Journal of Coastal Research	9	4	1054-1064	Fort Lauderdale, Florida	Fall 1993

Effect of Wind on Coastal Construction in Florida

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ABSTRACT

YAZDANI, N. and KADNAR, J.O., 1993. Effect of wind on coastal construction in Florida. *Journal of Coastal Research*, 9(4), 1054-1064. Fort Lauderdale (Florida), ISSN 0749-0208.

The State of Florida's tidal shoreline is 8,426 miles long. Both the east and the west coast of Florida are subjected to several coastal storms each year. The present study was undertaken to develop a consistent and rational wind design procedure for habitable structures located seaward of the Coastal Construction Control Line (CCCL). The first objective was to address the apparent inconsistency between the 110-mph design criteria and the 140-mph design criteria specified elsewhere. The rationale behind the two regulations was studied in depth, and it was found that a minimum fastest mile wind of 110 mph for most of Florida's coastline is appropriate to ensure a 100-year mean recurrence interval. This provision is being adopted by the Florida Department of Natural Resources (FDNR). The second objective was to recommend a building code best suited for Florida coastal construction. After a thorough comparison, the ANSI Code was found to be the most consistent, user friendly and rational code for wind design of Florida coastal construction. This code is now being adopted by the FDNR for design and analysis of new and existing structures.

ADDITIONAL INDEX WORDS: *Hurricanes, storm effect, coastal building codes, design wind speed, extreme wind.*

INTRODUCTION

The long Florida tidal shoreline, the high frequency of coastal storms and the rapid population growth with related coastal development generates an increased potential for wind induced damage along Florida's Atlantic and Gulf coasts. In recognition of this fact, Florida statutes require that any construction seaward of the CCCL must be designed taking into account the proper wind pressure on the main wind-force resisting systems (MWFRS) and the components and cladding. The Florida Department of Natural Resources (FDNR) is responsible for permitting construction on the sandy beach shoreline where there is a CCCL.

The present study was undertaken to develop a consistent, rational wind design procedure for habitable structures in Florida, seaward of the CCCL. The first objective was to address the apparent inconsistency between the requirements contained in Chapter 161, Florida Statutes (F.S.), as far as the design wind velocities are concerned. The second objective was to develop a guidance manual for wind design of habitable structures seaward of the CCCL for the FDNR complete with procedures, examples and tables/graphs, based on the best available code for Florida coastal construction.

DESIGN WIND VELOCITY

In 1976, FDNR adopted a minimum design hurricane wind speed of 140 mph for habitable construction seaward of the CCCL, as stipulated in Chapter 16B-33 of the Florida Administrative Code (F.A.C.) 1985. Chapter 161, Florida Statutes (1985), stipulates a fastest-mile wind velocity of 110 mph for wind design in the area defined as the Coastal Building Zone for most of Florida (except South Florida). These two different criteria are causing confusion in the wind design procedure for FDNR permit applications.

There are about one hundred U.S. weather stations, of which only three are in Florida near Jacksonville, Tampa and Key West for which reliable and relatively long (twenty years) wind speed records are available (SIMIU *et al.*, 1982). Some of these stations cover extremely large areas, which do not produce uniform results for the extreme wind climate (COLON, 1953; DURST, 1960; SIMIU *et al.*, 1979). Therefore, a problem exists in estimating extreme wind speeds at locations where long-term records are not available.

A comprehensive literature search revealed that no substantial research has been conducted re-

92004 received 16 January 1992; accepted in revision 15 March 1992.

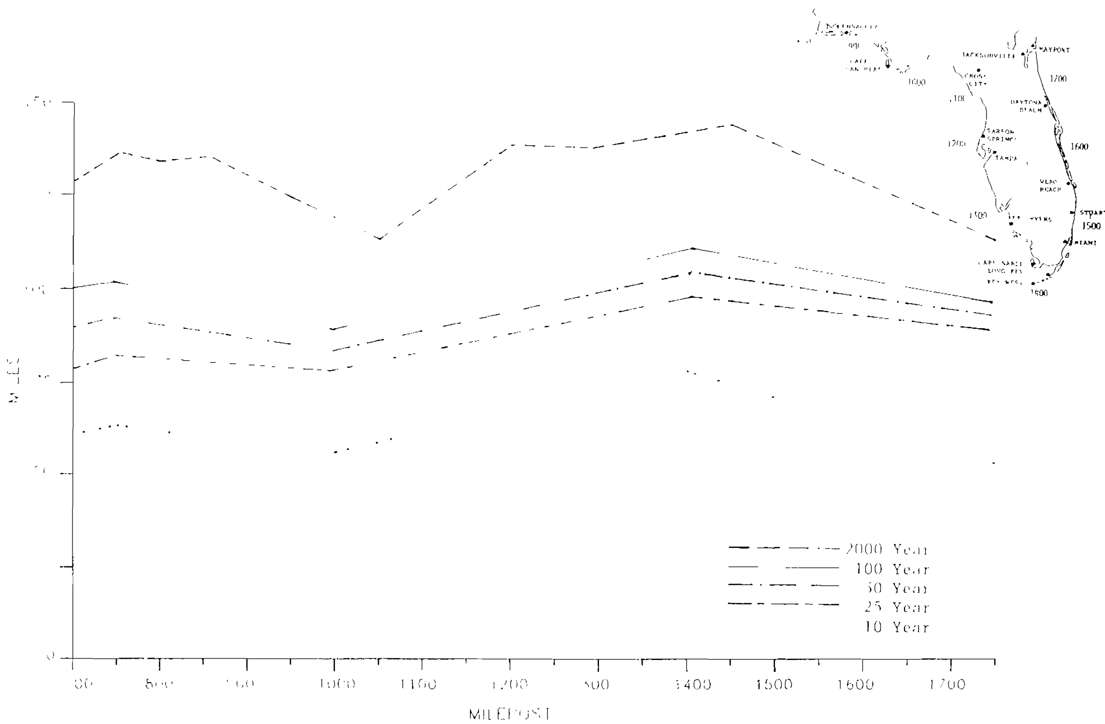


Figure 1. Estimated fastest-mile hurricane wind speeds in open terrain near the Florida coastline for various mean recurrence intervals.

cently in the computation of wind speeds along the Florida coastline. The last most authoritative studies were conducted by SIMIU *et al.* (1978, 1979). Apart from these documents, wind speed contours along the hurricane prone coastline are based on a Monte Carlo simulation of hurricane winds by BATTS *et al.* (1980). These are the only documents that give fair treatment to the highly susceptible Florida coastline. This was substantiated by statements from Dale Perry of the Metal Building Manufacturers Association (MBMA), Professor Minor at the University of Missouri, Rolla, and Professor Scanlan at the Johns Hopkins University.

Incoherent data for hurricanes that crossed the Florida coastline earlier in the century and prior, coupled with the difficulties in obtaining accurate data at or near the coastline, required considerable manipulation to arrive at the 100-year recurrence interval contour map shown in Figure 1, reproduced from references (BATTS, 1980; SIMIU *et al.*, 1978). This figure was constructed based on hurricane fastest mile wind speeds at 33 ft (10 m) above ground over open terrain at the coastline. The results of the calculations were smoothed by taking the average of the fastest mile wind speeds at the milepost considered and the two adjacent mileposts at the coastline. A least squares straight line was then fitted at each milepost for the average obtained. The values differ by a few percent from the original unsmoothed values for the coastal locations.

The smoothed estimates of Figure 1 represent hurricane wind speeds without regard to direction. Similar results were also obtained for winds blowing in specified directions as shown in Figure 2 for certain locations on Florida coastline. The number of strong storms blowing in specified directions is, in certain cases, very small. It was therefore not possible in those cases to estimate wind speeds corresponding to relatively short recurrence intervals. This is reflected by the blank portions on some of the curves in Figure 2.

Figure 1 shows that the 100-year mean recurrence design wind velocity for north and south Florida coastal areas averages approximately 95

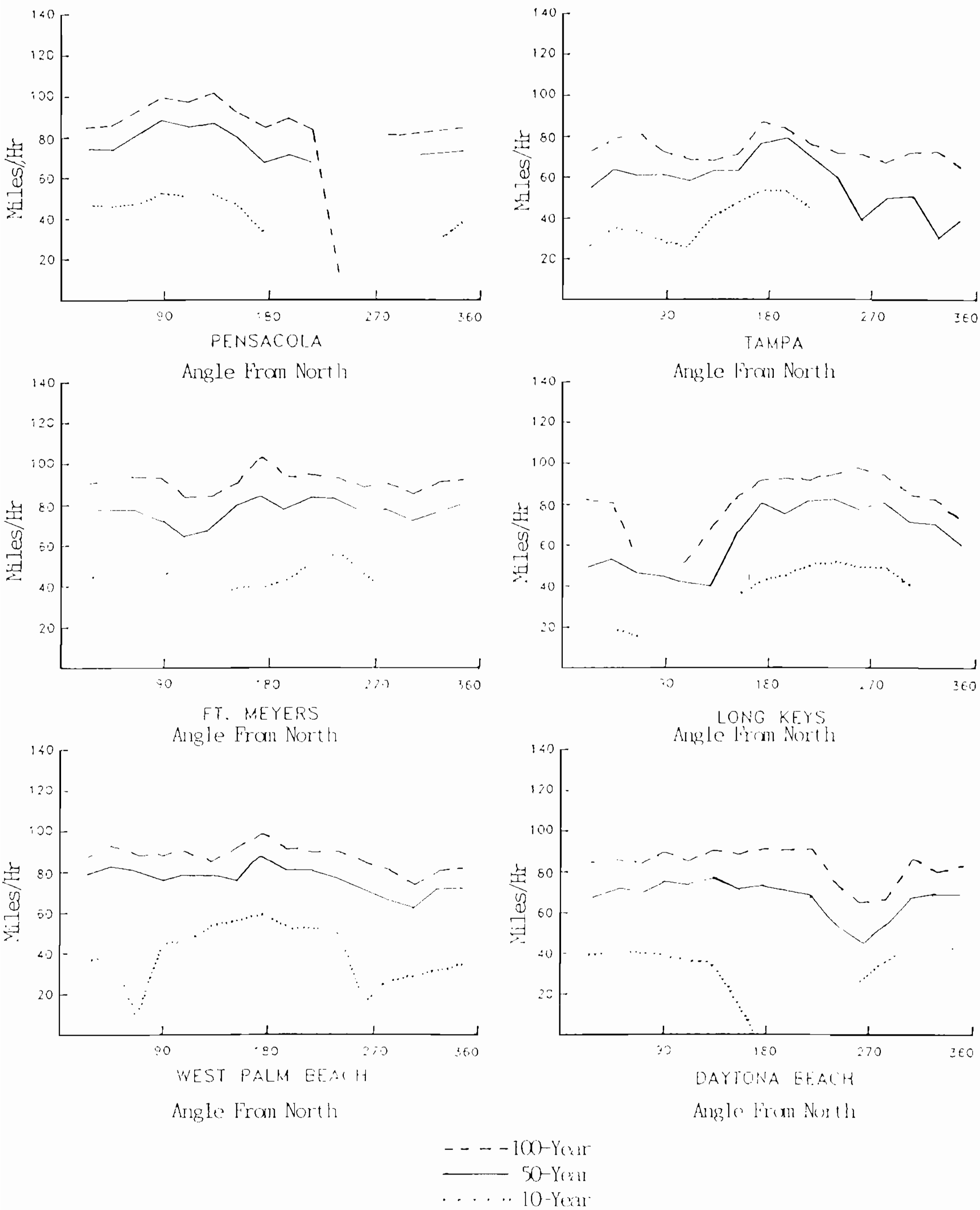


Figure 2. Hurricane wind speeds on Florida coastline blowing from various directions.

mph and 113 mph, respectively. In the process of reducing and simulating the vast data base, errors of the following four categories were introduced: (1) sampling errors, due to (a) the limited size of the data base used in making statistical inferences, and (b) the limited number of hurricanes generated by the Monte Carlo simulation; (2) probabilistic modeling errors, due to the imperfect choices of the distributing functions to which the data were fitted; (3) observation errors, due to the imperfect measurement or recording of the true values of data; and (4) physical modeling errors, due to the imperfect representation of the dependence of wind speed upon the various climatological characteristics. To account for the cumulative effect of these errors inherent in the modeling of such a complex system, code writers have suggested that the simulated wind speeds be increased by a factor of 1.15. With this increment, the 100-year design wind speed is estimated to average about 110 mph and 130 mph for north and south Florida, respectively. The 140-mph stipulation from Chapter 16B-33 F.A.C. appears to be overly conservative, especially for north Florida. The 140 mph stipulation was originally introduced to address the following effects: (a) the difficulty of obtaining representative wind measurement at the coastline because most weather stations are located inland; and (b) the increase in wind speeds due to gusts. The 110-mph stipulation from Chapter 161 F.S. for the Coastal Building Zone closely matches the design wind velocity for north Florida.

Most building code regulations, including ANSI-82 (1982), use a gust response factor which is an incremental factor applied to the basic design wind velocity. Using ANSI-82 as an example, the gust factor to be used in coastal areas is 1.15 for a low-rise building. Applying this value to the 100-year wind velocities, one obtains modified wind velocities of approximately 118 mph and 139 mph for north and south Florida, respectively. It is clear that the use of a 140-mph design wind velocity for coastal structures in Florida coupled with code specified gust response factors will result in overly conservative design, especially in north Florida.

COMPARATIVE STUDY OF WIND DESIGN CODES

Various building codes are used in Florida for determining the wind pressure on coastal habitable structures. Seaward of the CCCL, the more stringent of the FDNR or the local code applies. Landward of the CCCL, local agency standards apply in what is known as the Coastal Building Zone, which extends from a seasonal high water line to a point at least 1,500 ft landward of the CCCL. The state and local agency standards are based on regional or national building codes. The Standard Building Code (SBC) with 1986 revisions is applicable for wind design of habitable structures in this zone (Chapter 161, F.S.). The FDNR criteria are based on the SBC-86 Code with mandatory 140-mph wind speed for every location in Florida.

Most coastal counties in Florida have adopted the Standard Building Code (1986, 1988). Certain counties in south Florida use the South Florida Building Code (SFBC-1984) for the computation of wind loads (PERRY, 1986).

Traditionally, codes in the U.S. have used the following relationship to express wind pressure on buildings:

$$p_z = 0.5\rho V_0^2 K_z G_z C_p \tag{1}$$

in which p_z = pressure induced at height z above mean ground level, psf; ρ = mass density of air; V_0 = basic wind speed; K_z = exposure coefficient to account for variation in velocity with terrain; G_z = gust response factor intended for load amplification due to turbulence; and C_p = external pressure coefficient (or shape factor). In the design of components and cladding, the term C_p is to be reduced by C_{pi} (internal pressure coefficient) in order to include the effect of planned or unplanned openings.

The degree of sophistication involved in evaluating each parameter contained in the above equation separates the wind provisions of various codes. As the basic understanding of wind effect on structures has improved, the tendency has been to introduce refinements, with associated complexities, to wind provisions. Results of the comparative study are presented in Table 1.

ANSI-82 and SBC-88 utilize 50-year recurrence design wind speeds, which amount to 100 mph and 110 mph for north and south Florida, respectively. SBC-85 contains two sections for design wind. Section 1205, which is for all structures, uses the 100-year ANSI recurrence map. Section 1206, which may only be used for low-rise structures (height less than or equal to 60 ft) uses the ANSI-82 provisions for design wind speed. SFBC-84 uses a 140-mph wind within 3,000 ft of the coast.

ANSI-82 wind provisions include an impor-

Table 1. *Comparison of basic code design parameters.*

Factors Considered	ANSI-82	SBC-85 SEC. 1205	SBC-85 SEC. 1206	SBC-88/SBC-86 H ≤ 60′	SBC-88/SBC-86 H > 60′	SFBC
Wind speed	Fastest-mile	Fastest-mile	Fastest-mile	Fastest-mile	Fastest-mile	>120 mph
Mean speed	50-yr. MRI	100 yr. MRI	50-yr. MRI	50-yr. MRI	50-yr. MRI	
Importance factor	Yes	No	No	Yes	Yes	No
Gradient height	33′	30′	30′	33′	33′	30′
Terrain exposure	Yes	No	No	Yes	Yes	Yes
Gust response factor						
Variation with height	Yes	No	No	Yes	Yes	No
Dynamic provisions for flexible structures	Yes	No	No	No	Yes	No
Wind load determination						
Separate provisions for components and cladding	Yes	Yes	Yes	Yes	Yes	Yes
Pressure/force coefficients						
Gross structure	Yes	Yes	Yes	Yes	Yes	Yes
Components and cladding coefficients are a function of tributary area	Yes	No	Yes	Yes	Yes	No
Internal pressure coefficients for components and cladding	Yes	Yes	Yes	Yes	Yes	Yes

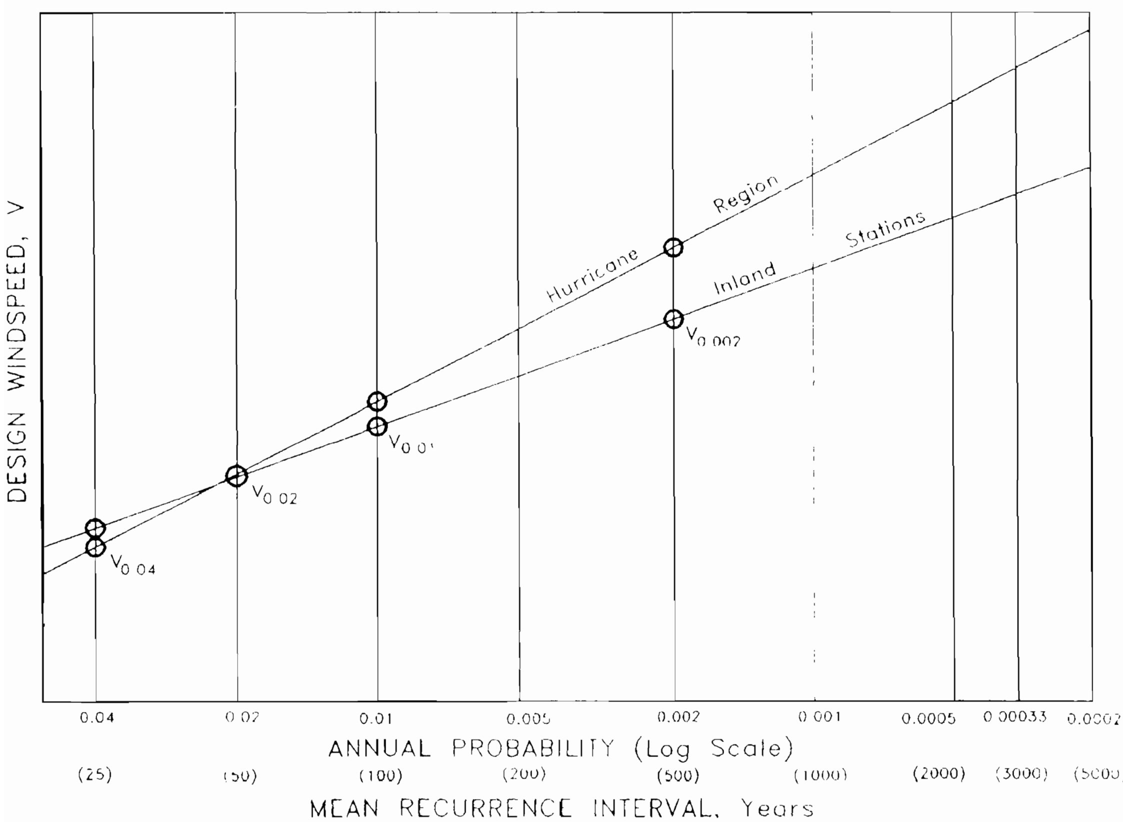


Figure 3. Measured velocities at inland vs. actual velocities on the coast.

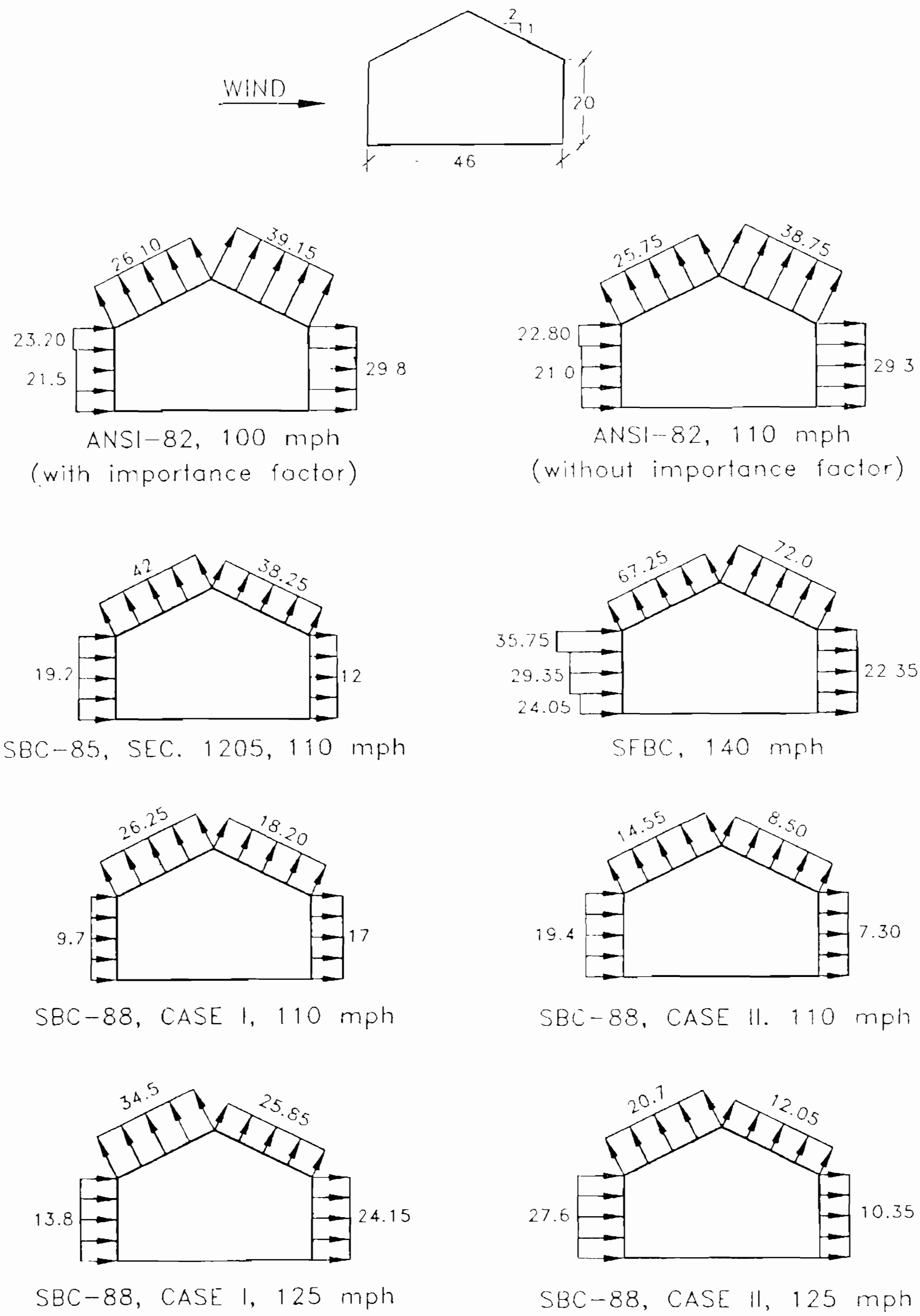


Figure 4. Design wind pressures; example low-rise gable roof building.

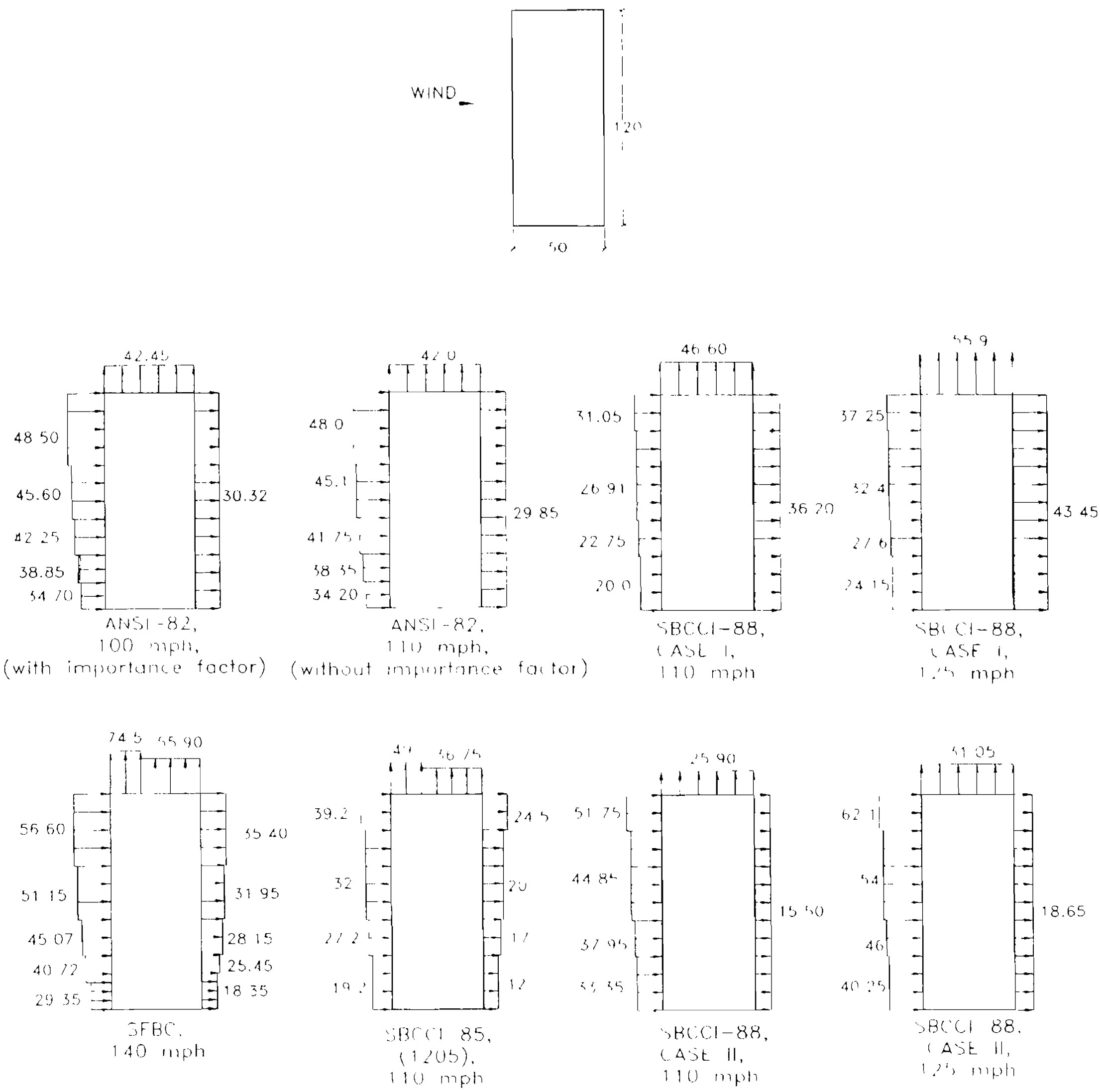
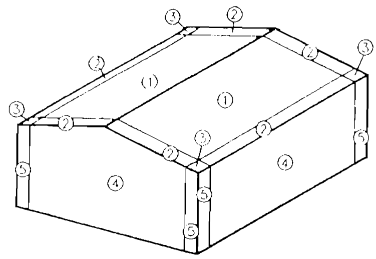


Figure 5. Design wind pressures; example medium-rise building.

tance factor I to adjust the specified 50-year recurrence wind speed to other levels of probability. These factors reflect the difference in probability distributions of hurricane wind speeds and those of inland regions, as shown in Figure 3. An importance factor is not needed in Section 1205, SBC-85, because a 100-year recurrence is used. Section 1206 uses a 50-year recurrence interval, but in spite of this, no importance factor is used. The SBC-88 uses an I factor which is slightly greater than the ANSI-82 values. The SFBC-84 does not use an I factor.

The ANSI-82 code provides for four exposure categories. Exposure D is to be used for coastal structures and is of relevance in this study. The SBC-88 coastal wind provisions are based on Exposure C. The SBC-85 does not differentiate between standard and coastal exposures. The SFBC-84 differentiates between terrain categories by using different wind speeds.

Table 2. *Components and cladding loads (psf) on a low-rise gable roof building from various codes.*



ZONE	ANSI-82 100 mph*	ANSI-82 110 mph**	SFBC-84	SBC-85 SEC. 1205	SBC-88 110 mph	SBC-88 125 mph
			TRIBUTARY AREA OF 5 SQUARE FEET			
1	-40.80	-39.75	-72.00	-42.00	-31.50	-41.40
2	-85.50	-84.30	-72.00	-42.00	-41.20	-53.45
3	-85.50	-39.75	-72.00	-42.00	-31.50	-41.40
4	46.00	44.95	39.35	-21.10	31.50	44.85
			-53.65	-28.80		
5	46.00	44.95	39.35	21.10	31.50	44.85
	-59.20	-58.15	-53.65	-28.80	-36.40	-51.75
			TRIBUTARY AREA OF 100 SQUARE FEET			
1	-35.50	-34.45	-72.00	-42.00	-27.90	-39.65
2	-59.20	-58.00	-72.00	-42.00	-33.95	-48.30
3	-59.20	-58.30	-72.00	-42.00	-33.95	-48.30
4	38.15	37.10	39.35	-21.10	26.70	37.95
	-39.45	-38.40	-53.65	-28.80	-29.10	-41.40
5	38.15	37.10	39.35	21.10	26.70	44.85
	-44.70	-43.65	-53.65	-28.80	-31.55	-51.75

* with Importance Factor
** without Importance Factor

To take care of gust response, ANSI-82 adopted an equation developed by VELLOZZI and COHEN (1968) for MWFRS. For components and cladding, the gust response factors have been merged with pressure coefficients. For buildings less than or equal to 60 ft high, SBC-88 has combined the gust factors with pressure coefficients. For buildings taller than 60 ft, SBC-88 uses similar gust factors as used in ANSI-82.

The pressure coefficients specified in SBC-88 for buildings taller than 60 ft are consistent with those found in ANSI-82 with two exceptions: (a) they include internal pressure coefficients of ± 0.2 for "enclosed buildings"; and (b) the coefficients for components and cladding have been reduced. In the SFBC-84 and the SBC-85 (section 1205), the pressure coefficients are called shape factors.

In recognition of hurricane hazard, the SFBC-84 was developed primarily for use in Dade and Broward counties. A comparison of the equations and factors provided by this code suggests that the design wind speed V can be interpreted as a "gust speed"

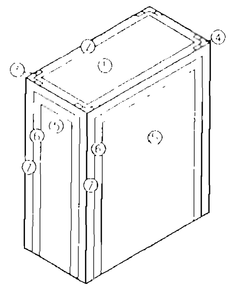
$$V = G^{0.5}V \tag{2}$$

for coastal category C. Thus, based on the ANSI-82 code, the design wind speed would correspond to 107 mph inland, and 125 mph near the coast. This compares favorably with the 110 mph provided by ANSI-82 for a 50-year mean recurrence interval period for Dade, Broward and Monroe counties. Therefore, one could rationalize the higher coastal values for buildings close to the shoreline based upon an assumed ANSI-82 exposure category D and the absence of an importance factor. However, it should be noted that for jurisdictions outside of these counties who adopt the provisions of SFBC-84, the wind loads for most of the Florida coastline will be increased by a factor of

$$(140/100)^2 = 1.96$$

which is in sharp conflict with ANSI-82 provisions. It appears that SFBC is overly conservative for other coastal counties.

Table 3. *Components and cladding loads (psf) on a medium-rise building from various codes.*



ZONE	ANSI-82 100 mph*	ANSI-82 110 mph**	SFBC-84	SBC-85 SEC. 1205	SBC-88 110 mph	SBC-88 125 mph
			TRIBUTARY AREA OF 5 SQUARE FEET			
1	-95.50	-94.00	-111.75	-73.50	-97.85	130.40
2	-116.75	115.25	-111.75	-73.50	-116.50	155.25
3	-180.40	-178.25	-111.75	-73.50	N/A	N/A
4	-222.85	-221.15	-111.75	-73.50	181.75	-243.00
5	65.50	64.00	62.25	43.10	62.10	74.50
			-84.90	-58.80		
6	65.50	64.00	62.25	43.10	N/A	N/A
	-94.60	-92.00	-84.90	-58.80		
7	65.50	64.00	62.25	43.10	62.10	74.50
	-133.40	-132.00	-84.90	-58.80	-98.80	-118 00
			TRIBUTARY AREA OF 100 SQUARE FEET			
1	-53.30	-52.00	-111.75	-73.50	-51.25	-68.30
2	-95.50	-94.25	111.75	-73.50	-97.85	-130.40
3	-95.50	-94.25	-111.75	-73.50	N/A	N/A
4	-95.50	-94.25	111.75	-73.50	97.85	-130.40
5	+ 65.50	64.00	62.25	43.10	56.90	68.30
			-84.90	-58.80	-62.10	-74.50
6	65.50	64.00	62.25	43.10	N/A	N/A
			-84.90	-58.80		
7	65.50	64.00	62.25	43.10	56.90	68.30
			-84.90	-58.80	-98.50	118.00

* with Importance Factor
** without Importance Factor

DESIGN EXAMPLES

Wind provisions from each code discussed herein were applied to two hypothetical buildings which are representative of a high percentage of buildings constructed on the Florida coast seaward of the CCCL. The examples are:

(1) A low-rise building, 48 ft long, 46 ft wide and 20 ft high at the eaves, with a gable roof having a 1:2 slope.
(2) A medium-rise building, 100 ft long, 50 ft wide and 120 ft high without a parapet wall.

Framing considerations were not addressed, except that for determining component and cladding loads, tributary areas of 5 and 100 square feet were assumed for the design of fasteners and structural components, respectively.

The design loads and their variations on the MWFRS for the example buildings, as specified by the various codes, are summarized in Figures 4 and 5. As per SBC-88, Cases I and II are for wind generally perpendicular to the ridge with internal pressure and suction, respectively. It is apparent that no code provides for consistently larger wind pressure values for all parts of an interior frame. Except for the leeward wall on the low-rise building, the SFBC-84 does provide for higher values of wind pressure on other elements. On the medium-rise building, the SFBC-84 consistently predicts higher wind pressures. This is as expected using a wind velocity of 140 mph.

Tables 2 and 3 provide comparisons of the design wind pressures for assumed tributary areas of components and cladding. The building surfaces were zoned with the guidelines of ANSI-82 and SBC-88. The SFBC-84 and the SBC-85 codes

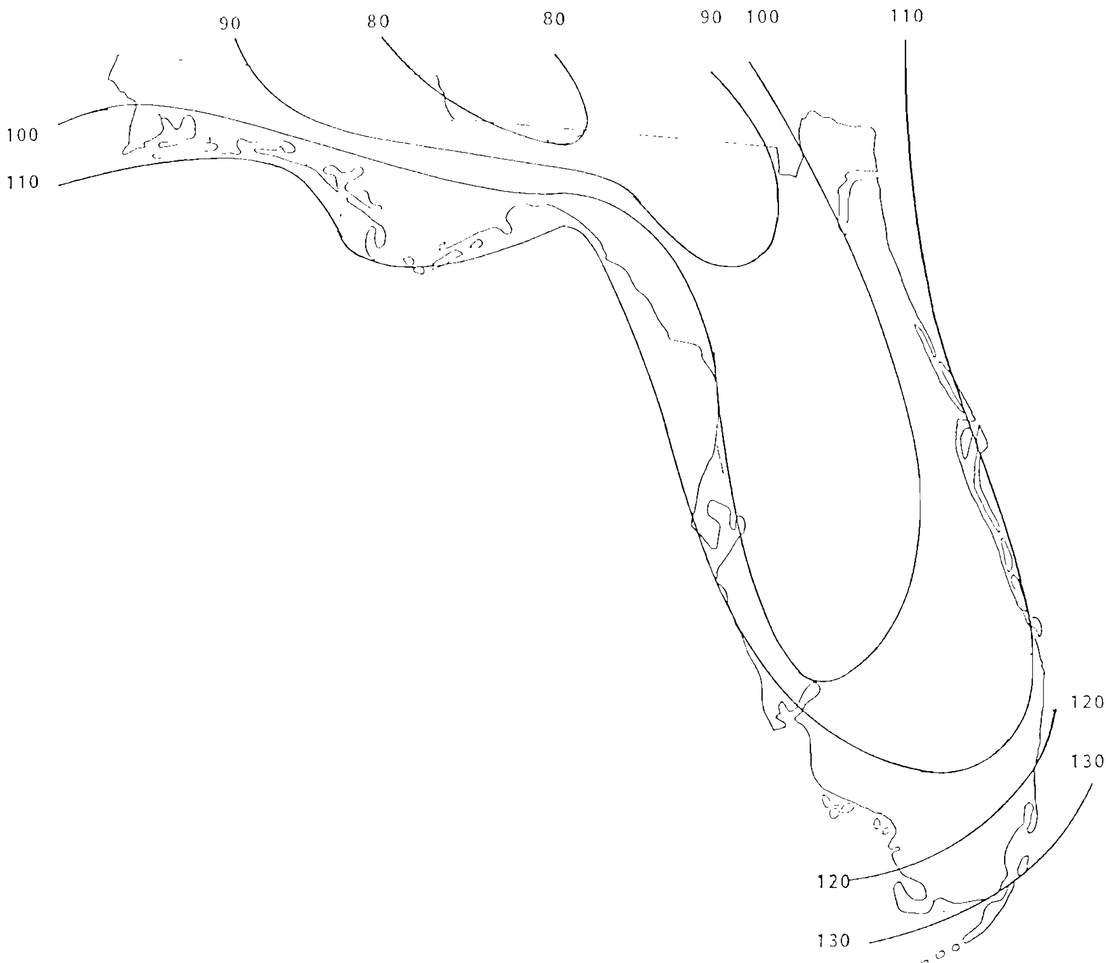


Figure 6. Basic design wind speed; 100-year mean recurrence interval.

do not identify specific zones on a building surface. It is noted that these loads are consistently higher for the ANSI-82 code than the SBC-88 for all zones. With respect to SFBC-84, the ANSI-82 code provides greater pressures on walls and roofs, except for zone 1.

CONCLUSIONS

It is appropriate to adopt a fastest mile wind speed of 110 mph for design of habitable structures seaward of the CCCL all along the Florida coastline, unless a higher design wind velocity is indicated from Figure 6. In that case, the value from Figure 6 should be interpolated and rounded to the next higher 5-mph increment. This will ensure a 100-year mean recurrence interval wind speed for the structures under consideration. The 140-mph design criterion is also impractical because no design methodology is available that would make it possible to use that high a wind speed.

The ANSI-82 code is the most suitable for the wind design of habitable structures seaward of the CCCL in Florida. This code is flexible, it provides for velocity variation along the coastline, it utilizes proper pressure coefficients, and it includes factors which take into consideration gustiness and terrain changes. Pressure coefficients are used for the determination of design loads for components and claddings based on their tributary areas and locations. This code also provides a method for calculating the gust factor for very tall and flexible buildings.

The ANSI-82 provides for comparable, if not greater, design wind loads for Dade, Broward and Monroe counties in south Florida without utilizing the excessive 140-mph wind velocity. It is concluded, therefore, that the ANSI-82 code provisions may be used together with a 100-year mean recurrence interval wind velocity for Florida coastal building design, with the exception that the importance factor I should be omitted from all calculations.

ACKNOWLEDGEMENT

The study presented in this paper was supported by a grant from the Florida Department of Natural Resources.

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