RISK ASSESSMENT OF HURRICANE MITIGATIVE OPTIONS INVOLVING CENTRAL PARK LODGE NURSING HOME

HRRC Publication 10R

Norris Stubbs

1986

HAZARD REDUCTION

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ACKNOWLEDGMENTS

This report is the result of the combined effort of several Texas A&M University faculty members and staff. In particular, I mention the contributions of Professor Carrol Claycamp and Robert Segner for their consultation on the overall structural performance of the building; Engineers Richard Schuler, Nathan Kathir, and Roberto Osegueda for performing the computer analysis and reliability calculations, and for proofing the manuscript; Engineer Charles Sikorsky for running the risk model and drawing the figures; and Patricia Lombard for typesetting the manuscript and keeping us organized.

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Problem Statement

After a series of consultations with the Tampa Bay Regional Planning Council (TBRPC), the following problem statement, in the form of a scenario, was proposed:

> "The Tampa Bay Region is threatened by the possible direct hit of a Category 3[a] hurricane. Building B, a nursing home for 100 invalid and semi-invalid residents, located in the central portion of the county (5 miles from the coast or Bay), must consider evacuation due to potential storm surge flooding.
>
> Nursing Home Administrators must decide whether to (1) move all residents to the host facility located 2.5 miles south (but out of the potentially surge-vulnerable area) or (2) move residents to the upper floor and remain in the facility (with and without modifications).
>
> Considering the inland location and hazard vulnerability (see Table 1), what is the least-risk option? Repeat the problem for other hurricane categories."

This report summarizes the results of a structural risk analysis of the Central Park Lodge Nursing Home located in Pinellas Park, Florida. The purpose of the report is to provide emergency management personnel with additional information on the probable behavior of the structure in a variety of hurricane environments. One objective of the selected methodology is to translate the normally esoteric description of "probable structural performance" into a format that non-engineers can readily appreciate. Another objective is to simultaneously and systematically account for the structural as well as

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[a] See Appendix D.

Table 1. Surge Levels at Existing Location

Hurricane Category	Surge Height* (ft)
1	----
2	----
3	4.0
4	10.8
5	12.8

*Data provided by TBRPC.

non-structural aspects of the problem. A final goal of the method utilized is to express the protection afforded by a structure in terms of the protection afforded to the occupant.

Method Used to Evaluate Safety of Occupants

A detailed description of the structure is provided in Appendix C. Relevant descriptions of the documents consulted, calculation procedures, loading models, and material properties used are summarized in Appendix A. A summary of the intermediate steps leading to the final results is also presented in Appendix C.

Results of the Analysis

The results of the analysis are shown in Tables 2 - 4 which are all obtained from Tables C.15 to C.17. Only the expected fraction of fatalities is utilized here. The numbers in Table 2 are obtained from those in Appendix C by multiplying the expected fraction of fatalities by the assumed number of occupants (which is taken here to be 100). Furthermore, the numbers indicating the risk of fatalities are only given to the nearest person. In Option (1), Table 2, the risk of transporting the inhabitants between locations is included. This number, which is to be supplied by others, is assumed to vary with the environmental conditions. In Option (3), the roofing and cladding of the structure were upgraded to resist a Category 3 hurricane.

Table 3 utilizes both the mean and standard deviations in Tables C.15 to C.17. It expresses the chance that more than 10 people will be killed in the various hurricanes. The amount by which the risks in Option 1 are increased depends upon the risk associated with transporting the residents from the existing facility to the host facility.

Table 4 is a recasting of Table 2 with the difference that the observed degradation in wind speed of the hurricane as it moves inland is taken into account. The host facility in Option 1 is assumed to be located five (5) miles inland from the existing facility in Option 2 and Option 3. Over this distance the wind speed is assumed to be reduced by 30 percent. Therefore, mean wind speeds of

Table 2. Summary of Risk (expressed in terms of expected fatalities) Associated With Selected Options in Various Hurricane Environments

Option Number	Description	Risk of Fatalities (Number of Persons) Hurricane Category 1	2	3	4	5
1	Move all residents to host facility 2.5 miles south	t_1+0[a]	t_2+0	t_3+34[b]	t_4+42	t_5+42
2	Move residents to upper two floors of existing nursing home	0	0	34	42	42
3	Move residents to upper two[c] floors of modified nursing home	0	0	0	30	42

[a] t_i (supplied by others) is the expected number of fatalities incurred during relocation in a hurricane of category i.
[b] This is estimated to the nearest person.
[c] Structure modified to resist a Category 3 hurricane.

Table 3. Summary of Risk (expressed in terms of the chance that more than 10 persons are killed) Associated With Selected Options in Various Hurricane Environments

Option Number	Description	Risk of Fatalities (Chance That > 10 Fatalities Occur)				
		Hurricane Category				
		1	2	3	4	5
1	Move all residents to host facility 2.5 miles south	> 5:100,000[a]	> 1:10,000	> 8:10	> 9:10	> 9:10
2	Move residents to upper two floors of existing nursing home	5:100,000	1:10,000	8:10	8:10	8:10
3	Move residents to upper two[b] floors of modified nursing home	5:1000,000	1:10,000	3:1,000	8:10	8:10

[a]Increase is due to transportation risks.
[b]Structure modified to resist a Category 3 hurricane.

Table 4. Summary of Risk (expressed in terms of expected fatalities) Associated With Selected Options in Various Hurricane Environments Assuming Wind Degradation

Option Number	Description	Risk of Fatalities (Number of Persons) — Hurricane Category at Existing Structure: 1	2	3	4	5
1	Move all residents to host facility 5 miles from nursing home	t_1+0[a]	t_2+0	t_3+0	t_4+0[b]	t_5+0
2	Move residents to upper two floors of existing nursing home	0	0	34	42	42
3	Move residents to upper two[c] floors of modified nursing home	0	0	0	30	42

[a] t_i (supplied by others) is the expected number of fatalities incurred during relocation in a hurricane of category i.
[b] This is estimated to the nearest person.
[c] Structure modified to resist a Category 3 hurricane.

84.5, 103, 120.5, 143, and 165 MPH (which, respectively, represent the mean values of Categories 1-5 hurricanes) at the existing facility become 59, 72, 84, 100, and 115 MPH at the host facility. The risks associated with these winds are obtained from Table 2.

In interpretating Tables 2 and 3, the following points should be kept in mind. The structure was subjected to hurricane winds corresponding to the hurricane categories defined by the Saffir-Simpson Scale. For example, for a Category 1 hurricane, the wind is anywhere between 73 and 96 MPH. If gusting should occur and the winds in the example hurricane exceed 96 MPH, then the structure for that period of time is experiencing a Category 2 hurricane and the risk associated with the latter intensity should be used.

Finally, we would like to point out that the fatalities presented for this study are based on a worst case scenario for the consequences of failure. It has been assumed that the consequences of cladding failure and roof failure are equal to that of frame and foundation failure. As more information is obtained in the future, the consequences of failure portion of the model will be modified to reflect this information.

Least-Risk Options

Using the results of the structural risk analysis as presented in Tables 2 to 4, the least-risk options for the scenarios proposed in the problem statement are summarized in Tables 5 and 6.

Table 5. Summary of Least-Risk Options Assuming No Wind Degradation

Hurricane Categories	Least Risk Option	Remarks
1	2 or 3	If cost to upgrade is not feasible, then option 2 is least-risk
2	2 or 3	If cost to upgrade is not feasible then option 2 is least-risk
3	3	
4	3	
5	No clear least-risk option	

Table 6. Summary of Least-Risk Options Assuming Wind Degradation

Hurricane Categories	Least Risk Option	Remarks
1	2	Cost to upgrade and risk to transport may not be feasible
2	2	Cost to upgrade and risk to transport may not be feasible
3	3	If cost to upgrade is not feasible, Option 1 may be selected
4	1	
5	1	

REFERENCES

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APPENDIX A

GENERAL NOTES

CONSTRUCTION DOCUMENTS

1. Construction plans and specifications of the building analyzed were supplied by the TBRPC. No shop drawings were made available.

2. The building was designed in accordance with the current Standard Building Code.

3. The structure and the surrounding terrain were visually inspected.

CALCULATION PROCEDURES

A schematic outlining the logic of the evaluation scheme is provided in Figure A.1. The key elements of the evaluation are as follows:

1. Failure functions for structural units (cladding elements, doors, windows, roof elements, etc.) were defined. To contain the complexity of the analysis, where possible linear failure functions were selected.

2. Loading statistics (derived from the hurricane) and resistance statistics (derived from the materials and the design specifications) were determined for the unit.

3. Approximate failure probabilities for the units were defined using Mean Value Methods from Structural Reliability Theory.

4. Failure scenarios for the building system were synthesized using Fault-tree Analysis.

5. Failure probabilities for the building system were then computed.

6. Risk of fatalities were computed using the previously developed algorithm.

7. Modifications were made to upgrade the structure.

8. New risk of fatalities were computed as in Steps 1-6.

FAILURE DEFINITIONS

Failure modes vary with the characteristics of the construction. Failure functions can only be written after a review and analysis of the plans and governing codes, and an inspection of the existing structure. The following procedure provides an indication of how failure definitions were developed in the present study.

1. Frame: Frame failure occured if the interstory drift for any floor due to the hurricane loading exceeded some limiting value. The value used in the buildings studied were determined as follows. Each frame was modelled using finite elements and loaded by its own weight and the vertical live load. A constant shear force was then applied to a single story of the structure and the bending moment at critical connections of the floor monitored. When the bending moment at any of the critical positions was equal to the resisting moment at the first yield of the section, the prevailing value of the interstory drift was taken as the limiting value for that floor. The procedure was repeated for each story of the frame.

2. Roof: Failure of the roof system occurs if a major structural unit supporting the deck (beam/panel) fails or if more than five percent of the deck area fails. To determine deck failure, the roof decking was divided into equal panel sizes and the failure probability of one panel determined. Failure characteristic of the deck system was estimated by assuming that the failure of each panel was independent and that the failure characteristics of the system could be modelled by a binomial distribution. The probability of failure of one panel was equated with the probability of a "success" in the binomial sense.

3. Cladding: Failure of the cladding system occurs if more than 10% of the cladding area on each wall on opposite sides of the building is lost. The building cladding area was divided into equal panel sizes and the reliability of one panel determined. Using the binomial distribution, as above, the failure probability of each side was determined.

4. Assumed panel sizes for the roof and cladding systems were based on engineering judgement. Factors considered included type of construction material, spacing of cladding supports, and spacing of decking supports.

5. Other failure definitions: Other definitions of failure were dictated by the behavior of the structural system in question.

LOADING STATISTICS

1. Hurricane categories were identified by the Saffir-Simpson Scale (see Appendix I). The mean and variance of the wind speed for each hurricane category were estimated assuming a uniform probability distribution. For example if V_a and V_b are the lower and upper surges for a given category, the mean speed is $(V_a + V_b)/2$ and the variance is $(V_b - V_a)^2/12$.

2. Wind pressure acting on the structural frame was determined by increasing the basic wind pressure ($P = 0.00256V^2$) by a shape factor of 1.3 ($C_D = 1.3$).

3. Wind pressures acting on the roof, cladding, and openings was determined by increasing the basic wind pressure by a shape factor of 1.5 ($C_D = 1.5$).

4. To model the hurricane wind field, the wind pressure acting on the building above a height of 30 ft was assumed constant. From ground level to a height of 30 ft wind presure was assumed to vary linearly.

5. Water force calculations were based on procedures provided in Reference 2.

RESISTANCE STATISTICS

1. The design resistance (R_{design}) for the various structural elements was assumed to be the allowable loads listed on the construction drawings.

2. If information was not available regarding the design resistance, it was estimated from the applicable building code.

3. Ultimate (nominal) resistances (R_n) were estimated as in Table A.1.

Table A.1. Nominal Resistance Values Assumed in Study

Building Component	Nominal Resistance (R_n)
Roof elements	1.1 (R_{design}*)
Door/windows	1.1 (R_{design})
Cladding	1.1 (R_{design})

*Minimum value required by applicable Standard Building Code.

4. Resistance statistics (mean and variance) were estimated based on the following values given in Table A.2.

Table A.2. Resistance Statistics Used in Study

Component	$\bar{R}^*/R_n$	COV	Assumed Distribution	Source
Door & windows	1.05	0.15	Normal	Engineering judgement
Cold formed steel members	1.17	0.17	Normal	Table C.5** A58.1
Cladding, general	1.05	0.10	Normal	Engineering judgement
Wood construction	1.10	0.20	Normal	Engineering judgement
Masonry	1.05	0.10	Normal	Engineering judgement
Reinforced concrete	1.22	0.16	Normal	Table B.3 A58.1

*$\bar{R}$ = Mean resistance.
R_n = Nominal resistance.
**See reference 3.

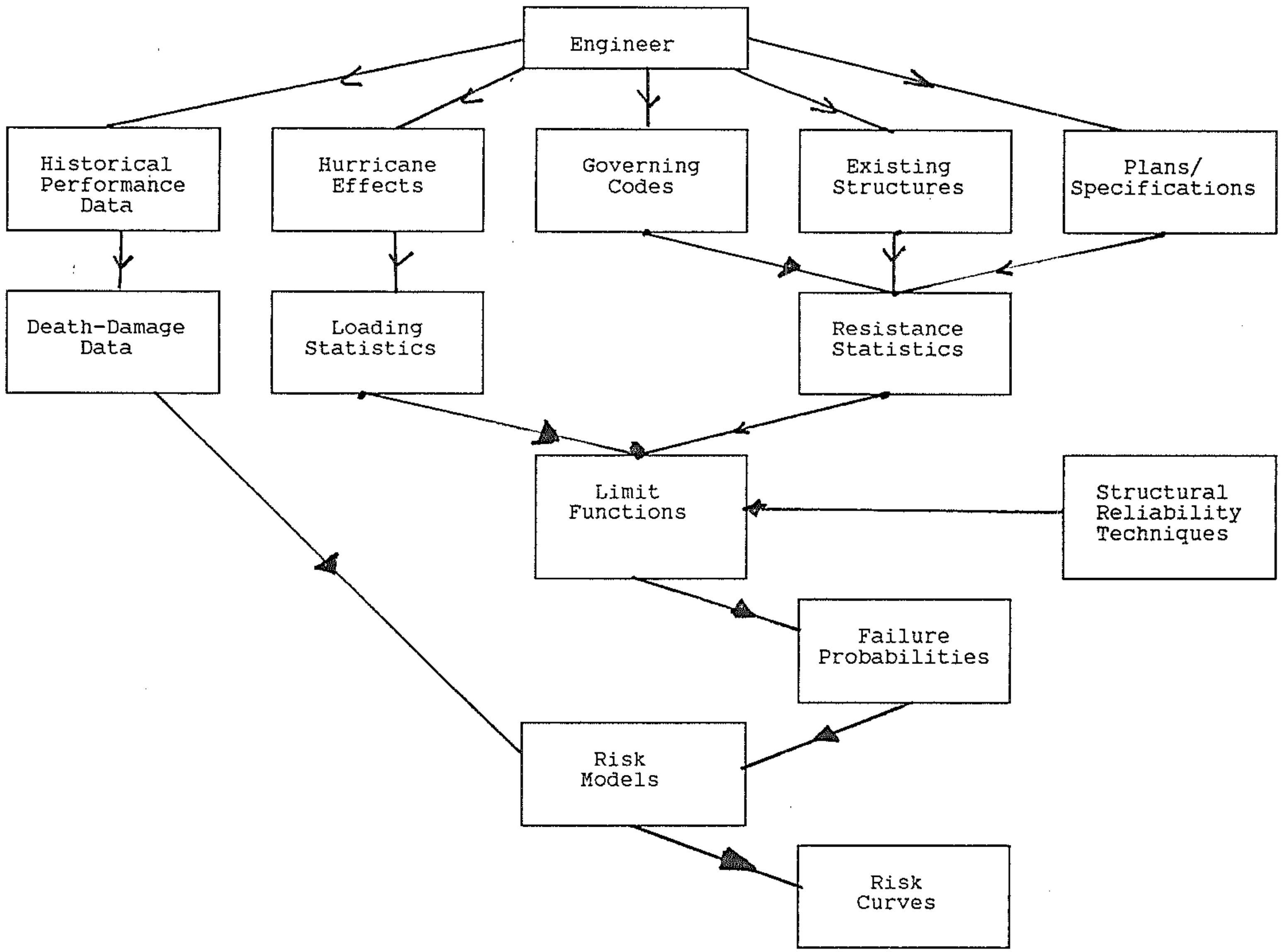

Figure A.1. Evaluation Scheme

APPENDIX B

LIST OF SYMBOLS

E = Modulus of elasticity of concrete

I = Moment of inertia of concrete structural element

K_i = Story stiffness (i = 1, 2, 3)

L_i = Story height (i = 1, 2, 3)

P_i = Lateral pressure due to category "i" hurricane

P_{ui} = Uplift pressure due to category "i" hurricane

P_{Rji} = Concentrated lateral load on shear model of structure (j = floor level, i = hurricane category)

R_C = Resistance of cladding unit

R_G = Resistance of window unit

V_i = Wind speed for category "i" hurricane

W_b = Dead load of panel and roof beam

W_i = Linearly distributed load due to category "i" hurricane

W_s = Dead load of roof panel unit

Z_i = Safety margin

a_j = Floor stiffness constant (j = 1, 2, 3)

Δ_{oi} = Limiting interstory drift for i^{th} story

APPENDIX C

DETAILED RESULTS OF RISK ANALYSIS

Description of Structure

The structure is located five miles inland in Pinellas Park, Florida and serves as a Nursing Home. The structure, built in 1982, covers a floor plan area of approximately 14,500 sq. ft. and has three stories. The height of the first story is 11.5 ft above ground level and the height of each succeeding floor is 9.0 ft. The building codes governing the building design include The Standard Building Code, the AISC Specifications for Design, Fabrication and Erection of Structural Steel for Buildings and ACI 318-77.

Figure C.1 shows a typical elevation and a typical floor plan of the structure. The foundation consists of 1' 4" deep reinforced concrete strip footings.

The lateral load resisting system is made-up of moment resisting reinforced concrete frames. Fifteen frames spaced at 12.2 ft O.C. resist the lateral forces in the east-west direction and 10 frames also spaced at 12.2 ft O.C. resist the lateral forces in the north-south direction. A typical frame is shown in Figure C.2. Stairwells at the ends of the structure also provide some lateral resistance. Elevator and stairwell core are built of load-bearing type masonry walls.

The floors and the roof are cast monolithically with the reinforced concrete frame. The roof deck is covered with 2" rigid insulation which in turn is covered with a 4-ply crushed stone topping. The exterior walls are the metal stud type with the studs placed at 24 inches O.C. The north, south, east, and west elevations have 30, 21, 22, and 19 windows, respectively.

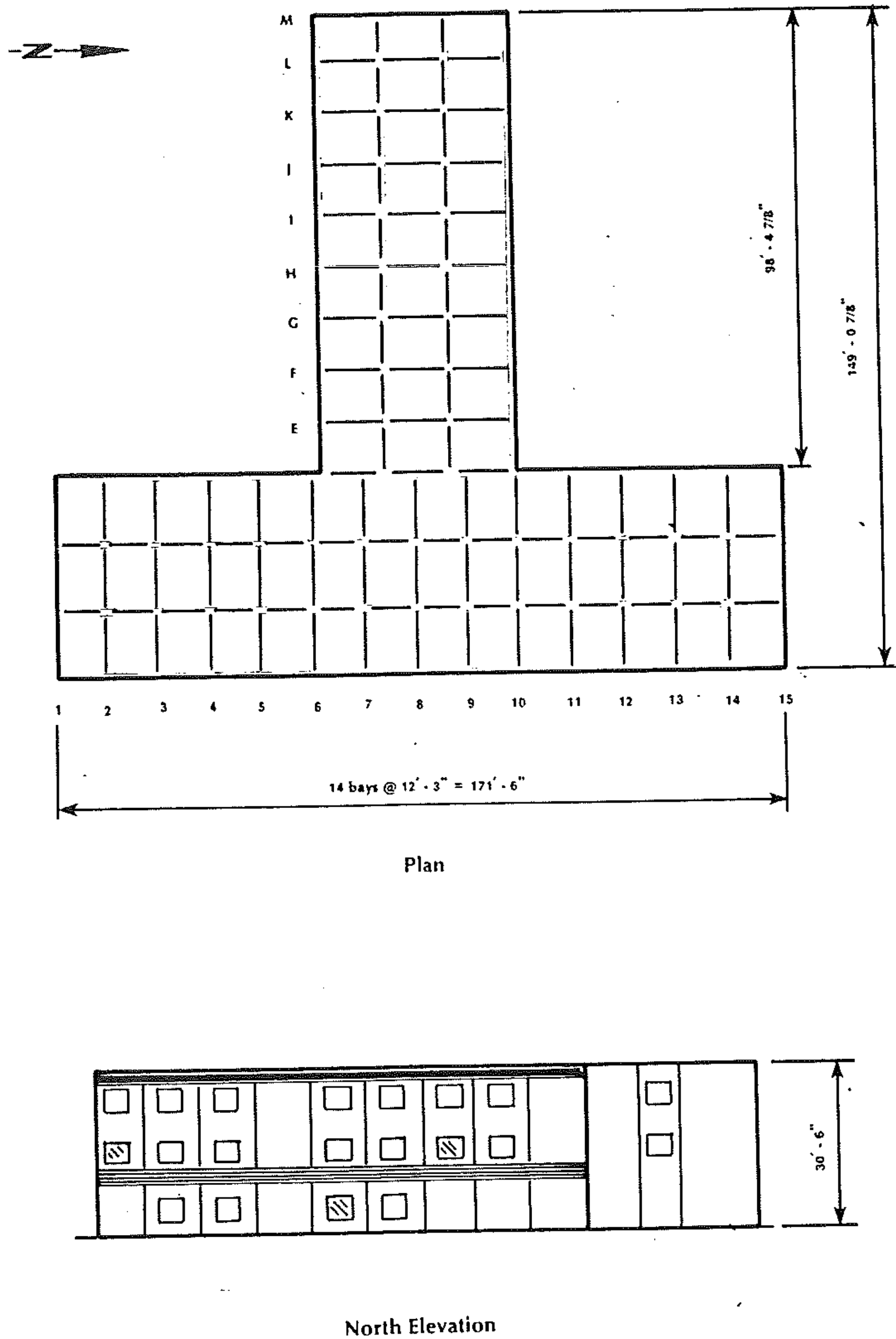

Figure C.1. Plan and Elevation of Example Structure.

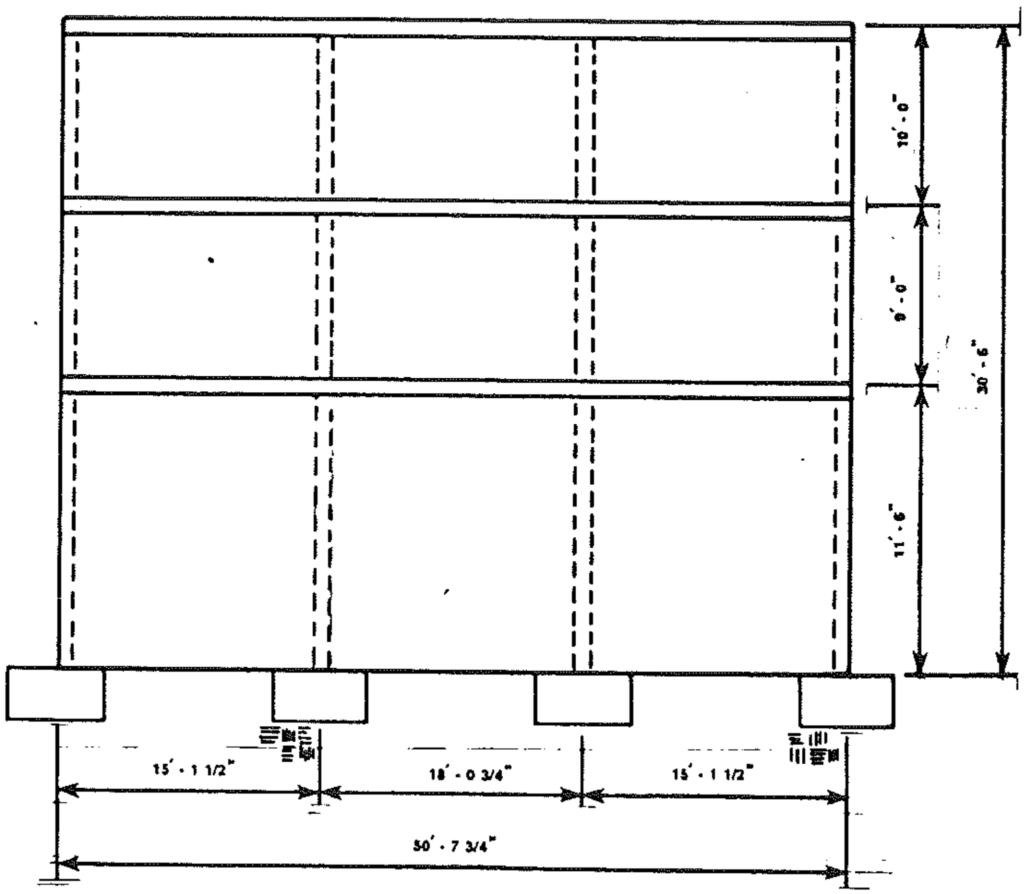

Figure C.2. Typical Frame

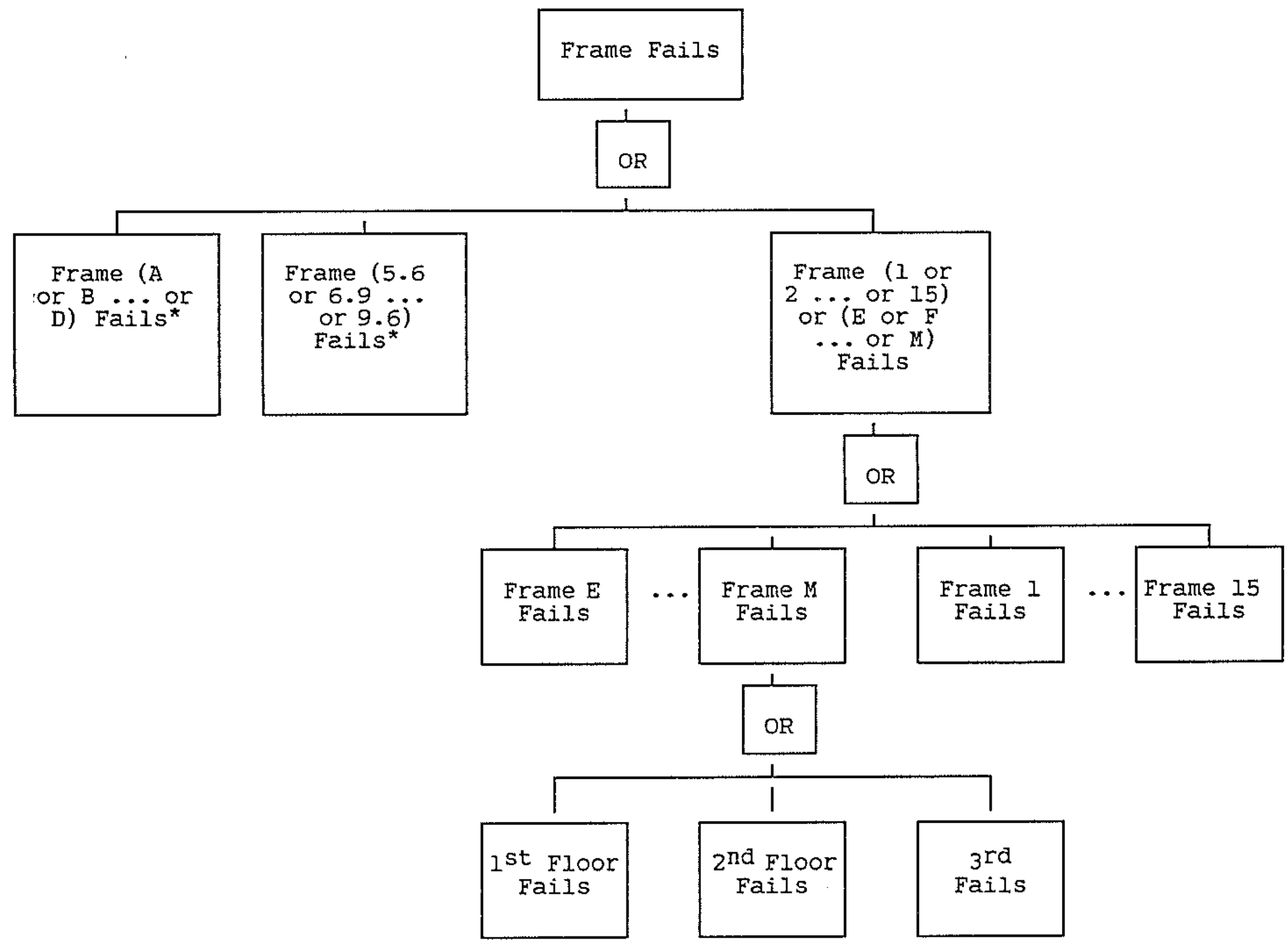

Figure C.3. Definition of Failure for the Lateral Load Resisting System

*Failure of these items were disregarded.

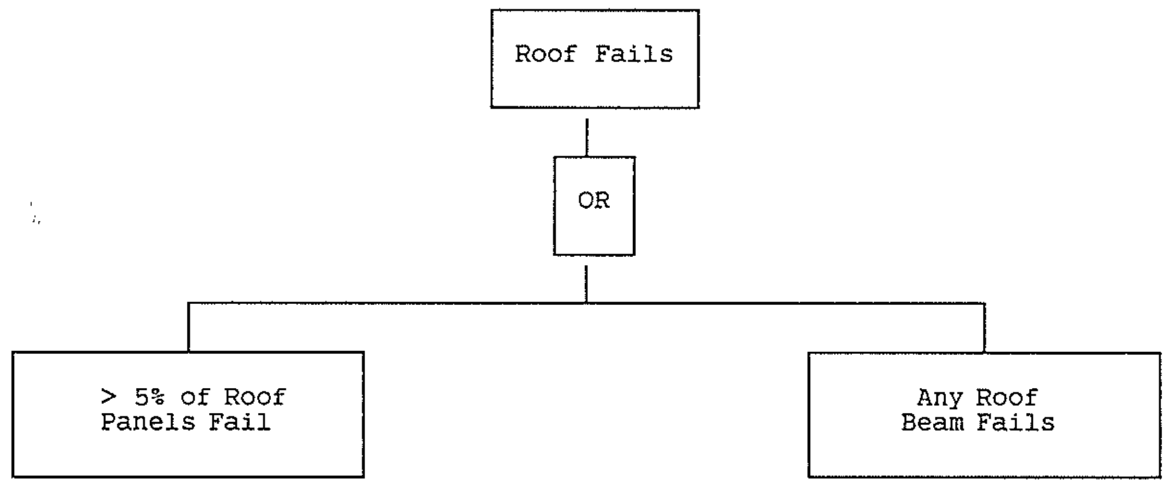

Figure C.4. Definition of Roof Failure

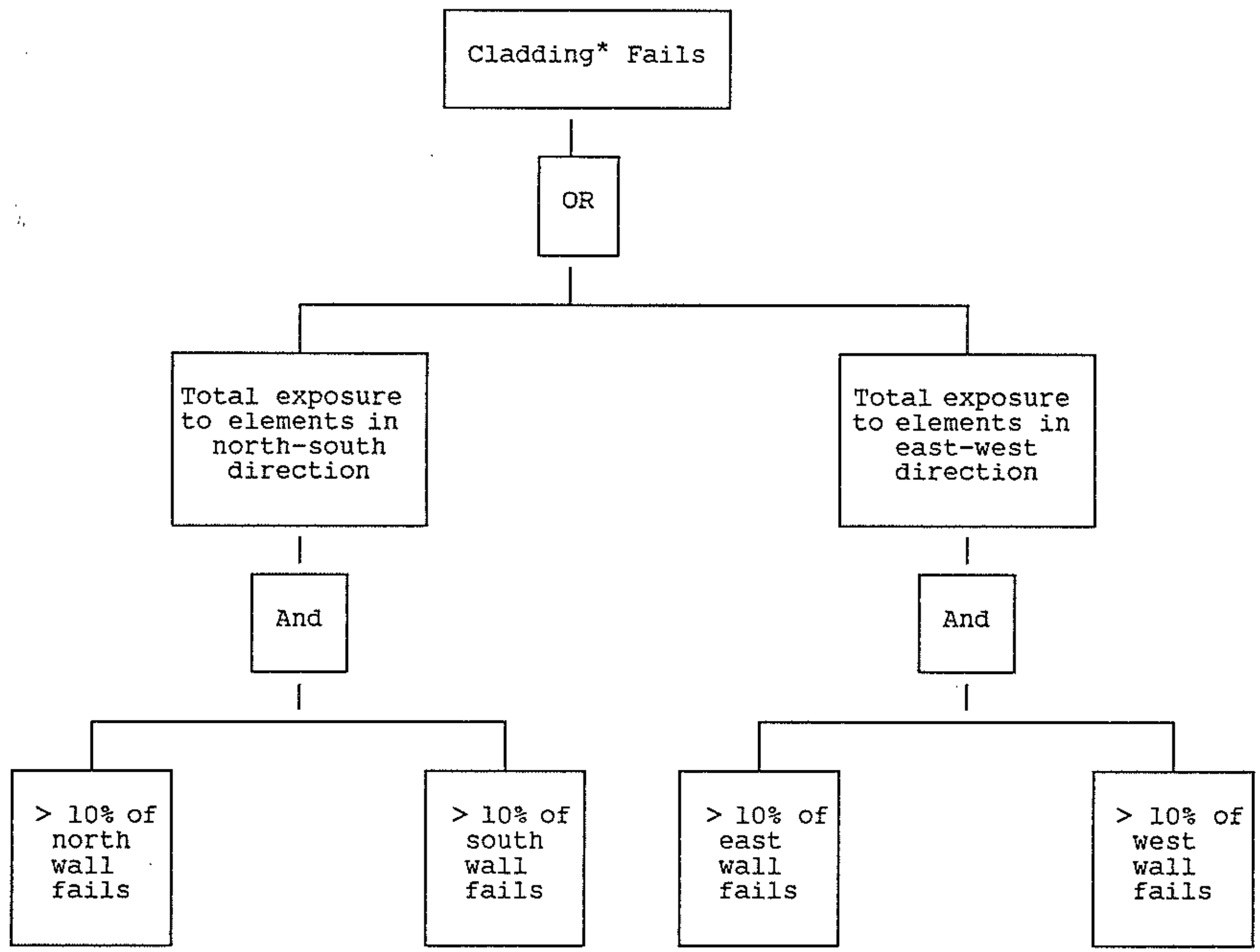

Figure C.5. Definition of Cladding Failure

*Windows included.

Table C.1. Failure Functions (Frame)

Description of Failure Mode	Safety Margin
Excessive interstory drift in 1st story	$Z_1 = \Delta_{o1} - P_{R1i}L_1^3/(a_1EI)$
Excessive interstory drift in 2nd story	$Z_2 = \Delta_{o2} - P_{R2i}L_2^3/(a_2EI)$
Excessive interstory drift in 3rd story	$Z_3 = \Delta_{o3} - P_{R3i}L_3^3/(a_3EI)$

Table C.2. Hurricane Categories and Their Resulting Loading on the Structure

Hurricane Category (i)	Parameters					
	Wind Speed V_i (MPH)		Wind Pressure P_i (psf)		Live Load W_i (plf)	
	mean	variance	mean	variance	mean	variance
1	84.5	12.25	23.76	9.52	$23.76l$	$9.52l^2$
2	103.0	5.44	35.31	15.02	$35.32l$	$15.02l^2$
3	120.5	10.03	48.32	29.80	$48.32l$	$29.80l^2$
4	143.0	16.00	68.05	60.81	$68.05l$	$60.81l^2$
5	165.5	10.03	91.15	95.26	$91.15l$	$95.26l^2$

Table C.3. Statistics of Resistance Variables for Frames

Variable	Symbol	Units	Mean	COV	Assumed Distribution
First floor limiting interstory drift	Δ_{o1}	inches	0.410	0.20	Normal
Second floor limiting interstory drift	Δ_{o2}	inches	0.264	0.20	Normal
Third floor limiting interstory drift	Δ_{o3}	inches	0.247	0.20	Normal
Lateral pressure due to category 1 hurricane	P_1	psf	23.76	0.13	Normal
Lateral pressure due to category 2 hurricane	P_2	psf	35.31	0.11	Normal
Lateral pressure due to category 3 hurricane	P_3	psf	48.32	0.11	Normal
Lateral pressure due to category 4 hurricane	P_4	psf	68.05	0.11	Normal
Lateral pressure due to category 5 hurricane	P_5	psf	91.15	0.11	Normal
Modulus of elasticity (concrete)	E	ksi	3,200	0.10	Normal
Moment of inertia of concrete columns	I	in^4	8716	0.05	Normal

Table C.4. Failure Functions for Roof Element

Description of Failure Mode	Safety Margin
Uplift resistance of any roof panel exceeded	$Z_4 = W_s - P_{ui}$
Uplift resistance of any roof beam exceeded	$Z_5 = W_b - P_{ui}$

Total number of beams = 88.
Total number of panels = 69.

Table C.5. Parameters used to Evaluate Safety of Roof

Variable	Symbol	Units	Mean	COV
Uplift resistance (roof panel) of existing structure	W_s	psf	80.00	0.10
Uplift resistance (roof panel) of modified structure	W_s	psf	96.80	0.10
Uplift pressure for Category 1	P_{u1}	psf	29.25	0.17
Uplift pressure for Category 2	P_{u2}	psf	43.45	0.13
Uplift pressure for Category 3	P_{u3}	psf	59.47	0.16
Uplift pressure for Category 4	P_{u4}	psf	83.76	0.13
Uplift pressure for Category 5	P_{u5}	psf	112.19	0.12
Uplift resistance (beam) of existing structure	W_b	psf	85.00	0.10
Uplift resistance (beam) of modified structure	W_b	psf	96.80	0.10

$*P = 0.00256 C_D V^2$, $\mu_{CD} = -1.6$, $COV[C_D] = 0.1$

Table C.6. Reliability Indices for Roof Failure

Failure Mode	Reliability Indices (Failure Probability) Hurricane Category 1	2	3	4	5
Existing Structure					
Roof beam failure (in uplift due to tension)	5.62 (*)	4.10 ($2.07X10^{-5}$)	1.98 ($2.39X10^{-2}$)	0.09 (0.46)	-1.71 (1.00)
Single panel failure (uplift)	5.35 (*)	3.76 ($8.50X10^{-5}$)	1.63 ($5.16X10^{-2}$)	-0.27 (1.00)	-2.06 (1.00)
> 5% of panels fail[1]	(*)	(*)	(0.48)	(1.00)	(1.00)
Modified Structure					
Roof beam failure (in uplift due to tension)	6.25 (*)	4.76 ($9.68X10^{-7}$)	2.75 ($2.98X10^{-3}$)	0.89 (0.19)	-0.92 (1.00)
Single panel failure (uplift)	6.25 (*)	4.76 ($9.68X10^{-7}$)	2.75 ($2.98X10^{-3}$)	0.89 (0.19)	-0.92 (1.00)
> 5% of panels fail[1]	(*)	(*)	($5.84X10^{-3}$)	(1.00)	(1.00)

[1]Total number of roof panels = 69.
*Probability of Failure < 10^{-7}.

Table C.7. Failure Functions (Cladding)

Description of Failure Mode	Safety Margin
Lateral forces exceed capacity of window unit	$Z_6 = R_G - P_i$
Lateral forces exceed capacity of wall unit	$Z_7 = R_C - P_i$

Table C.8. Resistance Parameters for Cladding Units

Variable	Symbol	Units	Mean	COV	Assumed Distribution
		Existing Structure			
Resistance capacity of window unit	R_G	psf	46.5	0.15	Normal
Resistance capacity of wall	R_C	psf	56.0	0.10	Normal
		Modified Structure			
Resistance capacity of window unit	R_G	psf	71.5	0.10	Normal
Resistance capacity of wall	R_C	psf	71.5	0.10	Normal

Table C.9. Reliability Indices (Failure Probabilities) for Cladding Systems

Events	Reliability Indices (Failure Probabilities)				
	Hurricane Category				
	1	2	3	4	5
			Existing Structure		
A single window fails	2.98 (1.44×10^{-3})	1.40 (8.08×10^{-2})	-0.21 (1.00)	-2.06 (1.00)	-3.72 (1.00)
A wall unit fails	5.04 (2.33×10^{-7})	3.04 (1.18×10^{-3})	0.98 (0.16)	-1.26 (1.00)	-3.12 (1.00)
> 10% of the north windows fail					
North windows fail	(1.15×10^{-7})	(0.22)	(1.00)	(1.00)	(1.00)
South windows fail	(3.91×10^{-6})	(0.24)	(1.00)	(1.00)	(1.00)
East windows fail	(4.52×10^{-6})	(0.26)	(1.00)	(1.00)	(1.00)
West windows fail	(2.85×10^{-6})	(0.19)	(1.00)	(1.00)	(1.00)
> 10% of the north stud walls fail					
North stud walls fail	(*)	(*)	(0.75)	(1.00)	(1.00)
South stud walls fail	(*)	(*)	(0.72)	(1.00)	(1.00)
East stud walls fail	(*)	(*)	(0.81)	(1.00)	(1.00)
West stud walls fail	(*)	(*)	(0.86)	(1.00)	(1.00)
			Modified Structure		
A single window fails	5.61 (*)	4.45 (4.29×10^{-6})	2.58 (4.94×10^{-3})	0.33 (0.37)	-1.62 (1.00)
A wall unit fails	5.61 (*)	4.45 (4.29×10^{-6})	2.58 (4.94×10^{-3})	0.33 (0.37)	-1.62 (1.00)
> 10% of the north windows fail					
North windows fail	(*)	(1.07×10^{-5})	(9.23×10^{-1})	(1.00)	(1.00)
South windows fail	(*)	(1.07×10^{-5})	(9.23×10^{-5})	(1.00)	(1.00)
East windows fail	(*)	(6.81×10^{-7})	(9.67×10^{-1})	(1.00)	(1.00)
West windows fail	(*)	(6.81×10^{-7})	(9.67×10^{-1})	(1.00)	(1.00)
> 10% of the north stud walls fail					
North stud walls fail	(*)	(1.07×10^{-5})	(9.23×10^{-1})	(1.00)	(1.00)
South stud walls fail	(*)	(1.07×10^{-5})	(9.23×10^{-5})	(1.00)	(1.00)
East stud walls fail	(*)	(6.81×10^{-7})	(9.67×10^{-1})	(1.00)	(1.00)
West stud walls fail	(*)	(6.81×10^{-7})	(9.67×10^{-1})	(1.00)	(1.00)

*Negligible < 10^{-7}

Table C.10. Results from the Analysis of Frame Failure

Subsystem Failing	Reliability Indices (Failure Probabilities) Hurricane Category 1	2	3	4	5
Wind Only:					
First floor	4.86 ($5.88X10^{-7}$)	4.79 ($8.35X10^{-7}$)	4.71 ($1.18X10^{-6}$)	4.60 ($2.11X10^{-6}$)	4.46 ($4.10X10^{-6}$)
Second floor	4.71 ($1.24X10^{-6}$)	4.57 ($2.44X10^{-6}$)	4.46 ($5.42X10^{-6}$)	4.15 ($1.66X10^{-5}$)	3.85 ($5.91X10^{-5}$)
Third floor	4.76 ($9.69X10^{-7}$)	4.63 ($1.74X10^{-6}$)	4.50 ($5.40X10^{-6}$)	4.29 ($8.94X10^{-6}$)	4.05 ($2.56X10^{-5}$)
Wind and Water:					
First floor	4.86 ($5.88X10^{-7}$)	4.79 ($8.35X10^{-7}$)	4.42 ($4.94X10^{-6}$)	4.09 ($2.16X10^{-5}$o)	5.00 ($2.87X10^{-7}$)
Second floor	4.71 ($1.24X10^{-6}$)	4.57 ($2.44X10^{-6}$)	4.40 ($5.42X10^{-6}$)	4.19 ($1.40X10^{-5}$)	5.00 ($2.87X10^{-7}$)
Third floor	4.76 ($9.69X10^{-7}$)	4.63 ($1.74X10^{-6}$)	4.50 ($3.40X10^{-6}$)	4.29 ($8.94X10^{-6}$)	4.05 ($2.56X10^{-5}$)

*Probability of failure < 10^{-7}.

Table C.11. Risk Model Data Input for Existing Nursing Home Subjected Only to Wind

Basic Event	Description of Basic Event	Basic Event Probabilities				
		Hurricane Category				
		1	2	3	4	5
X_1	Wind hazard occurs	1.00	1.00	1.00	1.00	1.00
X_2	Lateral forces exceed frame strength	$6.73X10^{-5}$	$1.20X10^{-4}$	$2.40X10^{-4}$	$6.63X10^{-4}$	$2.19X10^{-3}$
X_3	Person is exposed|frame fails	1.00	1.00	1.00	1.00	1.00
X_5	Foundation fails	*	*	*	*	*
X_6	Person is exposed|foundation fails	1.00	1.00	1.00	1.00	1.00
X_8	Lateral forces exceed roof strength	*	$2.07X10^{-5}$	$4.92X10^{-1}$	1.00	1.00
X_9	Person is exposed|roof fails	1.00	1.00	1.00	1.00	1.00
X_{11}	Lateral forces exceed cladding resistance	*	*	$9.98X10^{-1}$	1.00	1.00
X_{12}	Person is exposed|cladding fails	1.00	1.00	1.00	1.00	1.00
X_{14}	Lateral forces exceed opening** resistance					
X_{15}	Person is exposed|opening fails	1.00	1.00	1.00	1.00	1.00
X_{17}	Lateral forces exceed int. part. resistance	*	*	*	*	*
X_{18}	Person is exposed|partition fails	1.00	1.00	1.00	1.00	1.00

*Less than 10^{-7} or failure mode ignored.
**Included with cladding.

Table C.12. Risk Model Data Input for Existing Nursing Home Subjected to Wind and Water

Basic Event	Description of Basic Event	Basic Event Probabilities — Hurricane Category 1	2	3	4	5
X_1	Wind hazard occurs	1.00	1.00	1.00	1.00	1.00
X_2	Lateral forces exceed frame strength	6.71×10^{-5}	1.23×10^{-4}	3.30×10^{-4}	1.07×10^{-3}	6.28×10^{-4}
X_3	Person is exposed|frame fails	1.00	1.00	1.00	1.00	1.00
X_5	Foundation fails	*	*	*	*	*
X_6	Person is exposed|foundation fails	1.00	1.00	1.00	1.00	1.00
X_8	Lateral forces exceed roof strength	*	2.07×10^{-5}	4.92×10^{-1}	1.00	1.00
X_9	Person is exposed|roof fails	1.00	1.00	1.00	1.00	1.00
X_{11}	Lateral forces exceed cladding resistance	*	*	9.90×10^{-1}	1.00	1.00
X_{12}	Person is exposed|cladding fails	1.00	1.00	1.00	1.00	1.00
X_{14}	Lateral forces exceed opening** resistance					
X_{15}	Person is exposed|opening fails	1.00	1.00	1.00	1.00	1.00
X_{17}	Lateral forces exceed int. part. resistance	*	*	*	*	*
X_{18}	Person is exposed|partition fails	1.00	1.00	1.00	1.00	1.00

*Less than 10^{-7}.
**Included with cladding.

Table C.13. Risk Model Data Input for Modified Nursing Home Subjected to Wind and Water

Basic Event	Description of Basic Event	Basic Event Probabilities: Hurricane Category 1	2	3	4	5
X_1	Wind hazard occurs	1.00	1.00	1.00	1.00	1.00
X_2	Lateral forces exceed frame strength	$6.71X10^{-5}$	$1.22X10^{-4}$	$3.30X10^{-4}$	$1.07X10^{-3}$	$6.29X10^{-4}$
X_3	Person is exposed $\mid$ frame fails	1.00	1.00	1.00	1.00	1.00
X_5	Foundation fails	*	*	*	*	*
X_6	Person is exposed $\mid$ foundation fails	1.00	1.00	1.00	1.00	1.00
X_8	Lateral forces exceed roof strength	*	$9.68X10^{-7}$	$3.04X10^{-3}$	$9.99X10^{-1}$	1.00
X_9	Person is exposed $\mid$ roof fails	1.00	1.00	1.00	1.00	1.00
X_{11}	Lateral forces exceed cladding resistance	*	*	*	$1.88X10^{-1}$	1.00
X_{12}	Person is exposed $\mid$ cladding fails	1.00	1.00	1.00	1.00	1.00
X_{14}	Lateral forces exceed opening** resistance					
X_{15}	Person is exposed $\mid$ opening fails	1.00	1.00	1.00	1.00	1.00
X_{17}	Lateral forces exceed int. part. resistance	*	*	*	*	*
X_{18}	Person is exposed $\mid$ partition fails	1.00	1.00	1.00	1.00	1.00

*Less than 10^{-7}.
**Included with cladding.

Table C.14. Risk Model Fatality Input for Nursing Home

Basic Event	Description of Basic Event	Mean	Standard Deviation	Distribution
X_4	Injury is fatal| frame fails	0.40	0.41	Lognormal
X_7	Injury is fatal| foundation fails	0.40	0.41	Lognormal
X_{10}	Injury is fatal| roof fails	0.40	0.41	Lognormal
X_{13}	Injury is fatal| cladding fails	0.40	0.41	Lognormal
X_{16}	Injury is fatal| opening fails	0.40	0.41	Lognormal
X_{19}	Injury is fatal| partition fails	0.02	0.04	Lognormal

Table C.15. Risk of Using Existing Nursing Home in Various Hurricanes (Wind Only)

Hurricane Category	Expected Fraction of Fatalities	Standard Deviation of Expected Fatalities
1	$1.83X10^{-5}$	$3.23X10^{-3}$
2	$3.85X10^{-5}$	$4.69X10^{-3}$
3	$3.46X10^{-1}$	$3.04X10^{-1}$
4	$4.23X10^{-1}$	$3.05X10^{-1}$
5	$4.23X10^{-1}$	$3.05X10^{-1}$

Table C.16. Risk of Using Existing Nursing Home in Various Hurricanes (Wind and Water)

Hurricane Category	Expected Fraction of Fatalities	Standard Deviation of Expected Fatalities
1	1.83×10^{-5}	3.23×10^{-3}
2	3.90×10^{-5}	4.71×10^{-3}
3	3.46×10^{-1}	3.04×10^{-1}
4	4.23×10^{-1}	3.05×10^{-1}
5	4.23×10^{-1}	3.05×10^{-1}

Table C.17. Risk of Using Modified Nursing Home in Various Hurricanes (Wind and Water)

Hurricane Category	Expected Fraction of Fatalities	Standard Deviation of Expected Fatalities
1	$1.83X10^{-5}$	$3.23X10^{-3}$
2	$3.37X10^{-5}$	$4.38X10^{-3}$
3	$9.20X10^{-4}$	$2.29X10^{-2}$
4	$3.01X10^{-1}$	$2.95X10^{-1}$
5	$4.23X10^{-1}$	$3.05X10^{-1}$

Scale No. 5--Winds greater than 155 miles per hour. Shrubs and trees blown down; considerable damage to roofs of buildings; all signs down. Very severe and extensive damage to windows and doors. Complete failure of roofs on many residences and industrial buildings. Extensive shattering of glass in windows and doors. Some complete building failures. Small buildings overturned or blown away. Complete destruction of mobile homes. And/or: storm surge greater than 18 feet above normal. Major damage to lower floors of all structures less than 15 feet above sea level within 500 yards of shore. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Massive evacuation of residential areas on low ground within 5 to 10 miles of shore possibly required.

Reference: Herb Saffir: Personal communication.

APPENDIX D

THE SAFFIR/SIMPSON HURRICANE SCALE

Scale No. 1--Winds of 74 to 95 miles per hour. Damage primarily to shrubbery, trees, foliage, and unanchored mobile homes. No real damage to other structures. Some damage to poorly constructed signs. And/or: storm surge 4 to 5 feet above normal. Low-lying coastal roads inundated, minor pier damage, some small craft in exposed anchorage torn from moorings.

Scale No. 2--Winds of 96 to 110 miles per hour. Considerable damage to shrubbery and tree foliage; some trees blown down. Major damage to exposed mobile homes. Extensive damage to poorly constructed signs. Some damage to roofing materials of buildings; some window and door damage. No major damage to buildings. And/or: storm surge 6 to 8 feet above normal. Coastal roads and low-lying escape routes inland cut by rising water 2 to 4 hours before arrival of hurricane center. Considerable damage to piers. Marinas flooded. Small craft in unprotected anchorages torn from moorings. Evacuation of some shoreline residences and low-lying island areas required.

Scale No. 3--Winds of 111 to 130 miles per hour. Foliage torn from trees; large trees blown down. Practically all poorly constructed signs blown down. Some damage to roofing materials of buildings; some window and door damage. Some structural damage to small buildings. Mobile homes destroyed. And/or: storm surge 9 to 12 feet above normal. Serious flooding at coast and many smaller structures near coast destroyed; larger structures near coast damaged by battering waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Flat terrain 5 feet or less above sea level flooded inland 8 miles or more. Evacuation of low-lying residences within several blocks of shoreline possibly required.

Scale No. 4--Winds of 131 to 155 miles per hour. Shrubs and trees blown down; all signs down. Extensive damage to roofing materials, windows and doors. Complete failure of roofs on many small residences. Complete destruction of mobile homes. And/or: storm surge 13 to 18 feet above normal. Flat terrain 10 feet or less above sea level flooded inland as far as 6 miles. Major damage to lower floors of structures near shore due to flooding and battering by waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Major erosion of beaches. Massive evacuation of all residences within 500 yards of shore possibly required, and of single-story residences on low ground within 2 miles of shore.