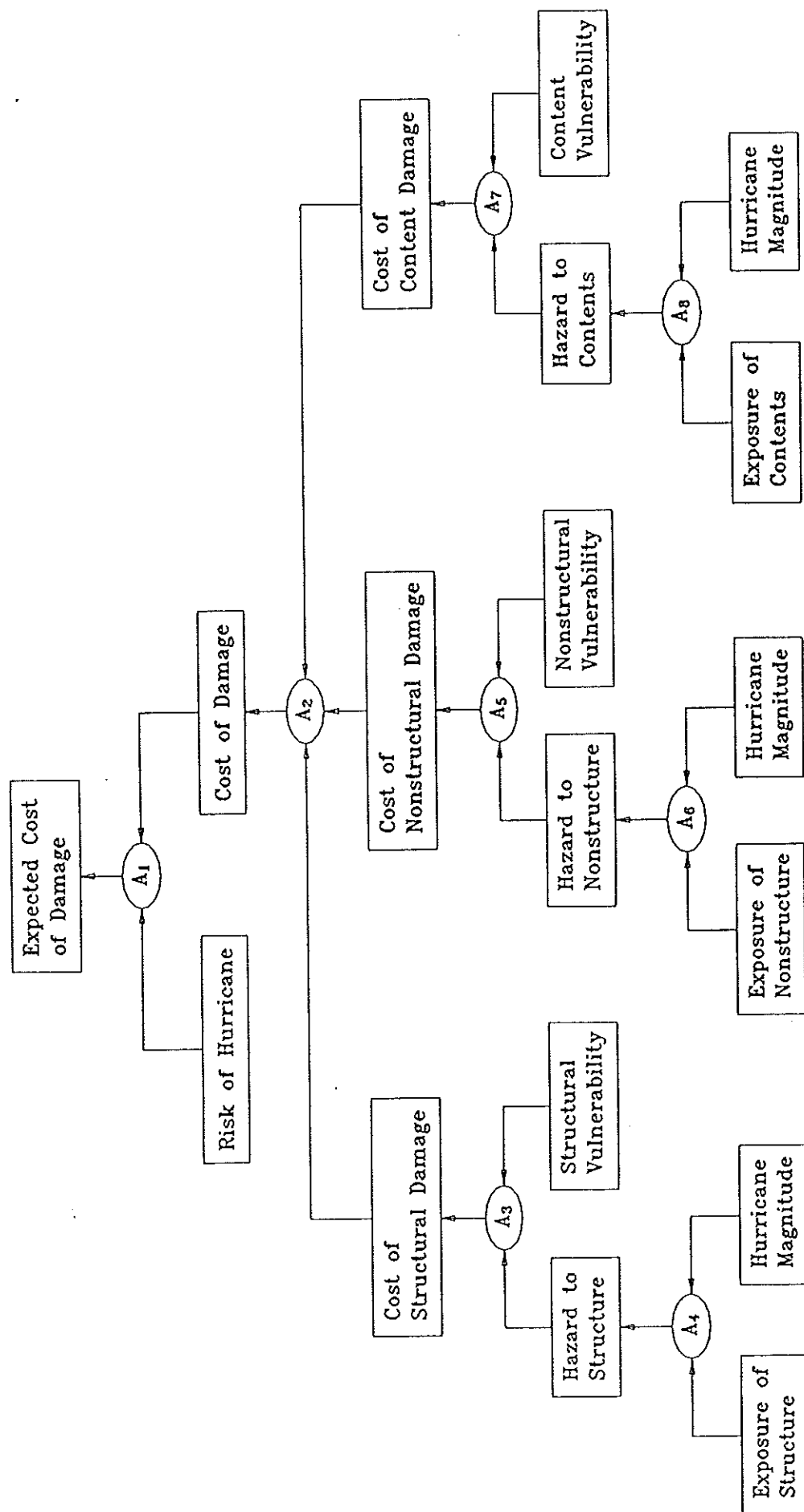


Figure 3.1. Generalized Scheme for Estimating Damage

4.0 IDENTIFICATION OF SOURCES OF INFORMATION FOR INPUT INTO LOSS CALCULATIONS

In the last section, we identified eleven variables and eight algorithms that are needed for input into a loss estimation calculation. Information on these variables can be obtained from the following sources:

1. Meteorological records,
2. Post-disaster studies in the Caribbean,
3. Caribbean building codes,
4. Field inspections of buildings during construction,
5. Field inspections of existing buildings,
6. Insurance payout records in the Caribbean, and
7. Expert opinion from Caribbean design/construction professionals.

Below we relate these seven sources of information to the eleven input variables needed for the loss calculation.

Information on hurricane risks as a function of hurricane magnitude can be found primarily in meteorological records; some information can also be found in building codes. Estimates of hurricane wind speeds above normal building heights are obtained from meteorological records. Estimates of the hurricane magnitude at building level can be obtained from post-disaster studies and by utilizing wind speed profile-height relationships provided in building codes. Information on the profile and trajectories of hurricanes is obtained primarily from meteorological records; additional information on hurricane profile and trajectory may be obtained from post-disaster studies.

Information on the exposure of the structure can be obtained from post-disaster studies, codes, field inspections, and local building professionals. Information on the vulnerability of the structure can be obtained from all sources mentioned except meteorological records and insurance payout records. Post-disaster studies, field inspections of structures (during and after construction), and local building professionals will provide information on the exposure of nonstructural elements and the exposure of contents. Information on the vulnerability of the nonstructural elements will be provided by the same set of sources named in the latter sentence with the addition of insurance payout records. Finally, information on the vulnerability of contents can be gleaned from post-disaster studies, field inspections after construction, insurance payout records, and local building professionals.

5.0 CLASSIFICATION SCHEMES FOR STRUCTURES

5.1 Background and Objective

There are two steps involved in establishing the vulnerability of buildings in a zone: developing an inventory of the buildings to be considered in the study, and establishing for each inventory category the relationship between hurricane magnitude and cost of damage. The objective of this section is to provide some guidelines for classifying buildings for loss analysis in the Caribbean Region. We achieve this objective in two steps: we discuss the development of appropriate classification criteria, then we provide some examples of existing classification schemes.

5.2 Classification Criteria

The development of classification criteria for the resulting classification system should be guided by considerations such as:

1. The buildings that end up in a single category should be described by the same vulnerability characteristics,
2. The number of categories selected should be finite and manageable,
3. The classification criteria should evolve from the engineering and cultural history of the specific region being studied, and
4. The classification system should be logically developed and internally consistent.

By internally consistent we mean that each term should be defined and used in a consistent way throughout the classification. In addition, each category should permit logical subdivisions which can be clearly defined and further subdivided to the extent that appears necessary and useful.

Some classification criteria that have been used to date include the following:

1. Construction material and number of stories,
2. Extent of professional engineering attention (i.e., no engineering to being fully engineered),
3. Code used and time period, and
4. Time period and number of stories.

5.3 Examples of Classification Systems

In setting up a functional classification system for buildings three tasks must be performed:

1. Categories are identified,
2. Each category is given a precise and useable definition, and
3. Consensus among users of the classification system is sought.

In Table 5.1 to Table 5.3, we present three different classification schemes. A classification scheme used in computing earthquake related losses is described in Table 5.1. Note that in the table, the classification criteria for the system included building material, number of stories, and footprint of the building. In Table 5.2 is described a building classification scheme utilized to perform a loss estimation of a portfolio of buildings in the greater New Orleans Area. In this case the classification criteria include period of construction and number of stories. Note also that in this case the building categories selected correlated very highly with certain aspects of the history of the study area. Finally, in Table 5.3, the classification scheme for general loss estimation in a wind environment is described. This

scheme utilizes classification criteria of building material, usage (i.e., residential or commercial), and number of stories.

Table 5.1: Construction Classes Used in the ISO and NOAA/USGS Methods

Building Class	Brief Description of Building Subclasses
1A-1	Wood-frame and stuccoed frame dwellings regardless of area and height
1A-2	Wood-frame and stuccoed frame buildings, other than dwellings not exceeding three stories in height or 3,000 square feet in ground floor area
1A-3	Wood-frame and stuccoed frame structures not exceeding three stories in height regardless of area
1B	Wood-frame and stuccoed frame buildings not qualifying under class 1A
2A	One-story, all metal; floor area less than 20,000 square feet
2B	All metal buildings not under 2A
3A	Steel frame, superior damage control features
3B	Steel frame, ordinary damage control features
3C	Steel frame, intermediate damage control features (between 3A and 3B)
3D	Steel frame, floors and roofs not concrete
4A	Reinforced concrete, superior damage control features
4B	Reinforced concrete, ordinary damage control features
4C	Reinforced concrete, intermediate damage control features (between 4A and 4B)
4D	Reinforced concrete, precast reinforced concrete, lift slab
4E	Reinforced concrete, floors and roofs not concrete
5A	Mixed construction, small buildings and dwellings
5B	Mixed construction, superior damage control features
5C	Mixed construction, ordinary damage control features
5D	Mixed construction, intermediate damage control features
5E	Mixed construction, unreinforced masonry
6	Buildings specifically designed to be earthquake resistant

Table 5.2: Construction Classes Used for a Hurricane Loss Study in New Orleans

Building Class	Description
1	Pre-1940: 1 Story
2	Pre-1940: 2 Story
3	(1940-1960): 1 Story
4	(1940-1960): 2 Story
5	(1960-1980): 1 Story
6	(1960-1980): 2 Story
7	Post-1980: 1 Story
8	Post-1980: 2 Story

Table 5.3: Partial Construction Classes Used for Loss Estimation in Hurricanes

Building Class	Description
a	Wooden, Single story, Residential
b	Wooden, Single story, Commercial
c	Wooden, Multiple Stories, Residential
d	Wooden, Multiple Stories, Commercial
	etc.

6.0 CHARACTERIZATION OF THE HURRICANE HAZARD FOR LOSS CALCULATIONS

6.1 Background and Objectives

Up to this point in the paper, we have focused on the qualitative aspects of hurricane-related losses. We have also discussed, in a qualitative manner, how to go about developing an appropriate classification scheme for buildings in a particular zone of interest. Ultimately, we need to have a better feel for how loss calculations are actually performed for single structures, classes of structures, and for structures in a zone of interest. We begin the quantitative journey in this section by summarizing the characterization of the hurricane hazard for loss calculations. We meet this objective by describing (1) hurricane risk models, (2) hurricane profiles, and (3) hurricane trajectories.

6.2 Hurricane Risk Models

In order to define a hurricane risk model, we need to know, for a specific location in the Caribbean, the probability that wind speed of a certain magnitude, say V_o , will be exceeded in a given year. A typical format for such information is provided in Table 6.1 for two hypothetical resort locations: Reggae Cay and Calypso Beach. These data can be constructed from historical records of hurricanes that have passed a given location and/or numerical simulations of such hurricanes. A typical plot of the extreme wind risk for one of the example locations is shown in Figure 6.1.

Once such a risk curve has been established, it becomes possible to define hurricanes of various magnitudes and assign probabilities of occurrences to those hurricanes. The procedure for selecting hurricane risk and hurricane magnitude pairs is shown graphically in Figure 6.2. In the figure, the probability of occurrence of an extreme event whose

magnitude is between wind speeds V_1 and V_2 is P (where $P = P_1 - P_2$). Note that P_1 is the annual probability of exceedence of V_1 and P_2 is the annual probability of exceedence of V_2 . Using this scheme on the hypothetical data in Table 6.1, we obtain the annual hurricane probabilities that are summarized in Table 6.2. Thus if data on the annual probability of exceedence can be developed for a given location, the hurricane risk model for the location can be straightforwardly developed.

6.3 Hurricane Profiles

In considering the damage inflicted by a particular hurricane, it is sometimes useful to have some knowledge of the hurricane profile. The hurricane profile is a plot of atmospheric pressure versus distance from the center of the hurricane. For damage calculations a plot of wind speed versus distance from the center is perhaps more useful. A plot of wind speed versus distance for an early model of hurricane profile is shown in Figure 6.3.

6.4 Hurricane Trajectories

In computing the long-term risk at a site, it might be of interest to take into consideration the historical trajectories of hurricanes. In Figure 6.4 we show the trajectories of all hurricanes in the Northern Atlantic during the period of 1886 to 1977. The majority of such hurricanes occur during the month of September; the trajectories for those hurricanes are shown in Figure 6.5.

Table 6.1: Annual Probability of Exceedence at Selected Sites

Annual Probability of Exceedence	Wind Speed (Fastest Mile)	
	Reggae Cay	Calypso Beach
0.002	126	133
0.005	115	121
0.010	105	111
0.020	95	100
0.040	85	89
0.100	69	73
0.200	49	52
1.00	46	48

Table 6.2: Probability of Occurrence for Hurricanes at Selected Sites

Category	Range mph	Annual Probability of Occurrence	
		Reggae Cay	Calypso Beach
1	74-96	.052	.064
2	97-110	.013	.016
3	111-130	.0056	.0075
4	131-150	.0011	.002
5	> 150	.0003	.0005

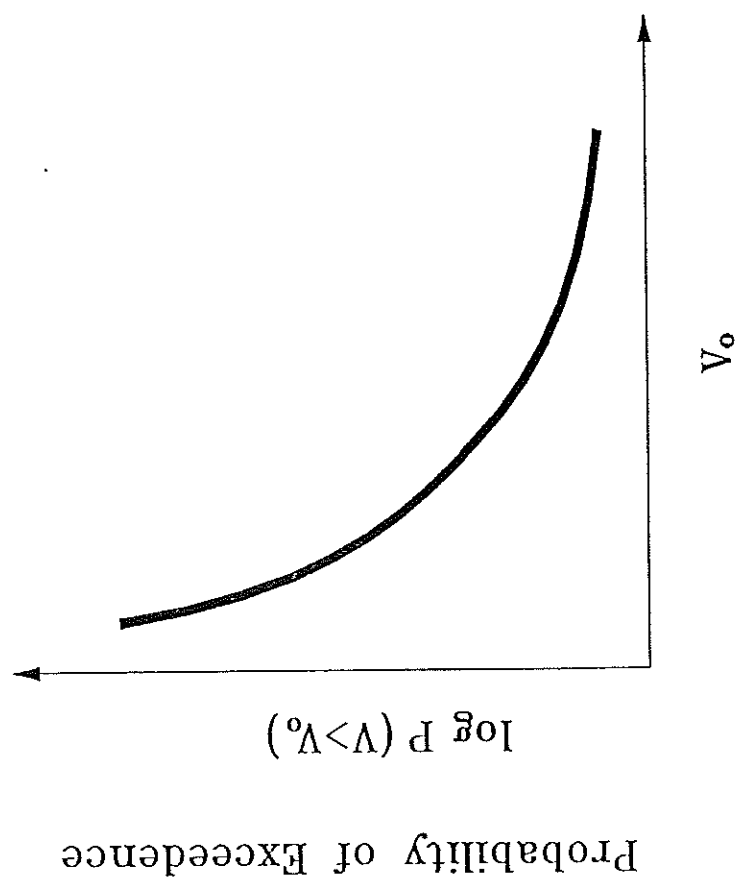


Figure 6.1 Extreme Wind Risk Curve

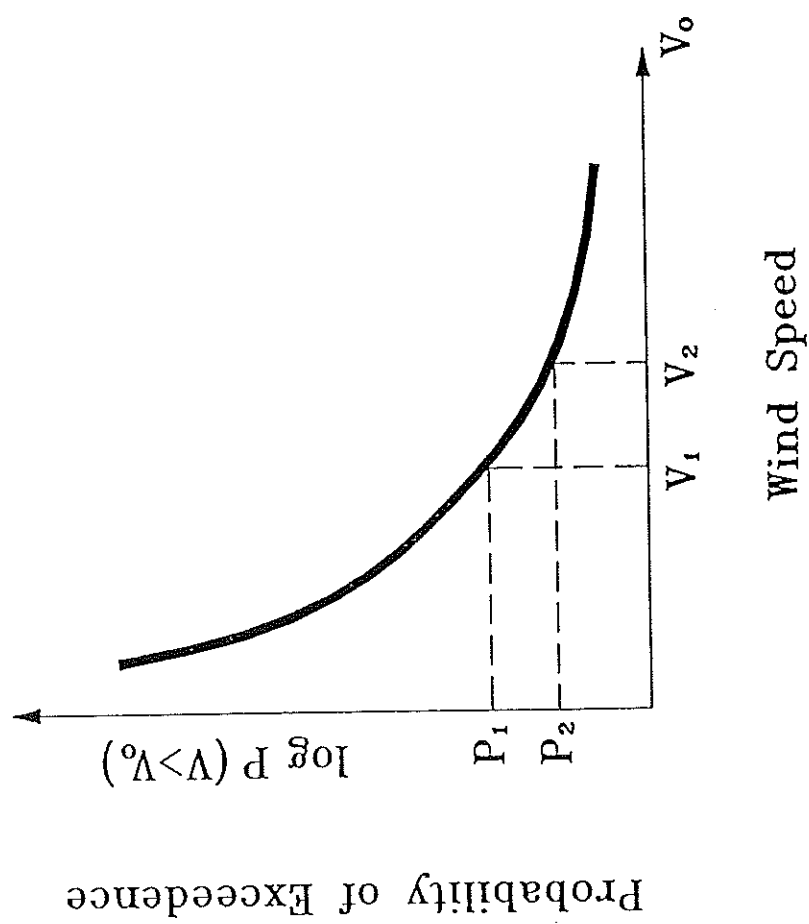


Figure 6.2 Probability of Occurrence for Hurricane of a Given Magnitude

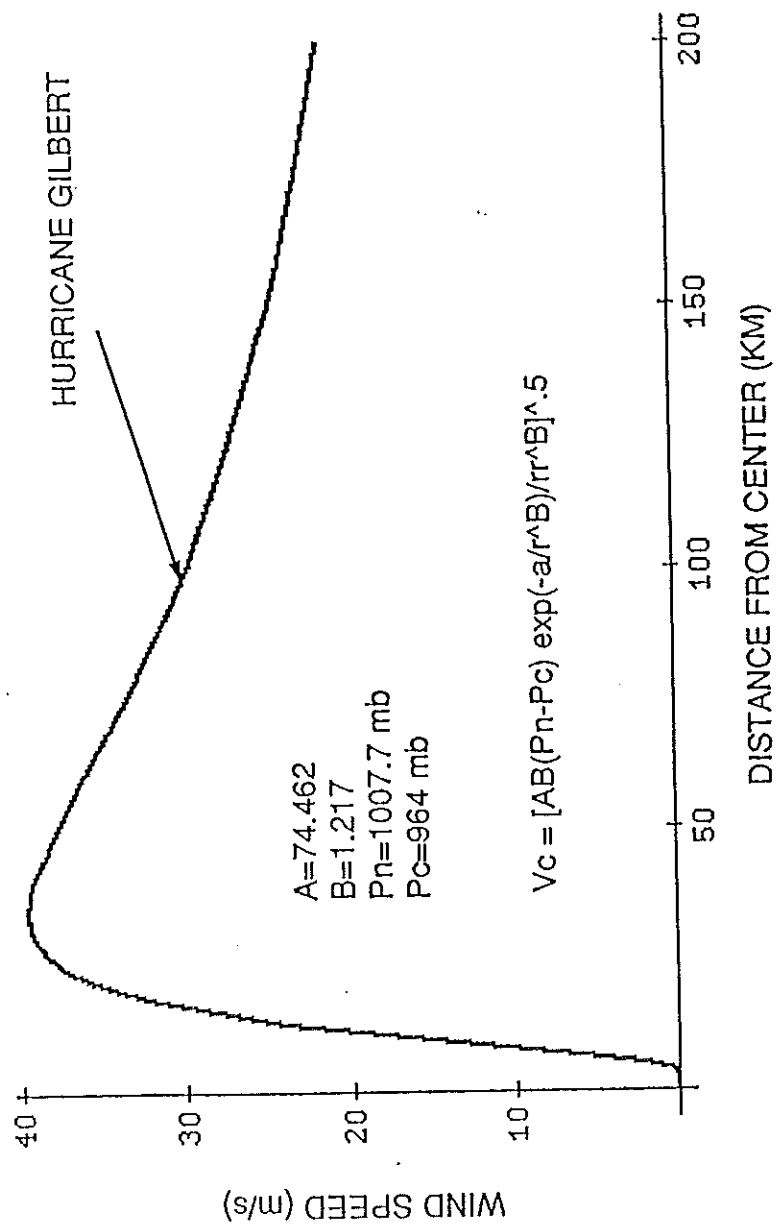


Figure 6.3 Wind Speed Profile for Hurricane Gilbert (1988)

TROPICAL CYCLONES, 1886-1977

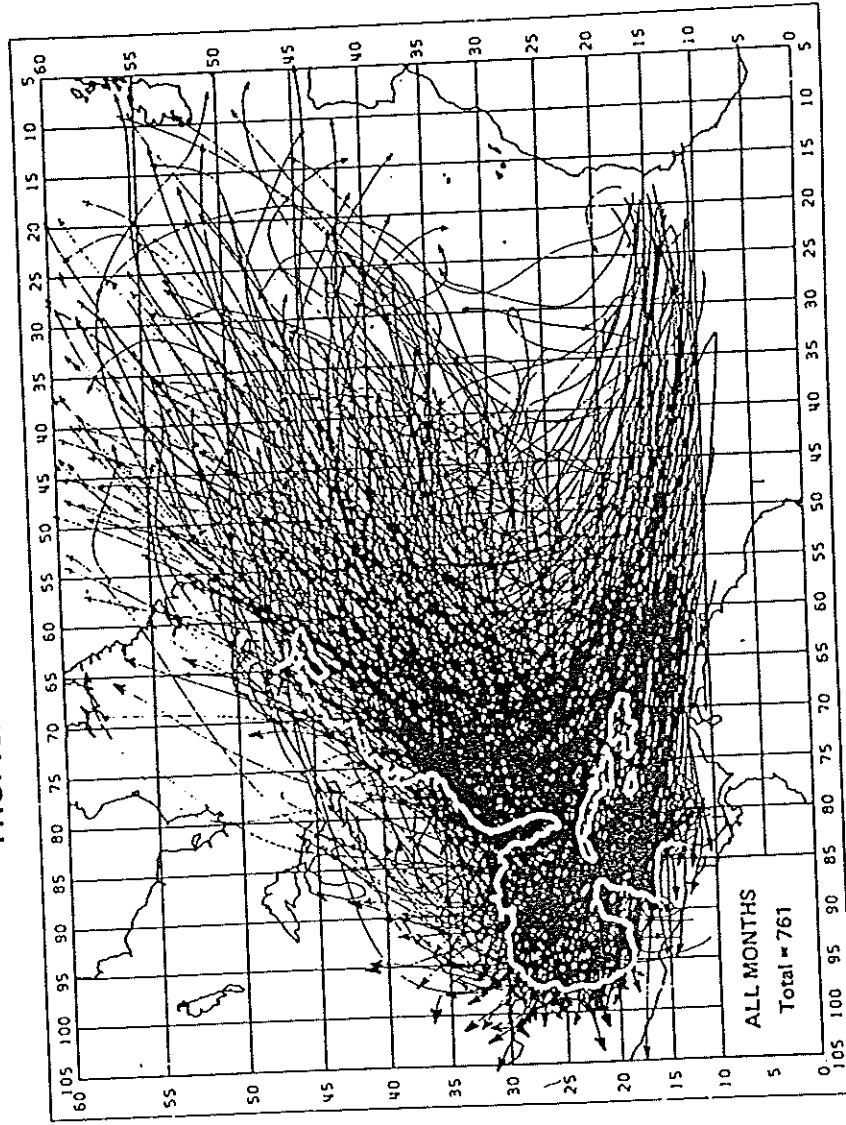


Figure 6.4 Trajectories for Hurricanes: 1886-1977 (Courtesy Dr. Dale Perry)

TROPICAL CYCLONES IN SEPTEMBER, 1886-1977

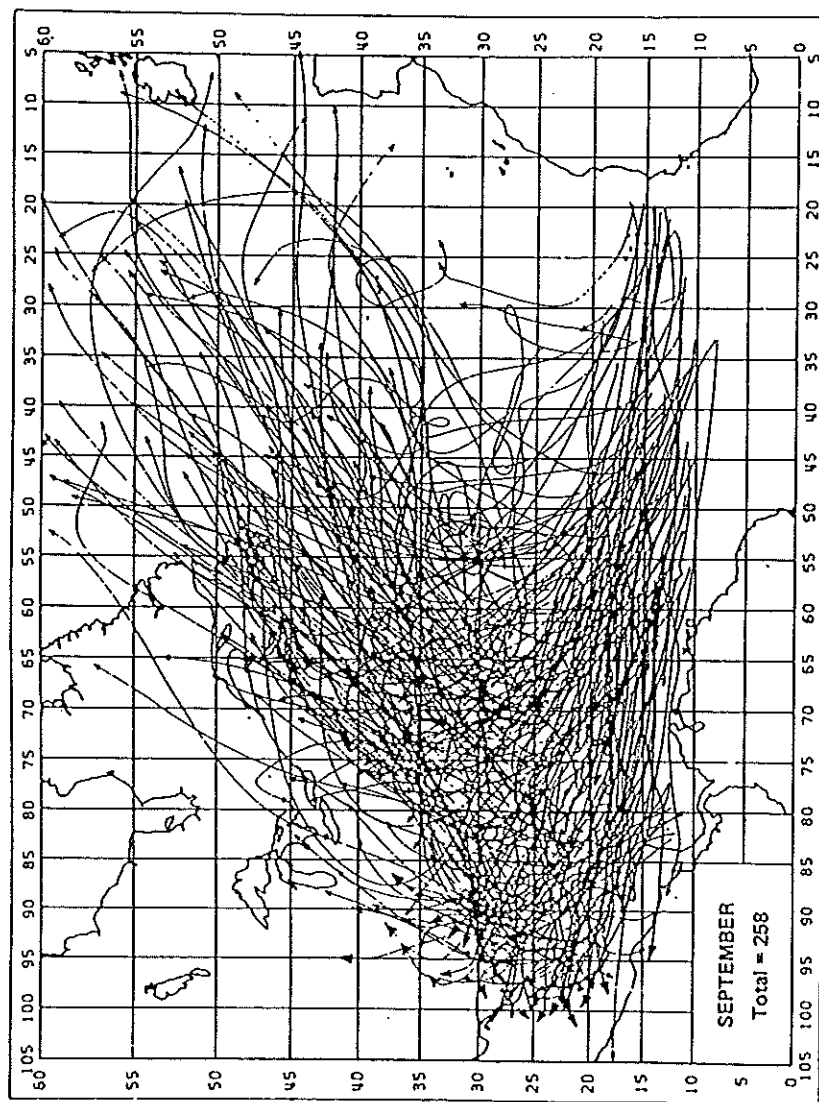


Figure 6.5 Trajectories for Hurricanes in September: 1886-1977 (Courtesy Dr. Dale Perry)

7.0 ESTIMATION OF COST OF STRUCTURAL DAMAGE

7.1 Background and Objectives

In the last section, we characterized the hurricane risk model, discussed hurricane profiles, and reviewed hurricane trajectories. That exercise constituted the definition of the hazard. The objective of this section is to provide one method of estimating the cost of structural damage. Other consultants may use less or more detailed methods to reach the same end. Furthermore, other consultants may use pressure instead of wind speed as the independent variable. We accomplish this objective by (1) proposing a general system failure model for buildings in terms of the building components, (2) developing a set of damageability models for the various building components, (3) writing expressions for the mean structural damage ratio of a building in terms of the component damageability, and (4) providing an example to show how the mean damage ratio can be calculated in hurricanes of various magnitudes.

7.2 System Failure Model for Buildings

We will develop our model for the cost of structural damage in four steps by: (1) identifying the basic failure modes in a building, (2) examining extreme system failure models that might explain the failure modes, (3) proposing system failure models that might more closely reflect the behavior of real structures, and (4) providing a simple example.

On the bases of many vulnerability analyses of buildings in wind environments, we have identified the following basic failure modes in buildings:

1. Roofing failure,
2. Roof decking failure,

3. Roof framing failure,
4. Roof frame-wall connection failure,
5. Lateral Bracing Failure,
6. Cladding Failure,
7. Openings Failure,
8. Frame-Foundation Connection Failure, and
9. Foundation Failure.

Two extreme system failure models using these nine components are shown in Figure 7.1 and Figure 7.2. The two figures represent the extremes of system behavior. In Figure 7.1, we have a so-called "weakest link" or series system in which the system fails if a single component fails. Buildings certainly do not follow this behavior. For example, if the roof covering in a multi-story structure fails, certainly some damage is incurred by the structure but the structure will not have failed. In Figure 7.2, we have at the other extreme a so-called "parallel system" in which system failure occurs only after each and every component has failed. Again this model is false for a structure. Wind may rip the cladding off the building while the frame still stands.

It is more likely that a structure will fail when not all components or a single component fails but rather when some of the basic components fail. That is, the system behaves somewhere in between the two extreme system models. A general mathematical equation which describes such systems, in which system failure is governed by the loss of some components, is given by:

$$P_f = \sum_{i=1}^N (w_i X_i^P)^{1/P} \quad (7.1)$$

where

P_f = the failure probability of the system,

w_i = is a weighting factor related to the relative importance of the component,

X_i = is a measure of the failure probability of the i^{th} component, and

P = is a parameter which determines the behavior of the system

A schematic of the behavior of the model in Equation (7.1) is shown in Figure 7.3. If, by analogy, we associate (1) the failure probability of the system, P_f , with the mean damage ratio, dr_s^v , sustained by the structure, and (2) the failure probability of the i^{th} component with the damage ratio of the i^{th} component, dr_i , then a model for the mean damage ratio of a structure in terms of the damage ratio of the components becomes:

$$dr_s = \sum_{i=1}^N (w_i dr_i^P)^{1/P} \quad (7.2)$$

Note that by damage ratio we mean the quotient of the cost to repair/cost to replace. Thus to completely specify our loss model, we need to (1) develop expressions for component damage ratios dr_i , (2) select values for the weights W_i , and (3) select values for the parameter P . The magnitude and form of these expressions will depend upon the type of structure and the class of structure.

7.3 Component Damageability Models

In order to estimate the mean damage ratio for a single building or a building class as a function of the hurricane magnitude, we first generate the "component damageability"

model, dr_i , for the building or class. In the way it is used here, a component damageability mode is analogous to a failure mode in the reliability sense (Thoft-Christensen and Baker, 1982). From Figure 7.4, the modes of component damageability identified in the model include the following:

1. Damageability of the Roof Covering,
2. Damageability of the Roof Decking,
3. Damageability of the Roof Framing
4. Damageability of the Roof Frame-Wall Connection,
5. Damageability of the Lateral Bracing System,
6. Damageability of the Openings,
7. Damageability of the Cladding,
8. Damageability of the Frame-Foundation Connection, and
9. Damageability of the Foundation.

Each damageability component curve expresses the mean damage ratio as a function of wind speed. Mean damage ratios are used here because, in a single structure, they represent the expected behavior of a component; in a class of structures they represent the average behavior of all structures in that class. Note that mean damage ratios do not give the distribution on the damage (e.g., how many buildings experienced minor or severe damage). The mean damage ratio directly estimates property loss. Note also that once a functional form of $dr_i(v)$ is selected, we can use probability theory to estimate the distribution of dr_i as a function of uncertainty in the parameters that define dr_i .

For each of the above nine damageability modes, we assume that a damageability curve of the type shown in Figure 7.5 exists. For example, for the i^{th} damage mode, the damage ratio $dr_i(V)$, where V is the wind speed (i.e., the hazard to the building), is given by

$$dr_i(V) = \begin{cases} 0 & v \leq a_{i1} \\ \frac{v - a_{i1}}{a_{i2} - a_{i1}} & a_{i1} < v \leq a_{i2} \\ 1 & v > a_{i2} \end{cases} \quad (7.3)$$

where a_{i1} and a_{i2} are the expert-supplied constants that represent, respectively, speeds at which damage will commence and end in that mode (i.e., the vulnerability of the structure). Estimates of constants a_{i1} and a_{i2} , for class of 1-2 story wooden structures along the Texas Coast, are listed in Table 7.1. Note that constants a_{i1} , and a_{i2} will change with the class of structure. They will also differ for the single structure versus the class of that structure. At this early stage in the art of loss estimation, we feel justified in selecting a simple representation of a component damageability curve. When more appropriate data become available, we can then compare model predictions with the data and, on the basis of such comparisons, continue to refine the models.

Other appealing features resulting from relating the damage ratio of the structure to the damage ratio of the components are that the adjustments can be directly related to such aspects as (1) the quality of the building by components, (2) the existing condition of the building by components, and (3) prevailing construction practices by components can be reflected in the selection of the constants a_{i1} , and a_{i2} .

7.4 Damage Ratio for Structures

Using arguments similar to those used for the justification of the selection of piecewise linear component damageability functions, we select here one of the more simple versions of Equation (7.1); namely, in Equation (7.1), we set $p = 1$ and determine the weights, w_i from a consideration of the relative importance of component i . An indication of how values are assigned to the relative importance constants I_i is also provided in Table 7.2. Note that the relative importance of a particular mode will depend upon the building class. For example, the consequences of the loss of roofing in a multi-story building is quite different than the consequences of the same event in a single-story structure. In fact, in a hurricane environment, the ultimate consequences of losing a roof in a single story masonry structure may be quite different from losing the roof in a single story wooden structure. In the case of the masonry structure, the walls may remain standing after the loss of the roof. In the case of the wooden structure, it is unlikely that the framing would remain intact.

The mean damage ratio for the single building or building class as a function of wind speed $dr_s(V)$ is thus estimated by the expression:

$$dr_s(V) = \frac{\sum_{i=1}^9 I_i dr_i(V)}{\sum_{i=1}^9 I_i} \quad (7.4)$$

where expert-supplied constants I_i represent the relative importance of the contribution of the consequence of damage in the i^{th} mode to the damage ratio of the completed structure.

7.5 Example: Determination of Mean Structural Damage Ratio

Problem: A class of buildings in Calypso Bay consisting of 1-2 story wooden structures is subjected to all five levels of hurricanes shown in the first and second column of Table 7.3. A more detailed description of the component's composition is shown in Table 7.4. If the damageability function of the building class is described by Equation (7.4) and the constants a_{i1} and a_{i2} are given by those in Table 7.1, compute the mean structural damage ratio for each hurricane and plot the damageability curve for the structure.

Solution: The damageability function for mode i is given by

$$dr_i(V) = \frac{V - a_{i1}}{a_{i2} - a_{i1}},$$

On using the values in Table 7.1, the damageability function for Roof Covering Damage is

$$dr_1(V) = \frac{V - 55}{110 - 55},$$

Similarly the damageability function for Decking Damage is

$$dr_2(V) = \frac{V - 86}{129 - 86}, \quad \text{etc.,}$$

Using the importance factors given in the second column of Table 7.1, the mean damage ratio for the structure is given by

$$dr_s(V) = \left\{ \frac{(V - 55)}{110 - 55} + \frac{2(V - 86)}{129 - 86} + \frac{3(V - 85)}{127 - 85} \dots + \frac{3(V - 115)}{150 - 115} \right\} / (1 + 2 + 3 + 3 \dots + 3)$$

Substituting in the above equation for the mean hurricane wind speeds shown in the second column of Table 7.3, we obtain the damage ratios shown in the third column of Table 7.3. For example,

$$dr_s(85) = \left\{ \frac{\frac{85-55}{110-55} + 0 + 0 + 0 + \frac{3(85-80)}{100-80} + 0 + \frac{85-60}{110-60} + \frac{85-80}{120-80} + 0 + 0}{23} \right\}$$

$= 0.08$

From the table, we expect a mean damage ratio of 0.08 in a Category 1 hurricane, a 0.44 mean damage ratio in a Category 2 hurricane, etc... A plot of the mean structural damage versus wind speed is shown in Figure 7.6. Note that although the underlying curves for the components were assumed to be piece-wise linear, the composite curve for the structure has the characteristic sigmoidal shape.

Table 7.1: Estimates of a_{i1} and a_{i2} for 1-2 Story Wooden Buildings, Texas Coast

Damage Mode	Relative Importance of Mode I_i	Resistance Thresholds* (mph fastest mile; Exp. C)	
		a_{i1}	a_{i2}
Roof Covering Damage	1	55	110
Roof Decking Damage	2	86	129
Roof Framing Damage	3	85	127
Roof-Wall Anchorage Damage via Suction	3	94	126
Roof-Wall Anchorage Damage via Suct. & Int Pressure	3	80	100
Building Damage via Failure of Lat. Bracing Sys.	3	90	125
Damage Due to Failure of Openings	1	60	110
Cladding Damage	1	80	120
Frame-Foundation Connection Damage	3	90	135
Foundation Damage	3	115	150

*On basis of Alicia and Elena wind speeds; Analysis of codes; and Expert opinion.

Table 7.2: Assignment of Relative Importance of Component Damageability Mode

Relative Importance of Mode	Numerical Value of Indicator (I_i)
Very Important*	3
Somewhat Important	2
Not Important	1

*To be agree upon by group consensus and empirical evidence

Table 7.3: Summary of Damage to Structure in Hurricanes

Hurricane Category	Hurricane Wind Speed (mph)	Mean Structural Damage Ratio
1	85	0.08
2	103	0.44
3	120	0.76
4	140	0.96
5	160	1.00

Table 7.4: Description of Typical 1-2 Story Building at Calypso Bay

Component	Description of Components
Roofing	15# felt, 220# Composition shingles, "Wind Resistant", 4 nails/shingle
Roof Decking	1/2" Plywood Decking
Roof Framing	Hip roof, 4:12 slope, 2x6 rafters, 2x8 ridgeboard and hip rafters, strongback and purlins
Roof Frame-wall Connections	300# anchor at every other stud to double top plate or rafter
Lateral Bracing, Exterior	1x4 Let-in corner bracing, one brace every 18 ft of wall
Lateral Bracing, Interior	1x4 Let-in for every load bearing interior wall
Cladding	Brick veneer, ties 16" o.c. every stud
Openings	No window protection
Frame-Foundation Connection	Anchor bolts 6 ft o.c., 300# anchor at every other stud to sole plate
Foundation	Non-engineered slab on grade

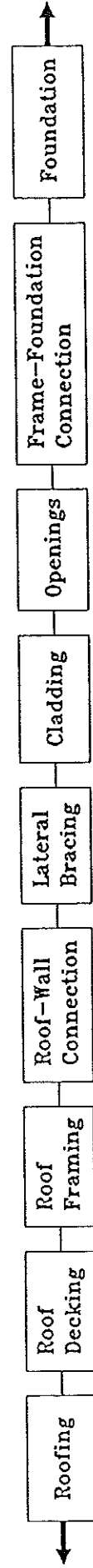


Figure 7.1 Weakest Link (Series) Model

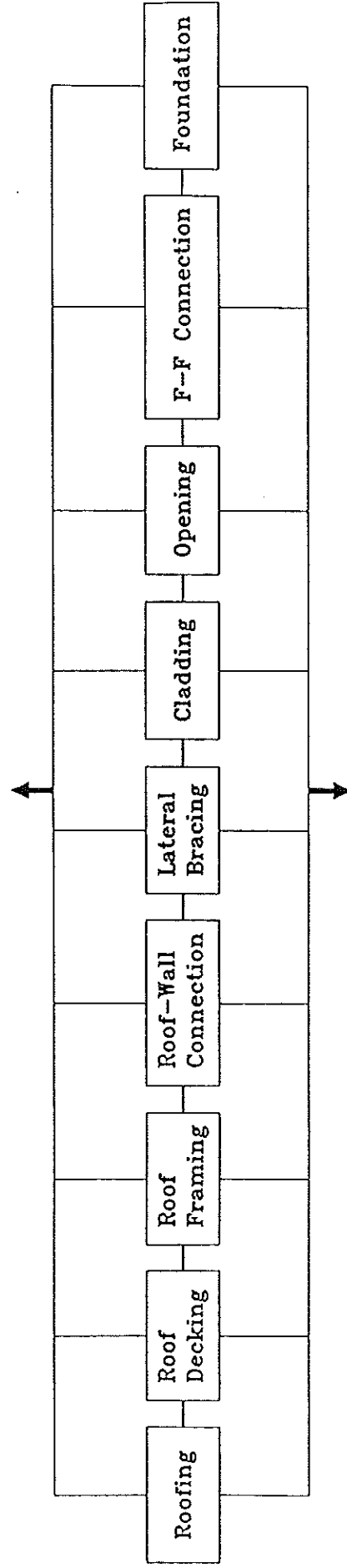


Figure 7.2 Parallel Model

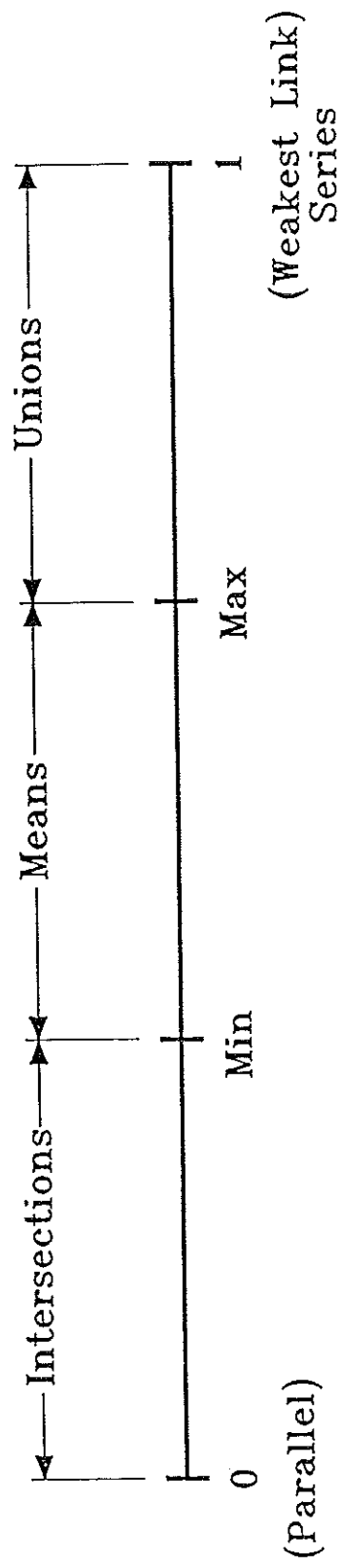


Figure 7.3 Range of Applicability of Probabilistic Systems Models

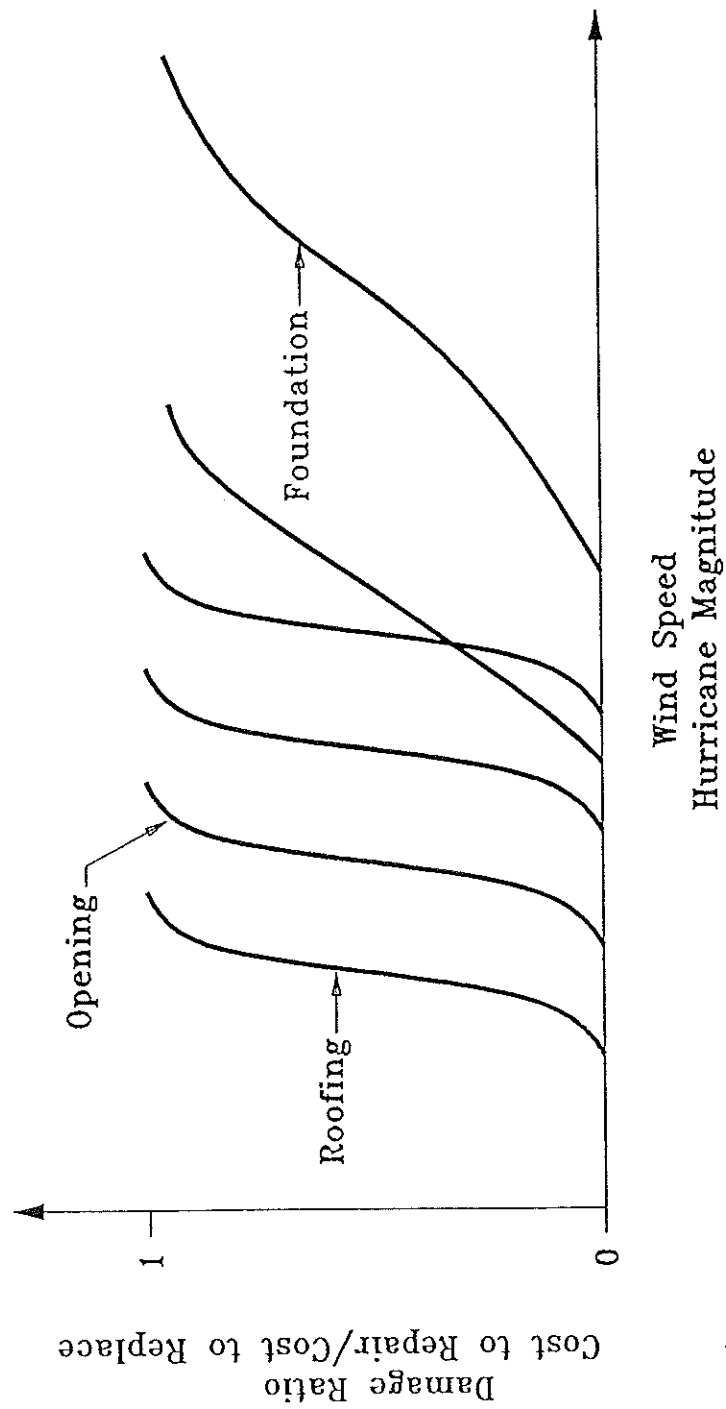


Figure 7.4 Hypothetical Component Damageability Functions for a Single Building or Building Class

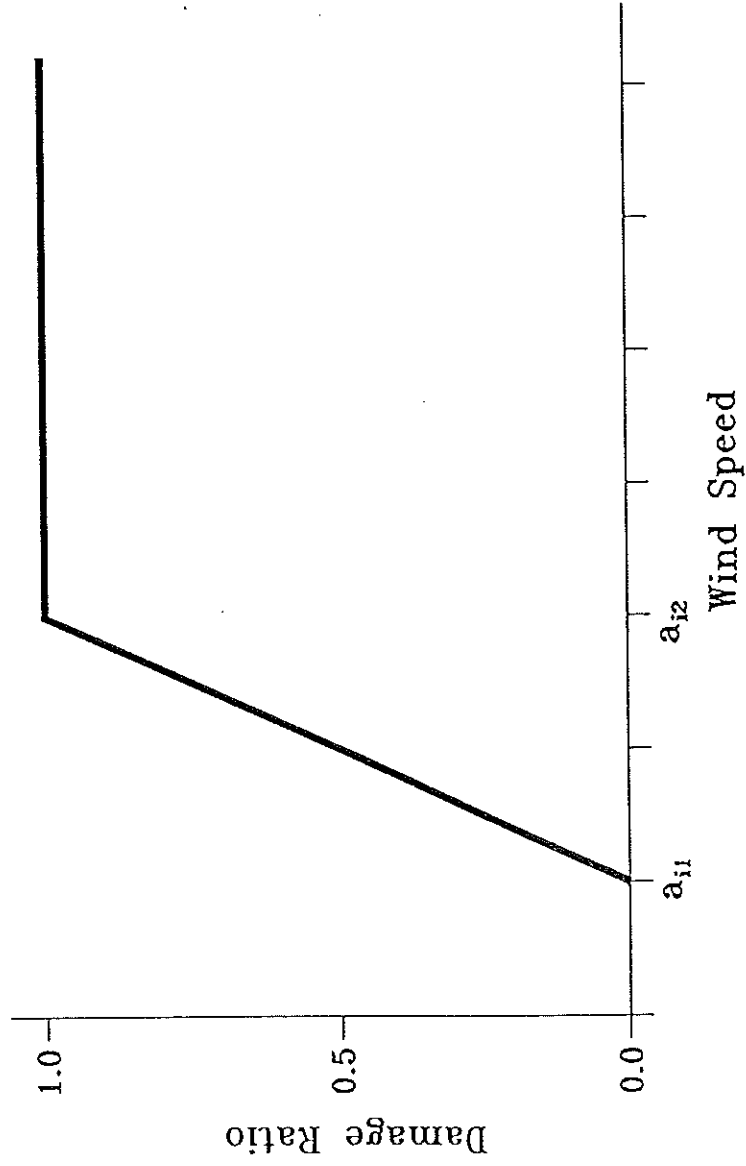


Figure 7.5 Typical Building Component Damageability Curve

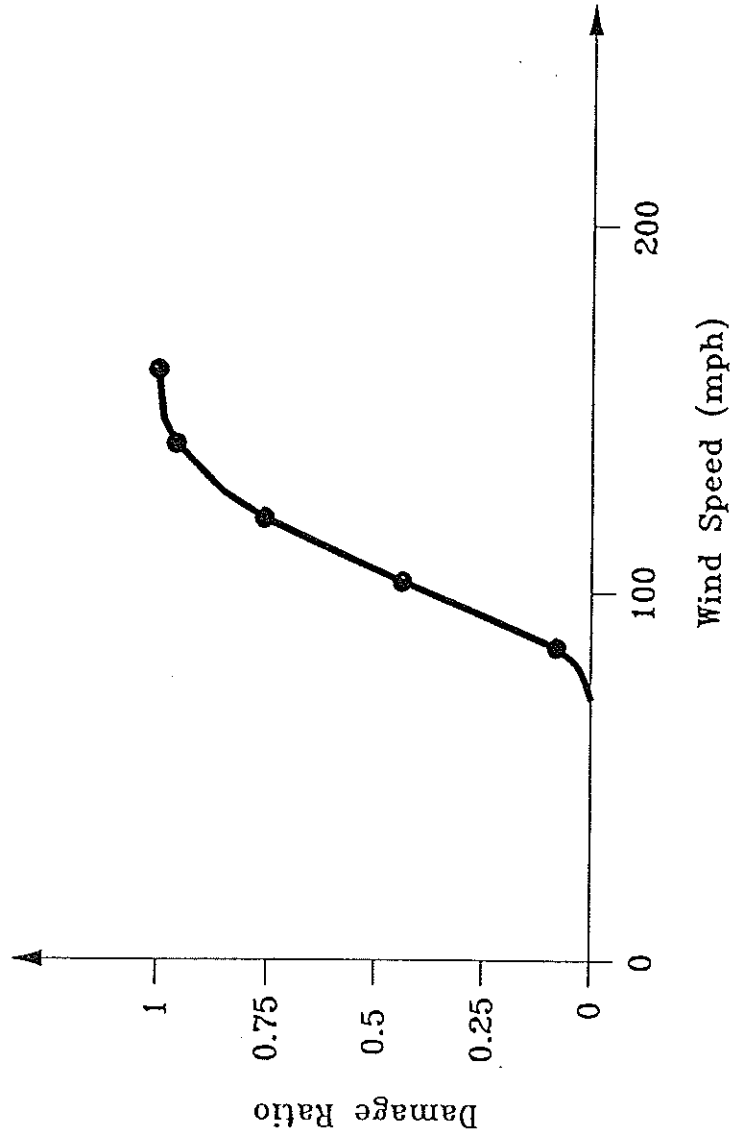


Figure 7.6 Structural Damage Ratio as a Function of Wind Speed

8.0 ESTIMATION OF CONTENT DAMAGE RATIO FOR STRUCTURES

8.1 Overview and Objectives

In many instances, damage to the structure may be insignificant; however, at the same time content damage may be quite severe. Furthermore, depending upon the type of contents in the building, contents may cost more than the structure. The objective of this section is to develop models for content damage comparable to those models developed for structural damage in the last section. We meet this objective by (1) presenting system failure models for content damage, (2) proposing component damageability models for contents, (3) developing expressions for the mean damage ratio for contents, and (4) providing a simple example.

8.2 System Failure Model for Content Damage

A weakest link system failure model for content damage is shown in Figure 8.1. As shown in the figure, content damage may be a consequence of any of the basic failure modes discussed in Section 7.0. Note here that the failure modes corresponding to damage to the lateral bracing, frame-foundation connection, and foundation have all been combined into one mode denoted by "gross structural damage". Using the same logic as that utilized in the last section, the most realistic failure model for damage to contents is given by the model described by Equation (7.1). Now the analogous model for damage to contents becomes:

$$dx_c = \sum_{i=1}^M (w_i dx_{ic}^p)^{1/p} \quad (8.1)$$

where

- W_i = the relative importance of the failure mode,
 dr_{ic} = the mean content damage ratio for the i^{th} content damageability mode,
 P = some parameter, and
 dr_c = the total mean content damage ratio.

8.3 Component Damageability Model for Contents

For contents to be damaged in a particular mode, three things must happen: (1) damage must occur to the structure in that mode, (2) the contents must be exposed, and (3) the contents are damaged given the damage to the structure and the exposure. This sequence of events is correctly modelled using the parallel system shown in Figure 8.2.

We can develop a simple model for the component damageability model for contents using the analogy from probability theory. Let, for example,

- P_i = Probability of roof covering damage,
 ϕ_i = Probability of contents being exposed|roof covering damage, and
 g_i = Probability of content damage|roof covering damage and content exposure

Then the probability of content damage P_{ic} given roof covering damage is

$$P_{ic} = P_i \phi_i g_i \quad (8.2)$$

By analogy, $g_i \equiv dr_i^c$, $P_i \equiv dr_i$, where dr_i^c is the damage ratio to contents given damage to the structure. The quantity dr_i is the same as in the last section.

A simple damageability model for the contents, given damage to component i of the structure, is given by:

$$dr_i^c = \begin{cases} 0 & dr_i \leq bb_{i1} \\ \gamma_i \frac{dr_i - (bb_{i1})}{(bb_{i2} - bb_{i1})} & bb_{i1} < dr_i \leq bb_{i2} \\ \gamma_i & dr_i > bb_{i2} \end{cases} \quad (8.3)$$

The damage ratio of the building component $dr_i(V)$ is discussed above. Expert-supplied constants bb_{i1} and bb_{i2} represent, respectively, the levels of damage to the building components at which damage to contents begins and ends (i.e., the vulnerability of the contents). The constant, γ_i , indicates the maximum level of expected damage to contents.

8.4 Mean Damage Ratio for Contents

The mean content damage ratio for all contents is given by

$$dr_c(v) = \frac{\sum J_i dr_i^c(v) dr_i \phi_i}{\sum J_i} \quad (8.4)$$

where expert-supplied constants J_i represent the relative importance of the contribution of the consequence of damage to component i to the damage ratio of the contents. Note that in Equation (8.3), the damage to the i^{th} building component becomes the hazard to the contents.

8.5 Example

Problem: The second class of buildings in Calypso Bay has contents with average vulnerability (i.e., $bb_1 = 0.015$, $bb_2 = 0.5$, $\gamma = .5$). Compute the mean damage content ratio for all hurricanes.

Solution:

Values of dr_i are computed using Equation (7.3) with the constants a_{i1} and a_{i2} given as before. dr_i^c is computed using Equation (8.3) with $bb_1 = 0.015$ and $bb_2 = 0.5$. Assume

that contents are fully exposed so that $\phi_i = 1$. Finally, compute the mean content damage ratio using Equation (8.4) with the relative importance constants J_i being given in Table 8.1. The results are given in Table 8.2. The mean damage ratio for constants versus the wind speed is shown in Figure 8.3.

Table 8.1: Assumed Relative Importance of Damageability Modes for Content Damage

Damageability Mode	Relative Importance (J_i)
Roof Covering Damage	3
Roof Decking Damage	3
Roof Framing Damage	3
Roof-Wall Connection Damage	3
Opening Damage	2
Cladding Damage	2
Gross Structure Damage	6

Table 8.2: Content Damage Ratio as a Function of Wind Speed

Hurricane Category	Mean Wind Speed (mph)	Mean Content Damage Ratio
1	85	0.11
2	103	0.36
3	120	0.77
4	140	0.95
5	160	1.0

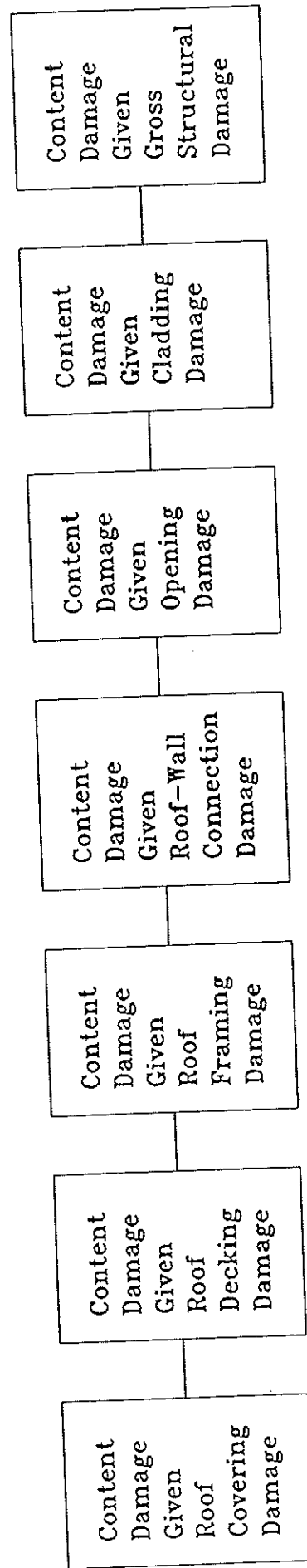


Figure 8.1 Series System Failure Model for Content Damage

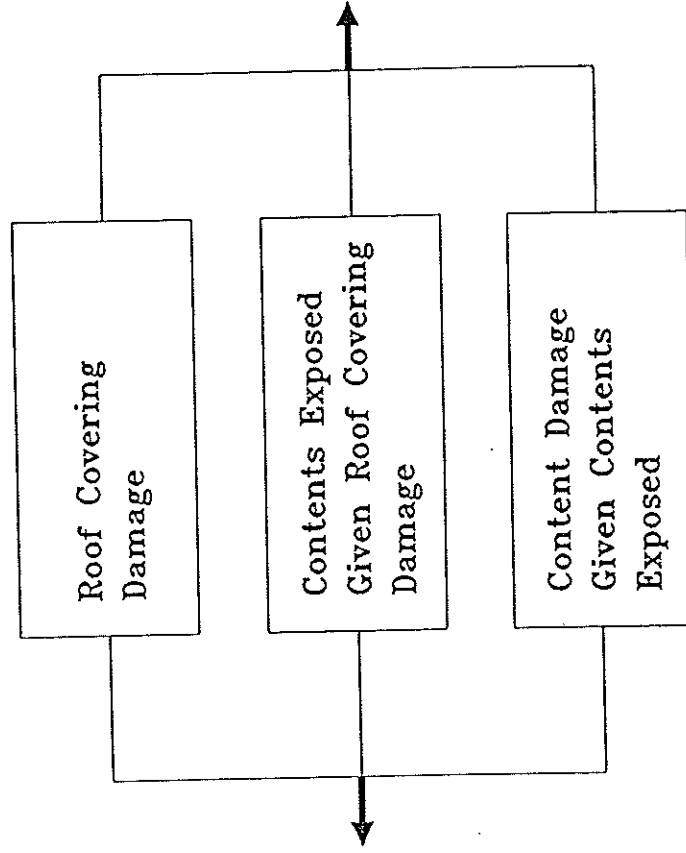


Figure 8.2 Parallel System for Content Damageability Model

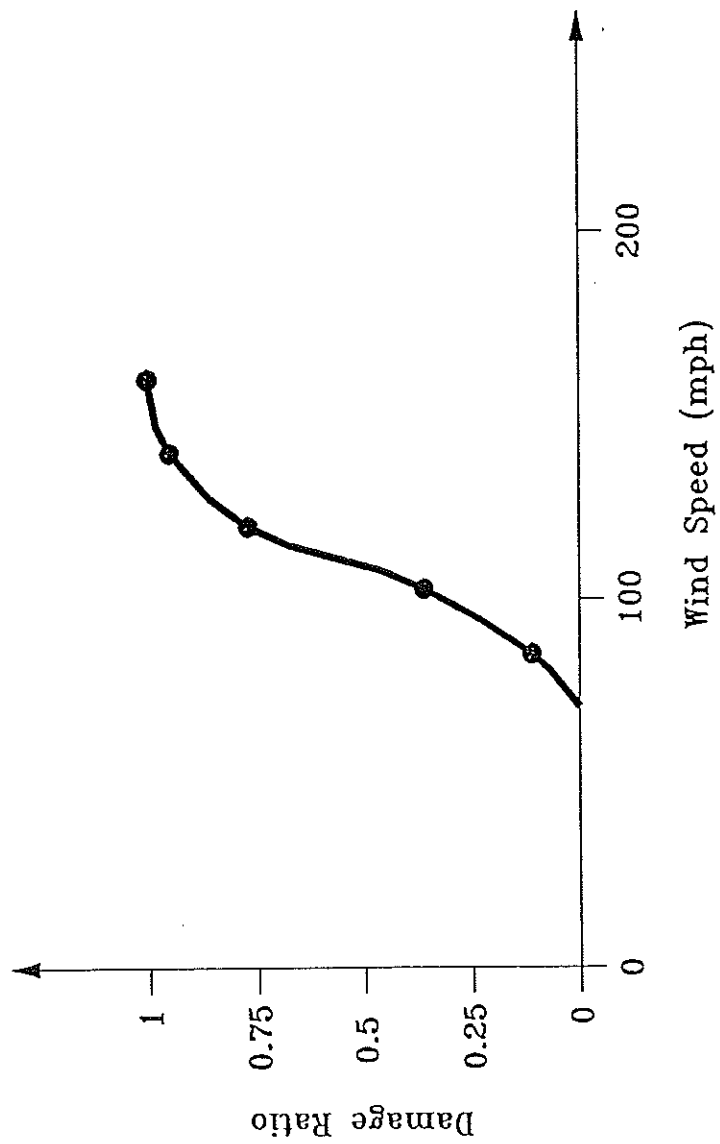


Figure 8.3 Content Damage Ratio as a Function of Wind Speed

9.0 COMBINING CONTENT DAMAGE AND STRUCTURAL DAMAGE

9.1 Background and Objective

In the last two sections, we demonstrated how the mean structural damage ratio and the mean content damage ratio can be estimated. In this section we demonstrate how the two kinds of damage can be combined to express losses in various formats. Here we will look at ways of combining content damage information and structure damage information for (1) a single hurricane event, (2) a single hurricane event on an annual basis, and (3) multiple hurricanes on an annual basis.

9.2 Combining Content and Structural Damage for a Single Event

Let:

C_s	=	Replacement cost of structure,
C_c	=	Replacement cost of contents,
P_i	=	Annual recurrence rate of Category i Hurricane (e.g., $i=1, 2, 3, 4, 5$)
$dr_s(V_i)$	=	Mean structural damage ratio for Category i Hurricane; and
$dr_c(V_i)$	=	Mean content damage ratio for Category i Hurricane

Then, for a single event i , the combined loss, L_i , is given by

$$L_i = dr_s(V_i) C_s + dr_c(V_i) C_c \quad (9.1)$$

Setting $C_c = aC_s$, where a is usually some predetermined fraction ~ 0.6 , we may write,

$$L_i = (dr_s(V_i) + a dr_c(V_i)) C_s \quad (9.2)$$

The weighted mean damage ratio, $dr(V_i)$ is given by

$$\begin{aligned}
dr(V_i) &= \frac{dr_s(V_i) C_s + dr_c(V_i) C_c}{C_s + C_c} \\
&= \frac{[dr_s(V_i) + a dr_c(V_i)]}{1 + a} \quad (9.3)
\end{aligned}$$

9.3 Combining Content and Structural Damage to Yield Expected Annual Loss for a Single Hurricane

From Equation (9.1), the annual expected loss, A_i , from a Category i Hurricane with probability of occurrence P_i is given by

$$A_i = P_i L_i \quad (9.4)$$

From Equation (9.3) the annual expected weighted mean damage ratio, l_i , is given by

$$\begin{aligned}
l_i &= P_i dr(V_i) \\
&= \frac{P_i [dr_s(V_i) + a dr_c(V_i)]}{1 + a} \quad (9.5)
\end{aligned}$$

Note that l_i is the annual mean damage ratio to be expected from a hurricane of Category i .

9.4 Annual Expected Combined Costs for all Hurricanes

From Equation (9.4), the annual cost of repair considering all hurricanes is given by

$$A = \sum_{i=1}^5 A_i = \sum_{i=1}^5 P_i L_i$$

$$= \sum_{i=1}^5 P_i C_s (dr_s(V_i) + a dr_c(V_i)) \quad (9.6)$$

The annual mean damage ratio l' to be expected from all hurricanes is given by

$$l' = \frac{\sum_{i=1}^5 P_i (dr_s(V_i) + a dr_c(V_i))}{1 + a} \quad (9.7)$$

10.0 LOSS CALCULATIONS FOR SINGLE STRUCTURES OR SINGLE BUILDING CLASSES

10.1 Background and Objectives

This section deals with the problem of estimating losses that are to be used as components of financial analyses. If these losses can be incorporated into standard financial analysis techniques, the insurer has the opportunity to consider in a rational manner many more options. For a single structure or a portfolio, insurers may need to evaluate losses in the broader framework of a financial analysis taking into consideration such items as the time value of money and specific periods of time. The objective of this section is to express the losses in forms that are convenient for financial decision making. We meet this objective by (1) providing expressions for the expected loss to a structure of a structural class given a single hurricane, (2) providing expressions for the maximum loss to a single structure or class of structures, and (3) developing expressions for the expected losses over specific periods of time.

10.2 Expected Loss: Single Hurricane

No matter which method we use to estimate losses due to structural or content damage, there will be some uncertainty in (1) our estimates of vulnerability characteristics, (2) our estimates of the hazard magnitude, and (3) the models we use. Instead of using the damageability models in Figure 7.5 and Figure 7.6, to reflect our ignorance, we should use models such as the one shown in Figure 10.1. In the figure and for any wind speed, we see that the damage ratio may range from a lower bound to an upper bound. In other words, we may think of the damage ratio for a given wind speed as a random variable. Under such conditions, what we have called the mean damage ratio is really the expectation of that

random variable. Thus if we use capital letters to represent random variables, from Equation (9.3), the random damage ratio is given by:

$$DR(V_i) = \frac{L_i}{C_c + C_s} = \frac{DR_s(V_i) + aDR_c(V_i)}{1 + a} \quad (10.1)$$

The mean damage ratio, which is the same as the expected damage ratio, is given by

$$E[DR(V_i)] = dr(V_i) = \frac{dr_s(V_i) + a dr_c(V_i)}{1 + a} \quad (10.2)$$

10.3 Maximum Loss: Single Structure or Single Class of Structures

For any wind speed, we can imagine the damage to be a random variable. A distribution for such a random variable, which is not necessarily symmetric, is shown in Figure 10.2. This random variable may be characterized by a mean, $dr(V_i)$, and a variance, $\text{Var}[DR(V_i)]$. The standard deviation of the damage ratio, σ_{DR} , is given by

$$\sigma_{DR_i} = \sqrt{\text{Var}[DR(V_i)]} \quad (10.3)$$

Thus the maximum loss to a single structure may be given by

$$\text{MaxLoss}(V_i) = dr(V_i) + n\sigma_{DR}(V_i) \quad (10.4)$$

The number n may depend upon the given decision practices of an insurance company. If $n=1$, there is 15.9% chance that some buildings in that class would experience more damage. If $n=2$, there is a 2.3% chance that some buildings in that class would experience more damage.

The next question is how do we estimate the standard deviation σ_{DR} ? One method of doing so is summarized below. Rewriting Equation (9.3), in terms of random variables

$$DR(V_i) = \frac{DR_s(V_i) + aDR_c(V_i)}{1 + a} \quad (10.5)$$

The mean damage ratio is given by

$$dr(V_i) = \frac{dr_s(V_i) + a dr_c(V_i)}{1 + a} \quad (10.6)$$

From probability theory,

$$\begin{aligned} Var[DR(V_i)] &= \left(\frac{1}{1 + a} \right)^2 Var[DR_s(V_i)] \\ &+ \left(\frac{a}{1 + a} \right)^2 Var[DR_c(V_i)] \end{aligned} \quad (10.7)$$

From Equation (7.2),

$$DR_s(V_i) = \sum_{j=1}^N W_j DR_j(V_i) \quad (10.8)$$

Therefore,

$$Var[DR_s(V_i)] = \sum_{j=1}^N \{ DR_j(V_i)^2 Var[W_j] + w_j^2 Var[DR_j(V_i)] \} \quad (10.9)$$

Note that $Var[W_j]$ represents the uncertainty in the weights assigned to the various damageability component modes and $Var[DR_j(V_i)]$ represents the uncertainty in the component damageability at a given wind speed. The uncertainty $Var[W_j]$ will depend upon the structural class. The uncertainty $Var[DR_j(V_i)]$ can be estimated from Figure 10.1. For example, for any wind speed V_i ,

$$\text{Var}[DR_j(V_i)] = \left[\frac{dx_j(V_i) - dx_j(V_i)}{4} \right]^2 \quad (10.10)$$

Similar expressions can be developed to estimate the variance of the content damage ratio, $\text{Var}[DR_c(V_i)]$. These values for the variances for structural and content damage are then substituted into Equation (10.7) to yield the variance in the combined damage ratio.

10.4 Expected Annual Loss - All Hurricanes

The expected annual loss for all hurricanes is given by Equation (9.6) and is repeated here for convenience.

$$A = \sum_{i=1}^5 P_i C_s(dx_s(V_i) + a dx_c(V_i)) \quad (10.11)$$

10.5 The Life-Cycle Losses for a Single Class or Structure

The life-cycle losses, here defined as the losses over the life-time of the structure or some predetermined period, for a single class or structures may be developed using the equation (see Newnan, 1991)

$$P = A \left[\frac{(1 + i)^n - 1}{i(1 + i)^n} \right] \quad (10.12)$$

where A is the annual cost to repair (Equation (9.6)), n is the time period in years, i is the interest rate, and P is the present value of the annual costs discounted to the present.

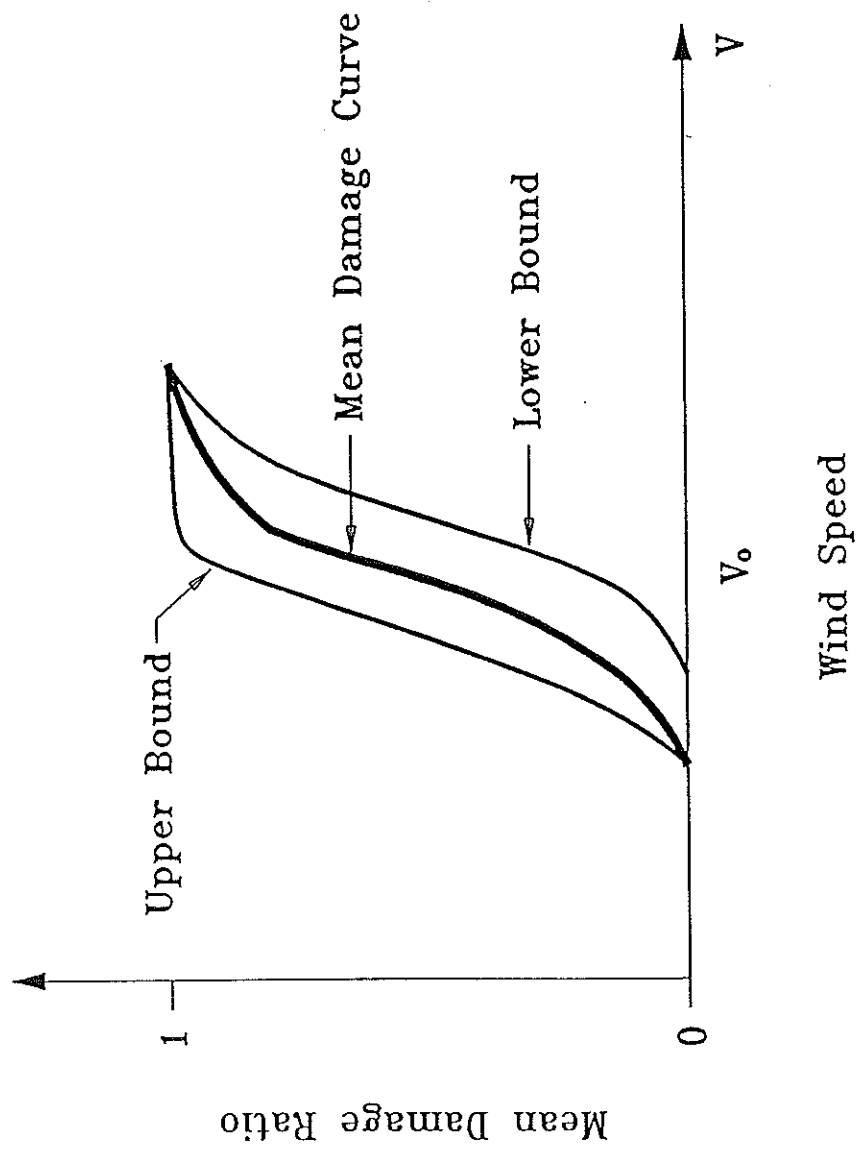


Figure 10.1 Upper and Lower Bound for Damage Ratio

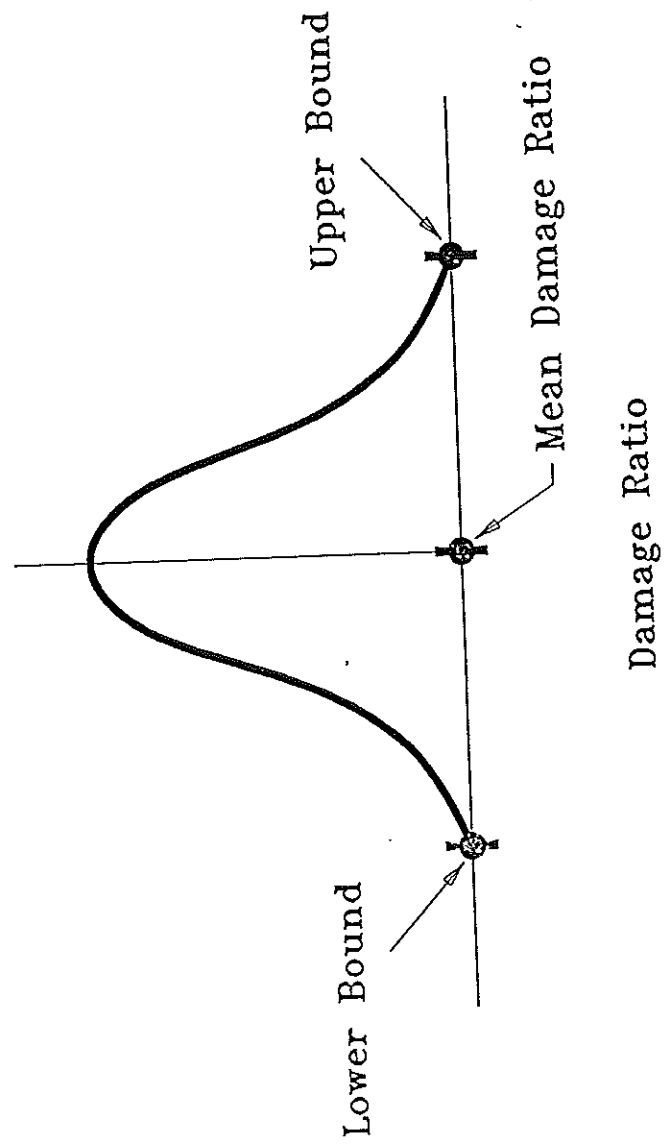


Figure 10.2 Distribution of Damage Ratio

11.0 LOSS CALCULATIONS FOR PORTFOLIOS

11.1 Background and Objectives

In the previous sections we established the necessary background needed to understand and perform loss calculations in a hurricane environment. Although we have provided some simple examples to demonstrate specific calculations, we have not yet integrated all of the techniques into a single, realistic loss calculation. Using a fairly realistic example, the purpose of this section is to provide an example of how the elements produced above may be integrated.

The objective of this section is to demonstrate a loss calculation on selected properties in the metropolitan New Orleans area. In this study the loss is indicated by the mean damage ratio (i.e., repair cost/replacement cost) of the building, the contents, or the insured valuables. The expected losses for each community is also used as an indicator of loss. The properties include residential structures and their contents located in zip codes 70118, 70115, 70005, 70130, 70116, 70124, 70002, and 70119. In addition, loss estimates were made for insured properties in St. Tammany Parish on the north shore of Lake Pontchartrain. Here, the collection of the eight zip codes and the parish will define a zone of interest. The study objective is met here by performing the four following tasks: (1) carefully redefining the objectives of the study, (2) developing appropriate loss models, (3) visiting the site and gathering the needed data required by the models, and (4) performing the loss analysis. This section is organized into the four following sections:

1. A statement of the problem,
2. A summary of the data gathering,

3. A summary of the key results obtained, and
4. An outline of the solution procedure used to obtain the results.

11.2 Statement of the Problem

The primary problem to be solved here is as follows: "Estimate the impact of an 'Andrew-like' storm hitting key properties in New Orleans area". In addition, the insurer would like some assessment of:

1. What is the relative impact of such a storm on the buildings?
2. What is the protection offered by any foliage in the area?
3. What is the impact of the age of the construction on the distribution of the damage? and
4. How does the predicted damage in the selected zip codes compare with that observed in Florida?

11.3 Hazard Determination, Vulnerability Assessment, and Building Classification

On the basis of a review of the wind field data associated with Hurricane Andrew, the relative location of the properties with respect to the Louisiana coastline, and a review of the meteorological data, (i.e., a comparison of the hurricane hazard on the Florida Atlantic Coast with that of the hurricane hazard on the Louisiana Gulf Coast), we decided that an Andrew-like storm in the region of interest would correspond to a wind speed of 100-120 mph (fastest-mile). Wind reduction factors to account for any protection provided by foliage were based on a field survey of the areas and engineering judgment of the impact that the foliage and housing density would have on the hurricane wind field near the ground surface. The type, age, and distribution of the construction in the areas of interest (Figure 11.1) were determined on the bases of a field survey of the area and data provided by the

insurer. The wind resistances of the properties were inferred on the bases of the age, type of construction, and openings protection.

Figures 11.2-11.9 provide a summary of the type of construction in the areas of interest. We categorized the construction into four major groups:

1. Pre-1940 suburban construction dating back to the ante bellum period (See Figures 11.2-11.4),
2. Pre-1940 urban construction also dating back to the ante bellum period (See Figures 11.5-11.7),
3. Residential construction built between 1940 and 1960, and
4. Post-1960 construction (See Figures 11.8 and 11.9)

The window protection common to the pre-1940 suburban construction is shown in Figures 11.10 and 11.11.

11.4 Summary of Results

The loss estimates for each zip code and all zip codes combined are given in Table 11.1. The loss for the eight zip codes and St. Tammany Parish combined is estimated to be 8.1%. Most of the damage is expected to be sustained in Zip Codes 70124 and 70002 for which the estimated losses (i.e., the weighted damage ratios) are 3.7 and 1.8 percent, respectively. Note that of the total expected loss of 33.27 million dollars for the nine communities, 68% (or 22.7 million dollars) of the losses are anticipated in Zip Codes 70124 and 70002. These zip codes correspond to properties located on the shore of Lake Pontchartrain (See Table 11.2). At least three factors explain the relatively large damage: the open exposure to the wind, the relatively weaker construction of the post-1960 era as compared to the heavier construction associated with the pre-1940 era, and the absence in

the lake front properties of high quality opening protection. A brief description of the calculation procedure is provided in the next section.

On the basis of these results we make the following comments, with regards to the questions raised by the insurer:

1. With respect to the relative impact of the storm on the buildings, the pre-1940 buildings in the Uptown and Garden districts will perform best while the waterfront, post-1960 buildings in Lake Shore and Lake Front will perform worst.
2. While there is some protection offered by foliage in the Uptown, Garden, and Metairie Communities, the protection is not as good as that observed in Memorial, River Oakes, or New Tanglewood Communities in Houston.
3. Age has a definite impact on the potential damage. The pre-1940 buildings with their heavier construction and in-place window protection will definitely out-perform the post-1960 structures.
4. Except for Zip Codes 70124 and 70002, the predicted damage is less than the damage observed in comparable regions in Florida during Hurricane Andrew.

11.5 Solution Procedure

1. The community name and the associated zip codes are summarized in Table 11.2.
2. The percentage of each construction type and the date of the construction is provided in Table 11.3. Note that each column in the table adds to unity.
3. The strength by age of the various types of construction is provided in Table 11.4. These ranges are based on the codes used, the historical performance of the structures, and the quality of construction in the region.
4. Table 11.5 summarizes our assessment of the protection provided by foliage and building density. For example, if the foliage is tall and dense, and the building density is low or high, the protection from the wind is judged to be good to excellent.
5. Table 11.6 quantifies the verbal description of the protection offered by the foliage and the housing density. These ranges are based on expert opinion and experience.

6. In Table 11.7 the level of protection offered by the foliage or building density in specific communities is assigned.
7. In Table 11.8 the losses to the structures of interest are assigned. The loss in the last row of Table 11.8 is obtained by weighting the loss value with the fraction of the building type.
8. In Table 11.9 the losses weighted relative to the replacement cost of the structure are provided for each zip code and the nine zip codes combined.
9. Table 11.10 expresses the wind speed ranges estimated to be experienced at the roof levels in each community. These speeds are used to compute the damage to contents assuming that the mechanism of roofing failure and water damage are the major cause of content damage.
10. The damage ratio for contents as a function of zip code or Parish is shown in Column 4 of Table 11.11. Note that content damage estimation also included the effect of missile damage to the openings. Note that content damage in Zip Codes 70124 and 70002 and St. Tammany Parish is substantial.
11. The damage ratio for valuables as a function of the zip code or Parish is shown in Column 4 of Table 11.12.

Table 11.1: Summary of Results

Zip Code	Str. ¹ D.R.	Con. ² D.R.	Val. ³ D.R.	Val. [*] Str.	Val. [*] Con.	Val. [*] Val.	Tot. [*] Ins.	Zip Code D.R.	Fract. of Tot. Value	Zone Damage Ratio	Expected Loss
70118	0.004	0.042	0.024	54.9	32.8	26.3	114.0	0.020	0.277	0.005	2.228
70115	0.004	0.042	0.024	58.2	34.2	11.3	103.8	0.019	0.252	0.005	1.940
70005	0.001	0.086	0.042	25.3	16.7	9.0	50.9	0.036	0.124	0.004	1.839
70130	0.002	0.042	0.024	22.9	19.3	8.3	50.5	0.021	0.123	0.003	1.056
Parish	0.043	0.158	0.062	17.2	10.1	2.5	29.7	0.084	0.073	0.006	2.490
70116	0.000	0.086	0.042	11.9	7.4	4.2	23.5	0.035	0.057	0.002	0.813
70124	0.990	0.990	0.500	12.0	7.3	3.6	22.9	0.913	0.056	0.037	15.160
70002	0.990	0.990	0.500	6.1	3.5	1.5	11.1	0.924	0.027	0.018	7.589
70119	0.000	0.086	0.042	2.9	1.7	0.2	4.8	0.032	0.012	0.000	0.155

Sum = 33.27

Sum = 411.2

* All values are in millions of dollars

¹Structure Damage Ratio in Fractions²Contents Damage Ratio in Fractions³Valuables Damage Ratio in Fractions

Table 11.2: Identification of Properties by Zip Code

Region	Community Name	Zip Code
1	Uptown	70118
2	Uptown	70115
3	Old Metairie	70005
4	Garden District	70130
5	St. Tammany	Parish
6	French Quarter	70116
7	Lake Shore	70124
8	Lake Front	70002
9	French Quarter	70119

Table 11.3: Construction Distribution of Predominant Houses by Zip Code

House Type	Fraction of Buildings in Zip Code								
	70118 (UPT)	70115 (UPT)	70005 (OM)	70130 (GD)	(STP)	70116 (FQ)	70124 (LS)	70002 (LF)	70119 (FQ)
Pre-1940: 1 Story									
Pre-1940: 2 Story	1.00	1.00		1.00		1.00			1.00
(1940-1960): 1 Story			0.5						
(1940-1960): 2 Story			0.5						
(1960-1980): 1 Story							0.5	0.5	
(1960-1980): 2 Story									
Post-1980: 1 Story							0.5	0.5	
Post-1980: 2 Story					1.00				

*Provided by insurer

UPT = Uptown; OM = Old Metairie; GD = Garden District; STP = St. Tammany Parish; FQ = French Quarter; LS = Lake Shore; LF = Lake Front

Table 11.4: Wind Resistance of Houses by Construction and Height

Construction	Wind Resistance (mph, Fastest Mile)	
	One Story	Two Story
Pre-1940	100-130	100-130
1940-1960	90-110	90-110
1960-1980	80-100	80-100
Post-1980	75-100	75-100

Table 11.5: Relative Protection from Wind Provided by Tree Cover and Housing Density

Description of Foliage	Protection from Wind	
	Low Building Density	High Building Density
Tall, dense, trees	Excellent	Good
Short, dense, trees	Good	Fair
Tall, dispersed, trees	Fair	Fair
Short, dispersed, trees	Poor	Poor

Table 11.6: Quantification of Wind Protection

Description of Protection	Wind Speed Reduction Factor*
Excellent	0.5 - 0.6
Good	0.6 - 0.75
Fair	0.75 - 0.90
Poor	0.90 - 1.00
(Lake Front)	1.00 - 1.1

*Wind speed at site = Reduction factor X Hurricane wind speed

Table 11.7: Assessment of Wind Protection by Community

No.	Community	Wind Protection Offered by Foliage and Housing Density
1	Uptown	Fair
2	Uptown	Fair
3	Old Metairie	Good
4	Garden Dist.	Fair
5	St. Tammany Parish	Good
6	French Qtr.	Good
7	Lake Shore	Poor
8	Lake Front	Poor
9	French Qtr.	Good

Table 11.8: Losses by Construction and Zip Code

House Type	Loss (Damage Ratio for Zip Codes or Parish: Percent)								
	70118 (UPT)	70115 (UPT)	70005 (OM)	70130 (GD)	(STP)	70116 (FQ)	70124 (LS)	70002 (LF)	70119 (FQ)
Pre-1940: 1 Story									0.00
Pre-1940: 2 Story	0.4	0.4		0.2		0.00			
(1940-1960): 1 Story			0.1						
(1940-1960): 2 Story			0.1						
(1960-1980): 1 Story							99.0	99.0	
(1960-1980): 2 Story									
Post-1980: 1 Story							99.0	99.0	
Post-1980: 2 Story									
Losses for Zip	0.4	0.4	0.1	0.2	4.3	0.00	99.0	99.0	0.00

UPT = Uptown; OM = Old Metairie; GD = Garden District; STP = St. Tammany Parish; FQ = French Quarter; LS = Lake Shore; LF = Lake Front.

Table 11.9: Structural Damage Ratio for All Zips

Zip Code	Values of Structures (millions of dollars)	Fraction of Value in Zip Code	Damage Ratio for Zip Code (Fraction)	Zone Damage Ratio (Fraction)
70118	54.9	0.26	0.004	0.001
70115	58.2	0.28	0.004	0.001
70005	25.3	0.12	0.001	0.001
70130	22.9	0.11	0.002	0.002
Parish	17.2	0.08	0.043	0.003
70116	11.9	0.06	0.000	0.000
70124	12.0	0.06	0.990	0.059
70002	6.1	0.03	0.990	0.030
70119	2.9	0.01	0.000	0.000
	211.4			0.1267

Table 11.10: Wind Speed Ranges Seen at Roof Tops at Zip Codes for a 100 mph Hurricane

Area No.	Zip Code	Wind Speed Range
1	70118	75-90
2	70115	75-90
3	70005	60-75
4	70130	75-90
5	Parish	60-75
6	70116	60-75
7	70124	90-100
8	70002	90-100
9	70119	60-75

Table 11.11: Contents Damage Ratio for Combined Zip Codes

Zip Code	Content Value (millions of dollars)	Fraction of Value in Zip Code	Damage Ratio for Contents (Fraction)
70118	32.8	.247	0.042
70115	34.2	.257	0.042
70005	16.7	.126	0.086
70130	19.3	.145	0.042
Parish	10.1	.076	0.158
70116	7.4	.056	0.086
70124	7.3	.055	0.99
70002	3.5	.026	0.99
70119	1.7	.013	0.086

Table 11.12: Valuables Damage Ratio for Combined Zip Codes

Zip Code	Valuables (millions of dollars)	Fraction of Value in Zip Code	Damage Ratio for Valuables (Fraction)
70118	26.3	0.393	0.024
70115	11.3	0.169	0.024
70005	9.0	0.135	0.042
70130	8.3	0.124	0.024
Parish	2.5	0.037	0.062
70116	4.2	0.063	0.042
70124	3.6	0.054	0.50
70002	1.5	0.022	0.50
70119	0.2	0.003	0.042

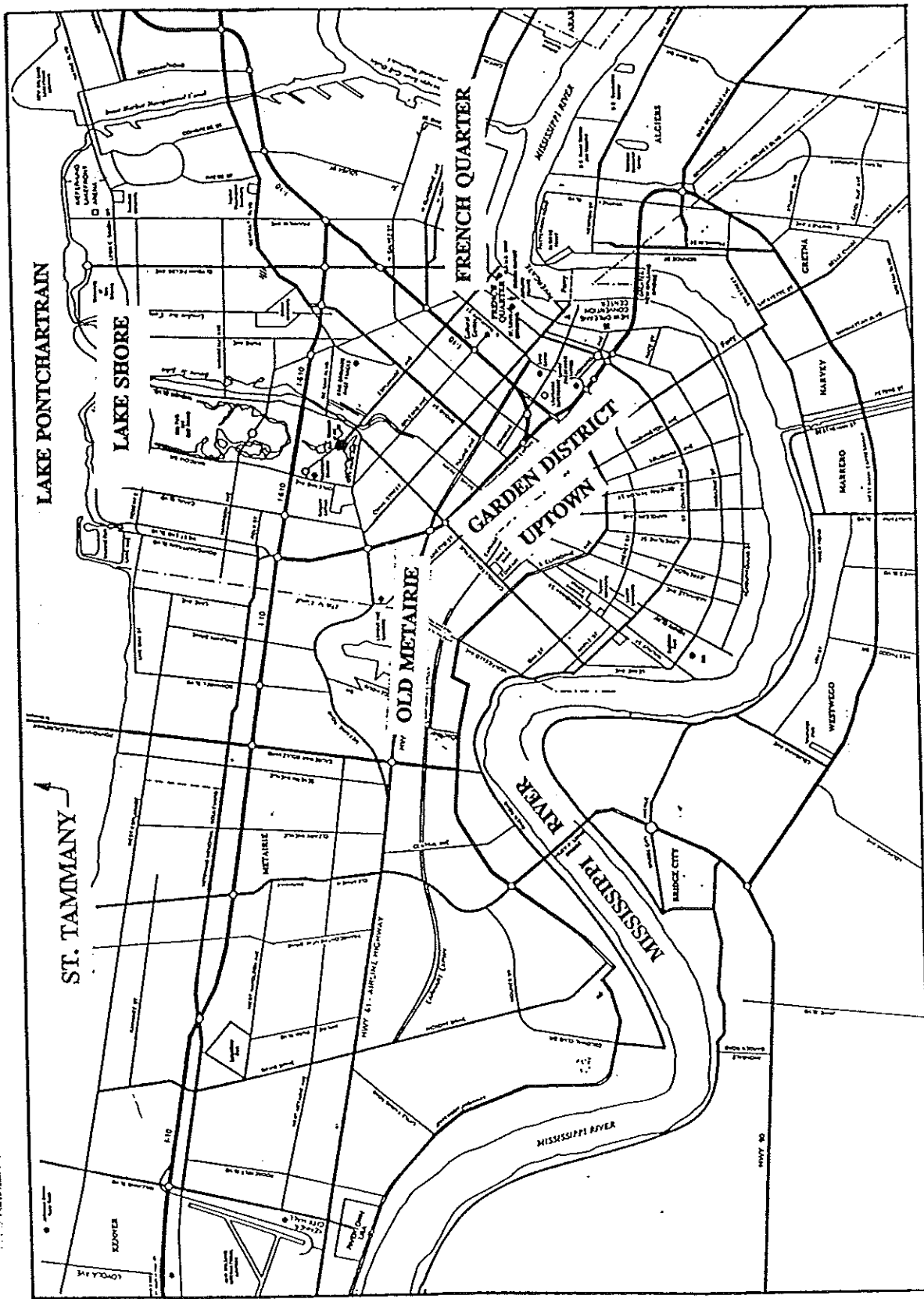


Figure 11.1 New Orleans Map Indicating Areas of Interest



Figure 11.2 Pre-1940 Urban Construction in Garden District

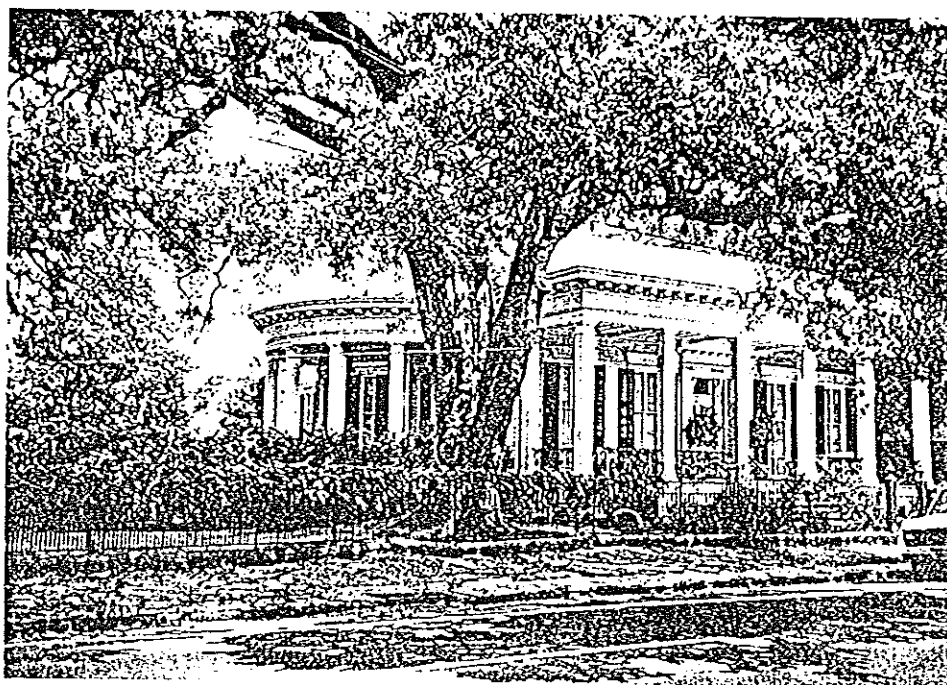


Figure 11.3 Pre-1940 Ante Bellum Period Construction in Garden District



Figure 11.4 Pre-1940 Ante Bellum Period Construction in Garden District



Figure 11.5 Pre-1940 Construction in French Quarter



Figure 11.6 Pre-1940 Construction in French Quarter



Figure 11.7 Pre-1940 Construction in French Quarter

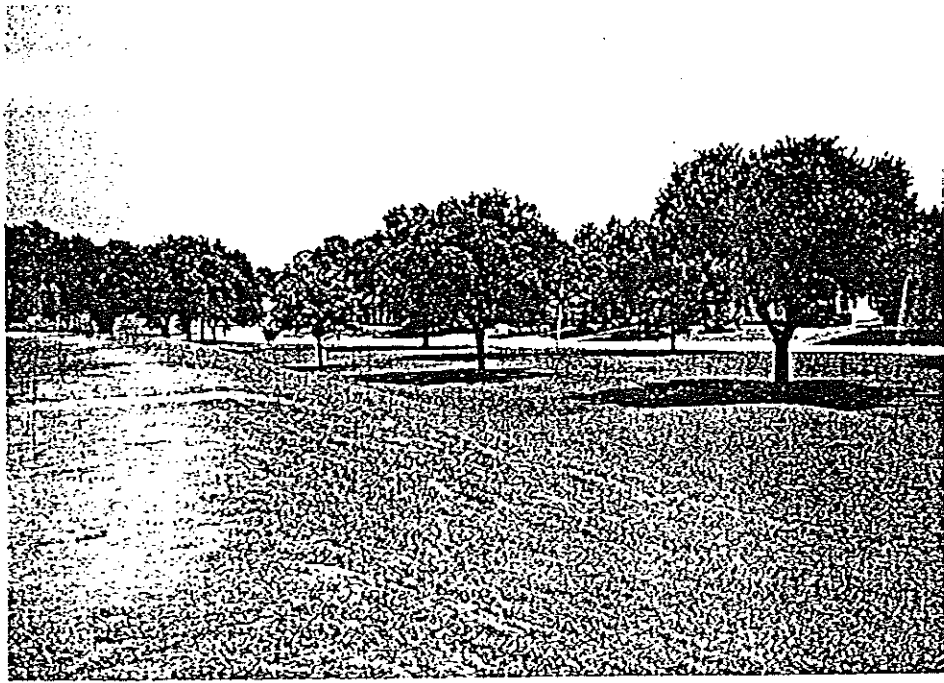


Figure 11.8 Post-1960 Construction Adjacent to Lake Pontchartrain

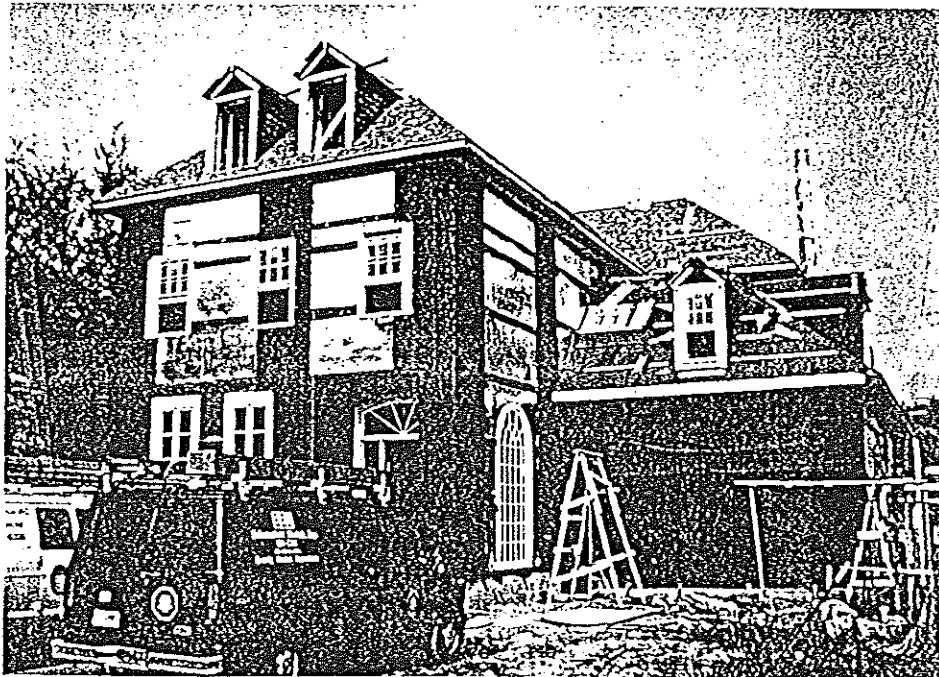


Figure 11.9 New Construction in Uptown District



Figure 11.10 Typical Window Protection of Urban Construction in Garden District

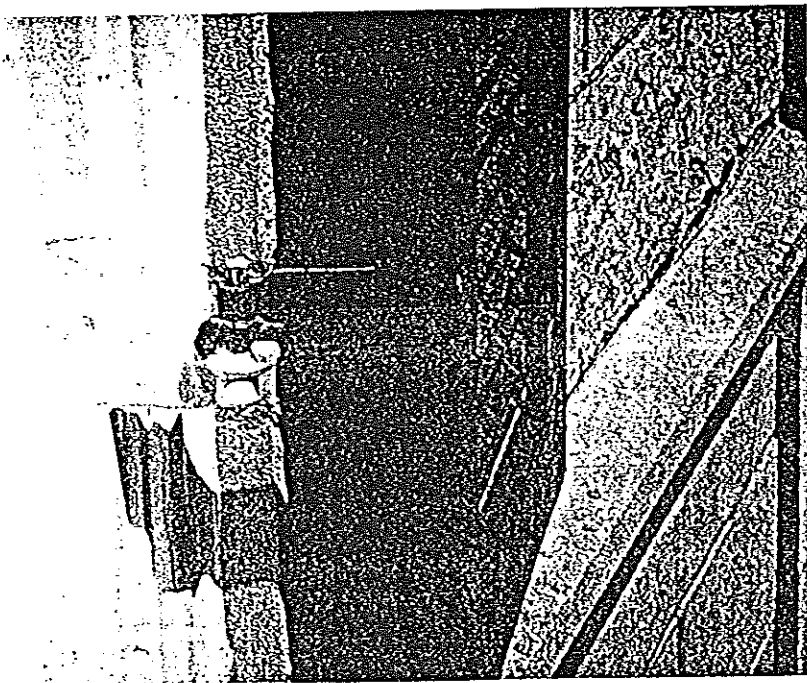


Figure 11.11 Close-up of Operable Shutters in Figure 11.10

12.0 EVALUATION OF OFFERERS OF LOSS CONSULTING SERVICES

12.1 Background and Objectives

In recent years, several organizations have developed commercial software packages to estimate various aspects of hurricane-related losses and are marketing packages in the Caribbean. Thus an urgent need exists for insurance companies in the Caribbean Region, and elsewhere, to rationally evaluate software packages. The material presented in the last eleven sections provides the basis upon which such an evaluation scheme can be developed. The objective of this final section is to provide insurance professionals in the Caribbean Region a rational framework for evaluating offerers of loss estimation calculations. We meet this objective by (1) suggesting a list of relevant selection criteria, (2) developing a method of generating numerical data to describe the criteria, (3) suggesting a method of combining the various criteria to produce a single rating, and (4) describing how the offers may be evaluated and rated.

12.2 Development of Criteria for Evaluating Offerers

On the basis of the foregoing material, offerers of loss consulting needs should be evaluated on the basis of at least the following criteria:

1. The appropriateness of the loss methodology to accommodate the building classes to be found in the Caribbean Region;
2. The capability of the loss methodology to provide loss information that can be used in a financial analysis involving the time value of money;
3. The existence of a clear description of the architecture of the loss estimation algorithm;
4. The methodology incorporates at least the eleven elements discussed in Section 3.4;

5. The methodology contains at least the eight algorithms (or their equivalent) discussed in Section 3.4;
6. A listing of the major assumptions used to operationalize the algorithms;
7. The methodology exploits sources of information such as local meteorological records, post-disaster studies in the Caribbean, Local building codes, field inspections, local insurance records, and local design/construction expert opinion;
8. The methodology rigorously characterizes the hurricane risk in the Caribbean Region;
9. The methodology incorporates the hurricane profile and trajectory;
10. The methodology incorporates a systems description for building behavior;
11. The methodology can provide an assessment of the sensitivity of structural damage to variations in the vulnerability of building elements;
12. The methodology accounts for the exposure and vulnerability of contents;
13. A statement on the accuracy of the results produced is provided to the client;
14. The system is user friendly;
15. The output from the system is easy to understand;
16. The output from the system is in a form readily useable to the client;
17. The cost of the system is within the resources of the client;
18. The offerer provides training and continuous support;
19. The offerer provides a list of previous clients in the Caribbean Region; and
20. The offerer provides examples of comparisons of predicted losses with observed losses.

12.3 Development of Data for Input into the Criteria

A service or product can be rated by generating some number which simultaneously reflects the importance of a criterion and the extent that criterion is addressed by the

product or service. In the opinion of the client, for example, a criterion may be judged very important, important, or not important. Such a scheme for the linguistic evaluation of the importance of a criterion and an accompanying set of numerical values are listed in Table 12.1. A similar system can be used to rate the extent to which a service or product addresses a criterion. Linguistic variables such as excellent, good, fair, poor, and very poor can be used to describe the extent to which a product or service addresses a criterion. A set of numerical values corresponding to the linguistic variables is listed in Table 12.2. Note that the degree of importance and the extent to which a criterion is addressed should be accomplished on the basis of group consensus.

12.4 Development of Aggregation Function to Combine Criteria

A schematic of a potential rating system (see Dong, 1986) is shown in Figure 12.1. If w_j is the numerical value of the importance assigned to the j^{th} component and r_{ij} is the rating of the j^{th} criterion, the i^{th} vendor may be evaluated using the aggregation function in the form of the weighted average:

$$\text{Rating of } A_i = \frac{\sum_{j=1}^n w_j r_{ji}}{\sum_{j=1}^n w_j} \quad (12.1)$$

where n is the number of criteria used in the evaluation. The value obtained for A_i will range between zero and 10.

12.5 Evaluation and Rating of Offerer

Using the scheme described above a numerical value of A_j will be assigned to each and every offerer. The vendors may now be rated in order of descending values of A_j . With










this rating, the client may make the selection of a vendor or utilize additional information in combination with the derived rating. Depending upon the needs of the client, other selection criteria may be utilized and rating systems for importance and the degree to which a particular criterion may be defined as appropriate.

Table 12.1: Linguistic Importance Ratings of Criteria and Accompanying Numerical Values

Importance Rating	Numerical Rating
Most Important	10
Very Important	7
Important	5
Rather Unimportant	3
Unimportant	1

Table 12.2: Linguistic Criterion Ratings and Accompanying Numerical Values

Criterion Rating	Numerical Rating
Excellent	10
Good	8
Fair	5
Poor	3
Very Poor	1
Not Addressed	0

	Importance of Criterion (weight) $= w_j$	Ratings = r_{ij}	
		Alternative 1 A_1	Alternative 2 A_2
Criterion (aspect) 1	$w_1 =$ Very Important	$r_{11} =$ Good	$r_{12} =$ Fair
Criterion (aspect) 2	$w_2 =$ Rather Unimportant	$r_{21} =$ Fair	$r_{22} =$ Good
	  	  	  
Overall Rating			

12.1

Figure 12.1 Example Ratings and Weights for Decision Analysis

13.0 SUMMARY AND CONCLUSIONS

The objective of this work was to produce a short working paper than would assist insurance companies in the Caribbean Region in (1) identifying their PML calculation consulting needs, (2) determining what should a PML calculation contain, and (3) evaluating offerers of consulting services for assistance with PML calculations. As an additional constraint, the OAS specified that the paper concentrate on hurricanes and the methodology discussed be applicable to seismic events.

In Section 2.0, we discussed the concept of PML and selected the definition of PML and the calculation procedures used by the State of California to represent the state-of-the-art in earthquake PML calculations. We next analyzed the applicability of the PML methodology in estimating hurricane-related losses in the Caribbean Region. On the basis of the analysis, we concluded that the traditional PML approach may not be the best methodology to estimate hurricane-related losses in the region. Beginning with the definition of an ideal state of hurricane-related loss estimation knowledge in the Caribbean, we developed a list of capabilities that consultants should provide. For a single structure, the ideal state of hurricane-related loss estimation knowledge might include the following items:

1. An accurate model to estimate the monetary loss to a single structure subjected to a single hurricane,
2. An accurate model to estimate the monetary loss on an annual basis to a single structure subjected to all hurricanes,
3. An accurate model to estimate the monetary loss to a single structure for the period of the useful life of the structure or some predetermined time period, and
4. Means by which the uncertainty in each of the models above can be quantified.

Similarly, for a class of structures, the ideal state of hurricane-related loss estimation knowledge might include the following items:

1. An accurate model to estimate the monetary loss to a class of structures subjected to a single hurricane,
2. An accurate model to estimate the monetary loss on an annual basis to a class of structures subjected to all hurricanes,
3. An accurate model to estimate the monetary loss to a class of structures for the period of the useful life of the structures or some predetermined time period, and
4. Means by which the uncertainty in each of the models above can be quantified.

Finally for a zone or portfolio, the ideal state of hurricane-related loss estimation knowledge might include the following items:

1. An accurate model to estimate the monetary loss to the zone subjected to a single hurricane;
2. An accurate model to estimate the monetary loss on an annual basis to the zone subjected to all hurricanes;
3. An accurate model to estimate the monetary loss to the zone for some predetermined time period; and
4. Means by which the uncertainty in each of the models above can be quantified.

Since we were not rigidly following the earthquake PML methodology, we opted to use the more general term of "loss estimation" instead of PML. In Section 3.0, we identified what a loss estimation calculation should contain. We outlined the general calculation procedure which is based on the risk analysis approach. We determined that the output of any loss calculation methodology was an estimation of the monetary loss incurred by a single structure, a class of structures, or a zone subjected to a single hurricane or combinations of

7. Algorithm to compute the cost of content damage as a function of the hazard to the contents and the vulnerability of the contents; and
8. Algorithm to compute the hazard to the contents as a function of the exposure of the contents and the magnitude of the hurricane.

In addition, we went on to identify sources of information for the required input into the methodology which included:

1. Meteorological records,
2. Post-disaster studies in the Caribbean,
3. Building codes,
4. Field inspections of buildings during construction,
5. Field inspections of existing buildings,
6. Insurance payout records, and
7. Local design/construction professionals

To further familiarize insurers with hurricane-related loss methodologies, we reviewed the problem of developing classification schemes for buildings and provided several examples of classifications. In the next several sections, we summarized a specific methodology for loss estimation of structural damage and contents damage and showed how the results can be presented in a format that is useful to insurance companies in the comprehensive evaluation of hurricane-related losses. We also provided an extended example of a loss calculation for a portfolio along the Gulf Coast, using the method as a basis.

Finally, on the basis of the materials presented in the eleven sections, we developed a list of twenty criteria that can be used to evaluate offerers of loss estimation in the

hurricanes. The input needed for such a methodology might consist of the following eleven elements:

1. The risk of the hurricane,
2. The hurricane magnitude,
3. The exposure of the structure,
4. The vulnerability of the structure,
5. The exposure of the nonstructural elements,
6. The vulnerability of the nonstructural elements,
7. The exposure of the contents,
8. The vulnerability of the content,
9. The hurricane profile, and
10. The hurricane trajectory.

We also identified the following eight algorithms that such a methodology should contain.

1. Algorithm to compute expected cost as a function of risk of hurricane and total cost of damage;
2. Algorithm to compute total cost of damage as a function of costs of structural damage, nonstructural damage, and damage to contents;
3. Algorithm to compute the cost of structural damage as a function of the modified hazard to the structure and the vulnerability of the structure;
4. Algorithm to compute the modified hazard to the structure as a function of the exposure of the structure and the hurricane magnitude;
5. Algorithm to compute the cost of nonstructural damage as a function of the hazard to the nonstructural elements and the vulnerability of the nonstructural elements;
6. Algorithm to compute hazard to the nonstructural elements as a function of the exposure of the nonstructural elements and the hurricane magnitude;

Caribbean. We further discussed how these criteria may be quantified and combined into a single indicator for rating purposes.

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