Guide for Design and Construction of Waterfront and Coastal Concrete Marine Structures

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Waterfront and coastal concrete marine structures are exposed to severe environmental conditions for which concrete is ideally suited. These conditions include wind; waves, including seiches and tsunamis; ice and ship impact; abrasion and impact from floating debris; passing vessel effects; and seismic events. As many of these structures are pile-supported, the seismic loading can be critical and, therefore, a discussion of piles and their installation is included in this guide. Also provided are the measures that can be taken to minimize the undesirable effects of these environmental factors and reduce the potential for serious problems.

This guide also defines waterfront and coastal concrete marine structures, discusses materials that can be used to construct them, describes potential durability issues and how to mitigate them, and presents sustainability and serviceability requirements. Design loads, analysis techniques, design methodology, and construction considerations are also presented. Other topics included are quality control (QC), above-water and below-water inspection of these structures, and repair of damaged structures. The materials, processes, QC measures, and inspections described in this guide should be tested, monitored, or performed as applicable only by qualified individuals holding the appropriate ACI certifications or equivalent.

Keywords: construction procedures; durability; inspection; marine structures; materials; quality control; serviceability; sustainability; structural analysis; structural design

CONTENTS

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CHAPTER 1—GENERAL

1.1—Introduction

The use of properly designed, durable, and sustainable concrete is an economical approach to the design of marine structures. Except for some criteria in ACI 357.1 and specialized criteria in other ACI guides on durability, there are no comprehensive guidelines or standards that cover the application of concrete in the marine environment for coastal marine structures. Current building codes and ACI standards do not address the requirements unique to the design of these structures, with the exception of special applications or requirements for piles and concrete durability. This guide provides design guidance for the use of concrete for coastal marine structures, and is intended to complement other design manuals and guides used for this purpose.

1.2—Scope

This guide primarily covers marine structures used for berthing marine vessels in protected harbors, and for supporting the associated loads. Structures covered by this guide include pile-supported platforms, bulkheads, and gravity structures. It is not intended to cover marine structures such as gravity block walls, tunnels, breakwaters, floating structures, or offshore platforms. Emphasis is placed on special considerations for marine concrete and guidance for the design and construction of marine structures. Because of the severe nature of the marine environment and associated loading conditions, certain recommendations in this report are intended to complement the requirements of ACI 318.

Existing design guides are used for basic concepts, loadings, marine hardware, and other criteria that affect the use of concrete in marine structures. There are some comprehensive manuals that cover functional and structural guidelines for the design of coastal marine structures (MIL-HDBK-1025 2006; BS 6349-1 to 8; Goda et al. 2009; EAU 2004; Ports, Customs and Free Zone Corporation 2007; Werner 1998; FEMA P-55 2011.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

D = dead loads
E = earthquake loads
EI = flexural stiffness
E_s = modulus of elasticity of steel
E_v = vertical seismic load

F = loads due to weight and pressure of fluids with well-defined densities and controllable maximum heights
F_a = flood load
H = loads due to weight and pressure of soil, water in soil, or other materials
I = moment of inertia of an uncracked reinforced concrete cross section
L = live loads
L_r = roof live load
M = moment
R = response modification factor, or rain load
S = snow load
T = cumulative effect of temperature, creep, shrinkage, differential and settlement
W = wind load
z_1 = distance between resultants of the internal compressive and tensile ties in strut-and-tie model

2.2—Definitions

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology," http://www.concrete.org/Tools/ConcreteTerminology.aspx. The definitions provided herein compliment that resource.

air gap—distance from the underside of the structures deck to the datum high water level.

arctic structures—floating or fixed structures for exploration and production of oil and gas in ice-infested waters above the Arctic Circle.

B-region—a portion of a member where the plane section assumption of flexural theory can be applied.

barge-like structures—a floating vessel with vertical walls and a near-rectangular plan; the bow and stern may be raked or shaped as required.

batter action—the phenomenon that occurs if a horizontal load is applied to a pair of piles connected in an A-frame configuration; one that causes an axial compressive load in the batter pile and a vertical tension load in the vertical pile of the A-frame.

batter piles—piles with a receding upward slope of the outer surface of the pile.

berm—a narrow shelf or ledge typically at the bottom of a slope.

coastal structure—any facility built in close proximity to the ocean.

D-region—The portion of a member within a distance h from a force discontinuity or a geometric discontinuity.

earthquake-induced liquefaction—for soils, the process of mudding or becoming a liquid.

fixed offshore structures—structures that are founded on the seabed and obtain their stability from the vertical forces of gravity.

floating structures—structures that are temporally, intermittently, or continuously afloat.

graving dock—another term for dry dock, which is a relatively narrow, long basin, into which a vessel can be floated and the water pumped out, leaving the vessel supported on blocks; used for building or repairing a vessel below the waterline.

gravity structures—see **fixed offshore structures**.

marine growth—a term applied to biofouling organisms that attach themselves to marine structures. The organisms are classified as hard or soft fouling types. Hard (Calcareous) fouling organisms include barnacles, encrusting bryozoans, mollusks, polychaete and other tube worms, and zebra mussels. Examples of soft (noncalcareous) fouling organisms are seaweed, hydroids, algae, and biofilm "slime." Together, these organisms form a fouling community that increases the drag forces on the structure from waves and tides.

marine structure—any facility built to function in contact with a body of water.

mudline—the top of the soil surface underlying a body of water.

offshore concrete structures—fixed reinforced or prestressed concrete, or both reinforced and prestressed concrete structures, for service in deeper waters far from the shoreline.

offshore terminal—facility built far from the shoreline but connected to the shore by roadways or bridges.

***p*-delta analysis**—analysis to quantify the changes in ground shear or overturning moment, or through axial force distribution at the base of a structural component, or all of the above, due to a lateral displacement.

***p*-*y* analysis**—Analysis to characterize the lateral load behavior of a single embedded pile.

pier—a platform structure extending from the shore into the sea for use as a landing place or promenade or to protect or form a harbor.

pucher influence field charts—a series of contour plots of influence surfaces for various plate and loading geometries that can be used for deck design. For example, local moments in the deck slab due to wheel loads can be determined.

rip-rap—a loose assemblage of stones erected in water to prevent erosion of a shoreline or foundation.

scour—Erosive action of moving water that removes material, creates holes, or lowers the sea floor adjacent to structures.

slipway—a sloping surface leading down to water on which ships are built or repaired. Marine structures can be moved to and from the water. Also called a marine railway on where ships or vessels can be moved to and from the water.

tidal fluctuations—the rise and fall of the water surface from low tide to high tide levels

waterfront structure—any facility built along the edge of a shoreline.

wharf—a structure built along, or at an angle from, the shore for berthing ships to receive and discharge cargo and passengers.