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An Assessment of the Value of Natural Hazards Damage Reduction in Dwellings Due to Building Codes: Two Case Studios

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I. INTRODUCTION

The potential for damage and destruction due to localized natural hazards, such as earthquakes, floods, and high winds, can be expected to elicit community and nationwide response by development of preventative measures. One of the most common measures adopted is the enforcement of building codes[1] developed to reduce property loss, injury, and death in community structures subject to regional natural hazards. Such measures can be costly, and in this era of heightened fiscal pressures on local and federal governments to justify expenditures on public programs, investigations and comparisons of the benefits and costs of such programs can provide crucial information to policy makers.

Unfortunately, benefits provided by public goods (such as building codes) often are not valued within the marketplace. In the analysis which follows, the direct cost method of valuing non-market goods will be applied to determine the value associated with publicly required building codes which address natural hazards in Los Angeles County and also the nine-county San Francisco area. The direct cost or productivity benefits methodology has been well-documented in previous studies.[2] However, it is widely recognized that the technique generally provides an underestimation of the true value of non-market goods due to its inability to capture all relevant "psychic" or esthetic values. Even so, the technique has the advantage of being relatively straightforward in that it utilizes available market information on direct costs which are avoided through the implementation of public policy. If benefits derived using the direct cost technique are high enough to justify the costs of the public policy, it may not be necessary to pursue more complex, though more comprehensive, valuation studies.

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1. In the United States, the most frequently referenced source on building code specifications is the UNIFORM BUILDING CODE, INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS—1976 (1979).

2. *See, e.g.*, FREEMAN III, THE BENEFITS OF ENVIRONMENTAL IMPROVEMENT at 234–47 (1979).

In the study which follows, the building code benefits investigated in the Los Angeles and San Francisco areas are those associated with prevention or reduction of potential damages to single family dwellings due to high wind hazards. For example, a recent storm which caused significant damage struck coastal California and surrounding inland areas. The storm was characterized by winds measuring up to 70–78 mph in and around Los Angeles County; such winds are slightly above hurricane level velocities. Some 1.75 million homes were without power due to fallen power lines and poles; in Los Angeles county alone, 2,000 trees were downed or uprooted, 10 percent of which struck houses.[3] Without wind resistant building codes, damages to dwellings by such high winds would undoubtedly have been far more extensive.

In areas of high seismicity such as coastal California, earthquake resistant building code requirements also meet required levels of wind resistance. For example, both seismic and wind resistant codes require extra structural bracing and extra bracing of the ceiling to the walls and of the walls to the foundation. Based upon a previous study of seismic codes,[4] we take as given a 1980 estimate of the cost of seismic (and thus wind resistant) building codes to be within a range of $1.53–$2.23 billion in Los Angeles county and $0.9–$1.35 billion in the San Francisco area.[5] The analysis which follows uses a direct cost approach to estimate the non-market value of congruent wind resistance benefits due to implementation of these building codes for the purpose of making an order of magnitude comparison with their cost.

In the following section, a theoretical basis is presented for determining the non-market value of benefits due to building codes which reduce potential wind damages to single family dwellings. Sections III and IV describe the relevant data and functional forms utilized to arrive at empirical estimates of benefits in the form of direct costs of wind hazards avoided in dwellings as a result of seismic/wind resistant building codes implemented in the two study areas. Section V presents conclusions and caveats.

II. THEORETICAL MODEL

The value to the individual household of wind resistance in a single family dwelling due to building codes can be represented as follows:

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3. *Many Homes Still in Dark in Storm's Wake,* The Los Angeles Times, Dec. 2, 1982 at 117, col. 1.

4. D. S. Brookshire, Methods Development for Valuing Hazards Information, at 106–122 (1980) (report to the U.S. Geological Survey).

5. *Id.* at 118. Cost estimates assume that 2–3% of the 1980 market value of single family dwellings built according to code specifications is due to extra costs of implementing seismic/wind resistant codes.

$$(1)\quad E(U) = (1-P)\cdot U(W) + P\cdot \tilde{U}[W-D(C)]$$

where:
- $E(U)$ = the expected value of household utility
- U = household utility, a function of total wealth
- W = household wealth, including the market value of the single family dwelling
- D = property damage, or the value of repairs required, in the event of damaging winds
- P = the annual probability that wind damage will occur
- C = index of the level of building codes, reflecting the extent of the potential for wind resistance in single family dwellings.

Utility is assumed to be a differentiable increasing function of wealth which is affected negatively by property losses due to wind damage. The extent of the damage, D, is a function of the level of building codes required, where $\frac{dD}{dC} < 0$.

By totally differentiating equation (1) and holding E(U) and P constant, we can solve for $\frac{dW}{dC}$:

$$(2)\quad \frac{dW}{dC} = P\cdot\left(\frac{-dD}{dC}\right)\cdot\left[\frac{1}{P+(1-P)\cdot\frac{U'}{\tilde{U}'}}\right]$$

The right-hand-side of equation (2) is a compensating variation measure of the value of wind resistant building codes to the individual household.

For relatively small values of D, it can be argued that $U' \approx \tilde{U}'$,[6] so that (2) reduces to:

$$(3)\quad \frac{dW}{dC} \approx P\cdot\left(\frac{-dD}{dC}\right)$$

By expression (3), the expected value of wind resistant building codes to the individual household can be approximated by multiplying the probability of wind damage to the single family dwelling by the reduction in damages attributable to increasing the level of wind resistant building codes. Assuming all households in a particular study area have similar preferences, the total annual expected value can therefore be approximated

6. This seems reasonable since in section III of this paper, we find that at the highest wind velocities considered plausible in our study area, estimated damage to even uncoded dwellings does not exceed 3% of dwelling replacement value. This clearly amounts to a small proportion of total wealth.

by multiplying the individual household valuation by the number of single family dwellings built according to wind resistant building codes.

A measure of the value of total annual expected benefits attributable to wind resistance, WR_t, due to building codes in single family dwellings within a study area for any year t is given below:

$$(4)\quad WR_t = \int_{\underline{v}}^{V} [f(v_t) \cdot [D^o(v) - D^1(v)] \cdot SFD \cdot W_{SFD} dv]$$

where:

WR_t = expected value of wind damages avoided in SFD's in year t due to existing seismic building codes which govern structural design

v = $\underline{v}, \ldots, V$; = extreme wind velocities with $\underline{v}$ the minimum velocity at which damage occurs, and V the maximum wind velocity that might reasonably be expected to occur in the study region.

$f(v)$ = frequency distribution of extreme wind velocities $\underline{v}, \ldots, V$

$D^o(v)$ = wind damage to buildings without wind resistant codes, increasing in wind velocity, as a percent of replacement cost

$D^1(v)$ = wind damage to buildings with wind resistant codes, increasing in wind velocity, as a percent of replacement cost

SFD = total market value of single family dwellings in the study area

W_{SFD} = weight reflecting the percent of SFD's in the region which are built according to wind resistant building code specifications.

This approximation reflects the fact that the annual probability of wind damage is based upon the frequency distribution f(v) of extreme wind velocities which may occur in any given year t. For a discrete change in the level of wind resistive building codes, say an increase in the level of coded wind resistance from C^o (no codes) to C^1 (current codes), D^o will exceed D^1 for any high wind speed v. Given $C^o < C^1$, $D^o(v) - D^1(v)$ is an estimate of the damages avoided for each of the potentially destructive wind velocities, $\underline{v}, \ldots, V$. Multiplying this measure by the probability of each velocity and summing over the range of potentially destructive wind speeds yields an expected annual value of benefits to an individual household within the study area. Since D^o and D^1 are expressed in terms of damages as a percent of dwelling replacement value, the measure of total expected annual benefits is obtained by multiplying by $SFD \cdot W_{SFD}$, the market value of single family dwellings in the area built according to wind resistant building code level C^1.

The following section describes data and functional forms utilized to estimate total expected annual benefits given by equation (4) for households in Los Angeles County. An additional application of the methodology is also presented for the nine-county San Francisco study area. In both cases, the results are obtained for dwellings built according to seismic/wind resistant building codes implemented since 1940 as compared to pre-1940 dwellings built under essentially no codes. Thus, estimates of damages avoided reflect the discrete change in the level of building codes from "uncoded" to "coded."

III. EMPIRICAL ANALYSIS: LOS ANGELES COUNTY

Determining the Frequency Distribution of Wind Velocities

Data on extreme wind velocities at the Los Angeles International Airport are collected and compiled continuously by the National Climatic Center.[7] However, since airports are often strategically located in low-wind locales, such data provide underestimates of extreme wind velocities. The 1972 updated version of the ANSI (American National Standards Institute) standard A-58 for design wind specifies adjustments to extreme velocity data for three different terrain exposure conditions since terrain exposure produces variability in the potential extreme values.[8] Also, since wind speeds vary with elevation, data series are typically adjusted to a standard thirty-foot elevation. Culver[9] and Simiu and Filliben[10] have "corrected" extreme wind velocity records for exposure and elevation[11] to approximate return periods for maximum wind speeds using Gumbel or Frechet cumulative distribution functions. Lew and Hart[12] further recommend that for microzonation purposes, wind design speeds should be corrected for directional variations; their results determining return periods of wind speeds (fastest mile measured in north direction) are given below:

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7. NATIONAL CLIMATIC CENTER, CLIMATOLOGICAL DATA—LOS ANGELES AIRPORT ANNUAL REPORTS (1945–1978).

8. Cohen, Vellozzi, & Thom, *Proposed American Standard Building Code Requirements for Minimum Design Wind Loads,* in WIND EFFECTS ON BUILDINGS AND STRUCTURES 1, PROCEEDINGS OF THE INTERNATIONAL RESEARCH SEMINAR (1968).

9. C. CULVER, NATURAL HAZARDS EVALUATION IN EXISTING BUILDINGS, NATIONAL BUREAU OF STANDARDS BUILDING SCIENCE SERIES 61 (1975).

10. E. SIMIU & J. FILLIBEN, STATISTICAL ANALYSIS OF EXTREME WINDS, TECHNICAL NOTE 868, NATIONAL BUREAU OF STANDARDS (1975).

11. Lew & Hart, *Microzonation and Wind Engineering,* 105 J. OF THE STRUCTURAL DIVISION, PROC. OF THE AM. SOC'Y OF CIV. ENGINEERS 975, 984 (No. ST3, June 1979).

12. *Id.*

	Return Period, in years			
	2	*25*	*50*	*100*
velocity (mph)	48	78	86	93[13]

Thus, Lew and Hart's adjusted data attaches a 50 percent probability to experiencing a 48 mph wind in any particular year, dropping off to a one percent chance of observing a 93 mph wind. Using this adjusted airport wind data for Los Angeles County, we approximate a frequency distribution of the following form:

$$(5) \quad t(v) = \rho v^{\gamma}$$

Linear regression is used to estimate the log-log form of equation (5):

$$(6) \quad \ln f(v) = \underset{(12.9)}{21.487} - \underset{(-14.8)}{5.71} \cdot \ln v \qquad DF = 2$$
$$R^2 = .986$$

Fitting the data to equation (5) thus yields the following values for ρ and γ

$$\rho = e^{21.487}; \gamma = -5.7146$$

The t-statistics given in parentheses below equation (6) demonstrate that both coefficients in (6) are significant at levels exceeding 99 percent. The R^2 indicates that almost 99 percent of the variation in ln f(v) is explained by the estimated frequency distribution. The estimated f(v) distribution is shown in Figure 1. In this study, it is assumed that $f(v) \rightarrow 0$ in Los Angeles County for wind velocities in excess of 110 mph.

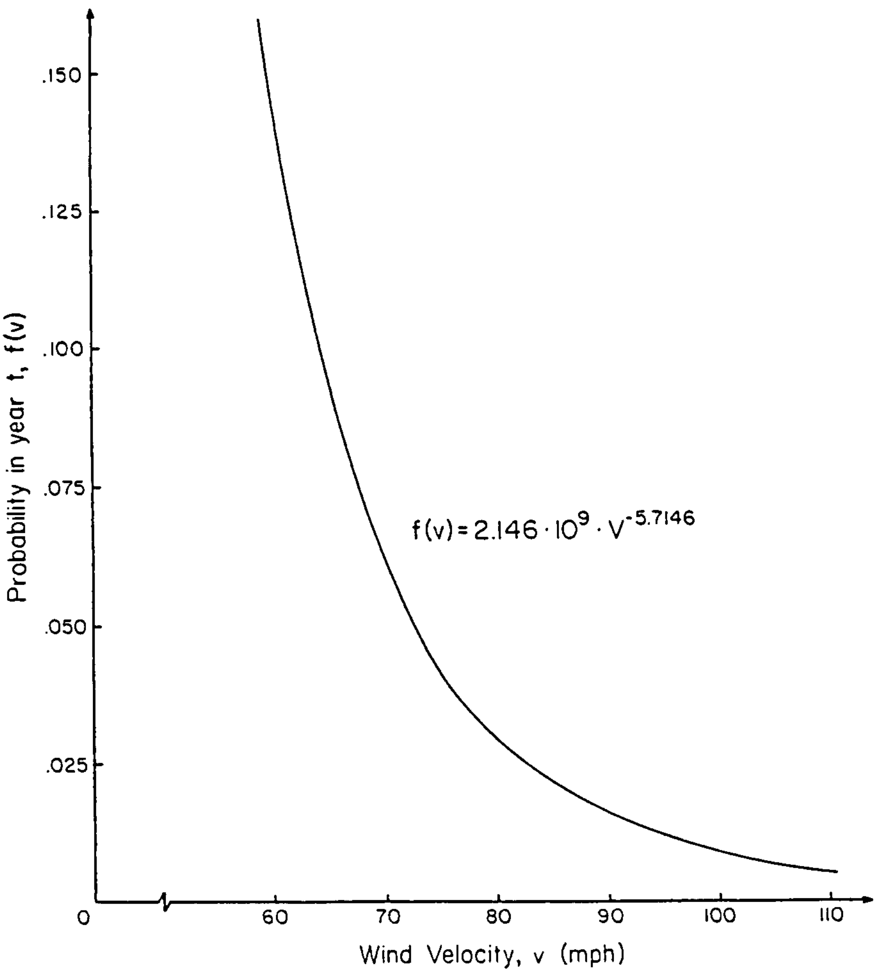
Estimation of Wind Damage Functions

Engineering analyses of wind damage to residential structures as a function of wind velocity have not been widely conducted in the United States. However, Leicester has estimated damage relationships for dwellings with respect to potentially high winds in various Australian regions where wind damage poses a hazard to residences.[14] Of the communities studied, Leicester determined that most of the residences in the Hedland region were relatively new and built with a high degree of wind resistance engineering input. In contrast, the communities of Geraldton and Brisbane showed a high degree of susceptibility to wind damage due to a high proportion of older homes characterized by lack of vertical ties in walls, inadequate tying of walls to ceilings, and inadequate bracing of roofs to

13. *Id. See* Table 3 at 987.

14. Leicester, Bubb, Dorman, & Beresford, *An Assessment of Potential Cyclone Damage to Dwellings in Australia*, PROCEEDINGS OF THE FIFTH INTERNATIONAL CONFERENCE ON WIND ENGINEERING (J. Cermak ed. 1980) 23–46.

Figure 1



walls.[15] For purposes of the L.A. County analysis, then, it will be assumed that for coded dwellings potential damage, D^i, as a function of wind velocity can be approximated by the damage estimates developed by Leicester for Hedland. An average of the damage estimates for Geraldton

15. Of five categories developed to assess dwellings' engineered wind resistance and susceptibility to damage, 78% of Hedland's housing fell in the two lowest damage categories, whereas 89% and 90% of Geraldton's and Brisbane's housing, respectively, fell in the two highest damage categories.

and Brisbane will be used to obtain an estimated damage function $D^o(v)$ for dwellings which are not built according to codes.[16]

The following functional forms are used to approximate damage in coded and uncoded dwellings:

$$(7)\quad D^i(v) = e^{(\alpha^i - \beta^i v)}$$

where:

i = 0; uncoded structures (Geraldton/Brisbane)
= 1; coded structures (Hedland)

Using the Leicester relationships between damage and wind velocities,[17] D^o and D^1 can be derived by applying ordinary least squares regression to estimate the semi-log form of equation (7):

$$(8)\quad \ln D^i = \alpha^i + \beta^i v$$

The estimated coefficients and relevant statistics are shown in equations (9) and (10):

$$(9)\quad \ln D^o = \underset{(-14.3)}{-14.588} + \underset{(10.4)}{.0991} \cdot v \qquad DF = 2$$
$$R^2 = .97$$

$$(10)\quad \ln D^1 = \underset{(-10.7)}{-15.085} + \underset{(7.7)}{.0896} \cdot v$$
$$R^2 = .97$$

As shown by the t-statistics in parentheses below the estimated coefficients, the vlaues for α^o, α^1, β^o, and β^1 are all significant at the 95 percent level or better. Furthermore, 97 percent of the variation in both dependent variables can be explained by the relationships specified in (9) and (10).

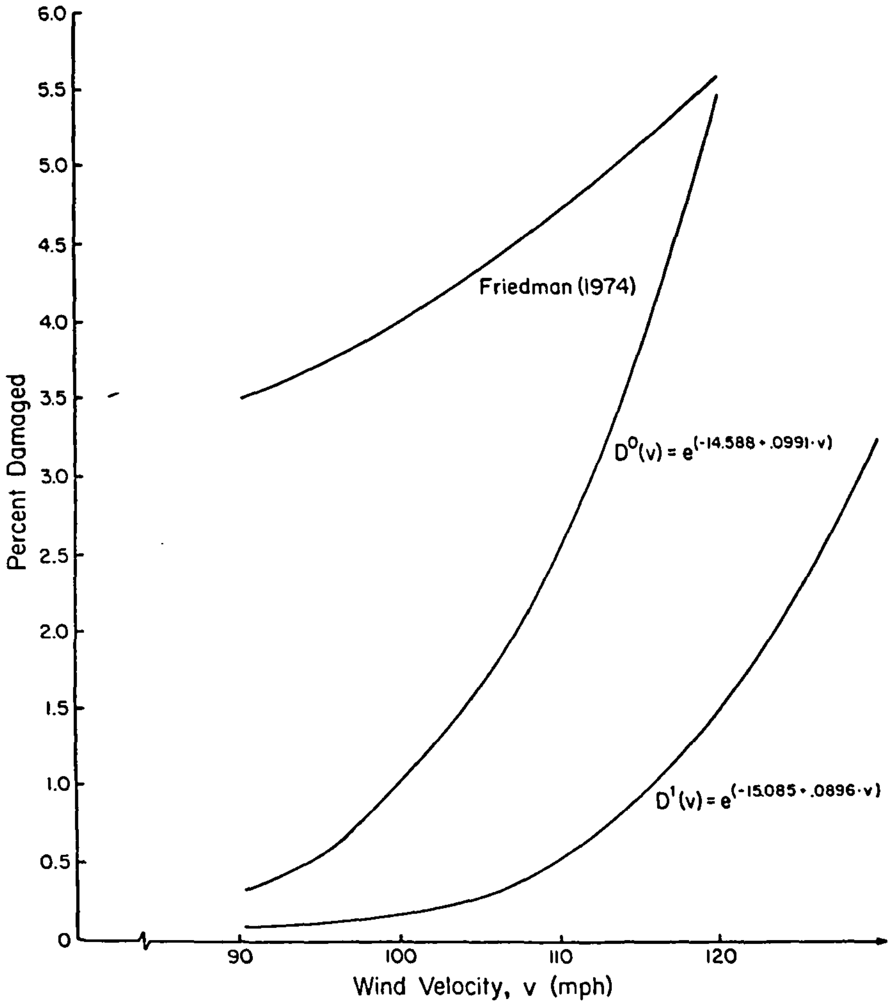
A plot of the estimated damage functions for uncoded dwellings and coded dwellings, $D^o(v)$ and $D^1(v)$ respectively, is provided in Figure 2. A convincing argument can be made that D^o and D^1 represent downwardly biased damage estimates in Los Angeles County for the following reasons:

1. The "coded" damages are based on data from regions where a significant proportion of the homes (almost one-fourth of total dwellings) are actually relatively "uncoded";
2. The "uncoded" damages are based on data in areas where, undoubtedly, *some* wind resistant design is incorporated into buildings (i.e., roofs are at least fastened to walls although not adequately

16. Leicester, *supra* note 14, at 23. Though Leicester addresses wind resistant design for structural codes, such design considerations are also met by stringent seismic building codes such as those in Los Angeles County and in San Francisco.

17. Leicester, *supra* note 14. See Figure 6, at 32. Data is converted from meters per second to velocity in miles per hour, and data relevant in the velocity range of 95–130 mph only are used to approximate the D^i's.

Figure 2



braced for extreme winds); if we actually assumed no wind resistant design we could expect much greater damages than reported (such as loss of entire roofs at relatively lower velocities);[18]

3. Many of the dwellings in Australian communities in the data set are low-set brick or concrete structures which would be expected

18. In fact, a crude calculation using physical laws of aerodynamics yielded the result that without ties between the roof and walls, loss of the roof could occur at velocities as low as 65 mph.

to better withstand high winds than lighter-weight wooden structures such as those found in most of southern California;

4. Lastly, for purposes of comparison, estimates made by Friedman of the most likely percentage of SFD's value lost in high winds[19] occurring in various regions of the U.S. are also plotted on Figure 2. In one of many hazard loss potential studies, Friedman's estimates were applied to his study area of the Gulf and Atlantic coastal states containing one-half of the nation's SFD's, some built according to seismic and/or wind building codes and some not.[20] Inspection of Figure 2 indicates that both the estimated D^o and D^1 generally fall below the Friedman recommendations.

Thus, it seems resonable to assume that (D^o–D^1) for any given velocity v is not an overestimate of the damages avoided at various wind velocities when single family dwellings benefit from wind resistance provided by coded structural design.

Empirical Results for Los Angeles County

To evaluate equation (4) and thus estimate WR_t benefits due to wind damages avoided annually when building codes are in place, expected damages as a percent of dwelling replacement value over a range of possible velocities in any year t are determined discretely by:

$$(11) \qquad \sum_{\underline{v}_t=60}^{V=110} f(v_t) \cdot [D^o(v_t) - D^1(v_t)]$$

The range of velocities of 60–110 mph is chosen to reflect a minimum velocity below which wind damages approach zero and a maximum velocity above which the frequency of velocity occurrence also goes to zero. Substituting the estimated functions specified in (6), (9), and (10) into (11) yields the result that expected wind damages avoided per coded dwelling annually due to seismic codes amount to almost one-fifth of one percent of the dwelling's value.

For any given year, total wind losses avoided (in expected value terms) is obtained by multiplying the sum in equation (11) by the value of coded single family dwellings in L.A. County. In a U.S. Geological Survey report prepared by Brookshire,[21] 1980 values for SFD and W_{SFD} in

19. D. FRIEDMAN, COMPUTER SIMULATION IN NATURAL HAZARD ASSESSMENT, INSTITUTE OF BEHAVIORAL SCIENCE AT UNIVERSITY OF COLORADO (1974). *See* Table IV-1, Single-Unit Residential estimates, at 70.

20. *Id.*

21. D. BROOKSHIRE, METHODS DEVELOPMENT FOR BENEFIT-COST ANALYSIS OF NATURAL HAZARDS INFORMATION, at 2–50 (report to the U.S. Geological Survey) (forthcoming).

equation (4) are \$103.1 billion and 74 percent respectively; i.e., 74 percent of the stock of single family dwellings in Los Angeles County has been built since 1940, the time at which seismic/wind resistance was incorporated into building code requirements. Substituting into equation (4), the obtained result is that the total expected benefits are \$150.4 million annually for single family dwellings in L.A. County.[22]

Finally, the present value of expected benefits from avoiding wind damages to coded SFD's is calculated by summing discounted annual benefits over a time horizon T:

$$\sum_{t=0}^{T} WR_t \cdot 1/(1+r)^t,$$

where r is the annual discount rate in real terms. Results for numerous time horizons using various discount rates are shown in Table 1. For purposes of comparison, the cost of wind resistant/seismic building codes in Los Angeles County ranges from \$1.53 to \$2.23 billion in 1980.

TABLE 1

Expected Present Value of Wind Resistance Benefits Due to Seismic/Wind Resistant Building Codes in Los Angeles County (in 1980 dollars, billions)

	Time Horizon				
Discount Rate	20 years	40 years	60 years	80 years	100 years
.02	2.508	4.195	5.331	6.095	6.610
.03	2.304	3.579	4.286	4.677	4.894
.05	1.968	2.709	2.988	3.094	3.133
.07	1.704	2.145	2.258	2.288	2.295

IV. EMPIRICAL ANALYSIS: SAN FRANCISCO AREA

The methodology used to evaluate the annual expected value of wind resistance benefits, WR_t, from seismic building codes in the San Francisco SFD's is essentially identical to that applied in the Los Angeles County study. The estimation of WR_t for the San Francisco area employs the same damage functions $D^0(v)$ and $D^1(v)$ described previously for Los Angeles, though data differences between the two study areas require the estimation of a new frequency distribution f(v) for extreme wind velocities.

Extreme wind data collected at the San Francisco airport indicate that

22. Note other types of buildings, e.g. commercial structures, apartments, etc. are not included in this estimate.

extreme wind velocities are somewhat higher than in Los Angeles in terms of a given return period; for example, over a 30-year record the extreme gust recorded at San Francisco Airport was 78 mph while Los Angeles Airport recorded 62 mph as the maximum for the same period.[23] Thus, f(v) is re-estimated for the nine-county San Francisco study area based on statistical data series of extreme annual gust velocities available from the California Department of Water Resources.[24]

Applying a Pearson Type III frequency distribution to a 33 year data set, the Department of Water Resources has published return periods for various peak gusts.[25] To use their data in this study of extreme winds in the nine surrounding counties, it is necessary to employ a simplistic version of the probabilistic wind models of extreme wind utilized by Simiu and Filliben[26] and Lew and Hart.[27] The following conversion factor[28] is employed here to adjust the statistical series on airport data to a standard 30-ft elevation:

$$(12) \quad v = v_e \cdot \left(\frac{30}{e}\right)^{\sigma}$$

where: e = elevation, in feet, where anemometer readings are taken (20 feet at the San Francisco airport)

σ = the "power law exponent" used to adjust for various terrains = $1/3$ for large cities and hilly terrain; $1/4.5$ for suburban areas, towns and city outskirts.

Since detailed data on single family dwellings' exposure to wind in the nine-county study area are not readily available, two simple adjusted data sets are derived, assuming (a) all winds occur in suburban areas, and (b) one-half of the winds occur in large city types of terrain and one-half occur in suburban areas so overall velocity is an average of the two:

Return Period, in years

		10	25	50	100
	Annual Probability	.1	.04	.02	.01
(a)	Peak Gust Velocity	81	88	89	94
(b)	Peak Gust Velocity	79	86	91	97

23. NATIONAL CLIMATIC CENTER, CLIMATOLOGICAL DATA—SAN FRANCISCO AIRPORT ANNUAL REPORTS (1945–1978).

24. W. MADSEN, WINDSTORMS IN CALIFORNIA, CALIFORNIA DEPT. OF WATER RESOURCES (1979). *See* Table 7, at 29. Data is converted from knots to mph.

25. *Id.*

26. E. SIMIU & J. FILLIBEN, *supra* note 10.

27. Lew & Hart, *supra* note 11, at 984–85.

28. C. CULVER, *supra* note 9, at 3–99.

Assuming, as in Los Angeles County, that $f(v) = \rho v^{\gamma}$, results from running regressions on the log-log form of the two data sets are given below:

$$\text{(13)} \quad \text{(a)} \quad \ln f = \underset{(12.2)}{54.914} - \underset{(-13)}{13.014} \cdot \ln v \qquad DF = 2$$
$$R^2 = .98$$

$$\text{(14)} \quad \text{(b)} \quad \ln f = \underset{(11.9)}{56.371} - \underset{(-12.6)}{13.414} \cdot \ln v \qquad DF = 2$$
$$R^2 = .98$$

The t-statistics reported below the estimated coefficients in equations (13) and (14) indicate significance at the 99 percent level, where the R^2 indicates that 98 percent of the variation in ln f for each data set is explained by the respective regression results. Figure 3 is a plot of the two frequency distributions dependent upon exposure assumptions (a) and (b).

Applying these frequency distributions for velocities in the 60–110 mph range to the damage functions based on Leicester[29] yields the result that the expected value of wind damage avoided due to building codes in place in the San Francisco area amounts to about three-fifths of one percent of SFD value per coded dwelling under assumption (a) and almost three-fourths of one percent under assumption (b). As estimated in Brookshire,[30] the value of SFD's in the nine-county San Francisco region in 1980 is $61.44 billion, 73 percent of which is assumed to incorporate seismic/wind resistant building codes. Therefore, in 1980 the wind resistance benefits in the San Francisco study area produced by seismic/wind resistant building codes in single family dwellings amount to:

(a) $259 million/year, or
(b) $334 million/year.

Results obtained by summing discounted expected wind resistant benefits over various time horizons are shown in Table 2 for different real discount rates. For comparison, the cost in 1980 dollars of these building codes for single family dwellings in the San Francisco area is $0.9–$1.35 billion.

V. CONCLUSIONS AND CAVEATS

A summary of the results obtained from using a direct cost approach for estimating non-market valuations of the expected benefits of wind resistant/seismic building codes applicable to single family dwellings is

29. Leicester, *supra* note 14. *See* Figure 6, at 32.
30. D. BROOKSHIRE, *supra* note 21, at 4.34.

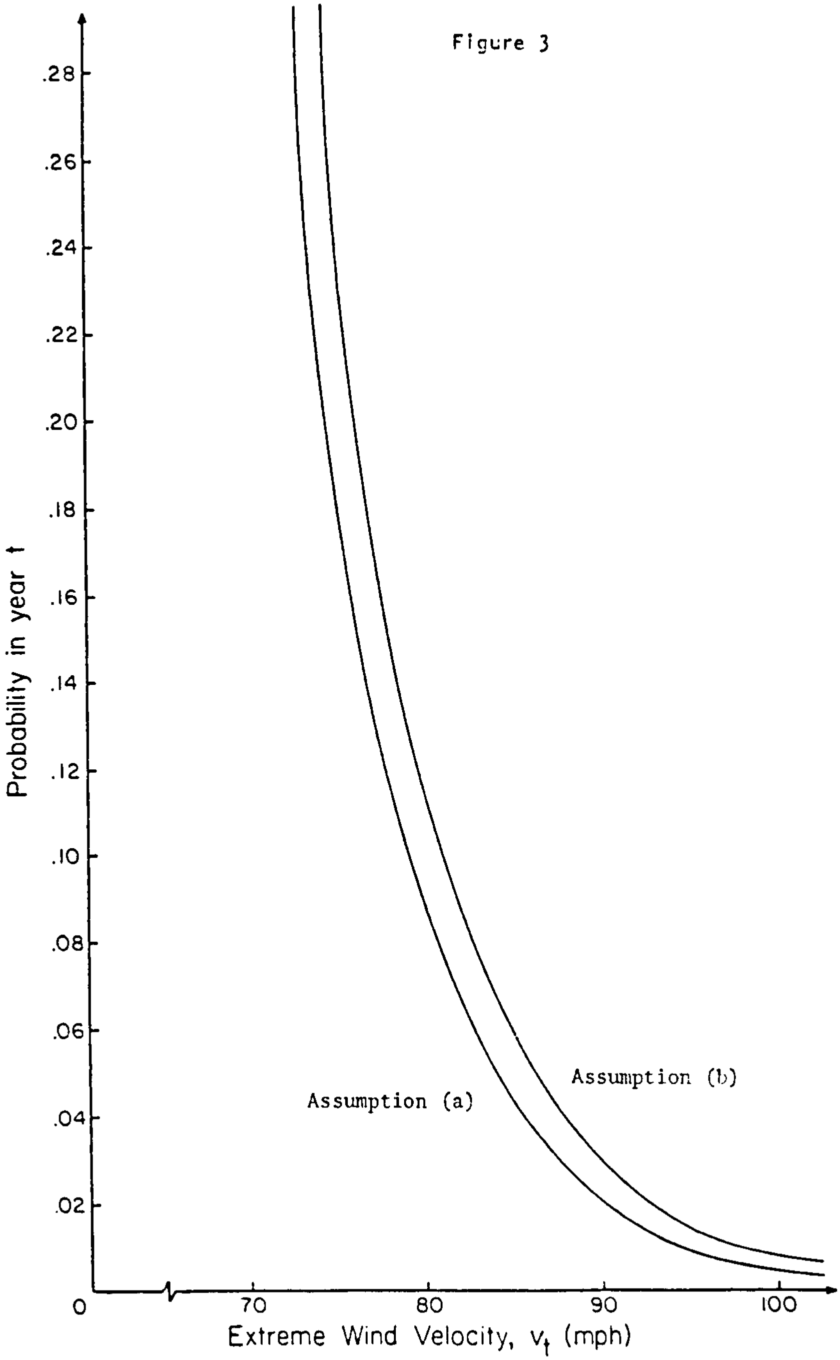


Figure 3
Probability in year t
.28
.26
.24
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
0
70
80
90
100
Extreme Wind Velocity, v_t (mph)
Assumption (a)
Assumption (b)

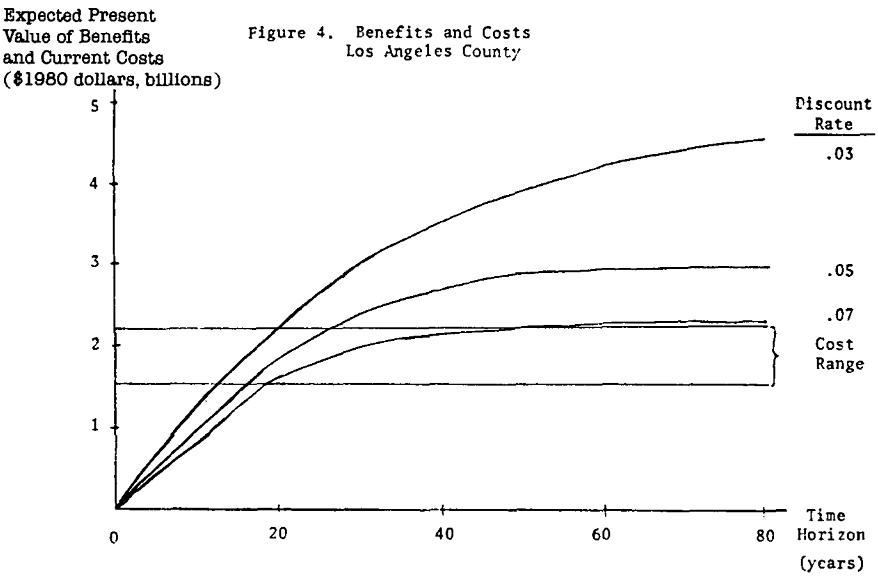
TABLE 2

Expected Present Value of Wind Resistance Benefits Due to Seismic/Wind Resistant Building Codes in the San Francisco Area (in 1980 dollars, billions)

Discount Rate	Time Horizon	20 years	40 years	60 years	80 years	100 years
.02	(a)	4.319	7.225	9.180	10.500	11.382
	(b)	5.576	9.329	11.855	13.555	14.699
.05	(a)	3.388	4.665	5.147	5.328	5.396
	(b)	4.375	6.024	6.646	6.880	6.968
.07	(a)	2.935	3.694	3.889	3.942	3.953
	(b)	3.791	4.770	5.022	5.088	5.105

provided in Figure 4 for Los Angeles County and Figure 5 for the nine-county San Francisco region. Depending upon the real discount rate chosen, benefits exceed the upper bound on costs in Los Angeles County over a period of fewer than twenty years at real discount rates of three percent or less. Even using a seven percent real discount rate, benefits exceed the lower bound on costs in less than 20 years, whereas the upper bound on costs is less than benefits after about 60 years of having the codes in place. In the San Francisco area, it appears that even for high real discount rates, the expected present value of benefits will exceed the

Figure 4. Benefits and Costs Los Angeles County



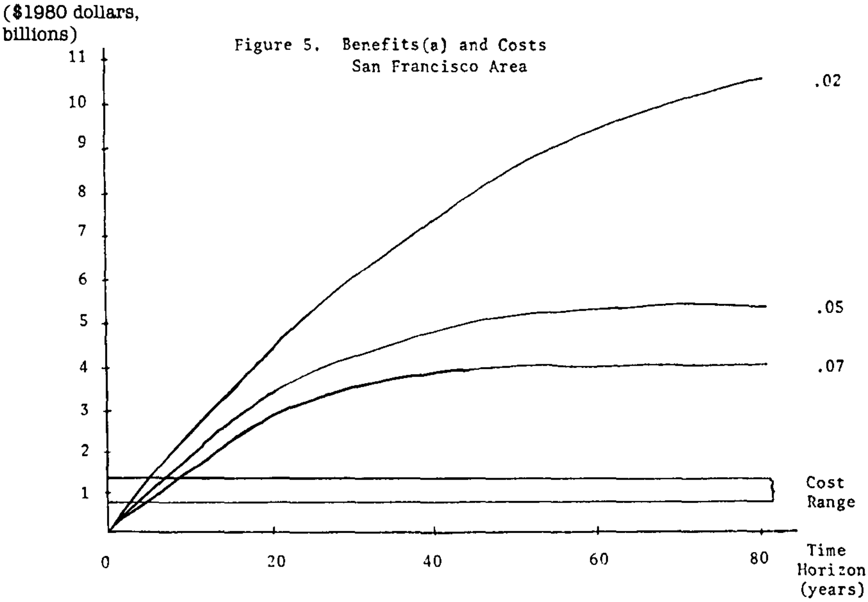


Figure 5. Benefits(a) and Costs San Francisco Area

cost of codes in single family dwellings within a time horizon much shorter than 20 years.

It is important to note that this analysis is not comprehensive since wind resistant benefits and costs due to building codes are estimated only for single family dwellings. The study could be expanded further to include the impacts, both in terms of damages avoided and increased costs of implementing codes, on other buildings within the study areas; i.e., commercial/industrial structures and multi-family dwellings.[31] Furthermore, the direct cost methodology used herein is an underestimation of total benefits since the value of safety to individuals in terms of reduced risk of injury or death in wind-damaged structures is not estimated, nor are esthetic values such as the beneficial impact on work, sleep, and so forth when building codes provide structural stability in high winds. This latter value would be especially prevalent in multi-story buildings subject to sway in high speed winds.

Finally, as stated at the outset, the wind resistant benefits are only one portion of the joint product provided by seismic/wind resistant building codes; i.e., for an appropriate and complete comparative benefit-cost study of such codes, earthquake resistant benefits should be added to the

31. Single family dwellings comprise 57% of the total market value of buildings in Los Angeles County; 63% of the total in the nine-county San Francisco area. *See* D. BROOKSHIRE, *supra* note 21, at 2.33 and 4.34.

wind resistant benefits reported here.[32] Given the fact that the benefits measures derived for wind resistance are only a portion of the total, one can conclude that the non-market value of expected benefits due to implementing building codes which address wind hazards in single family dwellings will exceed the cost within a time horizon of 20 to 60 years at most in Los Angeles County, and less than 20 years in the nine-county San Francisco area. Although this preliminary study provides orders of magnitude estimates of non-market valuations for the level of 1980 building codes in two selected regions, it is illustrative of how the methodology could provide useful information to communities considering public policy changes such as building code revisions aimed at reducing potential damage from natural hazards.

32. An expanded analysis of seismic/wind resistant benefits will be available in a forthcoming study, D. BROOKSHIRE, *supra* note 21, at 2.1–2.57 and 4.1–4.49.