STRUCTURAL DESIGN ASPECTS OF A COASTAL BUILDING CODE

by
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1 INTRODUCTION

Since 1957, the State of Florida, U.S.A., has witnessed the evolution of coastal regulatory concepts based upon coastal engineering design guidance. In 1978, the Florida Legislature encouraged counties and municipalities to adopt coastal construction zoning and building codes to supplement the existing minimum codes which include the Standard Building Code, the National Building Code and the South Florida Building Code. Subsequently, coastal building code guidelines were developed to provide statewide uniformity in the adoption of supplemental codes by coastal counties and municipalities.

It is the intent of this paper to present the structural design aspects required in a coastal building code using the code guidelines developed for and specifically applicable to Florida's coastal communities. These same design aspects and code guidance are applicable to most other state's or nation's developable sand shorelines which are subjected to coastal storm damage.

The purpose of a coastal building code in Florida communities is to supplement the existing minimum code by providing the structural design standards for construction within that portion of the beach and dune system which is subject to substantial scour, erosion, flooding, and loads accompanying the impact of a major hurricane. A coastal building code includes structural design standards for the construction of residential structures, enclosed commercial structures, coastal and shore protection structures, and other substantial structures of a semi-permanent nature. Although the few minimum codes currently in effect in the coastal communities are comprehensive for conventional construction, they do not adequately address the special structural design considerations identified for the Florida coast. Along a developable coast, special design considerations are necessary for the preservation of the beach and dune systems, as well as, for the structural adequacy of the construction.

The major concepts of coastal engineering design which are necessary in a coastal building code include:

1. Zone identification (horizontal and vertical).
2. Foundation design for erosion and scour.
3. Storm loading (including wind, waves, hydrostatic, and hydrodynamic loads).

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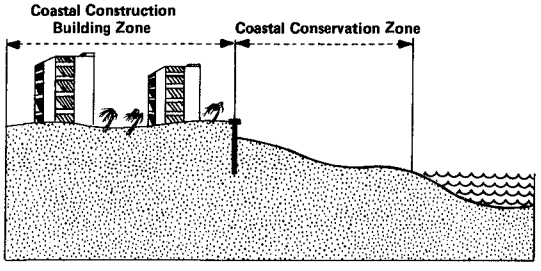
2 ZONES

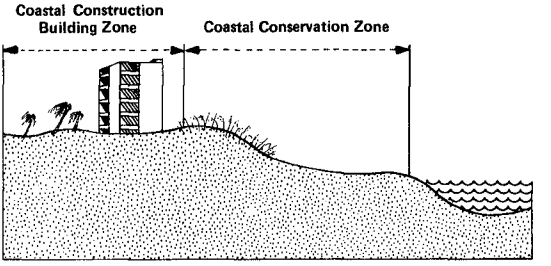
A coastal building code should identify the zone within which major construction should be designed for the physical environmental conditions accompanying a major storm event. The standard adopted by law in Florida is the zone of impact of a 100-year storm surge or of a number of lesser storms which cumulatively have an equivalent probability of occurrence. For coastal areas which are predicted to be flooded by the storm surge of a 100-year storm, a zone of impact is identified by the possible existence of breaking waves which are significantly large to cause structural damage. For coastal areas not overtopped by a predictable 100-year storm surge, the impact zone is identified by the wave runup and the erosion limits of that storm or of storms having impact with an equivalent cumulative probability.

Seaward of a coastal construction building zone, a coastal conservation zone should be identified within which no major habitable structures should be erected. The inland limits of this coastal conservation zone would coincide with the seaward limits of the coastal construction building zone and would identify the seaward-most dune and beach area in need of preservation from the impact associated with the construction of major habitable structures. Identification of the line of demarcation between a coastal construction building zone and a coastal conservation zone would have to result from a consideration of the existence and degree of existing development, as well as the predictable beach and dune response to high frequency (less than 20-year) storm events.

For developed coastal areas within which there exists a reasonably continuous line of rigid coastal protection structures, regardless of the design adequacy of these coastal protection structures, such a line should define the seaward limits of the coastal construction building zone. (See the following illustration.)



For developed and undeveloped coastal areas where there does not exist a line of rigid coastal protection structures, the dune system itself should be identified as a flexible coastal protection structure. Although guidance and rationale would vary in different locales, it is suggested that the inland limits of the coastal conservation zone be defined by the dune erosion limits of a 20-year storm event or the dune erosion which would be expected resulting from storms with an equivalent cumulative probability. (See the following illustration.)



Although horizontal zonation, that is identification of the coastal construction building zone and coastal conservation zone, is of primary importance, vertical zonation should be included by identifying the elevation above which major habitable structures should be constructed. The standard adopted by the State of Florida is the requirement to elevate the habitable structure such that the structural soffit or the underside of the lowest supporting structural member, excluding the foundation piles, is above the design breaking wave crests or wave uprush as superimposed on the storm surge of a 100-year storm.

3 FOUNDATION DESIGN

Foundation design within the coastal construction building zone should consider the topographic changes which may be expected over the design life of the structure. Foundation design should consider the erosion, scour, and loads accompanying a 100-year storm event.

Soil bearing foundations are discouraged within the coastal construction building zone and should be prohibited above the design grade. The elevation of the soil surface to be used in the calculation of bearing capacities should not be higher than that which would result from the erosion of a design storm. Calculation of the design grade should account for localized scour due to the presence of structural components. The maximum elevation of a soil bearing foundation should be set below the design grade resulting from the erosion (including scour) of a 100-year storm event. Erosion computations for foundation design should account for all vertical and lateral erosion and scour producing forces.

All habitable structures within the coastal construction building zone are recommended to be elevated on and securely anchored to an adequate pile

foundation. The structure should be anchored in such a manner as to prevent flotation, collapse or lateral displacement. A pile foundation should be designed to withstand all anticipated loads resulting from a 100-year storm event including wave, hydrostatic, hydrodynamic, and wind loads acting simultaneously with live and dead loads.

Design ratio of pile spacing to pile diameter is not recommended to be less than 8:1 for individual piles; however, this would not apply to pile clusters located below the design grade. Pile caps should be set below the design grade (which includes localized scour), while the piles should be driven to a penetration which achieves adequate bearing capacity taking into consideration the anticipated loss of soil above the design grade.

In addition to normal foundation analysis, pile foundation analysis should consider piles in column action from the bottom of the supported structure to the design grade. Consideration should also be given to the degree of exposure to wave attack and the resulting impact loads on lateral or diagonal bracing between piles. Lateral bracing should be designed to minimize resistance to flow and to the entrapment of floating debris.

Within the coastal construction building zone, substantial walls and partitions constructed below the level of the first finished floor should be prohibited. It is recommended that such a prohibition exempt stairways, utilities, shearwalls perpendicular to breaking waves, wind/sand screens, light open wood lattice partitions, elevator shafts, and breakaway or frangible walls designed to collapse under wave forces. Any construction within the vertical zone of design storm wave impact should be designed in such a manner so as to minimize the release of destructive hydrodynamic missiles.

4 STORM LOADS

A coastal building code should require that all habitable major structures be designed for the loads accompanying a 100-year storm event, including wind, wave, hydrostatic, and hydrodynamic loads. Within the coastal construction building zone and the coastal conservation zone, minor structures need not meet specific structural requirements for wind and wave forces, but they should be designed to minimize the potential for generating aerodynamically or hydrodynamically propelled missiles. Minor structures should also be designed to produce a minimum adverse impact on the beach or dune system.

The wind load requirements of a coastal building code need to be established considering historical records of storm generated wind velocities over water in the specific region. The problem with the wind requirements of the existing minimum codes in Florida was the inland location of the data from which the wind requirements were derived. Following recommendations of the National Hurricane Center, the University of Florida, and the Florida Department of Natural Resources, the State of Florida increased the required wind velocity for load computations to a minimum of 140 mph (225 kilometers per hour) at a height of 30 feet (9 meters) above the ground. The designer of a habitable major structure

should be aware, however, that localized wind forces under design hurricane conditions may exceed this minimum wind load requirement.

The coastal building code should be flexible to invite a detailed analysis of structures whose dynamic properties allow for wind sensitivity. In designing for hurricane generated winds, consideration should be given to the frictional effects and induced vortices due to the influence of topographic roughness and other existing structures. Consideration should also be given to the internal pressures on interior walls, ceilings, and floors resulting from damaged windows or doors.

The water related loads accompanying a design coastal incident storm event provide a major area of deficiency in most building codes, with wind generated waves producing the most analytically complex yet the most critical of forces to which the coast and its structures are subjected. The coastal building code should require that major habitable structures be designed in consideration of the expected shore-propagating wave conditions upon the surge of a 100-year storm event. Breaking, broken, and non-breaking waves should be considered as applicable. Design wave loading analysis should consider vertical uplift pressures and all lateral pressures to include impact, as well as, dynamic loading and the harmonic intensification resulting from repetitive waves. Recommended sources from which to base minimum criteria and methodology in design wave computations are the Department of Navy, Naval Facilities Engineering Command Design Manual NAVFAC DM-26, the Department of the Army Corps of Engineers Shore Protection Manual, Volume II, Department of the Army Coastal Engineering Research Center Technical Papers and Reports, and Florida Department of Natural Resources, Division of Beaches and Shores Technical and Design Memoranda.

In addition to the wind and wave loads, a coastal building code should require that all major habitable structures be designed for the hydrostatic and hydrodynamic loads which would be expected under the conditions of maximum inundation associated with a 100-year storm event. Calculations for hydrostatic loads should consider the maximum water pressure resulting from a peaked breaking wave superimposed on the storm surge of a 100-year storm event. Both free and confined hydrostatic loads should be considered, while confined hydrostatic loads should be determined using the maximum elevation to which the confined water would freely rise if unconfined.

Vertical hydrostatic loads should be considered as forces acting both vertically downward and upward on horizontal or inclined surfaces of major structures (e.g. floors, slabs, roofs, walls). Lateral hydrostatic loads should be considered as forces acting horizontally above and below grade on vertical or inclined surfaces of major structures and coastal or shore protection structures. Hydrostatic loads on irregular or curving geometric surfaces may be determined in consideration of separate vertical and horizontal components acting simultaneously under the distribution of the hydrostatic pressures.

Calculations for hydrodynamic loads should consider the maximum water pressures resulting from the motion of the water mass associated with a

100-year storm event. A more detailed discussion of these loads may be found in the definitions which follow.

When considering water related loads, specialized loads of importance to the coastal building code are battering loads. Habitable major structures including the foundation should be designed to resist the battering loads which may reasonably be anticipated resulting from isolated floating or suspended objects during a 100-year storm event.

5 EXCAVATIONS

A major consideration of a coastal building code, excavation is generally not recommended within the coastal construction building zone and should be prohibited within the coastal conservation zone. Any proposed excavation design should consider the coastal topographic changes accompanying a 100-year storm event and those anticipated topographic changes which have an equivalent probability of occurrence. Upon consideration of these topographic changes, any excavation within the coastal construction building zone which have the potential for a negative impact or would accelerate erosion should be prohibited. Excavation associated with the construction of a major structure within the coastal construction building zone should be limited to that incidental to the construction of the foundation and necessary for utilities. Excavation required for swimming pool construction within the coastal construction building zone should be minimized, located as far inland as possible, and not result in a net loss of sediment in the immediate area. All beach compatible excavated material or an equivalent volume of beach compatible material should be used as fill to be placed generally seaward of the excavation.

6 COASTAL AND SHORE PROTECTION STRUCTURES

The coastal building code should address coastal and shore protection structures as a separate classification for design. In general, the construction or rehabilitation of flexible coastal and shore protection structures such as beach nourishment, dune construction and stabilization, and sand fencing should be encouraged over the construction of rigid coastal and shore protection structures (seawalls, bulkheads, revetments, rubble mounds, groins, etc.) if such beach and dune restoration activity is of acceptable coastal engineering design and is compatible with the existing coastal systems. The construction of isolated rigid coastal or shore protection structures on undeveloped property is not recommended nor should such structures be designed primarily to protect minor structures.

Seawalls and other rigid coastal protection structures are intended to protect upland structures and property and not to protect the beach. In fact, rigid coastal protection structures usually may be expected to have a long term adverse effect on the adjacent beach. In those instances in which a rigid coastal or shore protection structure is the only feasible means of protecting existing upland structures and property, then that rigid

coastal or shore protection structure should be located as far landward as possible, consistent with design and construction requirements. Any seawall or other rigid coastal protection structure should be designed to minimize its erosion impact. Sloping rock revetments, rubble mound structures, and toe-scour protection with rock in front of vertical bulkheads and seawalls are recommended over vertical or sloping solid walls which due to their reflective surface cause substantially greater erosion losses to the adjacent beach.

The major design considerations for coastal and shore protection structures should include structural siting, foundation (e.g. geotextiles), crest (or cap) elevation, toe elevation, structural slope(s), components as impacted by waves superimposed upon the design storm surge, expected scour, impact on the beach and dune system, and impact on the adjacent properties. Coastal and shore protection structures should be designed for the minimum wave loads which are applicable for the design storm conditions which justify the structures. Seawalls, revetments, and rubble mound structures are generally designed for a 20 to 50-year storm event. Recommended sources from which to base minimum criteria and methodology in the design of coastal and shore protection structures are the Department of the Army Corps of Engineers Shore Protection Manual, the Department of the Army Coastal Engineering Research Center Technical Papers and Reports, the Department of Navy, Naval Facilities Engineering Command Design Manual NAVFAC DM-26 and DM-7, and Florida Department of Natural Resources, Division of Beaches and Shores Technical and Design Memoranda.

The coastal building code should also address those cases where development is proposed upland of an existing seawall or other rigid coastal protection structure. Such development should be located a sufficient distance upland from the coastal protection structure to allow for the containment of partial failures and to provide adequate room for routine maintenance and future repair to the coastal protection structure. Wave and runoff induced seepage in fill behind coastal protection structures should be considered to avoid partial or complete failure due to piping of fill material under the structures.

7 CODE DEFINITIONS

The following definitions are recommended for inclusion within the coastal building code, in order to clarify the coastal engineering and construction terminology adopted.

BEACH: The zone of unconsolidated material that extends landward from the low water line to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation. Unless otherwise specified, the seaward limit of a beach is the mean low water line. Beach is alternatively termed the "shore."

BREAK-AWAY WALL or FRANGIBLE WALL: A partition independent of supporting structural members that will withstand design wind forces but will fail under hydrostatic, wave and runup forces associated with the

design storm surge. Under such conditions, the wall should fail in such a manner that it dissolves or breaks up into components that will not act as potentially damaging missiles.

COASTAL AND SHORE PROTECTION STRUCTURES: Shore hardening structures, such as seawalls, bulkheads, revetments, rubble mound structures; groins and breakwaters; aggregates of materials other than beach sand used for shoreline protection; beach and dune restoration; and other structures which are intended to prevent erosion or protect other structures from wave and hydrodynamic forces. Coastal protection structures are intended for the protection of upland properties and structures, whereas, shore protection structures are intended for the protection of the beach or shoreline.

COLUMN ACTION: The elastic instability in piles or columns resulting from stresses due to axial and/or lateral loads.

DUNE: A mound or ridge of loose sediment, usually sand-sized, lying upland of the beach or shore, and deposited by any natural or artifical mechanism (e.g., a dune may also include a beach ridge, dune ridge, chenier, etc.).

EROSION: The wearing away of land or the removal of beach or dune material by wave action, tidal currents or deflation. Erosion includes but is not limited to:

(a) Horizontal recession, which is where the storm surge intersects but does not inundate the profile and where horizontal littoral activity due to waves, currents and runup erodes the profile.
(b) Scour, which is where the topography is completely inundated by the storm surge, and where wave and current forces erode the profile in the vertical direction.

EXCAVATION: Any mechanical removal of rock or unconsolidated material.

HYDRODYNAMIC LOADS: Those forces resulting from a mass of water in motion, e.g., the flow accompanying a storm surge. Hydrodynamic loads are generally lateral forces, but also include effects of the turbulence resulting from the interaction of the flowing water mass with a rigid structure. Hydrodynamic load computations for construction consider all predominant forcing functions responsible for the motion of the aquatic mass, which are the astronomical tide and the storm waves (including the orbital particle transport, longshore mass transport, and shore-normal mass transport), as well as the storm surge. Gravity and forced flow resulting from the inundation accompanying the storm surge of a 100-year storm event are considered. Hydrodynamic load computations consider the processes of mass transport, heat transport, and momentum transport, along with the corresponding natural laws which are the conservation of matter, the conservation of energy (first law of thermodynamics), and Newton's second law (the equation of motion). Hydrodynamic load computations also consider the various flow forms including forms referring to spatial variation (uniform and non-uniform flow), forms referring to variation in time (steady, quasi-steady, and non-steady flow), forms referring to the

nature of flow (laminar and turbulent flow), and forms referring to the type of flow energy (subcritical, critical, and supercritical flow). In addition, hydrodynamic load computations include the transformation of flow energy form from supercritical flow to subcritical flow, and vice versa, including all classifications of hydraulic jump. Hydrodynamic load computations consider hydraulic flow across both a fixed bed and a movable bed where applicable.

HYDROSTATIC LOADS: Those lateral and vertical (including uplift) forces resulting from a mass of water standing either above or below the soil surface. These loads are equal to the product of the water pressure at the centroid of the plane surface area on which the pressure acts times the area of that surface. The hydrostatic pressure is equal to the product of the unit weight of the water times the elevation of the water above the point of measurement. Hydrostatic loads which are confined may be determined using the elevation to which the confined water would freely rise if unconfined. Hydrostatic pressures at any point are equal in all directions and act normal to the applied surface and are passive in nature.

INUNDATE: To cover or overflow as with a flood.

MAJOR STRUCTURES: Houses, mobile homes, apartment buildings, condominiums, motels, hotels, restaurants, other types of residential or commercial buildings, towers, swimming pools, piers, pipelines, and other projects having the potential for substantial impact on the beach and dune systems. Major structures include any structure which is neither a "minor structure" nor a "coastal or shore protection structure."

MINOR STRUCTURES: Elevated dune and beach walkover structures, beach access ramps and walkways, stairways, pile-supported elevated viewing platforms, gazebos, boardwalks, lifeguard support structures, pile supported or cantilevered decks or porches on new or existing structures, slab patios, sidewalks, driveways, and other uncovered paved areas (e.g., parking areas, shuffleboard courts, tennis courts, etc.), earth retaining walls, sand fences, privacy fences, ornamental walls, ornamental garden structures, aviaries, subgrade utilities (e.g., wells, septic tanks, and drain fields) which require material alteration and restoration of topography, and ornamental projects. Usage is not the only criterion used to classify structures as minor. It is a characteristic of minor structures that they are considered to be expendable under wind and wave forces.

ONE-HUNDRED-YEAR STORM: A shore-incident hurricane or any other storm with accompanying wind and wave intensity having a one-percent chance of being equaled or exceeded in any given year during a 100-year interval.

PILE FOUNDATION: A system of piles providing the support of a structure, including those piles terminating below grade at pile caps and those piles extending above grade to superelevate a structure.

STORM SURGE: The rise above normal water level on the open coast due to a number of factors, including the action of wind stress on the water surface and the rise in level due to atmospheric pressure reduction.

UPLIFT PRESSURE: Any upward hydrostatic, hydrodynamic, or wind pressure on the soffit, base, deck or floor of a structure.

WAVE: A ridge, deformation, or undulation of the surface of a liquid. Storm generated ocean waves shore-propagating upon the storm surge are considered for design purposes. The wave forces are dependent upon the type of wave considered (i.e., unbroken, broken or breaking).

8 CONCLUSION

Special design standards are needed specifically for the construction of structures fronting on the open coast exposed to extreme storm events. Predicting waves, flooding, erosion and scour is a necessary requirement for the proper design of ocean front construction. By systematically identifying the special design aspects for coastal construction, a coastal building code may be developed to supplement the minimum design standards set forth in the current building codes.

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