COST-EFFECTIVENESS OF THE NEW BUILDING CODE FOR WINDSTORM RESISTANT CONSTRUCTION ALONG THE TEXAS COAST

FINAL REPORT

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ABSTRACT

The Texas Department of Insurance has produced a prescriptive building code based on the wind pressures derived from ASCE 7-88. The Department of Insurance has contracted with the Texas Engineering Experiment Station to determine if the additional cost required to comply with the new code is justified by the reduction in losses from wind storms. The objective of this report is to perform a cost-effectiveness evaluation of the new code. To meet this objective the following tasks are performed. An overview of the approach, which is based on hierarchical structures in expert systems, is described. Next the key algorithms needed to operationalize the methodology (i.e., algorithms to compute damageability to the structure, damageability to the contents, and to evaluate the relative feasibility of implementing the new code) are described. In the next step, we carefully outline the methodology used to evaluate the cost-effectiveness of the new code. In the final phase, we operationalize the methodology.

In this work, the cost-effectiveness of the new code is evaluated in terms of the so-called "break-even cost" for the new code cost-effectiveness. The break-even cost is defined to be the present value of the additional cost to implement the code when the reduction in losses resulting from the use of the new code balances the cost needed to implement the new code. On comparing the break-even costs for all cases of applicability of the new code (i.e., Inland and Seaward) with detailed estimates of the cost to implement the new code, we find that in each and every case the estimated cost to implement the new code is less than the break-even cost to implement the new code. We therefore conclude that the new

code is cost effective and that the reduction in losses resulting from the implementation of the code justifies the additional cost to implement the code.

Finally, although we have found the New Code, relative to the Current Code, to be cost effective, the New Code is not necessarily optimal. To this end, we have included an appendix to this report for areas of the code in which certain requirements may be reduced (or increased) to improve the efficiency of the New Code.

INTRODUCTION

The Texas Department of Insurance has produced a prescriptive building code (Texas Department of Insurance, 1994) based on the wind pressures derived from ASCE 7-88 (ASCE, 1988). Below, this code will be referred to as the "New Code". The New Code has not yet been implemented by the Texas Department of Insurance. Here, the currently enforced building code (Texas Department of Insurance, 1989) will be referred to as the "Current Code". The main intent of the New Code is to minimize wind storm damage in a cost-effective manner. The Texas Engineering Experiment Station was selected by the Texas Department of Insurance to determine if the additional cost required to comply with the New Code is justified by the reduction in losses from wind storms. If the life cycle costs required to comply with the New Code are less than the life cycle costs associated with the Current Code, the New Code is cost-effective. To evaluate the cost-effectiveness of the New Code the Texas Engineering Experiment Station was contracted to perform the following Tasks:

1. Define structures, sites, and alternatives of interest;
2. Review site conditions and design-construction practices;
3. Document the additional costs required to comply with the New Code;
4. Compute the reduction in losses resulting from the application of the New Code; and
5. Perform a benefit/cost analysis of the alternatives.

With these tasks in mind, the objective of this report is to describe the cost-effectiveness evaluation process for the New Code. To meet this objective the following items are addressed here: Firstly, we provide an overview of the theory of the approach used here for the cost-effectiveness evaluation of the code. Secondly, we describe the key algorithms and hypotheses that were specially developed to achieve the stated objective. Thirdly, we outline, in more detail, the specific procedures used to accomplish the intended objective. Fourthly, we report the results of each of the major computational steps. Fifthly, we provide the results of the cost-effectiveness evaluation of the code. Finally, on the basis of the results in the last step, we summarize our efforts and state any significant conclusions we have drawn from the experience.

OVERVIEW OF THEORY OF THE APPROACH

The code cost-effectiveness evaluation methodology proposed here utilizes the so-called "backward chaining" approach (Dong, 1986). A backward chaining system tries to prove a specific goal by checking known facts in the context of the goal. The system is triggered when an attempt is made to verify the goal. The conditions which are needed to prove the goal are examined. If these conditions cannot be verified, they become sub-goals and conditions for the sub-goals are in turn examined. The system keeps on chaining backwards until conditions are reached which can be verified directly, extracted from known facts in a database, determined from a user query, or obtained by executing an algorithmic program. Here we will refer to such conditions as "basic conditions". If all necessary conditions are true, the original goal is proved.

The necessary conditions to validate a goal are embodied in a set of rules. The rules may be organized in a hierarchical tree leading downward from the general to the specific. Figure 1 shows an example of this structure. A main idea to be evaluated, called the top level goal, is placed as the hypothesis at the highest level. Evidence for the goal lies below. These ideas themselves may be hypotheses with other ideas below as support. Thus, the tree continues downward through additional levels of increasingly specific support until levels are reached where the ideas can be evaluated directly. These bottom-level ideas (i.e., basic conditions) should be answers to relatively objective questions and the user is queried by the system for their answers. The values of the hypotheses are ascertained by combining the values of their supporting factors and hypotheses through various logical relationships or algorithms. Each group of attributes below a hypothesis must be linked together so that they can be evaluated and a conclusion can be reached about the hypothesis (see Figure 2).

An overview of the theoretical framework that forms the basis of this cost-effectiveness evaluation is presented schematically in Figure 3. The goal here is to evaluate the cost-effectiveness of the New Code. According to the figure, if we had a measure of a "break-even cost for cost-effectiveness", an estimate of the additional cost to implement the New Code, and a criterion of cost-effectiveness in terms of the break-even cost and the estimated costs, then we would have a means of evaluating the cost-effectiveness of the New Code. The notion of a break-even cost for code effectiveness is elaborated upon below. The task of estimating the cost to implement the New Code is described in the accompanying report (Lombard et al., 1995).

Returning to Figure 3, we propose that a break-even cost for code cost-effectiveness could be generated if we knew the following pieces of information:

1. The hurricane hazard for the site;
2. The structural damage sustained, in all hurricane environments, by a referenced structure designed using the Current Code;

3. The damage to contents of the same referenced structure, for all hurricane environments, also designed using the Current Code;
4. The structural damage sustained, in all hurricane environments, by an upgraded structure designed using the New Code;
5. The damage to the contents of the latter structure in the same set of hurricane environments;
6. The cost of money during the intended period of analysis; and
7. The useful life of the structure.

Using basic techniques from Engineering Economic Analysis (Newnan, 1991), these seven variables can be combined to yield a break-even cost for a given code. Our proposed analysis to achieve this end is provided below. Please note that in realizing the controversial and complex nature of an analysis such as this, we will be the first to point out here that this model is not the model of all models; many items, for example, business interruption and costs for temporary housing after hurricanes may have to be included in future refinements. At any rate, the consideration of these seven variables should certainly put the results of the analysis in the proverbial "ball park". However, on the bases of our experience with hurricane losses for residential structures, structural damage costs and content damage costs are among the more significant costs incurred in a hurricane event. Until such time as we have access to insurance industry data on the relative magnitude of content and structural damage versus, for example, cost of temporary housing, we have no choice but to base our analyses on structure and content damage costs.

Information regarding the hurricane hazard risk model is readily available. Works such as Peterka (1992), Peterka and Shahid (1993), and ASCE (1994) can be used directly to estimate, for any location on the Texas Coast, the following pieces of information:

1. The annual probability of exceedence of a hurricane of a given magnitude, and
2. The surrounding exposure, in the wind engineering sense, of a given structure.

The reader should refer to the accompanying report (Perry and Stubbs, 1995) for more details regarding the definition of the wind hazard model.

Information regarding the cost of money and the life of a given structure must be assumed in the analysis.

In order to compute the damage to the structure and the damage to the contents of the structure, we have developed damageability models. By structural damage, in this report, we mean damage to any part of the building system. Our definition of structural damage is not the limited definition often accepted by structural engineers. These damageability models utilize information on the possible resistances of various building components (e.g., roofing, decking, bracing, etc.) and the magnitude of the hurricane hazard. The main function of a building code is to increase these resistances such that damage in a future event will be below some acceptable level. The output of the damageability models is either the damage ratio (expressed as a ratio of repair cost to replacement cost) for the structure or the damage ratio for contents expressed in the same units.

KEY ALGORITHMS AND HYPOTHESES

Structural Damageability Model

On the bases of our vulnerability analyses of buildings in a hurricane environment, we have developed schemes which analyze buildings in terms of the following components:

1. Roofing,
2. Roof decking,
3. Roof framing,
4. Roof frame-wall connection,

5. Lateral bracing,
6. Cladding,
7. Openings,
8. Frame-Foundation connection, and
9. Foundation.

In order to define a "generic" building for a given class, we assign instantiations of the components that we feel would represent a typical building in a sample. For example, assuming the need to generate a damage curve that reflects one-story residential buildings along the Gulf Coast, we may propose the following abbreviated definition of a generic structure for that building class as:

1. Roofing: Composition Shingles;
2. Roof Decking: Plywood Sheathing;
3. Roof Framing: Hip with rafters;
4. Roof-Wall Connection: Toe Nail;
5. Lateral Bracing: 1"x4" let-ins;
6. Cladding: Brick Veneer;
7. Openings: Casement Windows;
8. Frame-Foundation Connections: Toe nail; and
9. Foundation: Nonengineered Slab on Grade.

As we will demonstrate later in this report, these building subsystems can be described in more detail, provided a particular code is selected.

In order to estimate the damage ratio for the generic building as a function of the wind speed, we first generate the "component damageability" model (shown in Figure 4) for a building system. 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 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.

For each of the above nine damageability modes, we assume that a damageability curve of the type shown in Figure 5 exists. For example, for the i^{th} damage mode, the damage ratio $DR_i(\nu)$, where ν is the wind speed (i.e., the hazard to the structure), is given by

$$DR_i(\nu) = \begin{cases} 0 & \nu \le a_{i1} \\ \dfrac{\nu - a_{i1}}{a_{i2} - a_{i1}} & a_{i1} < \nu \le a_{i2} \\ 1 & \nu > a_{i2} \end{cases} \tag{1}$$

where a_{i1} and a_{i2} are expert-supplied constants that represent, respectively, speeds at which damage will commence and end in that mode (i.e., the vulnerability of the structure). Constants a_{i1} and a_{i2}, for 1-2 story wooden structures along the Texas Coast, are listed in Table 1. The damage ratio for the entire structure $DR_s(\nu)$ is estimated by the expression

$$DR_s(\nu) = \frac{\sum_{i=1}^{9} I_i \, DR_i(\nu)}{\sum_{i=1}^{9} I_i} \tag{2}$$

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 complete structure. The values of the constants have been embedded in the program used subsequently. Note that these constants have been selected such that the differences between observations and predictions of damage in the systems of interest have been minimized.

Content Damageability Model

The foregoing discussion was limited to structural damage. To compute the damage ratio for contents, we followed an analogous procedure to the one provided above. This model is a refinement of a prior model for content damage prediction (Stubbs and Boissonnade, 1993). A damageability model for contents in terms of component damageabilities is provided in Figure 6. The damageability for the building components are given by the structural model discussed above. The damageability model for the contents, given damage to component i of the structure, is given by:

$$DR_i^c = \begin{cases} 0 & DR_i \leq bb_{i1} \\ \gamma_i \dfrac{DR_i - (bb_{i1})}{(bb_{i2} - bb_{i1})} & b_{i1} < DR_i \leq bb_{i2} \\ \gamma_i & DR_i > bb_{i2} \end{cases} \tag{3}$$

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. The content damage ratio $DR_c(v)$ for the entire structure is given by

$$DR_c(v) = \frac{\Sigma\ J_i\ DR_i^c\ DR_i}{\Sigma\ J_i} \tag{4}$$

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 (3), the damage to the i^{th} building component becomes the hazard to the contents.

Break-even Cost for Code Cost-effectiveness

Assuming the use of the Current Code as the basis for design of a structure, the windstorm-related costs associated with the structure during its useful life include the following costs: the initial design cost, the costs to repair or replace structural components after damage in a windstorm, and the costs to repair or replace the contents after the same windstorm. If we assume that a structure with the same geometry, space requirements, etc., were designed using the New Code, the magnitude of design, repair, and replacement costs should change, although the wind-related cost categories would remain the same.

Treating the use of the Current Code and the use of the New Code as two competing engineering alternatives, we can select the more feasible alternative by first identifying which economic selection criterion applies to this decision problem. The economic criterion should be one of the following:

1. If costs are fixed, then maximize the benefits.
2. If benefits are fixed, then minimize the costs.
3. If neither costs nor benefits are fixed, then maximize the difference between benefits and costs.

The main benefit provided by either of the two alternatives is the use of the structure by its occupants for the same useful life. Thus while Criterion 3 above might be argued to be the most realistic of the three criteria, Criterion 2 may provide a more practical basis for developing a feasibility criterion. We will therefore select the best alternate from among the New Code and the Current Code on the basis of the criterion:

Minimize the present worth of cost; i.e., the alternative with the minimum present worth is the cost effective option.

Let:

C_s = Initial cost of structure using Current Code;

C_c = Cost of contents of structure;

P_i = annual recurrence rate of category i Hurricane ($i = 1,2,3,4,5$);

α_{is} = structural damage sustained in category i Hurricane;

α_{ic} = Content damage sustained in category i Hurricane

Then the annual cost for structural damage and content damage is given by

$$A_i = P_i(\alpha_{is}C_s + \alpha_{ic}C_c) \tag{5}$$

with $C_c = a\, C_s$; for a given building class and for all hurricane categories:

$$A = \sum_{i=1}^{5} A_i = \sum P_i C_s(\alpha_{is} + a\alpha_{ic}) \tag{6}$$

Note that for ordinary residential construction (i.e., ≤$150k), depending upon location, the constant "a" is typically taken to be ~ 0.6. The present worth of costs associated with the Current Code is given by

$$PW_{current} = C_s + (P/A,j,n)A$$

$$= C_s + (P/A,j,n)[\Sigma P_i C_s(\alpha_{is} + a\alpha_{ic})] \tag{7}$$

where P/A is the so-called "series present worth factor" (Newnan, 1991), n is the useful life of the structure, and j is the interest rate. Similarly the present worth of costs associated with the New Code is given by

$$PW_{new} = (1+\beta)C_s$$

$$+ (P/A),j,n)[\Sigma P_i(1+\beta)C_s(\alpha'_{is} + a\alpha'_{ic})] \tag{8}$$

where β is the fractional increase of the cost of the structure using the Current Code to implement the New Code and α_{is}' and α_{ic}' are the damage ratios associated with the structure designed using the New Code. We may define a break-even cost β_o C_s from the condition:

$$PW_{new} = PW_{current} \tag{9}$$

i.e.,

$$\beta_o C_s + (P/A,j,n)[\Sigma P_i(1+\beta_o)C_s(\alpha'_{is} + a\alpha'_{ic})]$$

$$= (P/A,j,n)[\Sigma P_i C_s(\alpha_{is} + a\alpha_{ic})] \tag{10}$$

Canceling C_s and solving for β_o, we get

$$\beta_o = \frac{(P/A,j,n)\{\Sigma P_i[(\alpha_{is} - \alpha_{is}') + (\alpha_{ic} - \alpha_{ic}')a]\}}{1 + (P/A,j,n)\,\Sigma P_i[\alpha_{is}' + a\,\alpha_{ic}']} \qquad (11)$$

Thus the break-even cost can be computed/estimated from a knowledge of the seven previously identified parameters (i.e., j, P_i, n, α_{is}, α_{ic}, α_{is}', α_{ic}'). Let β_c be the fractional cost, developed on the basis of a cost-estimate to implement the New Code. (Note that these values are generated in the accompanying report, Lombard et al., 1995). Then the New Code is cost-effective, if $\beta_c < \beta_o$.

OUTLINE OF METHODOLOGY

Having discussed the theory of the approach, we now list the methodology we pursued in evaluating the cost-effectiveness of the New Code. In summary, we adopted the following procedure:

1. Define structures to be used in the analysis,
2. Assign resistances to the selected structures to reflect the Current Code and the New Code,
3. Define physical sites for the structures,
4. Obtain hurricane hazard risk models for the sites,
5. Compute probability of occurrence of hurricanes of various intensities,
6. Estimate structural damage for hurricane category,
7. Estimate content damage for each hurricane category,
8. Assume interest rates and useful life values for the structure,
9. Compute the break-even costs for code cost-effectiveness,
10. Summarize estimated cost to implement codes, and
11. Evaluate the cost-effectiveness of the New Code.

Detailed descriptions of these steps and the results obtained in working them through are provided below.

RESULTS OF MAJOR STEPS

Definition of Structures

The structures selected for analysis in this study represent the most common type of construction observed in our surveys of the building practices in the coastal first tier counties. The selected structure was a 1-2 story wooden residential structure. An abridged description of such a 1-2 story wooden structure was described in Table 1 and also in the section on structural damageability models.

Assignment of Resistances to Selected Structures

The assignment of resistances to the selected building class was accomplished in four steps. First we reviewed relevant postdisaster reports on Hurricane Alicia, Hurricane Frederic, Hurricane Elena, and other storms (Beason et al., 1984; Ellifritt, 1984; Mehta et al., 1983; Minor et al., 1978; Kareem, 1985; Kareem, 1986; Sparks et al., 1991) and then inferred wind speed-damage correlation for the nine building components mentioned previously. In places where data were not available, we utilized our combined experiences (75 years) of the performance of residential wooden structures in the hazardous wind environment. The resistances of the various building subsystems (discussed in the latter section) were estimated by the wind speed at which that subsystem (e.g., roofing) would be expected to begin to experience damage and when the subsystem is completely destroyed. The results for a reference building are listed in Table 1. Those values are assumed to define the structure designed using the Current Code-Inland.

In the next step, we developed even more detailed indicators of quality for each of the original nine building components. We then reviewed each major part of the two codes (i.e., Current Code-Inland, Current Code-Seaward, and New Code-Inland, New Code-Seaward) and assigned the relative improvement over the Current Code-Inland version. These indicator weights were then combined to produce a single relative weight for the original subcomponent. The relative weights for the quality indicators are listed in Table 2. Finally, the relative weights obtained from Table 2 were combined to produce the resistances associated with the Current Code-Seaward, New Code-Inland, and New Code-Seaward. These values are listed in Table 3 to Table 5.

Definition of Physical Sites

The sites selected for the damage evaluation were Brownsville, Corpus Christi, Galveston, and Texas City.

Hurricane Risk Models for Site

The hurricane risk models for the selected sites are summarized in Table 6. Note that the annual probability of exceedence is essentially the same for Brownsville and Corpus Christi, and for Galveston and Texas City. Thus, the results for Galveston will also apply to Texas City. We will treat the entire island of Galveston as Seaward and what we refer to as Galveston-Inland in the remaining report, will essentially apply to Texas City.

Probability of Occurrence of Hurricanes

From the annual probability of exceedence data provided in Table 6, we defined five hurricanes with the following wind speed ranges (fastest mile): 74-96, 97-110, 111-130, 131-150, and >150. For each location, we computed the annual probability that a hurricane in each and everyone of these speed ranges would occur. These results are listed in Table 7.

Estimation of Structural Damage for All Hurricanes

Each of the five hurricanes defined in the last section were then modelled by a single wind speed. In the case of the first four hurricanes, the mean wind speed was selected. In the last case, a hurricane of speed greater than 150 miles per hour was given a nominal value of 160 mph. Thus the five hurricanes are represented by the wind speed values: 85, 103, 120, 140, and 160.

We next utilized the structural damageability model (see Equation 2) to compute the structural damage ratio for structures with resistances defined in Table 1, Table 3, Table 4, and Table 5. The results of the computation are summarized in Table 8. Recall that the damage ratio is the quotient of the cost to repair the structure over the cost to replace the structure.

Estimation of Content Damage for All Hurricanes

Content damage was estimated for a structure subjected to the same set of hurricanes defined in the latter section. Content damage was estimated using a computer algorithm based on the models discussed in the section on Content Damageability (see Equation 3). The estimated content damage ratios for the two codes for the one to two-story wooden structure, assuming typical residential contents, as opposed to sensitive electronic equipment or hardy raw materials, are listed in Table 9. Note that the content damage ratio in the table is the quotient of the cost to repair the contents over the cost to replace the contents.

Interest Rates and Useful Life of Structures

Computations were performed on structures for which the useful life varied from twenty to eighty years. Since the cost of money could vary significantly over this period of time, we also varied the interest rates in the calculations from five to fifteen percent.

Break-even Costs for New Code Cost-effectiveness

The data generated in the foregoing steps provide the input required for the break-even cost model discussed in the algorithm section of this report (see Equation 11). A typical output for a structure located at Corpus Christi considering both inland and seaward areas, is provided in Table 10. In the examples shown in Table 10, the interest rate of 10% was assumed along with a useful life of sixty years. The results show that the break-even cost for code cost-effectiveness in the case of the Inland Code is 12.62%. This value can be interpreted as follows: if one has to invest more than 12.62% of the cost of the structure to achieve the estimated increase in resistance, then it is more feasible to use the Current Code. Stated another way, if it is possible to achieve the same level of building performance at a cost less than 12.62% of the cost of the structure, the New Code is cost-effective.

To provide a somewhat more realistic picture of the sensitivity of the break-even cost to the interest rate, we ran a series of studies for the two locations and versions of the code. Theses results are recorded in Tables 11 to 14.

Estimated Costs to Implement New Code

A detailed description of the estimated costs to implement the New Code is provided in the accompanying document (Lombard et al., 1995). We present here only those elements from that document that are needed to establish the cost-effectiveness of the New Code. A typical description of the prescriptive requirements of the Current Code and the New Code, relative to the building subsystems utilized in this report, is provided in Table 15. Four building sizes were analyzed: a 1,000 square foot residential structure, a 1,664 square foot residential structure, a 2,040 square foot residential structure, and a two-story 3,000 square foot building. On the basis of the cost analysis, the increase in cost, given as a percentage of the cost to build the structure using the Current Code to implement the New Code is given in Tables 16 to 19. Note that the cost increase is given as a function of the structure size and the cost per square foot of the construction. For the case of Galveston, for example, for a 1,000 square foot residential structure, the additional cost to implement the New Code may range from 1.72% of the base construction cost, for construction at one hundred dollars per square foot, to 2.86%, for construction at sixty dollars per square foot. Corresponding to the case of a 1,000 square foot house at a construction cost of sixty dollars per square foot, the maximum increase in costs was 3.32% of the base construction cost for the New Code Inland, Corpus Christi (see Table 18). Corresponding to the case of a 1,664 square foot house at one hundred dollars per square foot, the minimum increase in costs is 1.54% of the base construction cost for the New Code Inland, at Galveston (see Table 16).

Evaluation of New Code Cost-effectiveness

We can now evaluate the cost-effectiveness of the New Code by comparing the results of Table 11 to Table 14 (i.e., the break-even costs for code cost-effectiveness) with Tables 16 to Table 19 (i.e., the estimated costs to implement the New Code). The measure of cost-effectiveness we select here is simply the ratio of the cost to implement the New Code divided by the break-even cost for code-effectiveness. Thus the New Code is cost-effective at a given location, if this ratio is less than one. The smaller the ratio the more cost-effective is the code. The results, for the two locations analyzed here are summarized in Table 20 to Table 23, for a useful life of 20 years and an interest rate of 15%. In each and every case, the ratio of the cost to implement the break-even cost is significantly less than one. Therefore, the New Code is cost-effective, both inland and seaward, and at extreme locations along the Texas Coast.

DISCUSSION OF COST-EFFECTIVENESS

To readers who may not be familiar with the type of analysis presented in the last section, the determination of cost-effectiveness, as it was presented here, may seem quite abstract. For example, most people do not normally think in terms of ratios; they tend to think in terms of specific dollar amounts dispersed at specific times. In other words, the argument to document the cost-effectiveness of the New Code could be more convincing, if it were delivered in terms of cash flows.

With the goal of making the cost-effectiveness analysis easier to understand, the objective of this discussion is to present the results of the latter analysis in terms of cash flows. We achieve this objective in three steps: first, we restate the problem in an equivalent form; second, we generate, for the extreme cases, cash flows that reflect costs associated with the use of the Current Code and the New Code; finally, we demonstrate the cost-effectiveness of the New Code by comparing the resulting cash flows.

To perform the proposed analysis, we need to know three things: (1) the annual cost to repair or replace the structure and its contents, if the structure is built according to the Current Code; (2) the annual cost to repair/replace the structure and its contents, if the structure is built according to the New Code; and (3) the additional cost to implement the New Code. The annual costs to repair/replace the structure and its contents can be computed using Equation (6). To illustrate the approach, assume for the purpose of explanation that the annual cost of damage is $8,200, if the Current Code is used. (Note that these numbers are hypothetical; cost related to actual structures will be provided below!) Assume also that the cost to implement the New Code is $15,000. Finally, assume that the annual cost of damage is reduced to $5,100, if the New Code is used. (In reality the cost to implement the New Code is obtained from the accompanying report). With these costs defined, we can now restate the cost-effectiveness problem as follows: For a specific structure, should an expenditure of $15,000 be made to reduce the annual repair and replacement costs associated with hurricanes from $8,200 to $5,100? Suppose that money is worth 10% and the life of the building is ten years.

A cash flow for this hypothetical example is shown in Table 24. For the numbers provided, it is obvious from the cash flow that use of the New Code results in a positive annual cash flow of $3,100. That is, the potential saving increases over the life of the project. Without accounting for the time value of money, we can see that the expenditure has been repaid in approximately five years (see the last column in Table 24). In a more precise evaluation of the two codes, it is necessary to reduce these cash flows to a common basis (in this case, the present worth) and then determine whether the objective of 10% rate of return has been achieved. From the appropriate interest tables and the appropriate calculations (see, e.g., Newnan, 1991), the interest rate at which the present worth of the option using the Current Code is equal to the present worth of the option using the New Code is found to be 16%. Since this rate of return is greater than the 10%, i.e., the cost of money, the New Code option is preferred. In the ensuing example, we discuss costs that are based on the actual evaluation of the two codes.

The annual damage costs for the Current Code and the New Code at Galveston and Corpus Christi are summarized in Table 25. Note that the estimates were obtained using Equation (6) and they include the impact of all hurricane magnitudes. Note also that from the latter section on the cost-effectiveness evaluation, we found that the least cost-effective single story building at Galveston Inland was the 1,000 square foot building at $60 per square foot. The actual annual damage costs associated with this structure are summarized in Table 26. The numbers in Table 26 are obtained by multiplying the fractions in Table 25 by 60,000. Note, for example, that the impact of the New Code is to reduce the annual damage cost from $2,256 to $1,152, for the Inland Code at Galveston, and from $1,974 to $786 for the Seaward Code at Galveston.

More cash flow models for the four cases (Inland and Seaward for both Corpus Christi and Galveston) associated with the structure are summarized in Tables 27 to 30. Note that the cost to implement the code is taken directly from the results of the cost estimates performed in the accompanying report. From Table 27, we see that, for the case of Galveston, Inland, the amount expended in adopting the New Code, i.e. $1,719, is regained in approximately two years, ignoring the time value of money. If we assume a useful life of forty years, the return on the investment of the New Code versus the Current Code is 64%! Similar results for all four cases presented in Tables 27-30 are summarized in Table 31.

In summary, if the New Code is implemented, the savings by way of reduced annual costs for damage will make up for the additional cost to implement the New Code in two - three years. In addition, if the useful life of the building is typically forty years, the return on the investment, which results from adopting the New Code over the Current Code, ranges from 40% to 64%, for the least cost-effective building.

SUMMARY AND CONCLUSIONS

The objective of this report was to describe the cost-effectiveness evaluation process for the New Code relative to the Current Code. To meet this objective, we addressed five items. Firstly, we provided an overview of the theory of the approach that was used to determine the cost-effectiveness of the New Code. Secondly, we described the key algorithms and hypotheses that were required to operationalize the theory. Thirdly, we outlined the specific list of procedures and sequence of steps that were to be followed in the analysis. Fourthly, we summarized the major results at the end of each and every step in the calculation procedure. Fifthly, we reported the results of the cost effectiveness evaluation in terms of a break-even cost for cost effectiveness. Finally in order to make the results understandable to a larger audience, we expressed the cost effectiveness in terms of cash flows and the rate of return on the investment option to utilize the New Code as compared to the Current Code.

The break-even cost was defined as the cost to implement the New Code at the point at which there was no economic advantage in using the New Code over the Current Code. The point of no economic advantage was determined from the economic condition that the present worth of the sum of the cost to implement the New Code and the annual costs to repair or replace damage to the structure or its contents, due to hurricanes likely to occur over the lifetime of the structure, equals the present worth of the annual costs to repair or replace the damaged structure or its contents given that the Current Code was used as a basis of the design and construction of the building. To compute the break-even cost, we had to assume a useful life of the structure and an average interest rate for that period of time. We estimated that typical values for the break-even costs ranged from approximately 8% to 30% of the cost of the structure designed using the Current Code. The exact value of the break-even cost depended upon the assumed useful life of the structure and the interest rate.

The results of the detailed estimates of the costs to implement the New Code indicate that for a variety of house sizes, at extreme locations along the Texas coast, the cost to implement the New Code ranged from approximately 2% to 5% of the cost to build the house using the Current Code. On the basis of these results, we conclude that it is cost-effective to adopt the New Code.

To illustrate the cost effectiveness from another perspective, we generated and analyzed cash flows that included the additional cost to implement the New Code and the annual costs resulting from hurricane damages associated with the use of the New Code as well as the Current Code. The results indicate that the use of the New Code will reduce the annual cost of damage from hurricanes to approximately 50% of the annual cost of damage if the Current Code is used. The savings realized by this reduction in annual expenditure for hurricane damage will compensate for the additional cost to implement the New Code in two to three years. Furthermore, if we assume the useful life of a building to be forty years, the rate of return on the investment of using the New Code ranges from 40% to 60%.

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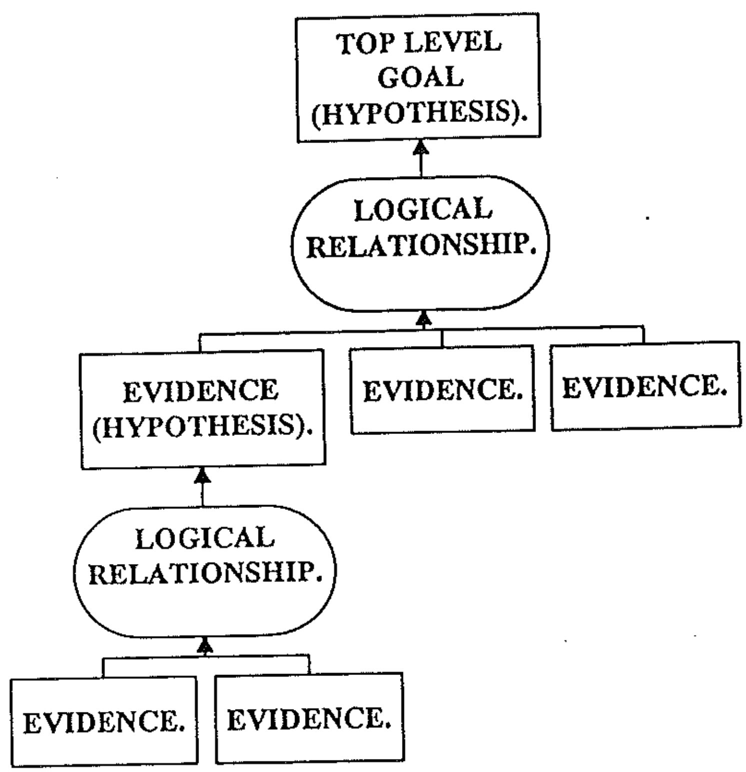

Figure 1: Hierarchical Tree Structure

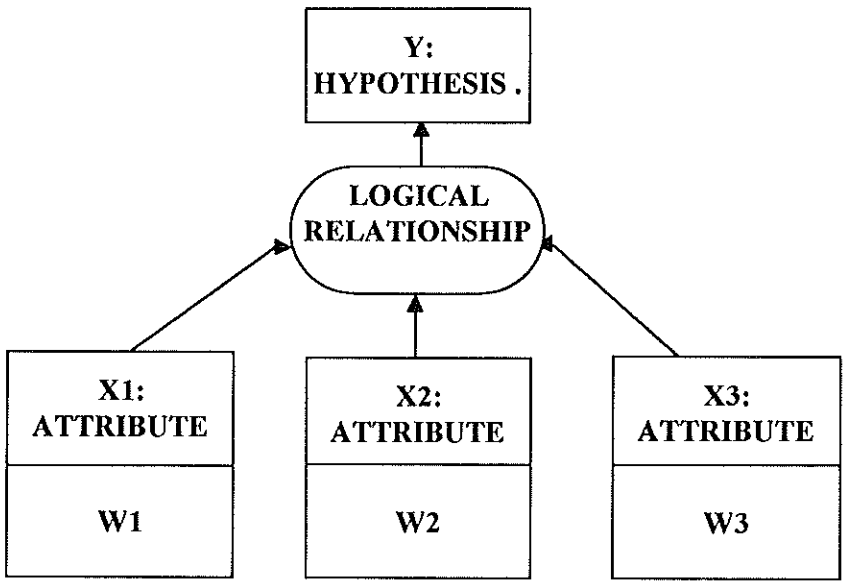

Figure 2: Linkage of Attributes to Hypotheses

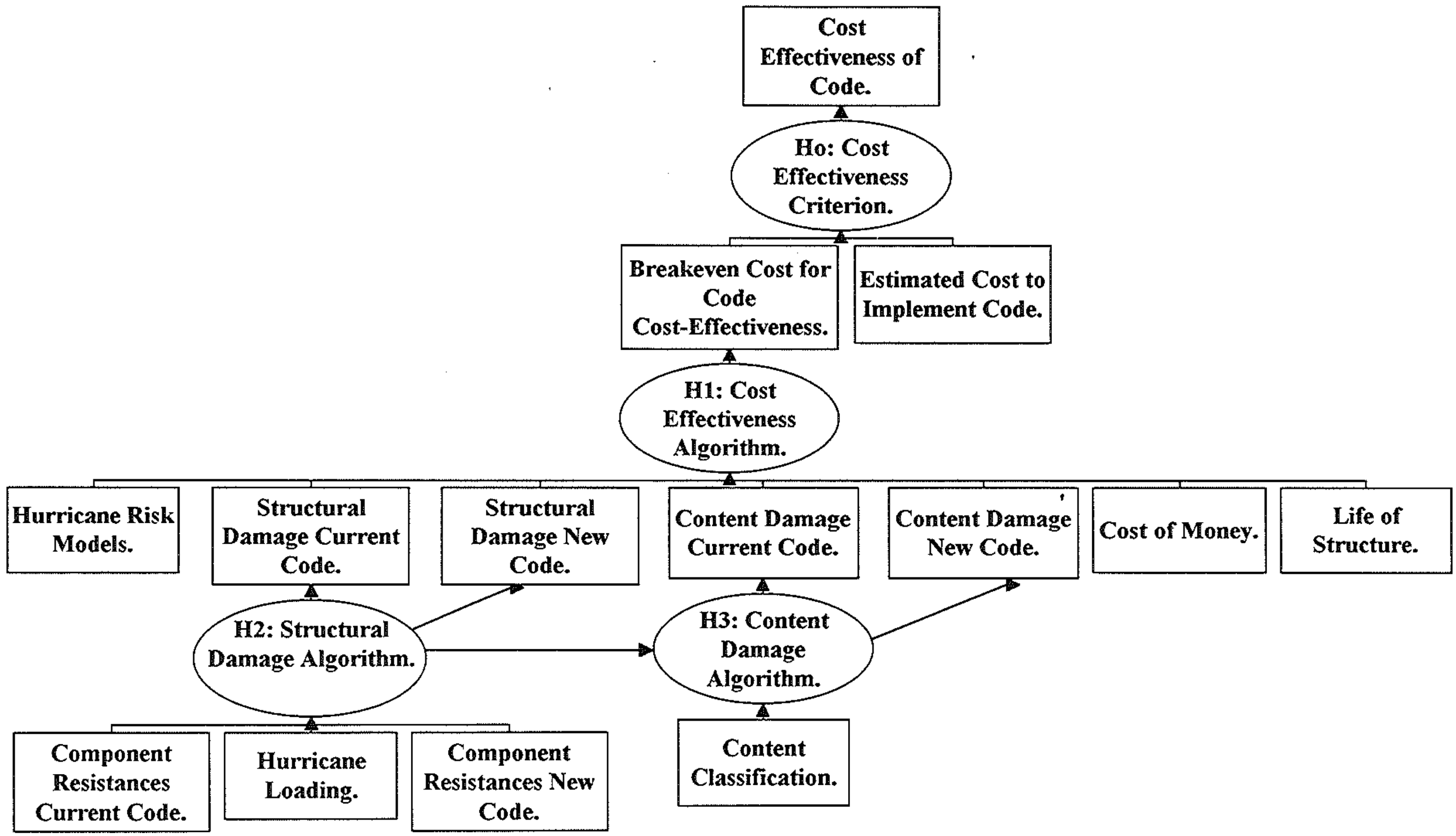

Figure 3: Hierarchical Tree Structure for Cost-effectiveness Evaluation

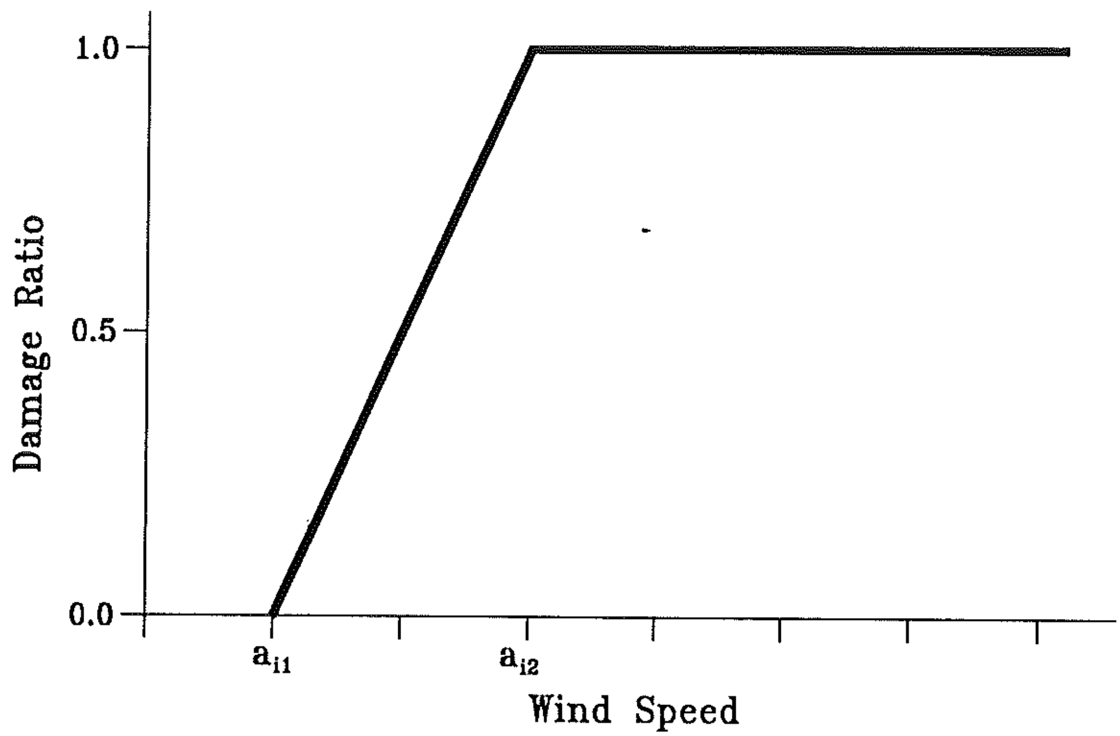

Figure 4: Typical Building Component Damageability Curve

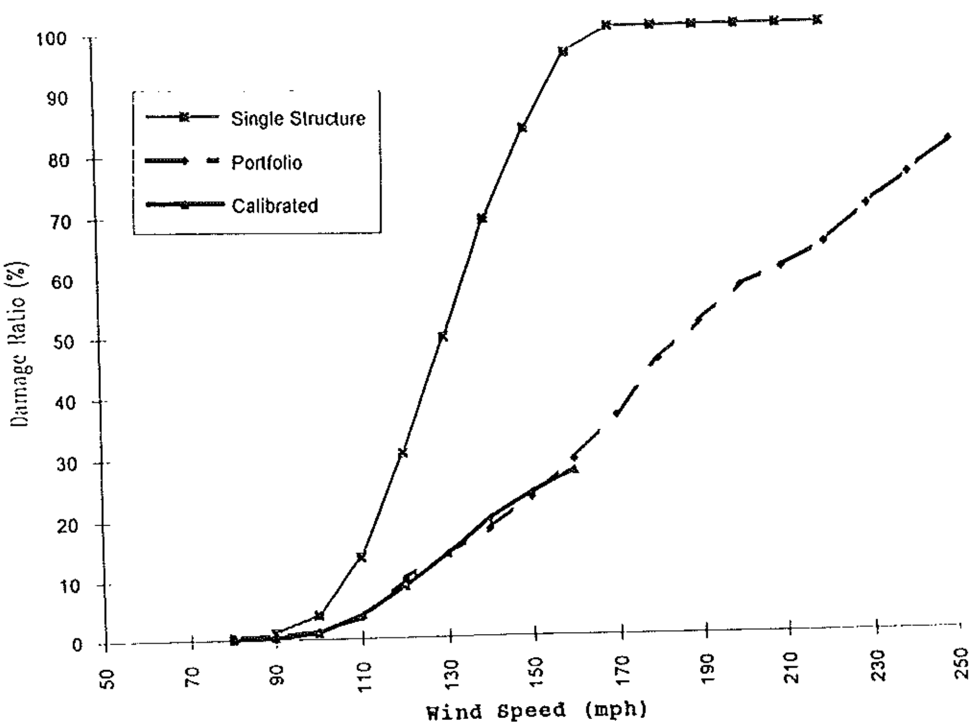

Figure 5: Typical Damageability Curve For Structure

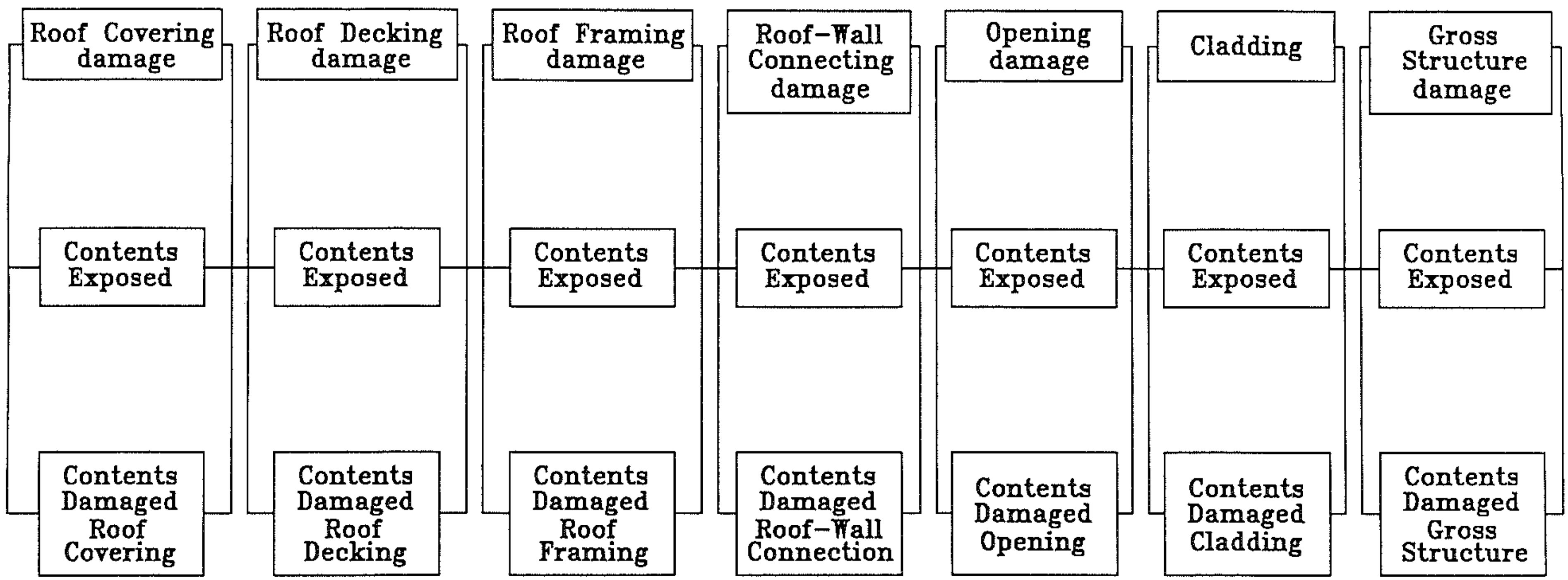

Figure 6: Damageability Model for Contents

TABLE 1: RESISTANCES FOR CURRENT INLAND CODE

Damage Mode	Resistance Thresholds* (mph fastest mile; Exp. C)		
	Low		High
Roof Covering Damage	55	-	110
Roof Decking Damage	80	-	120
Roof Framing Damage	80	-	120
Roof-wall Anchorage Damage via Suction	90	-	120
Roof-wall Anchorage Damage via Suct. & Int Pressure	80	-	100
Building Damage via Failure of Lat. Bracing Sys.	90	-	125
Damage Due to Failure of Openings	60	-	110
Cladding Damage	80	-	120
Frame-foundation Connection Damage	90	-	135
Foundation Damage	115	-	150

*On basis of Alicia and Elena Wind speeds; Analysis of Codes; and Expert Opinion.

TABLE 2: ASSIGNMENT OF MODIFIERS FOR THE VARIOUS CODES

	Relative Modifier Weights			
	Inland		Seaward	
Modifiers	Current	New	Current	New
ROOF COVERING DAMAGE				
Quality of covering material	1.0	1.2	1.0	1.2
Quality of covering fastening	1.0	1.1	1.0	1.1
Specificity of covering installation instructions	1.0	1.2	1.0	1.2
Quality of felt	1.0	1.2	1.0	1.2
Quality of felt attachment materials to decking	1.0	1.2	1.0	1.2
Specificity of felt installation instructions	1.0	1.2	1.0	1.2
Specified inspection of roof covering installation	1.0	1.0	1.0	1.0
ROOF DECKING DAMAGE				
Quality of sheathing	1.0	1.2	1.1	1.2
Quality of sheathing attachment materials	1.0	1.2	1.1	1.2
Specificity of deck installation instructions	1.0	1.2	1.0	1.2
Increase in design loads	1.0	1.3	1.2	1.4*
Specified inspection of roof deck installation	1.0	1.0	1.0	1.0
ROOF FRAMING DAMAGE				
Quality of framing materials	1.0	1.0	1.0	1.0
Increase in design loads	1.0	1.3	1.2	1.4*
Increase in bracing	1.0	1.2	1.1	1.2
Improvement in connections	1.0	1.1	1.05	1.1
Specificity of framing installation instructions	1.0	1.0	1.0	1.0
Specified inspection of roof framing installation	1.0	1.0	1.0	1.0

*From design loads

TABLE 2: ASSIGNMENT OF MODIFIERS FOR THE VARIOUS CODES (Continued)

	Relative Modifier Weights			
	Inland		Seaward	
Modifiers	Current	New	Current	New
ROOF-WALL ANCHORAGE DAMAGE VIA SUCTION				
Quality of anchoraging materials	1.0	1.1	1.0	1.1
Increase in anchoraging resistance	1.0	1.3	1.2	1.4*
Improved specificity of anchorage installation	1.0	1.3	1.0	1.3
Specified inspection of anchorage installation	1.0	1.3	1.0	1.3
ROOF-WALL ANCHORAGE DAMAGE VIA SUCT. & INT PRESSURE				
Quality of anchoraging materials	1.0	1.1	1.0	1.1
Increase in anchoraging resistance to int. press.	1.0	1.4	1.0	1.6
Increased resistance of openings	1.0	1.0	1.0	1.2
Specified inspection of anchorage	1.0	1.3	1.0	1.3
BUILDING DAMAGE VIA FAILURE OF LAT. BRACING SYS.				
Quality of bracing materials	1.0	1.4	1.0	1.4
Improved resistance of shear walls bracing	1.0	1.4	1.0	1.5
Resistance of end wall bracing	1.0	1.5	1.0	1.8
Improved specificity of bracing installation	1.0	1.0	1.0	1.0
Specified inspection of bracing system	1.0	1.2	1.0	1.2
DAMAGE DUE TO FAILURE OF OPENINGS				
Improvement in opening materials	1.0	1.0	1.0	1.4
Increase in opening resistance	1.0	1.0	1.0	1.5
Improved specificity of opening installation	1.0	1.0	1.0	1.2
Specified inspection of opening installation	1.0	1.0	1.0	1.3

*To be revisited

TABLE 2: ASSIGNMENT OF MODIFIERS FOR THE VARIOUS CODES (Continued)

Modifiers	Relative Modifier Weights			
	Inland		Seaward	
	Current	New	Current	New
CLADDING DAMAGE				
Improvement in cladding materials	1.0	1.0	1.0	1.0
Improvement in cladding-frame connections	1.0	1.2	1.05	1.2
Increase in cladding resistance	1.0	1.2	1.0	1.3
Improved specificity of cladding installation	1.0	1.2	1.0	1.2
Specificity of instructions for cladding installation	1.0	1.2	1.0	1.2
FRAME-FOUNDATION CONNECTION DAMAGE				
Improvement in connection materials	1.0	1.2	1.0	1.2
Improvement in connection resistance	1.0	1.4	1.0	1.6
Specificity of instructions for installation	1.0	1.2	1.0	1.2
Specified inspection of connections	1.0	1.2	1.0	1.2
FOUNDATION DAMAGE				
Improvement in foundation materials	1.0	1.2	1.0	1.2
Improvement in foundation resistance	1.0	1.2	1.0	1.2
Specificity of instructions for foundation installation	1.0	1.2	1.0	1.2
Specified inspection of foundation installation	1.0	1.0	1.0	1.0

TABLE 3: RESISTANCES FOR THE NEW INLAND CODE

Damage Mode	Resistance Thresholds* (mph fastest mile; Exp. C)		
	Low		High
Roof Covering Damage	63	-	127
Roof Decking Damage	94	-	142
Roof Framing Damage	88	-	132
Roof-wall Anchorage Damage via Suction	113	-	150
Roof-wall Anchorage Damage via Suct. & Int Pressure	96	-	120
Building Damage via Failure of Lat. Bracing Sys.	117	-	163
Damage Due to Failure of Openings	60	-	110
Cladding Damage	80	-	120
Frame-foundation Connection Damage	113	-	169
Foundation Damage	132	-	173

*On basis of Alicia and Elena Wind speeds; Analysis of Codes; and Expert Opinion.

TABLE 4: RESISTANCES FOR THE CURRENT SEAWARD CODE

Damage Mode	Resistance Thresholds* (mph fastest mile; Exp. C) Low		High
Roof Covering Damage	55	-	110
Roof Decking Damage	86	-	129
Roof Framing Damage	85	-	127
Roof-wall Anchorage Damage via Suction	94	-	126
Roof-wall Anchorage Damage via Suct. & Int Pressure	80	-	100
Building Damage via Failure of Lat. Bracing Sys.	90	-	125
Damage Due to Failure of Openings	60	-	110
Cladding Damage	80	-	120
Frame-foundation Connection Damage	90	-	135
Foundation Damage	115	-	150

*On basis of Alicia and Elena Wind speeds; Analysis of Codes; and Expert Opinion.

TABLE 5: RESISTANCES OF THE NEW SEAWARD CODE

Damage Mode	Resistance Thresholds* (mph fastest mile; Exp. C)		
	Low		High
Roof Covering Damage	63	-	127
Roof Decking Damage	96	-	144
Roof Framing Damage	90	-	134
Roof-wall Anchorage Damage via Suction	115	-	154
Roof-wall Anchorage Damage via Suct. & Int Pressure	104	-	130
Building Damage via Failure of Lat. Bracing Sys.	124	-	173
Damage Due to Failure of Openings	81	-	148
Cladding Damage	80	-	120
Frame-foundation Connection Damage	117	-	176
Foundation Damage	132	-	173

*On basis of Alicia and Elena Wind speeds; Analysis of Codes; and Expert Opinion.

TABLE 6: ANNUAL PROBABILITY OF EXCEEDENCE AT SELECTED SITES

Annual Probability of Exceedence	Wind Speed (Fastest Mile) Brownsville & Corpus Christi	Galveston & Texas City
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 7: PROBABILITY OF OCCURRENCE FOR HURRICANES AT SELECTED SITES

Category	Range mph	Probability of Occurrence Corpus/Brownsville	Probability of Occurrence Galveston/Texas City
1	74-96	.052	.064
2	97-110	.013	.016
3	111-130	.0056	.0075
4	131-150	.0011	.002
5	> 150	.0003	.0005

Note: Data is derived from annual probability of occurrence of exceedence at Brownsville and Corpus Christi and Galveston. Note that the data for Corpus and Brownsville were the same and Texas City and Galveston were identical.

TABLE 8: SUMMARY OF DAMAGE TO STRUCTURE IN HURRICANES

Hurricane Wind Speed (mph)	Structural Damage Ratio			
	Current Code Inland	New Code Inland	Current Code Seaward	New Code Seaward
85	0.11	0.04	0.08	0.02
103	0.50	0.19	0.44	0.12
120	0.83	0.45	0.76	0.34
140	0.96	0.72	0.96	0.67
160	1.00	0.93	1.00	0.89

TABLE 9: SUMMARY OF DAMAGE TO CONTENTS IN HURRICANES

Hurricane Wind Speed (mph)	Damage Ratio			
	Current Code Inland	New Code Inland	Current Code Seaward	New Code Seaward
85	0.11	0.06	0.11	0.02
103	0.46	0.24	0.36	0.17
120	0.85	0.52	0.77	0.44
140	0.95	0.79	0.95	0.74
160	1.0	0.94	1.0	0.94

TABLE 10: TYPICAL OUTPUT: NEW CODE COST-EFFECTIVENESS AT CORPUS CHRISTI

Input	Inland Codes	Seaward Codes
Structural Damage	Table 8	Table 8
Content Damage	Table 9	Table 9
Hurricane Probability of Occurrence	Table 7	Table 7
Interest rate = 10%	N/A	N/A
Useful life = 60 yrs	N/A	N/A
Output		
Break-Even Cost-Effectiveness (Percent Cost of Structure)	12.62	13.89

TABLE 11: BREAK-EVEN COSTS FOR NEW CODE-INLAND AS A FUNCTION OF USEFUL LIFE OF STRUCTURE AND INTEREST RATE (GALVESTON)

Useful Life of Structure (Yrs)	Break-even Cost (Percent Cost of Structure, Current Code)		
	Interest Rate%		
	5	10	15
20	18.50	13.47	10.28
40	23.77	15.16	10.85
60	25.57	15.41	10.88
80	26.23	15.44	10.88

TABLE 12: BREAK-EVEN COSTS FOR NEW CODE-SEAWARD AS A FUNCTION OF USEFUL LIFE OF STRUCTURE AND INTEREST RATE (GALVESTON)

Useful Life of Structure (Yrs)	Break-even Cost (Percent Cost of Structure, Current Code)		
	Interest Rate%		
	5	10	15
20	20.83	14.90	11.26
40	27.21	16.86	11.89
60	29.46	17.15	11.93
80	30.28	17.19	11.94

TABLE 13: BREAK-EVEN COSTS FOR NEW CODE-INLAND AS A FUNCTION OF USEFUL LIFE OF STRUCTURE AND INTEREST RATE (CORPUS CHRISTI)

Useful Life of Structure (Yrs)	Break-even Cost (Percent Cost of Structure, Current Code)		
	Interest Rate%		
	5	10	15
20	15.30	10.98	8.32
40	19.93	12.41	8.78
60	21.54	12.62	8.81
80	22.13	12.65	8.81

TABLE 14: BREAK-EVEN COSTS FOR NEW CODE-SEAWARD AS A FUNCTION OF USEFUL LIFE OF STRUCTURE AND INTEREST RATE (CORPUS CHRISTI)

Useful Life of Structure (Yrs)	Break-even Cost (Percent Cost of Structure, Current Code)		
	Interest Rate%		
	5	10	15
20	16.98	12.02	9.02
40	22.46	13.65	9.54
60	24.41	13.89	9.57
80	25.13	13.92	9.57

TABLE 15a: PRESCRIPTIVE REQUIREMENTS FOR INLAND CODES

Subsystem	Current Code	New Code
Roofing	15# felt, 220# Composition shingles, "Wind Resistant", 4 nails/shingle	30# felt, 220# Composition shingles, "Wind Resistant", 6 nails/shingle
Roof Decking	1/2" CD	15/32" CD
Roof Framing	Hip roof, 4:12 slope, 2x6 rafters, 2x8 ridgeboard and hip rafters, strongback and purlins	Hip roof, 4:12 slope, 2x8 rafters, 2x10 ridgeboard and hip rafters, bracing of every rafter over span
Roof Frame-wall Connections	300# anchor of every other stud to double top plate or rafter	Anchorage per table, every stud to double top plate and rafter
Lateral Bracing, Exterior	1x4 Let-in corner bracing, one brace every 18 ft of wall	Shear walls minimum 3 ft at every corner, additional length per table
Lateral Bracing, Interior	1x4 Let-in for every load bearing interior wall	None
Cladding	Brick veneer, ties 16" o.c. every stud	Brick veneer, ties 16" o.c. every stud
Openings	No window protection	No window protection
Frame-Foundation Connection	Anchor bolts 6 ft o.c., 300# anchor every other stud to sole plate	Anchor bolts 4 ft o.c., anchorage per table, every stud to sole plate, holddowns at every corner and at end of each shear wall
Foundation	Non-engineered slab on grade	Reinforced slab on grade

TABLE 15b: PRESCRIPTIVE REQUIREMENTS FOR SEAWARD CODES

Subsystem	Current Code	New Code
Roofing	15# felt, 220# Composition shingles, "Wind Resistant", 4 nails/shingle	30# felt, 220# Composition shingles, "Wind Resistant", 6 nails/shingle
Roof Decking	5/8" veneer	15/32" CD
Roof Framing	Hip roof, 4:12 slope, 2x8 rafters, 2x10 ridgeboard and hip rafters, strongback and purlins	Hip roof, 4:12 slope, 2x8 rafters, 2x10 ridgeboard and hip rafters, bracing of every rafter over span
Roof Frame-wall Connections	300# anchor of every other stud to double top plate or rafter	Anchorage per table, every stud to double top plate and rafter
Lateral Bracing, Exterior	1x4 Let-in corner bracing, one brace every 18 ft of wall	Shear walls minimum 3 ft at every corner, additional length per table
Lateral Bracing, Interior	1x4 Let-in for every load bearing interior wall	None
Cladding	Brick veneer, ties 12" o.c. every stud	Brick veneer, ties 16" o.c. every stud
Openings	No window protection	2x4 and 3/4" plywood attached with barrel bolts
Frame-Foundation Connection	Anchor bolts 6 ft o.c., 300# anchor every other stud to sole plate	Anchor bolts 3.5 ft o.c., anchorage per table, every stud to sole plate, holddowns at every corner and at end of each shear wall
Foundation	Non-engineered slab on grade	Reinforced slab on grade

TABLE 16: ADDITIONAL COST TO IMPLEMENT NEW CODE-INLAND AS A FUNCTION OF SIZE OF STRUCTURE AND CONSTRUCTION COST (GALVESTON)

Construction Cost $/Sf	Cost to Implement New Code (Percent Construction Cost)			
	Size of House (sf)			
	1000	1664	2040	3000*
60	2.86	2.56	2.67	2.87
75	2.29	2.05	2.14	2.29
85	2.02	1.81	1.89	2.02
100	1.72	1.54	1.60	1.72

*Two-story Structure

TABLE 17: ADDITIONAL COST TO IMPLEMENT NEW CODE-SEAWARD AS A FUNCTION OF SIZE OF STRUCTURE AND CONSTRUCTION COST (GALVESTON)

	Cost to Implement New Code (Percent Construction Cost)			
	Size of House (sf)			
Construction Cost $/Sf	1000	1664	2040	3000*
60	3.29	3.12	3.32	4.64
75	2.64	2.50	2.65	3.72
85	2.33	2.20	2.34	3.28
100	1.98	1.87	2.00	2.79

*Two-story

TABLE 18: ADDITIONAL COST TO IMPLEMENT NEW CODE-INLAND AS A FUNCTION OF SIZE OF STRUCTURE AND CONSTRUCTION COST (CORPUS CHRISTI)

Construction Cost $/Sf	Cost to Implement New Code (Percent Construction Cost)			
	Size of House (sf)			
	1000	1664	2040	3000*
60	3.32	2.92	3.01	3.23
75	2.65	2.33	2.40	2.58
85	2.34	2.06	2.12	2.28
100	1.99	1.75	1.80	1.94

*Two-story

TABLE 19: ADDITIONAL COST TO IMPLEMENT NEW CODE-SEAWARD AS A FUNCTION OF SIZE OF STRUCTURE AND CONSTRUCTION COST (CORPUS CHRISTI)

Construction Cost $/Sf	Cost to Implement New Code (Percent Construction Cost)			
	Size of House (sf)			
	1000	1664	2040	3000*
60	3.36	3.09	3.22	4.76
75	2.69	2.47	2.58	3.81
85	2.37	2.18	2.28	3.36
100	2.02	1.85	1.93	2.86

*Two-story

TABLE 20: COST-EFFECTIVENESS OF NEW CODE-INLAND AS A FUNCTION OF SIZE OF STRUCTURE AND CONSTRUCTION COST (GALVESTON)

Construction Cost $/Sf	Cost to Implement Code/Break-Even Cost*			
	Size of House (sf)			
	1000	1664	2040	3000**
60	0.29	0.25	0.26	0.28
75	0.22	0.20	0.21	0.22
85	0.20	0.18	0.18	0.20
100	0.17	0.15	0.16	0.17

*20 year useful life and 15% interest rate
**Two-story

TABLE 21: COST-EFFECTIVENESS OF NEW CODE-SEAWARD AS A FUNCTION OF SIZE OF STRUCTURE AND CONSTRUCTION COST (GALVESTON)

Construction Cost $/Sf	Cost to Implement Code/Break-Even Cost*			
	Size of House (sf)			
	1000	1664	2040	3000**
60	0.29	0.28	0.29	0.41
75	0.23	0.22	0.24	0.33
85	0.21	0.20	0.21	0.29
100	0.18	0.17	0.18	0.25

*20 year useful life and 15% interest rate
**Two-story

TABLE 22: COST-EFFECTIVENESS OF NEW CODE-INLAND AS A FUNCTION OF SIZE OF STRUCTURE AND CONSTRUCTION COST (CORPUS CHRISTI)

Construction Cost $/Sf	Cost to Implement Code/Break-Even Cost*			
	Size of House (sf)			
	1000	1664	2040	3000**
60	0.40	0.35	0.36	0.39
75	0.32	0.28	0.29	0.31
85	0.28	0.25	0.25	0.27
100	0.24	0.21	0.22	0.23

*20 year useful life and 15% interest rate
**Two-story

TABLE 23: COST-EFFECTIVENESS OF NEW CODE-SEAWARD AS A FUNCTION OF SIZE OF STRUCTURE AND CONSTRUCTION COST (CORPUS CHRISTI)

Construction Cost $/Sf	Cost to Implement Code/Break-Even Cost* — Size of House (sf)			
	1000	1664	2040	3000**
60	0.37	0.34	0.36	0.53
75	0.30	0.27	0.29	0.42
85	0.26	0.24	0.25	0.37
100	0.22	0.20	0.21	0.32

*20 year useful life and 15% interest rate
**Two-story

TABLE 24: HYPOTHETICAL TABULATION OF CASH FLOW FOR TWO CODES

Year	Current Code (A)	New Code (B)	Difference (B-A)
0		-$15,000	-$15,000
1	-$8,200	-$5,100	+$3,100
2	-$8,200	-$5,100	+$3,100
3	-$8,200	-$5,100	+$3,100
4	-$8,200	-$5,100	+$3,100
.			
.			
.			
40	-$8,200	-$5,100	+$3,100

TABLE 25: ANNUAL DAMAGE COST AS A FUNCTION OF LOCATION

Location	Annual Damage Cost* (Fraction of Cost of Structure)			
	Current Code		New Code	
	Inland	Seaward	Inland	Seaward
Galveston	0.0376	0.0329	0.0192	0.0131
Corpus Christi	0.0289	0.0251	0.0144	0.0096

*Values obtained using Equation (6)

TABLE 26: ANNUAL DAMAGE COST FOR $60,000 - 1000 SQUARE FOOT HOUSE AS A FUNCTION OF LOCATION

Location	Annual Damage Cost (Dollars)			
	Current Code		New Code	
	Inland	Seaward	Inland	Seaward
Galveston	2,256	1,974	1,152	786
Corpus Christi	1,734	1,506	864	576

TABLE 27: TABULATION OF CASH FLOW FOR INLAND (GALVESTON)

Year	Cost in Dollars		
	Current Code (A)	New Code (B)	Difference (B-A)
0	-	-1719	-1719
1	-2256	-1152	+1104
2	-2256	-1152	+1104
3	-2256	-1152	+1104
4	-2256	-1152	+1104
.			
.			
.			
40	-2256	-1152	+1104

TABLE 28: TABULATION OF CASH FLOW FOR SEAWARD (GALVESTON)

Year	Cost in Dollars		
	Current Code (A)	New Code (B)	Difference (B-A)
0		-2,236	-2,236
1	-1974	-786	+1188
2	-1974	-786	+1188
3	-1974	-786	+1188
4	-1974	-786	+1188
.			
.			
.			
40	-1974	-786	+1188

TABLE 29: TABULATION OF CASH FLOW FOR INLAND (CORPUS CHRISTI)

	Cost in Dollars		
Year	Current Code (A)	New Code (B)	Difference (B-A)
0		-1990	-1990
1	-1734	-864	+870
2	-1734	-864	+870
3	-1734	-864	+870
4	-1734	-864	+870
.			
.			
.			
40	-1734	-864	+870

TABLE 30: TABULATION OF CASH FLOW FOR SEAWARD (CORPUS CHRISTI)

Year	Cost in Dollars		
	Current Code (A)	New Code (B)	Difference (B-A)
0		-2,266	-2,266
1	-1506	-576	+930
2	-1506	-576	+930
3	-1506	-576	+930
4	-1506	-576	+930
.			
.			
.			
40	-1506	-576	+930

TABLE 31: OTHER INDICATORS OF COST-EFFECTIVENESS OF NEW CODE

Location and Code	ROR* (Percent)	Approximate Payback Time (Years)
Inland Galveston	64	2
Inland Corpus Christi	53	3
Seaward Galveston	41	3
Seaward Corpus Christi	40	3

*Rate of return for using New Code assuming 40 yr. useful life

APPENDIX A

DEFINITION OF AREAS IN NEW CODE FOR POSSIBLE REDUCTION (OR INCREASE) IN REQUIREMENTS

DEFINITION OF AREAS IN NEW CODE FOR POSSIBLE REDUCTION (OR INCREASE) IN REQUIREMENTS

Objective of Task

The objective of this section is to define areas in the New Code for possible reduction (or increase) in requirements with minimal effect on the resistance of the structure. Note that the end result of this exercise is a description of "what is to be done". Exactly how these recommendations are to be implemented is the responsibility of TDI.

Approach to be Used

To accomplish this objective we will adopt the following approach:

1. Using the design assumptions for the New Code, we will establish target resistance values for each of the major building components;

2. Using data generated in the body of this report (i.e., Tables 3 and 5), we will assign estimates of the actual resistances achieved by the New Code;

3. On comparing our estimates of the resistance with the resistances derived from the design assumptions, we will evaluate the extent to which each component of the building is over-designed or under-designed; and

4. On the basis of the extent of over-design or under-design, we will define areas in the New Code for possible increase (or decrease) in requirements.

In this exercise, results will be generated for the Galveston location, since that location is the most hazardous on the Texas Coast.

Note that this approach is based on the procedures and recommendations put forth by Taguchi et al. (1989) in their attempts to improve the uniformity of a product by using parameter design.

Target Resistance Values from Code Assumptions

The target resistances for the New Code are listed in Table A1. The values provided are for Galveston and Corpus Christi. In concert with the current convention, the design wind speeds are based on the 50 yr return period. In table A1, we have increased the 50 yr inland and seaward values to incorporate the safety factor associated with the design process. To arrive at a safety factor, we assumed the load factor of 1.3 that is suggested in ASCE 7-93 (ASCE, 1994) and arrived at an equivalent wind speed factor equal to the square root of 1.3. The resistances, in terms of wind speeds incorporating the load factor, are listed in the last row of Table A1.

Estimated Resistances for New Code

We next used the wind speeds from Table 3 and Table 5 in the main body of this report to represent resistance of the various building components for the appropriate structure designed according to the New Code. From Table 3, for example, we listed the range of resistance for the roof covering system to include speeds from 63 to 127 mph (fastest-mile). The value we assign to the resistance of the roof covering is the mean of this range; namely, 95 mph. Similar calculations were performed for all elements of the damage modes in Table 3 and Table 5.

Evaluation of Design Quality of Building Components

In Tables A2 and A3, the evaluations of the relative performance of the building components for inland and seaward sections of the New Code are summarized. In each and every case, the target resistance is compared to the assigned resistance. Depending on the relative value of the two resistances, we make the determination that the component is under-designed, very near to the target design, over-designed, or highly over-designed.

Definition of Areas in New Code for Reduction (or Increase) in Requirements

For the inland section of the New Code, we identify the following areas:

1. Increase the resistance of the roof covering to resist an additional 15 mph of wind speed;

2. Increase the resistance of openings to resist an additional 25 mph of wind speed;

3. Increase the resistance of the exterior cladding to resist an additional 10 mph of wind speed;

4. Do not change the resistances of the roof framing, roof decking, and roof-wall anchorages;

5. Reduce the resistance of the foundation connections to resist a decrease of 30 mph in wind speed;

6. Reduce the resistance of the foundation to resist a decrease of 40 mph in wind speed[1]; and

7. Reduce the resistance of the lateral bracing to resist a decrease of 30 mph in wind speed.

For the seaward section of the New Code, we identify the following areas:

1. Increase the resistance of the roof covering to resist an additional 20 mph of wind speed;

2. Increase the resistance of the exterior cladding to resist an additional 15 mph of wind speed;

3. Do not change the resistances of the roof framing, roof decking, roof-wall anchorages, and openings;

4. Reduce the resistance of the foundation connections to resist a decrease of 30 mph in wind speed;

5. Reduce the resistance of the foundation to resist a decrease of 40 mph in wind speed[2]; and

6. Reduce the resistance of the lateral bracing to resist a decrease of 35 mph in wind speed.

TDI should now revisit the appropriate sections of the code and make adjustments consistent with these suggestions.

REFERENCES

ASCE, *Minimum Design Loads for Buildings and Other Structures, ASCE Standard ASCE 7-95* (proposed, 4th draft), Revision of ASCE 7-88, New York: American Society of Civil Engineers, September 1994.

Taguchi, G., Elsayed, E.A., and Hsiang, T., *Quality Engineering in Production Systems, Industrial Engineering and Management Science*, ed. J.L. Riggs NY: McGraw-Hill, 1989.

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[1]Note that such resistances in foundation strength may not be practical given current design and construction practices.

[2]Ibid.

TABLE A1: RESISTANCE VALUES FROM CODE ASSUMPTIONS

	Target Resistance in Wind Speed (Fastest-mile)			
	Galveston		Corpus Christi	
Load Basis	Inland	Seaward	Inland	Seaward
50 yr. Rtn. Interval	95	100	95	100*
With load Factor**	109	114	109	114

*See Fig. 1, ASCE-7-93
**Load Factor = 1.3 (See also ASCE 7-93)

TABLE A2: EVALUATION OF NEW CODE FOR INLAND (GALVESTON)

Building Component	Target Resistance in mph (From Code)	Assigned Resistance in mph (Table 3)	Evaluation
Roof Covering	109	95	Under-designed
Roof Decking	109	118	Over-designed
Roof Framing	109	110	Near target design
Anchorage/Suction	109	132	Over-designed
Anchorage/Suc & Int	109	108	Near target design
Lateral Bracing	109	140	Over-designed
Openings	109	85	Under-designed
Cladding	109	100	Under-designed
Foundation Connection	109	141	Highly over-designed
Foundation	109	153	Highly over-designed

TABLE A3: EVALUATION OF NEW CODE FOR SEAWARD (GALVESTON)

Building Component	Target Resistance in mph (From Code)	Assigned Resistance in mph (Table 5)	Evaluation
Roof Covering	114	95	Under-designed
Roof Decking	114	120	Over-designed
Roof Framing	114	112	Near target design
Anchorage/Suction	114	135	Over-designed
Anchorage/Suc & Int	114	117	Near target design
Lateral Bracing	114	149	Highly over-designed
Openings	114	115	Near target design
Cladding	114	100	Under-designed
Foundation Connection	114	147	Highly over-designed
Foundation	114	153	Highly over-designed