A Model to Predict Hurricanes Induced Losses for Residential Structures

by

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ABSTRACT

This paper presents a practical probabilistic model for the projection of annualized damage costs to residential structures due to hurricanes. The estimation of the damage is accomplished by first defining the basic damage modes for components of specific building types and their probabilities of occurrence as functions of estimated wind speeds. The damage modes are then combined in possible damage states, whose probabilities of occurrence are calculated from Monte Carlo simulations carried on engineering numerical models of typical houses. Once this is done it is possible to estimate repair/replacement costs associated with building damage induced by windstorms. The calculation of damage (repair/replacement costs) allows us to estimate building vulnerabilities. Finally, we discuss and illustrate the estimation of expected losses for groups of buildings, including regional expected annual losses, and expected losses induced by a hurricane event. The probabilistic input is based on statistical surveys of the Florida building population, laboratory studies, post-damage surveys, insurance claims data, engineering analyses and judgment, and Monte Carlo simulation methods.
KEYWORDS: Hurricane, Monte Carlo simulation, probability, residential structures, vulnerability, wind speeds.

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1.0 INTRODUCTION

Within the U.S., windstorms are one of the costliest natural hazards, far outpacing earthquakes in total damage (Wind Engineering, 1997; Landsea et al, 1999). A recent analysis of windstorm damage for the U.S. East and Gulf coasts by Pielke et al. (1998) suggests that the average annual economic loss is about $5 billion. This agrees closely with National Oceanic and Atmospheric Administration (NOAA) estimates of 84 billion dollars in hurricane related damage since 1980. Over half of the hurricane-related damage in the U. S. occurs in the state of Florida, which has $1.5 trillion in existing building stock currently exposed to potential hurricane devastation. With approximately 85 % of the rapidly increasing population situated on or near the 1200 miles of coastline, Florida losses will continue to mount in proportion to coastal population density. It is therefore critical for the state of Florida, and the insurance industry operating in that state, to be able to estimate expected losses due to hurricanes and their measure of dispersion. For this reason the Florida Department of Insurance asked a group of researchers to develop a public hurricane loss projection model. This paper describes a model for the estimation of the damage to residential buildings due to hurricane or severe storms.

Although a number of commercial loss projection models have been developed, only a handful of studies are available in the public domain to predict damage for hurricane prone areas. Most studies use post-disaster investigations of available claim data to fit damage versus wind speed vulnerability curves. (e.g. Mitsuta et al. 1996; Huang et al., 2001). Although simple, this approach is highly dependent on the type of construction and construction practices common to the areas represented in the claim data. Recent changes in building codes or construction practices cannot be adequately reflected by vulnerability curve based on past data. In addition, damage curves obtained by regression from observed data can be misleading, because very often, as was the case for hurricane Andrew, few reliable wind speed data are available.

In contrast, a component approach explicitly accounts for both the resistance capacity of the various building components and the load effects produced by wind events to predict damage at various wind speeds. In the component approach the resistance capacity of a building can be broken down into the resistance capacity of its components and the connections between them. Damage to the structure occurs when the load effects from wind or flying debris are greater than the component's capacity to resist them. Once the strength capacities, load demands, and load path(s) are identified and modeled, the vulnerability of a structure at various wind speeds can be estimated. Estimates are affected by uncertainties regarding on one hand the behavior and strength of the various components and, on the other, the load effects produced by hurricane winds. A damage prediction model that incorporates elements of a component approach is being implemented for the HAZUS project (Minor and Schneider, 2001).

The purpose of this paper is to present and illustrate the principle of a probabilistic component approach to the prediction of wind-induced damage and of corresponding repair/replacement costs. Our approach makes use of probabilistic information on *basic damage modes.* This information is used to calculate probabilistic information on *combined damage states.* The latter consist of combinations of basic damage modes, determined by engineering judgment, post-disaster observations, and/or analysis.

The next section discusses basic damage modes and their probabilistic characterization. We then consider combined damage states and the derivation of their probabilistic characteristics. Once this is done it is possible to estimate repair/replacement costs associated with building damage induced by windstorms. Such costs are referred to as *wind-induced building damage*, or for short *damage.* Note that we will occasionally refer to some types of damage in a physical, as opposed to monetary sense. For example, we will refer to the physical damage of, say, tiles. We will omit the adjective "physical" and refer to physical damage more briefly as "damage" whenever the context is sufficiently clear that no confusion can result from this use. The calculation of damage (repair/replacement costs) allows the estimation of building vulnerabilities. In a wind engineering context we will define *vulnerability* as a measure of the susceptibility to damage, expressed as a function of the wind speed. Finally, we discuss and illustrate the estimation of expected damage for groups of buildings, including regional expected annual damage, and expected damage induced by a hurricane event. Uncertainties associated with such estimates will be dealt with in a subsequent paper. A companion team of researchers for this project is developing the wind field model that will provide this damage model with the probabilities of occurrence of various wind speeds, thus allowing the estimation of annualized insurable loss. Development of the wind field model is not a part of this paper, and will be the subject of a forthcoming separate document.

2.0 BASIC DAMAGE MODES

This research is currently focused on residential low-rise structures of different types that make up the overwhelming bulk of the Florida building stock. For purposes of illustration, the paper presents the approach for a building belonging to a specified type: an unreinforced masonry house with timber gable roof covered with tiles. Its most vulnerable types of components are shown in Fig. 1. They correspond to the following five significant basic damage modes: (1) breakage of openings (O); (2) loss of tiles (T); (3) loss of roof or gable end sheathing (S); (4) roof to wall connection damage (C); and (5) masonry wall damage (W). For a specified wind speed *v* the building will either not experience damage, or experience several of these five basic damage modes. Some damage modes are independent of each other (e.g., loss of tiles and breakage of openings); others are not (e.g., given that the building has experienced window breakage, the probability of its losing sheathing increases)

The model is further refined by dividing each basic damage mode into several sub-damage modes (e.g., O_i, i =0,1,2,3) according to the degree of damage: no damage, light, moderate, or heavy damage. For example, we can define O_0 as zero loss of opening (no damage), O_1 as loss of less than 25% of openings (light), O_2 as loss of 25% to 50% of openings (moderate), and O_3 as loss of in excess of 50% of openings (heavy). Sub-damage modes can similarly be defined for the other basic damage modes, denoted by T_j, S_k, C_l, W_m (j,k,l,m =0,1,2,3). The sub-damage modes corresponding to a damage mode must be so defined that they are mutually exclusive. For example, the union of the sub-modes O_i (i = 1,2,3) is equal to the mode O, and the sum of their probabilities is equal to the probability of O.

A first step toward the estimation of wind-induced damage is the probabilistic characterization of the basic damage (or sub-damage) modes. This requires estimates of (1) probabilities that, under wind speeds contained in specified intervals defined by a speed *v*, a building of a specified type will experience damage (sub-damage) modes of various kinds, and (2) measures of statistical dependence between the events associated with those modes. The wind speeds *v* considered in the study are 3 sec average gust wind speeds at 10 m. For purposes of illustration, Table 1 lists assumed probabilities of occurrence of the sub-damage modes for the case of opening failures (see Figure 1), conditional on wind speeds belonging to 5m/s intervals centered on values of *v* varying from 45 to70 m/s. For example, the fifth column-second row cell states that for *v* in the interval $57.5\text{m/s} < v \leq 62.5\text{m/s}$, $P(O_2|v)$=35% is the probability that a building will experience moderate opening damage, and the fifth column- third row cell $P(O_3|v)$= 60% is the probability that the building will experience heavy opening damage. To simplify the notation we may omit the notation "$|v$" in all subsequent developments, that is, we will use the shorthand notation P(x) in lieu of $P(x|v)$.

For each damage mode the event "no damage" (i=0) is unity minus the sum of the probabilities of the three sub-damage modes (i=1,2,3). For example, for *v*=55 m/s the probability of no opening damage is $P(O_0)=1-P(O)=1-[P(O_1)+P(O_2)+P(O_3)]$ = 100%-5%-40%-40%=15%.

The requisite probabilities of basic damage modes can in principle be obtained directly: (1) from laboratory tests (e.g., Baskaran and Dutt, 1995), after translating physical damage usually reported in laboratory tests into monetary terms; (2) from post-disaster observations of damage, duly accounting for the fact that reported damage includes damage due to effects other than wind (for example storm surge); (3) from numerical studies entailing simulations; and, (4) last but by no means least, from engineering judgment needed to supplement or interpolate between sparse data.

The choice of basic damage modes is in general determined by practical considerations such as the type of structure, the format of the requisite probabilistic information and the extent to which it is available, the need for keeping the model reasonably simple, and the requisite accuracy of the loss estimation. The methodology described in this paper is independent of the basic damage modes being considered in the calculations.

3.0 COMBINED DAMAGE STATES

When a windstorm causes damage to a structure, it will usually cause different damage modes to different components at the same time. We shall refer to these combinations of damage modes as combined damage states. Since the resulting combined damage states require not only set-theoretical but also architectural and structural engineering scrutiny, it is appropriate to use an engineering approach to their definition. The damage states being considered must satisfy the following requirements:

- They must be combinations of the damage modes described previously
- They must be chosen with a view to enabling damage estimates to be made correctly, in the sense that no possible damage state is omitted, and no double or multiple counting of damage states occurs.
- They must make sense from an architectural and structural engineering point of view. For example, for a building covered by conventional sheathing, it may be assumed that wall damage will not occur without some loss of sheathing. Similarly, although tile and opening failures do not necessarily cause roof-to-wall connection damage, it is reasonable to assume that no roof to wall connection damage will occur without some tile loss and opening breakage.

The basic damage modes are represented in the diagram of Figure 2. The partial or total overlap of the basic damage modes is based on engineering judgment. Figure 2 is the point of departure in the process of defining combined damage states. Associated with the basic damage modes O, T, S, W and C are events -- combined damage states – whose union represents the total damage universe shown in Figure 2. Combined damage states can similarly be considered that involve sub-damage modes. We consider the events associated with the occurrence of the following combinations of sub-damage modes:

Event 1. O_0T_0 (no damage). See hatched area in Fig. 3a. Since it is assumed that all damage involves first some opening breakage and/or tile loss, the lack of both of these is equivalent to no damage.

Events 2, 3, 4. O_i T_0 – i=1, 2, 3 (opening failure and no tile loss). The hatched area in Fig. 3b represents the sum of events 2,3,4 or (O T_0). Recall that each area O_i is a subset of the set O; for convenience this is not shown in any of the graphs of Fig. 3.The probabilities of these sub-states will help to estimate the cost of repair of homes that have only opening failures.

Event 5, 6, 7. O_0 T_j S_0 –i=1, 2, 3 (tile failure and no opening or sheathing loss). The hatched area in Fig. 3c represents the sum of events 5,6,7 or (O_0 T S_0). The probabilities of these sub-states will help to estimate the cost of repair of homes that have only roof cover failures (e.g., homes with effectively boarded openings and strong garage doors).

Events 8 through 16. O_i T_j S_0 – i,j=1,2,3 (opening and tile failure and no sheathing loss). The hatched area in Fig. 3d represents the sum of events 8 to 16 or (O T S_0).

Events 17 through 25. O_0 T_j S_k – j, k=1,2,3 (tile and sheathing failure and no opening failure). The hatched area in Fig. 3e represents the sum of events 17 to 25 or (O_0 T S).

Events 26 though 52. O_i T_j S_k W_0 C_0 (opening, tile and sheathing loss and no wall and connection failure) – i, j, k =1, 2, 3. The hatched area in Fig. 3f represents the sum of events 26 to 52 or (O T S W_0 C_0).

Events 53 through 133. O_i T_j S_k C_l W_0 -i,j,k,l=1,2,3 (opening, tile, sheathing and connection failure and no wall failure). The hatched area in Fig. 3g represents the sum of events 53 to 133 or (O T S C W_0).

Events 134 through 214. O_i T_j S_kW_m C_0 - i,j,k,m=1,2,3.(opening, tile, sheathing and wall failure but no connection failure). The hatched area in Fig. 3h represents the sum of events 134 to 214 or (O T S W C_0).

Events 215 through 457. O_i T_j S_k C_l W_m – i,j,k,l,m=1,2,3.(opening, tile, sheathing, wall, and connection failure). The hatched area in Fig. 3i represents the sum of events 215 to 457 or (O T S W C).

There are a total of 457 damage state events. However, not all of these events are of interest from a damage estimation point of view. Engineering considerations allow the elimination of a number of events. There are several scenarios:

When roof cover damage (T) and sheathing damage

(S) occur at the same time, the damaged area of the roof cover must be equal or larger than the damaged area of sheathing. We can therefore eliminate all the damage states which pertain to damaged area of roof cover smaller than the damaged area of sheathing, i.e. eliminate events that contain T_jS_k when $j<k$.

When roof cover damage (T) or sheathing damage (S) or opening damage (O) occur together with wall damage (W) or connection damage (C), the level of damage for T or S or O should be larger than for W or C. That is, there is only a small probability that a wall would suffer heavy damage while the roof cover has suffered light damage. Thus we can eliminate all the damage states which contain lower levels of roof covering damage and decking damage and opening damage than wall damage and connection damage. i.e. eliminate events containing O_i, S_k, T_j, W_m, and C_n when i, j, k < m, n. In particular, when severe wall damage and severe roof to wall connection damage occur together, the whole structure collapses. So if roof to wall connection and wall damage are both heavy (i.e., if W_3 and C_3 occur), the only significant damage event will be$O_3T_3S_3W_3C_3$, so that we can eliminate all events $O_iT_jS_kW_3C_3$ for which i, j, k =1,2.

These engineering considerations allow the elimination of 240 damage states, leaving 217 damage states. Note from Fig. 2 that, for any specified wind speed, any two distinct damage states are mutually exclusive. For example, a structure cannot experience both the state $O_i\, T_j\, S_k\, W_0\, C_0$ and the state $O_i\, T_j\, S_k\, W_0\, C_l$.

The implementation of this model is currently under way. The determination of values for the basic damage modes, and the combined damage state events rely upon the use of a component-based Monte Carlo simulation engine. The simulation relates estimated probabilistic strength capacities of building components to 3 sec average gust wind speeds through a detailed wind and structural engineering analysis that includes effects of wind-borne missiles. The component approach taken in the Monte-Carlo simulation explicitly accounts for both the uncertain resistance capacity of the various building components and the load effects produced by wind events to predict damage at various wind speeds. The resistance capacity of a building is broken down into the resistance capacity of its components and the connections between them. Damage to the structure occurs when the load effects from wind or flying debris are greater than the component's capacity to resist them. The probabilistic strength capacities, load paths, and load sharing between components are identified and modeled. The probable damage to a particular building class at a given wind speed is estimated through many simulations of the same structure at that wind speed, randomly sampling component capacities between each simulation. Each simulation represents an instance of a storm of same intensity. Changes in loading on components as a result of component /connection failure within a single simulation are accounted for. The wind speed is then increased to the next discrete value and the process repeated. The end result is a table describing the probability of combined damage levels to the components, conditioned upon peak wind speeds.

No duration effect is included in the model. It is assumed that the wind speed represents the highest 3 sec peak gust speed over the duration of a storm at a particular location, and when applied to the building model it produces the maximum loading for that storm. Since the component strengths are set, if they do not fail at the highest 3 second gust, they won't fail at all. Other average wind speeds could be considered for the simulation (e.g. 1 min or 10 min average wind speed), in which case, the pressure coefficients to compute the pressure distributions would be adjusted accordingly, resulting in the same maximum pressures. The wind speed – whatever form it is expressed in – thus serves as an index of the storm intensity; and the damage is independent of whether the index being used is the 3-sec, 1-min, 10-min, or mean hourly speed. The 3 sec average was adopted because it is the standard in the U.S.A (see ASCE7, 2002).

A possible resulting damage matrix is summarized in Table 2.The wind field model will come into play when the results of the simulation are used to calculate annualized damage probabilities, as discussed in the following sections. The resulting probabilities of the 217 combined damage states will be assessed as necessary to ascertain the extent to which they are physically realizable. This will provide useful guidance to the future development of the simulation procedure.

4.0 STATISTICAL ANALYSIS OF THE BUILDING STOCK

The goal of this research is to estimate hurricane losses over a large geographical area with a building population composed of different structural types. Although Figure 1 represents a standard masonry house with gable roof, the methodology described above can be applied to any other type of residential houses. It is therefore important to identify all the structural types that make up the building stock of the different regions of Florida. For each structural type, a model will be built and a Monte Carlo simulation performed, so that each structural type will end up with its own damage matrix. Finally, when computing the overall damage in any given area, as explained in the next section, it will be necessary to know the probability of occurrence of each structural type in that region.

The first step in the analysis of the building stock is therefore to identify the most common structural types in the target area. The authors obtained the property tax appraiser databases of 9 Florida Counties, which contain structural information for most single family residential houses, including exterior wall types, roof types and roof cover. These counties are distributed among four different regions of Florida with different building characteristics, as shown in Figure 4.

These counties include: Escambia, Walton, and Leon in the Northern region; Brevard, Pinellas, and Hillsborough in the Central region; Palm Beach, and Broward in the Southeast region; and Monroe County for the Keys. Besides, they have also obtained information for 1691 houses in the Miami-Dade county in Southeast Florida. The statistical significance of the samples (in terms of population covered) in each of the four regions is highlighted in Table 3.

Based on the information contained in the databases, four known plus one unknown or generic structural types were defined in each region. In addition, due to the variety of the building stock in the Keys, four additional types were defined for the Keys. They are all listed in Table 4. Table 5 lists their probability of occurrence per region. It should be noted that for types 1 to 4 the statistics could be divided between structures with tiles and structures with shingles.

5.0 DAMAGE ESTIMATION

Consider a residential community consisting of total number of *n* homes of different structural types *m* in a zone with specified surrounding terrain conditions. .

Assume the probability of occurrence of a storm with a peak 3-second gust wind speed within the interval $\{v- \Delta v/2,\ v + \Delta v/2\}$ m/s is $P(v)=p(v)\Delta v$, where $p(v)$ is the probability density distribution of the largest yearly wind speed (such information will be provided by the associated probabilistic wind field development team). Assume that the repair/replacement cost data for each possible damage state listed in Table 2, e.g. $O_3T_2S_1W_0C_0$, is obtained from insurance adjusters, and that the probabilities of occurrence of damage states, e.g. $P(O_3T_2S_1W_0C_0)$, are estimated conditional upon wind speed. The probable expected damage, expressed as a percentage, can be estimated as follows.

Step 1. The probable damage for a structure of type *m* in the zone subjected to a wind speed in the interval $\{v- \Delta v/2,\ v + \Delta v/2\}$ m/s is the sum of all the relative possible damage states listed in Table 2 for speed *v* in that interval multiplied by their probabilities of occurrence. For example, for v=60 m/s, Δv=10 m/s, the following equation results:

$$damage_{(60m/s,\ type\ m)} = [P_{type\ m}(O_3T_2S_1W_0C_0|60\text{ m/s}- 5\text{ m/s} < v < 60\text{ m/s} + 5\text{ m/s}) \times c(O_3T_2S_1W_0C_0)$$

$$+ [P_{type\ m}(O_3T_2S_2W_0C_0|\ 60\text{ m/s}- 5\text{ m/s} < v < 60\text{ m/s} + 5\text{ m/s}) \times c(O_3T_2S_2W_0C_0) + \ldots] + \ldots =$$

$$\Sigma_i\, P_{m,i}(subdamage\_state_i|60\text{ m/s}) \times c(subdamage_i) \quad (1)$$

In Eq. 1, $c(O_3T_2S_1W_0C_0)$ denotes the repair cost corresponding to subdamage state $O_3T_2S_1W_0C_0$ as a percentage of the building replacement value, and c(*subdamage*$_i$) is similarly defined.

In modeling the repair cost, the procedure needs to incorporate the fact that, the combined repair cost of components cannot exceed the replacement cost of the facility. In practice, the combined repair costs taper off to reach the replacement cost. Moreover, if the repair cost of the combined structure exceeds 50% to 60% of the replacement value of the building; it is considered economical to demolish the building. For this case the cost of demolishing and removal of debris must be used in the estimates.

It was stated at the end of section 3 that our 5-mode model is decomposed into 217 combined damage states. It is not reasonable to expect that a distinct cost can be assigned to each of these states. Rather, the many combinations will be associated with a handful of classes of damage. For example, 128 states, say, may all lead to 20% of replacement cost, 56 states may lead to 40 % replacement cost, and so forth. The simplification inherent in this observation is to be incorporated into the estimation procedure, and will require the input of experienced insurance adjusters.

Step 2. An expression similar to Eq. 1 applies to each of the wind speeds. Table 2 takes into account the probability of occurrence of wind speeds in the intervals of interest. The damage equation is

$$\text{Annual\_damage}_{\text{type } m} = \sum_{\textit{windspeed } i} \text{damage}(_{v_i,\text{type } m}) \times P(v_i - \Delta v/2 < v_i < v_i + \Delta v/2) \qquad (2)$$

Step 3. The damages for types 1, 2, … are multiplied by the respective relative frequency of those types in the building population of the zone (see Table 5). The damage equation becomes:

$$\text{Average\_Annual\_Damage} = \text{Annual\_damage}_{\text{type 1}} \times P(\text{type 1}) + \text{Annual\_damage}_{\text{type2}} \times P(\text{type2}) + \ldots \qquad (3)$$

Step 4. The total estimated expected damage to buildings for a particular zone is the damage calculated by using Eq. 3 times the total number *n* of houses in the zone. The process is repeated for each zone, and the results for each zone are added to obtain the estimated expected hurricane-induced annual damage to buildings for the entire state.

6.0 UNCERTAINTIES

The purpose of this paper is to illustrate the conceptual framework of the methodology used for damage computation. A detailed discussion of the uncertainties involved will be the focus of a follow-up paper. Main types of uncertainties include selection of the types of structural models for the simulations, repairment cost uncertainties, the properties or parameter inputs into the Monte Carlo simulations and relationship between wind speed and resultant force on roof. The estimates of the wind speed itself involve a significant degree of uncertainty that affects the final damage estimate. As noted earlier, the probabilistic wind model, including the uncertainties associated with it, is being developed in parallel with the effort reported here. Sensitivity studies are being conducted to define the influence of the different parameters on the outputs of the models and to identify the most critical sources of uncertainty.

7.0 CONCLUSIONS

This paper presents a probabilistic framework for the estimation of annual damages due to windstorms in the state of Florida. The framework is illustrated for the case of five basic damage modes, although additional modes could be considered. The framework assures that no type of damage is counted more than once, no type of possible damage is omitted from the calculations, and interactions between various types of damage are accounted for. The costs are calculated by correctly accounting for the dependence between various damage modes (e.g., window breakage and roof uplift). The damage is appropriately modeled as a stepwise process, as damage to openings gives sudden rise to increases of internal pressures, and sudden collapse of the roof results in immediate damage to walls.

A key ingredient of the proposed procedure is the development of a Monte Carlo simulation approach that relates probabilistic strength capacities of building components subjected to wind action through a detailed aerodynamic and structural engineering analysis. The results of the Monte Carlo simulation are used to fill in the cells of damage matrices used for the estimation of expected damage due to a windstorm event, and of expected annual damage, both at a specified location and over a larger geographical area.

An important component of the methodology is the determination of the right mix of structural types or models that characterize the building population in any given area. The definition of these structural types was achieved through statistical analyses of building databases for several counties throughout the state of Florida. A more accurate definition could be obtained in the future if all the counties were surveyed.

Work is in progress on the development of the Monte Carlo simulation methodology and its application to the various types of structures defined through the county surveys. Work is also in progress on quantifying the uncertainties in loss calculations, based on uncertainties in the estimation of probability matrices, associated conditional probabilities, hurricane wind speeds, structural behavior, component properties, and building population. Work is in progress on the development of the probabilistic wind field model. Preliminary predictions of annual vulnerability are planned once such development is completed.
One of the main advantages of this methodology is its transparency. The probabilities in the damage matrices are based on engineering models that will be continuously updated and refined as more knowledge on the strength of the component, load path, and wind effects becomes available.

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Table 1. Assumed probabilities of occurrence of sub-damage modes $O_{i,}$ conditional on wind speed intervals associated with the speeds *v*.

v(m/s)	45	50	55	60	65	70
$P(O_1 \mid v)$	6%	10%	5%	5%	5%	0%
$P(O_2 \mid v)$	4%	30%	40%	35%	20 %	10%
$P(O_3 \mid v)$	0%	10%	40%	60%	75 %	90%

Table 2: Example of estimated probabilities of damage states, conditional on wind speed intervals associated with the speeds *v*

v (m/s)	45	50	55	60	65	70
P (O_0T_0)	82%	38.%	6.0%	0.0%	0.0%	0.%
P(O T_0)	9.1%	40.%	54.0%	20.0%	0.0%	0.%
P(O_0 T S_0)	7.6%	10.%	3.7%	0.0%	0.0%	0.%
P(O_0 T S)	0.5%	0.5%	0.3%	0.0%	0.0%	0.%
P(O T S_0)	0.4%	2.0%	6.3%	30.%	20.%	0.%
P($OTSW_0C_0$)	0.5%	0.5%	0.33%	1.0%	10.%	0.%
P($OTSCW_0$)	0.%	3.%	3.87%	6.0%	0.%	0.%
P($OTSWC_0$)	0.%	0.%	3.57%	9.0%	0.%	0.%
P(OTS CW)	0.%	6.%	21.9%	34.%	70.%	100%

Table 3. Population information for each area

Region	Northern	Central	Southeast	Keys
Total number of counties	34	27	5	1
Number of sample counties	3	3	2	1
Total population	2,885,559	7690240	5,326,990	79589
Sample population	574,463	2396660	2,754,202	79589
% of population in sample	20%	30%	54%	100%

Table 4: Structural types definitions

	Structure	Roof Materials	Roof Type
Type 1	concrete blocks	Shingle/Tile	Gable
Type 2	concrete blocks	Shingle/Tile	Hip
Type 3	timber	Shingle/Tile	Gable
Type 4	timber	Shingle/Tile	Hip
Type 5	concrete blocks	Metal	Gable
Type 6	concrete blocks	Metal	Hip
Type 7	timber	Metal	Gable
Type 8	timber	Metal	Hip

Table 5: Percentage of each type for 4 regions.

	Nort hern	Centra l	South east	Keys	
Type 1	25%	43%	46%	22%	Type5 . 12%
Type 2	12%	29%	23%	11%	Type6 . 6%
Type 3	32%	12%	13%	12%	Type7 . 9%
Type 4	16%	6%	6%	6%	Type8 . 5%
Unknow n Type	15%	10%	12%	17%	

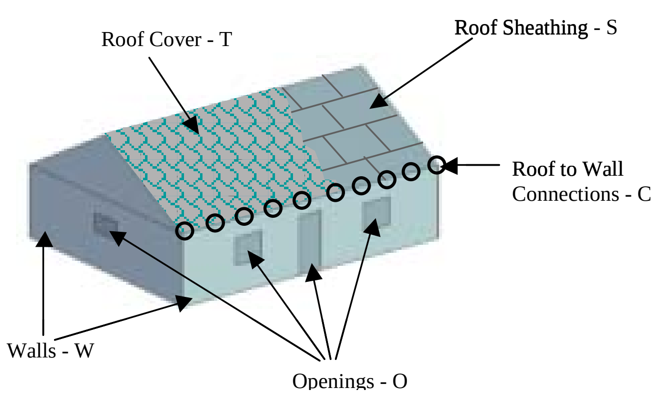

Figure 1: Components of a single family home

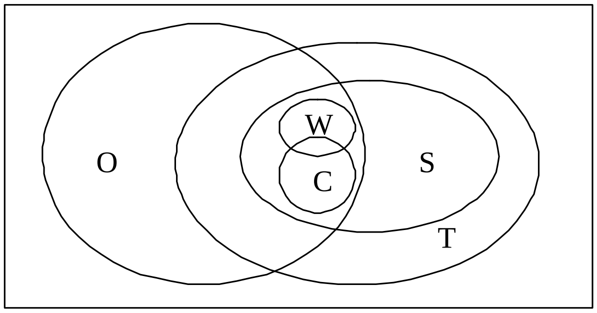

Figure 2: Venn diagram for the basic damage modes of a masonry home

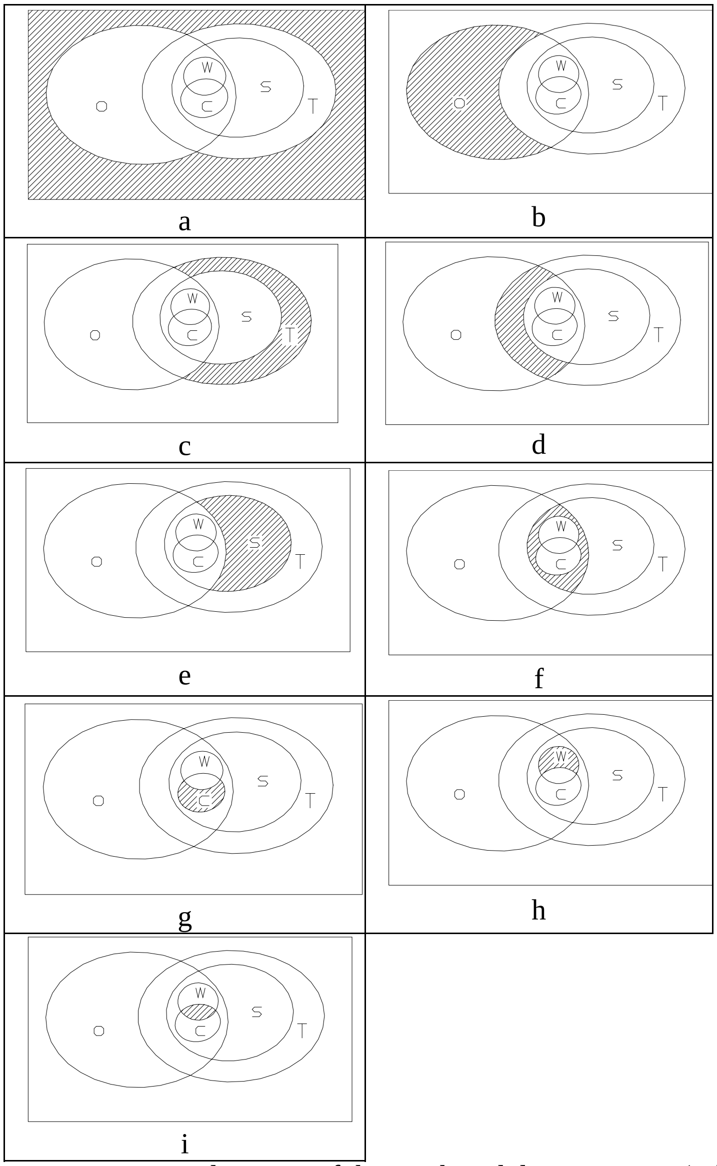

Figure 3: Venn diagrams of the combined damage states (subsets of Figure 2)

Figure 4. Florida counties and regions