A Model Coastal Zone Building Code for Massachusetts

Residential and small commercial structures must be designed to withstand static flood water level forces, hydrodynamic velocity forces and high winds in coastal areas.

AD HOC COMMITTEE ON COASTAL ZONE BUILDING CODES OF THE BSCES WATERWAY, PORT, COASTAL & OCEAN ENGINEERING TECHNICAL GROUP

In June 1989 the Boston Society of Civil Engineers Section/ASCE (BSCES) Waterway, Port, Coastal and Ocean Engineering (WPCOE) Technical Group executive committee voted to form an ad hoc advisory committee on coastal zone building codes. The purpose of this ad hoc committee was to review the adequacy of the existing provisions of Section 2102.0 of the Massachusetts State Building Code (MSBC) on construction requirements in flood plains and coastal high hazard areas, and to make recommendations for its improvement in the light of recent coastal storm experience and coastal engineering developments. It was determined at an early stage of the committee's work that the development of an independent Model Coastal Zone Building Code for Massachusetts would be informative and could be subjected to general peer review prior to making definitive recommendations for incorporation into the MSBC. The model code was presented in final working draft form at the Coastal Zone Construction Seminar sponsored by the WPCOE Technical Group on April 6, 1991, and is commented on below.

Introduction

Building structures that are located in coastal flood plains and coastal high hazard areas should be designed to resist (or preferably to avoid) the forces imposed by static flood water levels and, in high hazard areas, by hydrodynamic velocity forces. In addition, these structures are typically exposed to unusually high winds that are unimpeded by flat terrain and overwater exposures. Their location along the ever-changing coastline makes them vulnerable to both short and long term erosion related damage. Recent coastal storm experience demonstrates that residential structures in particular are either inadequately designed and constructed, or they are improperly situated to cope with flood water forces and high wind exposures. For example, in the "Blizzard of 1978" over 2,000 residential homes were de-

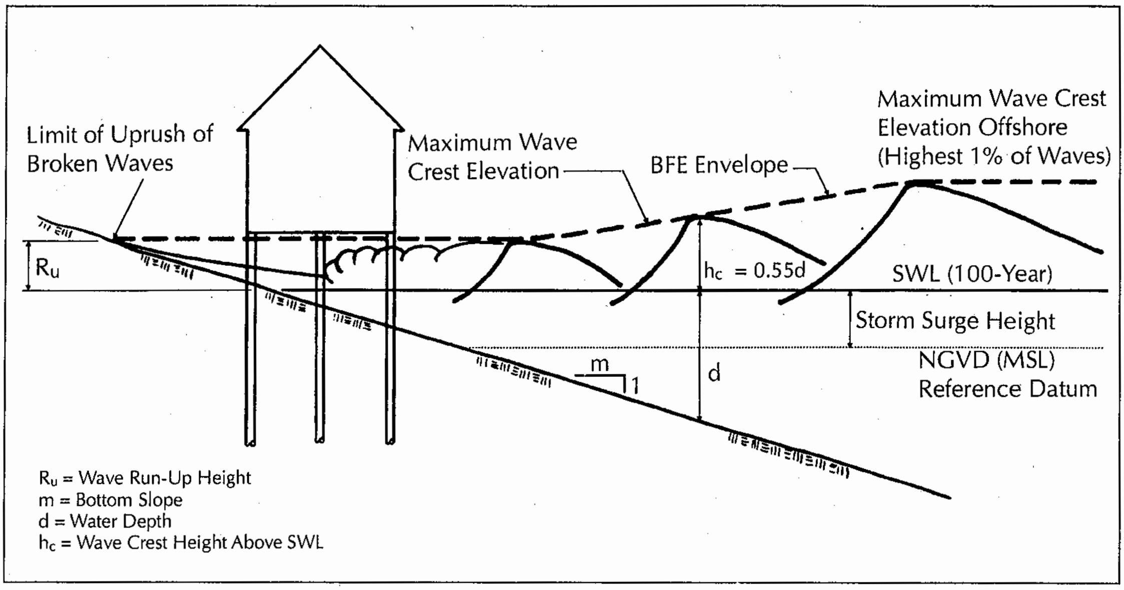

FIGURE 1. Base flood elevation definition sketch (FEMA criteria).

stroyed, over 10,000 damaged and up to 30,000 were otherwise affected by the storm's fury.[1,2] Structural investigations along the South Carolina coast,[3,4] in the wake of Hurricane Hugo in 1989 have demonstrated the same lessons learned from past storm investigations. Damage on the United States mainland from that hurricane was estimated to exceed $7 billion in losses and 15,000 homes were destroyed.

The committee reviewed these and other findings and various other attempts at producing local coastal zone codes[5-10] and adapted applicable requirements to Massachusetts. As of 1988, Massachusetts insured coastal property exposures totaled approximately $180 million. The incremental cost of constructing one- and two-family dwellings in order to meet prescriptive coastal wind requirements is on the order of 1.5 to 4 percent of the cost of normal construction.[11] Construction of an elevated pile foundation designed to meet coastal high hazard area requirements are estimated to result in an increased cost on the order of 10 to 20 percent over that of normal at-grade construction, under most circumstances.

Massachusetts is nearly unique in having two distinctive types of coast: *i.e.,* the coast of New England north of Cape Cod has many rocky headlands and steep cobble beaches typical of Atlantic Boreal regions, while also possessing notable barrier beach systems; south of Cape Cod the coastline generally consists of long sandy beaches typical of the Mid-Atlantic regions. The Massachusetts coast north of Cape Cod is particularly vulnerable to extra-tropical winter storms known as "Northeasters,"[12,13] while the southern Massachusetts coast is more likely to be severely affected by tropical storms known as "Hurricanes."[14,15] Since the meteorological characteristics of such storms may have a profound influence on site specific conditions to be encountered (*e.g.,* the simultaneous occurrence of maximum wind speeds from a given direction and maximum storm surge), flood levels and wave heights should be taken into consideration when siting a structure and determining design criteria. Recent projections of accelerating rates of sea level rise[16] that have not historically been considered by other codes have been incorporated into the model code.

The Federal Emergency Management Agency (FEMA) has produced Flood Insurance Rate Maps (FIRMs) along with Flood Insurance Study Reports for most Massachusetts coastal communities.[17] The FIRMs specify minimum base flood elevations (BFEs) associated with a 100-year return period or an event having a one percent probability of occurrence in any given year. The BFE represents the maximum still water level (SWL) associated with storm surge

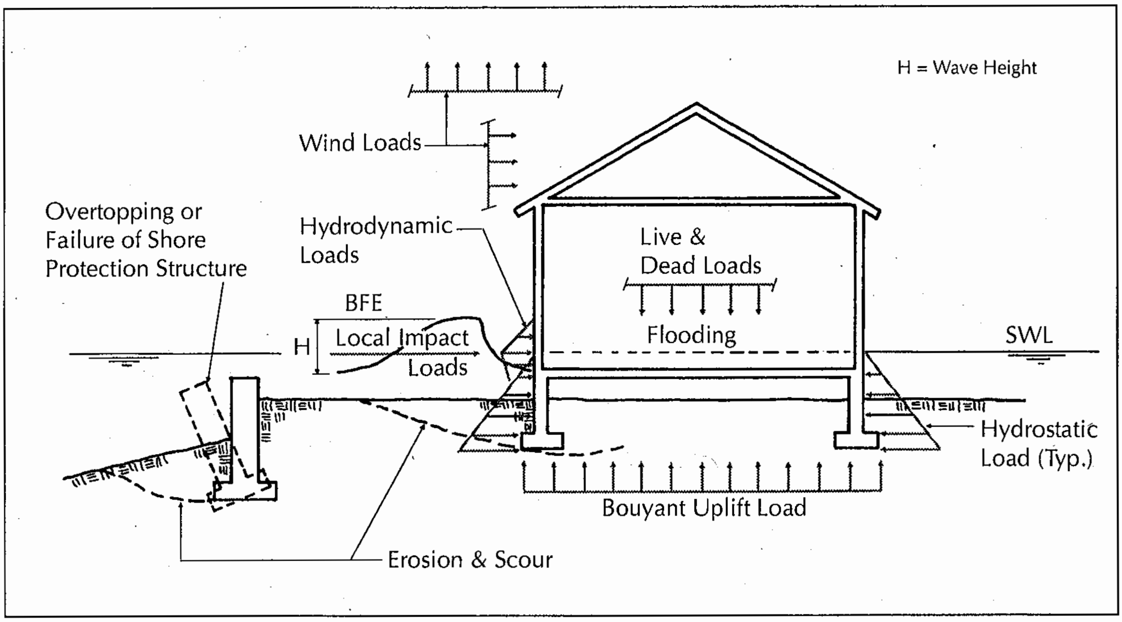

FIGURE 2. Summary of storm related loads acting on a coastal building.

tide elevations for "coastal flood plains" and the maximum wave crest or run-up elevation for "coastal high hazard zones" designated as V-Zones on the FIRMs (see Figure 1). The FIRM BFEs are recognized by the current MSBC, however the model code has attempted to clarify their application with specific FEMA design guidance.[18] Additional FEMA guidelines and general design guidance can be found in a number of sources.[19-28]

Coastal Storm Damage

Figure 2 illustrates the types of forces acting on a building under coastal storm conditions and Table 1 summarizes the typical structural problems in approximate ascending order of severity and descending order of frequency. The primary destructive agent is moving flood waters that result in buoyant uplift, impact and velocity forces (including impact of waterborne debris, "flotsam"), and erosion and scour of foundation materials. The deleterious effects of the latter cannot be overemphasized.

Figure 3 illustrates the damage to a coastal residence due to the infamous Blizzard of 1978. Water velocity forces are best dealt with by designing to avoid them rather than to resist them. The solution is relatively simple in principle: *i.e.,* raise the enclosed building structure above the highest expected flood level including the wave crest height and/or run-up height above the SWL or BFE. Doing so often results in buildings constructed on elevated pile or pier foundations (see Figure 4) that allow flood waters to move essentially unobstructed below the first habitable floor elevation. Below the first floor, "break-away walls" may be provided for aesthetic reasons or to provide partial enclosure for storage or parking areas.

It is essential that adequate depth of foundation piles or pier footings be provided in order to allow for both the effects of long term shoreline erosion and the scour depths that may occur during a major storm event. Both the foundation and overall structure must be adequately anchored and braced to resist lateral and uplift forces due to combined wind and water forces. Appurtenant structures — such as stairs, porches, car ports, *etc.* — are often a source of structural problems since they are often lightly constructed and poorly attached to the main structure. Their failure may cause damage to the main building structure by causing damage or weakness at points of connection and/or by causing impact damage as flotsam.

A few basic design principles for sound coastal zone building construction can be summarized:

TABLE 1
Typical Coastal Zone Building Structural Problems

Severity	Frequency	Type of Damage	Primary Mechanism	Structural Deficiency
Most Severe	Least Frequent	Foundation Failures	Erosion/Scour Buoyancy	Inadequate Foundation Depth/Scour Allowance, Inadequate Uplift Anchorage
↑	↓	Roofing & Cladding Failures	Wind	Inadequate Connections for Local Suction Pressures
		Localized Failures (Especially Appurtenant Structures)	Wave & Current, Impact of Waterborne Debris	Exposure to Wave & Water Impact. Inadequate Construction & Connection of Appurtenant Structures
Least Severe	Most Frequent	Flooding (Water Damage)	Static Water Level Rise	Inadequate Elevation Above Storm Surge & Wave Crest Elevation

- Elevate the lowest floor above the maximum storm surge elevation plus wave crest/run-up elevation and set the structure back from breaker zone as far as possible.
- Provide deep foundation with adequate scour allowance, lateral capacity and uplift resistance.
- Provide adequate bracing in order to transmit lateral loads throughout the structure with particular attention to connection details.
- Provide adequate wind anchors for roofing and cladding in order to resist localized suction pressures.
- Eliminate and/or reduce the number of projections and appurtenant structures. Provide suitable connections where appurtenant structures are unavoidable, use storm shutters on exposed windows, *etc.*

Although the model code applies in general only to habitable residential and commercial building structures, a few comments on the application of shore protection structures — *i.e.*, seawalls, bulkheads, revetments, *etc.* — are warranted. Unfortunately, many such structures are poorly constructed and inadequately designed, and may lead to a false sense of security and/or may actually cause the kinds of problems that they were designed to solve (see Figure 3).

The investigation of structural damage has lead to the following conclusions:

- Buildings should not be founded directly on seawalls or revetments.
- Seawalls, bulkheads and revetments, *etc.*, should not be counted on to protect buildings unless they are properly engineered and constructed by specialists.
- Improperly designed or constructed shore protection may pose a hazard to buildings. For example, ballistic stones due to under-designed mound structures, walls that accelerate erosion or reflect wave energy, *etc.*

FIGURE 3. Wave impact damage to timber frame structure at Gray's Beach, Manchester, Massachusetts, due to the "Blizzard of 1978." Note the total destruction of the concrete seawall.

Commentary on the Proposed Model Code

The model code consists of seven sections (see Table 2 for a listing of the code's contents), the composition and intent of which are briefly described as follows:

Section 1 provides the general background, scope and purpose of code, as well as definitions of key words and acronyms. It also defines designated areas and projects as well as compliance with other regulations and standards. Since the model code is essentially a "performance" type code, Section 1 lists references that provide specific design guidance and that are considered an integral part of the code.

Section 2 describes siting requirements. Although the code is not intended to perform a regulatory function, it recognizes certain geographic and topographic regions

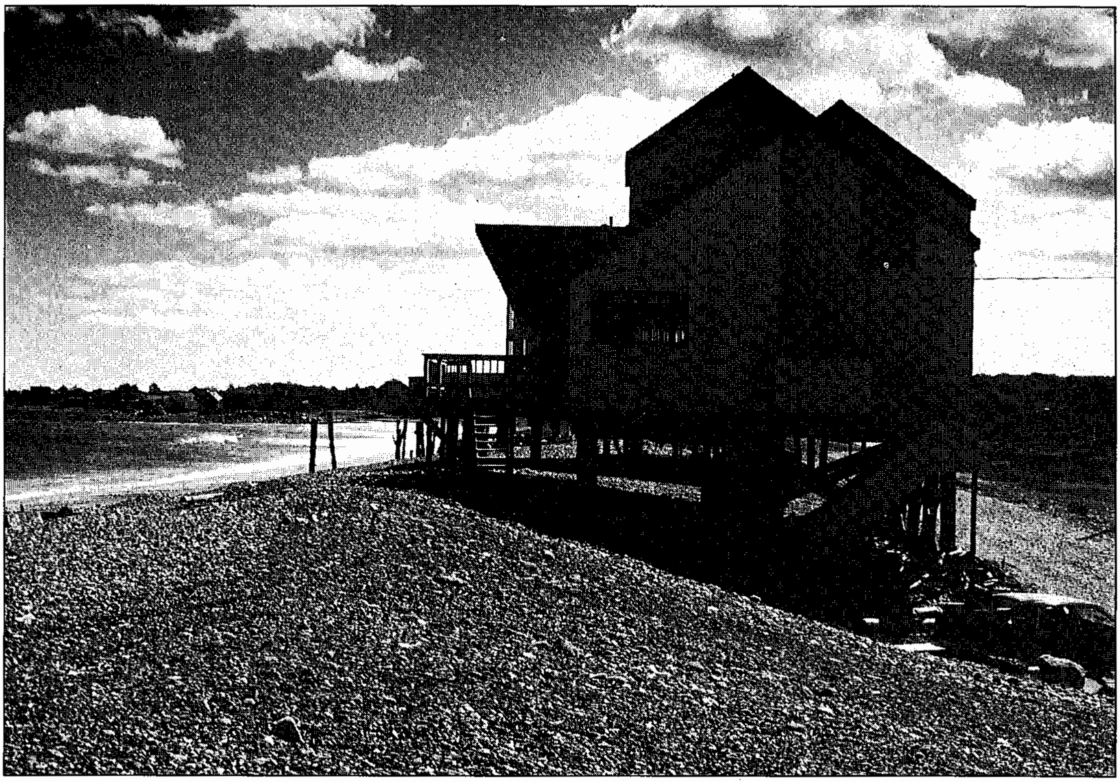

FIGURE 4. House on an elevated pile foundation at Mann Hill Beach, Scituate, Massachusetts. A previous home on this site was destroyed by the "Blizzard of 1978."

where local geologic conditions — *i.e.*, long term shoreline change, short term erosion potential and/or unsuitable foundation materials — would render any construction vulnerable to significant damage or destruction over its life regardless of the stringency of structural design requirements. Such areas, therefore, are prohibited for new building construction on the basis of technical design considerations. The application of shore protection structures in relation to building construction is also described. The model code further recognizes a distinction between coastal "flood plains" that are exposed primarily to static flood water levels (FEMA designated A-Zones) versus coastal "high hazard areas" that are additionally exposed to wave action and higher velocity flood waters (FEMA designated V-Zones).

Section 3 outlines criteria and provides general design guidance for the evaluation of structural loadings. This section recognizes the site specific nature of storm loadings with particular regard to the probability of simultaneous occurrence of maximum water levels, with winds and waves from a given direction, and to the meteorology of storm conditions. Figure 5 is reproduced from the model code and defines three major storm zones. The design windspeeds shown represent the 100-year "fastest mile" hurricane windspeeds from any direction after Batts, *et al.*, for coastal exposure.[29] Structures should be designed to resist the forces associated with the given windspeed from any direction in the given zone. The zones are dictated by the nature of storm driven waves and flood levels that are most likely to occur. Zone I is primarily subject to the highest storm tide elevations and protracted wave action caused by Northeasters, whereas Zone III is primarily affected by Hurricanes and Zone II is vulnerable to both types of storm. Section 3 also requires that the recently predicted accelerated rate of sea level rise[16] due to global warming should also be

TABLE 2
Model Coastal Zone Building Code for Massachusetts

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considered in evaluating the maximum SWL to be applied to the structure's final design. This section further prescribes certain minimum loadings, such as for impact and velocity forces on cross bracing, where the selection of appropriate design criteria is otherwise vague. The U.S. Army Corps of Engineers' *Shore Protection Manual* is cited in this section for the evaluation of hydrodynamic loads[30] and ASCE 7-88 for the evalu-

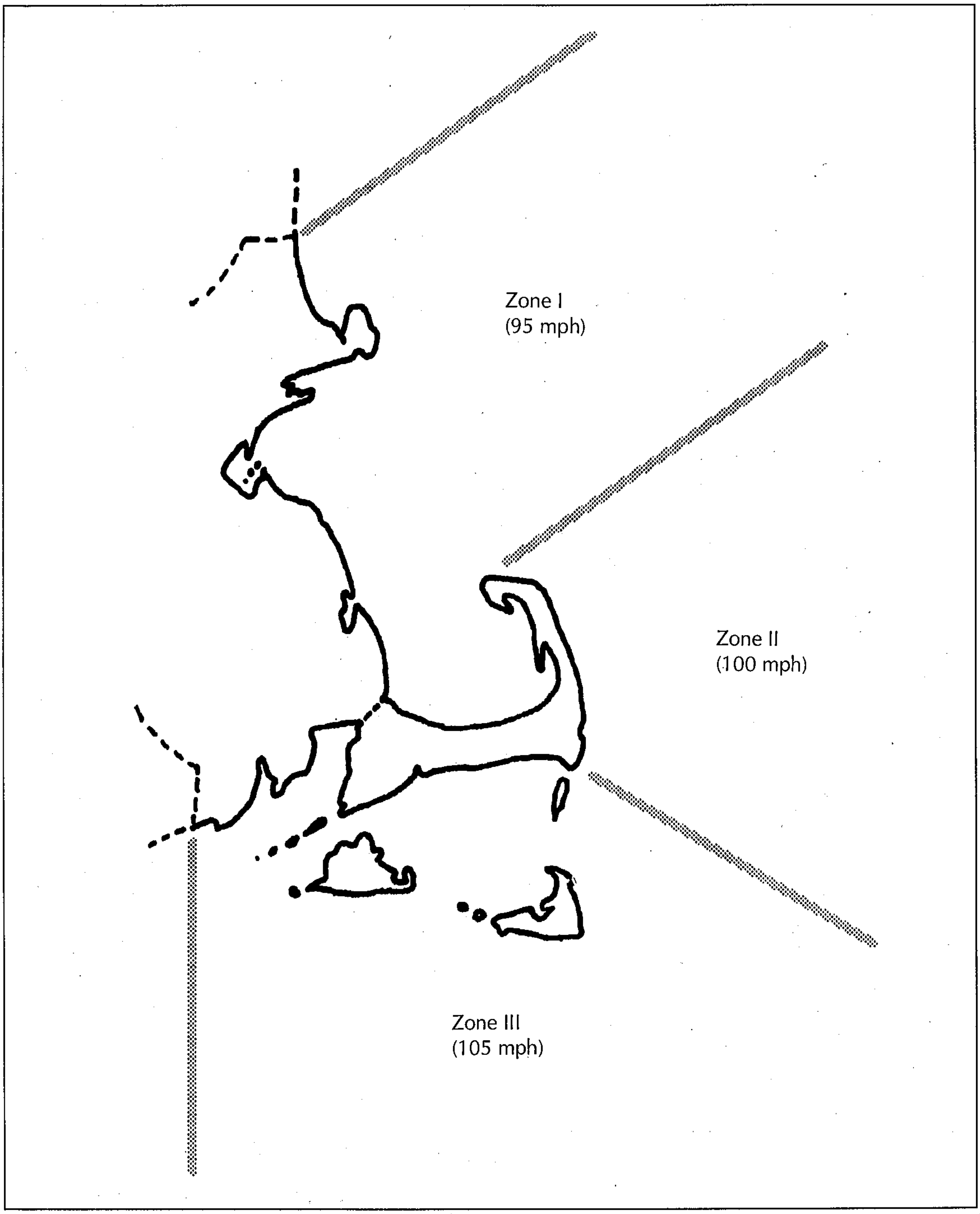

FIGURE 5. Coastal Massachusetts storm hazard zones (basic design windspeeds are shown in parentheses).

ation of wind, seismic and all other structural loadings.[31]

Section 4 provides specific structural design requirements in an essentially "performance" type format. Certain minimum dimension "prescriptive" requirements are cited, primarily for single family and duplex residential construction where detailed engineering investigations would be too costly.[18] The requirements of this section emphasize proper connection strength and details, lateral bracing systems and uplift anchorage. Allowable stresses under given load combinations are addressed. Recommended design load criteria for break-away walls are promulgated in order to assure that such walls do not impose excessive loads on the main building structure prior to their failure. The FEMA *Coastal Construction Manual* is cited in the section for further structural design guidance.[18]

Section 5 provides specific foundation design requirements again in an essentially performance type format. This section, however, is prescriptive in prohibiting the use of slab on grade and shallow wall type footings in coastal high hazard areas. The use of fill for structural support is not allowed and minimum dimensions are prescribed for piles and piers in coastal high hazard areas. Minimum pile embedments and scour allowances are also considered.

Section 6 provides additional design requirements for the location and security of utility systems and for mobile homes.

Section 7 requires certification of compliance with the general code requirements including as built records of floor elevations, pile penetrations or footing depths, and receipt of design plans and specifications stamped by a qualified engineer or architect.

Conclusion & Implementation

There is a need for a coastal zone building code for Massachusetts and the purpose of the proposed model code should fulfill that need. The final model code can either be attached as an appendix to the MSBC or its salient features could be rewritten into the existing MSBC format of Section 2102.0. Another option would be for the model code to serve as an attachment to Article 34 of the MSBC for One and Two Family Dwellings. In the case of one and two family dwellings, the model code could be rewritten in a more "prescriptive" format in order to reduce engineering design costs, review time and effort by building officials while assuring substantial compliance with the performance requirements of the model code. Whatever the final disposition of the model code, the working draft and this discussion of its development should contribute to a better understanding of the peculiar design requirements of buildings that are situated along the coast and that are subject to coastal flood hazard.

NOTE — *A working draft of the proposed model code was presented at a BSCES/WPCOE Group Coastal Zone Construction Seminar on April 6, 1991, and a copy is available for review at the BSCES offices at the Engineering Center, 1 Walnut St., Boston, MA 02108. Review and comment on the code is welcomed and any comments that are received will be considered when the model code is finalized.*

ACKNOWLEDGMENTS — *The Ad Hoc Committee on Coastal Zone Building Codes of the BSCES Waterway, Port, Coastal and Ocean Engineering Technical Group executive committee consists of seven members who together represent over 100 years of experience in waterfront and coastal construction. The members are listed with technical expertise from several key disciplines noted: Richard Baker, Physical Oceanography, Metcalf & Eddy, Inc.; John Bannon, Structural Engineering, Childs Engineering Corp.; Louis Nucci, Geotechnical Engineering, Nucci Vine Associates; David Porter, Structural Engineering, Childs Engineering Corp.; Lester B. Smith, Jr., Coastal Geology, Daylor Consulting Group, Inc.; Peter J. Williams, Coastal Engineering, Gale Associates, Inc.; John W. Gaythwaite, Chairman, Structural Engineering, Maritime Engineering Consultants.*

REFERENCES

1. Gadoury, R., "Coastal Flood of February 7, 1978, in Maine, Massachusetts & New Hampshire," U.S. Dept. of Int., U.S.G.S., WRI 79-61, 1979.

2. Fair, T., & Feit, D., "The Blizzard of '78," *Mariners Weather Log*, N.O.A.A., EDS, Vol. 22, No. 4, July 1978.

3. Wang, H., "Water & Erosion Damage to Coastal Structures — South Carolina Coast, Hurricane Hugo, 1989," *Journal of the American Shore & Beach Preservation Association*, Vol. 58, No. 4, October 1990.

4. Rogers, S.M., & Sparks, P.R., "Damage to Buildings (Hurricane Hugo)," *Journal of the American Shore & Beach Preservation Association*, Vol. 58, No. 4, October, 1990.

5. Clarke, R.R., "Structural Design Aspects of a Coastal Building Code," *Proc. of 18th Coastal Eng. Conf., ASCE,* Cape Town, South Africa, November 1982.

6. Collier, C.A., "Guidelines for Beachfront Construction in Florida," *Ocean Engineering,* Vol. 5, pp. 309–320, Pergamon Press Ltd., 1978.

7. Conner, H. Wietial, "Roof Connection in Houses: Key to Wind Resistance," *Proc. ASCE,* Vol. 5, pp. 309–320, Pergamon Press Ltd., 1978.

8. Kareem, A., "Structural Performance and Wind Speed Damage Correlation Hurricane Alicia," *Proc. ASCE,* Vol. 111, No. 12, December 1985, (ST) (incl. Discussions; Vol. 113, No. 11, November 1987).

9. Machemehl, J.F., "Model Building Code for Coastal Hazard Areas," *Proc. ASCE,* Coastal Zone 1978, Specialty Conf. 1978.

10. Okaloosa County Board of County Commissioners, "Ordinance No. 86-05 An Ordinance Providing Minimum Standards for the Design and Construction of Buildings and Structures in the Coastal Building Zone and on Coastal Barrier Islands," Okaloosa County, Florida, April 1986.

11. All-Industry Research Advisory Council, "Surviving the Storm: Building Codes, Compliance and the Mitigation of Hurricane Damage," Oak Brook, Illinois, December 1989.

12. Peterson, K.R., & Goodyear, H.V., "Criteria for a Standard Project Northeaster for New England North of Cape Cod," U.S. Weather Bureau, N.H.R.P. #68, Washington, D.C., 1964.

13. Stone & Webster Engineering Co., "Development & Verification of a Synthetic Northeaster Model for Coastal Flood Analysis," prepared for U.S. Dept., H.U.D., Boston, Massachusetts, 1978.

14. Graham, H.E., & Nunn, D.E., "Meteorological Considerations Pertinent to Standard Project Hurricanes, Atlantic & Gulf Coasts of the U.S.," U.S. Dept. of Comm., NHRP #33, Washington, D.C. 1959.

15. Gilman, C.S., & Meyers, V.A., "Hurricane Winds for Design Along the New England Coast," *Proc. ASCE,* WW-2, Vol. 87, May 1961.

16. National Academy of Science, *Responding to Changes in Sea Level-Engineering Implications,* National Research Council, National Academic Press, Washington, D.C., 1987.

17. FEMA, *National Flood Insurance Program and Related Regulations,* October 1988.

18. FEMA, *Coastal Construction Manual,* FEMA-55, February 1986.

19. FEMA, *Elevated Residential Structures,* FEMA-54, March 1984.

20. FEMA, *Design Guidelines for Flood Damage Reduction,* FEMA-15, December 1981.

21. FEMA, *Flood Emergency and Residential Repair Handbook,* FIA-13, March 1986.

22. FEMA, *Design Manual for Retrofitting Flood-Prone Residential Structures,* FEMA 114, September 1986.

23. FEMA, *Floodproofing Non-Residential Structures,* FEMA-102, May 1986.

24. FEMA, *Questions and Answers on the National Flood Insurance Program,* FIA-2, August 1987.

25. FEMA, *User's Manual for Wave Height Analysis,* June 1980.

26. U.S. Army Corps of Engineers, *Flood Proofing Regulations,* U.S. Army Office of the Chief of Engineers, Washington, D.C., 1972.

27. U.S. Army Corps of Engineers, *Design & Construction Practices for Coastal Buildings,* Coastal Engineering Research Center, CETN-III-20, November 1983.

28. Pilkey, O.H., *et al., Coastal Design: A Guide for Builders, Planners & Home Owners,* Van Nostrand Rienhold, N.Y., 1983.

29. Batts, M.E., *et al.,* "Hurricane Windspeeds in the United States," U.S. Dept. of Commerce, NBS Building Science Series No. 124, Washington, D.C., May 1980.

30. U.S. Army Corps of Engineers, *Shore Protection Manual, Volumes I and II,* Coastal Engineering Research Center, Vicksburg, Mississippi, 1984.

31. American Society of Civil Engineers, *Minimum Design Loads for Buildings and Other Structures,* (Formerly ANSI A-58.1), ASCE, 7-88, New York, July 1990.