ACI 357R-84

(Reapproved 1997)

Guide for the Design and Construction of Fixed Offshore Concrete Structures

Reported by ACI Committee 357

Harvey H. Haynes, chairman   A.E. Fiorato, secretary

A. Leon Abolitz
Arthur R. Anderson
Jal N. Birdy
Irvin Boaz
Anthony D. Boyd
William J. Cichanski
George F Davenport
Joseph A. Dobrowolski
J.M. Duncan
Svein Fjeld
Ben C. Gerwick, Jr.
William A. Ingraham
Richard W. Litton
Alan H. Mattock
Karl H. Runge
B.P. Malcolm Sharples
Charles E. Smith
Raymond J. Smith
Stanley G. Stiansen
Alfred A. Yee
Shu-Yin Yu

Associate Members

Nicholas Carino
John Clarke
Odd E. Gjørv
Eivind Hognestad
Masatane Kokubu
W. Frank Manning
T.H. Monnier

The report provides a guide for the design and construction of fixed reinforced andlor prestressed concrete structures for service in a marine environment. Only fixed structures which are founded on the seabed and obtain their stability from the vertical forces of gravity are covered.

Contents include: materials and durability; dead, deformation, live, environmental, and accidental loads; design and analysis; foundations; construction and installation; and inspection and repair. Two appendixes discuss environmental loads such as wave, wind, and ice loads in detail, and the design of offshore concrete structures for earthquake resistance.

Keywords: anchorage (structural); concrete construction; construction materials; cracking (fracturing); dynamic loads; earthquakes; earthquake resistant structures; foundations; grouting; harbor structures; inspection; loads (forces); ocean bottom; offshore structures; post-tensioning; prestressed concrete; prestressing steels; reinforced concrete; repairs; static loads; structural analysis; structural design; underwater construction.

CONTENTS

Supersedes ACI 357-78 (Reaffirmed 1982).

PREFACE

Concrete structures have been used in the North Sea and other offshore areas of the world. With the rapid expansion of knowledge of the behavior of concrete structures in the sea, and discoveries of hydrocarbons off North American shores, there will likely be an increased use of such structures. This report was developed to provide a guide for the design and construction of fixed offshore concrete structures. Reference to the following documents is acknowledged:

API Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms, API RP2A, American Petroleum Institute.

Recommendations for the Design and Construction of Concrete Sea Structures, Fédération International de la Précontrainte.

Rules for the Design, Construction, and Inspection of Offshore Structures, Det Norske Veritas.

Where adequate data were available, specific recommendations were made, while in less developed areas particular points were indicated for consideration by the designer. The design of offshore structures requires much creativity of the designer, and it is intended that this guide permit and encourage creativity and usage of continuing research advancements in the developme

able and economical.

NOTATION

A = accidental load
C_m = hydrodynamic coefficient
D = dead load, diameter of structural member
E = environmental load
E_c = concrete modulus of elasticity
E_i = initial modulus of elasticity
E_o = frequently occurring environmental load
E_{max} = extreme environmental load
E_s = reinforcing steel modulus of elasticity
L = live load
L_{max} = maximum live load
L_{min} = minimum live load
T = deformation load
W/C = water-cement ratio
b = section width
d_b = diameter of reinforcing bar
d_e = effective tension zone
f_c = stress in concrete
f_{CD} = allowable design stress in concrete
f_S = stress in reinforcing bar
f_{SD} = allowable design stress in reinforcing bar
f_t = mean tensile strength of concrete
f_y = yield stress of reinforcing bars
f_c' = 28-day strength of concrete (ACI 318)
h = section thickness
x = depth of compression zone
γ_c = material factor for cohesive soils
γ_f = material factor for friction type soils
γ_L = load multiplier
γ_m = material factor
γ_{mc} = material factor for concrete
γ_{ms} = material factor for reinforcing bars
Δ_{ps} = increase in tensile stress in prestressing steel with reference to the stress at zero strain in the concrete
ε = strain
λ = wave length
ϕ = strength reduction factor

CHAPTER 1-GENERAL

1.1-Scope

This report is intended to be used as a guide for the design of fixed reinforced and/or prestressed concrete structures for service in a marine environment. Only fixed structures which are founded on the seabed and obtain their stability from the vertical forces of gravity are covered herein. Such structures may be floated utilizing their own positive buoyancy during construction and installation, however.

This report is not intended to cover maritime structures such as jetties or breakwaters, or those which are constructed primarily as ships or boats. ACI 318 should be used together with this report. Because of the nature of the marine environment, certain recommendations herein override the requirements of ACI 318.

ndation where it is necessary to actively control conditions to insure an adequate margin of safety for the structure, instrumentation should be provided to monitor the conditions. Such conditions might be fluid level, temperature, soil pore water pressure, etc.

Adequate instrumentation should be provided to insure proper installation of the structure.

When new concepts and procedures that extend the frontier of engineering knowledge are used, instrumentation should be provided to enable measured behavior to be compared with predicted behavior.

1.3-Auxiliary systems and interfaces

Special consideration should be given to planning and designing auxiliary nonstructural systems and their interfaces with a concrete structure.

Auxiliary mechanical, electrical, hydraulic, and control systems have functional requirements that may have a significant impact on structural design. Special auxiliary systems may be required for different design phases of an installation, including construction, transportation, installation, operation, and relocation.

Unique operating characteristics of auxiliary systems should be considered in assessing structural load conditions. Suitable provisions should be made for embedments and penetrations to accommodate auxiliary equipment.

CHAPTER 2-MATERIALS AND DURABILITY

2.1-General

All materials to be used in the construction of offshore concrete structures should have documentation demonstrating previous satisfactory performance under similar site conditions or have sufficient backup test data.

2.2-Testing

2.2.1- Tests of concrete and other materials should be performed in accordance with applicable standards of ASTM listed in the section of ACI 318 on standards cited. Complete records of these tests should be available for inspection during construction and should be preserved by the owner during the life of the structure.

2.2.2- Testing in addition to that normally carried out for concrete Structures, such as splitting or flexural tensile tests, may be necessary to determine compliance with specified durability and quality specifications.

2.3-Quality control

2.3.1- Quality control during construction of the concrete structure is normally the responsibility of the contractor. Supervision of quality control should be the responsibility of an experienced engineer who should report directly to top management of the construction firm. The owner may provide quality assurance

construction firm.

2.4-Durability

2.4.1- Proper ingredients, mix proportioning, construction procedures, and quality control should produce durable concrete. Hard, dense aggregates combined with a low water-cement ratio and moist curing have produced concrete structures which have remained in satisfactory condition for 40 years or more in a marine environment.

2.4.2- The three zones of exposure to be considered on an offshore structure are:

(a) The submerged zone, which can be assumed to be continuously covered by the sea water.

(b) The splash zone, the area subject to continuous wetting and drying.

(c) The atmospheric zone, the portion of the structure above the splash zone.

2.4.3- Items to be considered in the three zones are:

(a) Submerged zone-Chemical deterioration of the concrete, corrosion of the reinforcement and hardware, and abrasion of the concrete.

(b) Splash zone-Freeze-thaw durability, corrosion of the reinforcement and hardware and the chemical deterioration of the concrete, and abrasion due to ice.

(c) Atmospheric zone-Freeze-thaw durability, corrosion of reinforcement and hardware, and fire hazards.

2.5-Cement

2.5.1- Cement should conform to Type I, II, or III portland cements in accordance with ASTM C 150 and blended hydraulic cements which meet the requirements of ASTM C 595.

2.5.2- The tricalcium aluminate content (C_3A) should not be less than 4 percent to provide protection for the reinforcement. Based on past experience, the maximum tricalcium aluminate content should generally be 10 percent to obtain concrete that is resistant to sulfate attack. The above limits apply to all exposure zones.

2.5.3- Where oil storage is expected, a reduction in the amount of tricalcium aluminate (C_3A) in the cement may be necessary if the oil contains soluble sulfates. If soluble sulfides are present in the oil, coatings or high cement contents should be considered.

2.5.4- Pozzolans conforming to ASTM C 618 may be used provided that tests are made using actual job materials to ascertain the relative advantages and disadvantages of the proposed mix with special consideration given to sulfate resistance, workability of the mix, and corrosion protection provided to the reinforcement.

2.6-Mixing water

2.6.1.- Water used in mixing concrete should be clean and free from oils, acids, alkalis, salts, organic materials, or other substances that may be deleterious to concrete or reinforcement. Mixing water should not contain excessive amounts of chloride ion. (See Section 2.8.6).

2.7-Aggregates

o the requirements of

r applicable.