IN-LB	Inch-Pound Units
SI	International System of Units

Heavyweight Concrete: Measuring, Mixing, Transporting, and Placing

Reported by ACI Committee 304

ACI 304.3R-20

American Concrete Institute
Always advancing

First Printing
November 2020
ISBN: 978-1-64195-125-8

Heavyweight Concrete: Measuring, Mixing, Transporting, and Placing

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. In spite of these efforts, the users of ACI documents occasionally find information or requirements that may be subject to more than one interpretation or may be incomplete or incorrect. Users who have suggestions for the improvement of ACI documents are requested to contact ACI via the errata website at http://concrete.org/Publications/DocumentErrata.aspx. Proper use of this document includes periodically checking for errata for the most up-to-date revisions.

ACI committee documents are intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. Individuals who use this publication in any way assume all risk and accept total responsibility for the application and use of this information.

All information in this publication is provided “as is” without warranty of any kind, either express or implied, including but not limited to, the implied warranties of merchantability, fitness for a particular purpose or non-infringement.

ACI and its members disclaim liability for damages of any kind, including any special, indirect, incidental, or consequential damages, including without limitation, lost revenues or lost profits, which may result from the use of this publication.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Participation by governmental representatives in the work of the American Concrete Institute and in the development of Institute standards does not constitute governmental endorsement of ACI or the standards that it develops.

Order information: ACI documents are available in print, by download, through electronic subscription, or reprint and may be obtained by contacting ACI.

Most ACI standards and committee reports are gathered together in the annually revised the ACI Collection of Concrete Codes, Specifications, and Practices.

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org

Heavyweight Concrete: Measuring, Mixing, Transporting, and Placing

Reported by ACI Committee 304

Tarek S. Khan, Chair

Hakim S. Abdelgader
David J. Akers
Casimir J. Bognacki
David A. Burg
Manjit S. Chopra*
Carl L. Cunningham
Bernard J. Eckholdt III
J. Mitchell Englestead
Michael R. Gardner
Brian H. Green
T. J. Harris
Thomas Kjellberg
Larry W. Matejcek
Avi A. Mor
Mike Murray
Dipak T. Parekh
James S. Pierce
Jorge L. Quiros
James M. Shilstone
William W. Squyres
Boris Y. Stein
William L. Thrasher
Kevin D. Wolf
Samuel X. Yao
Richard Yelton

Consulting Members

Jacques A. Bertrand
Thomas R. Clapp
Neil R. Guptill

*Task Group leader.

This document presents recommended methods and procedures for measuring, mixing, transporting, and placing heavyweight concretes that are used principally for radiation shielding in nuclear construction. Also covered are recommendations on cement, heavyweight aggregates, water, and admixtures. Mixture proportioning of heavyweight concrete is discussed. Mixing equipment, form construction, placing procedures, and methods of consolidation are described. Quality control, inspection, and testing are emphasized, and a list of references is included. Preplaced heavyweight concrete is not discussed in this version of 304.3R. It is covered in the 2004 version of the document.

Keywords: admixtures; aggregates; barite; concrete construction; consolidation; construction equipment; conveying; density (mass/volume); formwork (construction); grout; heavyweight aggregates; heavyweight concretes; hematite; ilmenite; limonite; magnetite; mass concrete; materials handling; mixture proportioning; mixing; placing; quality control; radiation shielding; segregation; ultra-heavyweight concrete.

CONTENTS

CHAPTER 1—INTRODUCTION, p. 2
1.1—Introduction, p. 2
1.2—Scope, p. 2

CHAPTER 2—MATERIALS, p. 2
2.1—Cement, p. 2
2.2—Aggregates, p. 2
2.3—Mixing water, p. 3
2.4—Admixtures, p. 3
2.5—Heavyweight mortar and grouts, p. 4

CHAPTER 3—CONCRETE CHARACTERISTICS, p. 4
3.1—Physical properties, p. 4
3.2—Mixture proportioning, p. 4

CHAPTER 4—EQUIPMENT, p. 4

CHAPTER 5—FORMWORK, p. 5

CHAPTER 6—PLACEMENT, p. 6

CHAPTER 7—QUALITY CONTROL, p. 6
7.1—Samples and tests, p. 6

ACI 304.3R-20 supercedes ACI 304.3R-96(04), was adopted July 30, 2020, and published November 2020.

7.2—Cement, p. 6
7.3—Aggregate, p. 6
7.4—Admixtures, p. 7
7.5—Control tests, p. 7
7.6—Inspection, p. 7

CHAPTER 8—REFERENCES, p. 7
Authored documents, p. 7

CHAPTER 1—INTRODUCTION

1.1—Introduction

The procedures for manufacturing of heavyweight concrete are similar to conventional concrete. Mixing, transporting, and placing heavyweight concrete are similar to those used in conventional concrete construction; however, special expertise and thorough planning are necessary for the successful completion of this type of concrete work. Use of heavyweight concrete, typically produced via batching with heavyweight aggregate, should be managed by personnel experienced with the required specialized handling needs, including those defined in this report.

1.2—Scope

Heavyweight concrete is used in counterweights of bascule, lift, and cable-stay bridges. It is used for counterweights for both cranes and concrete-conveying equipment. It has also been used for sound and vibration attenuation in subway systems where extra mass helps in protecting sensitive instruments. Large quantities are used as coarse dry-pack cementitious coating on offshore oil and gas transmission lines. However, the most common application of heavyweight concrete is for providing biological shielding against radiation in nuclear-power-generating plants and cancer therapy clinics. The mass of heavyweight concrete compared to conventional concrete reduces the barrier thickness, thereby conserving space by reducing the footprint of the facility.

When heavyweight concrete is used to absorb gamma rays, the density and materials costs are of prime importance (Pihlajavaara 1972). For some radiation shielding applications, heavyweight shielding concrete is also used to attenuate neutrons. The neutron energy accompanying gamma radiation requires lightweight or low-atomic-weight elements such as hydrogen and boron to slow these neutrons by inelastic collision. The resulting gamma radiation from these collisions is stopped by heavyweight elements, such as iron, that are incorporated in the heavyweight concrete. Hydrogen is always present in concrete because of the hydration of the cement and mixing water. In addition to the portland cement, supplemental cementitious materials can provide hydrogen that is "locked in" during the process of hydration (Davis 1972a). Once the cement is hydrated, the water of hydration cannot escape unless the concrete is heated at high temperatures for extended time periods.

Some heavyweight mineral aggregates such as goethite (α-$Fe^{3+}O(OH)$) and limonite ($FeO(OH)\cdot nH_2O$) contain water in their chemical structure and are known as hydrous minerals. They can be used as sources of hydrogen because they can retain water of their crystallization at elevated temperatures. Use of these minerals ensures a presence of hydrogen not necessarily present in conventional aggregates. Use of minerals containing hydrogen in their chemical structure will assure a content of hydrogen, even when the hydrated cement loses its chemically combined water at high temperatures.

In addition to hydrogen, another desirable element is boron, which has the ability to capture thermal (slow) neutrons produced by collision of high-energy neutrons with hydrogen. The gamma radiation resulting in this energy transfer is captured by heavyweight elements, such as iron in heavyweight aggregates in heavyweight concrete. Care should be taken to minimize possible retardation of the concrete mixture due to influence of boron and its compounds, boric acid and borax, on the hydration of portland cement.

ACI Committee 349, Concrete Nuclear Structures, has several standards and code requirements concerning this type of construction, including ACI 349-13, "Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary." This code covers the proper design and construction of concrete structures that form part of a nuclear power plant and that have nuclear safety-related functions, but does not cover concrete reactor vessels and concrete containment structures (as defined by Joint ACI-ASME Committee 359). The structures covered by the code include concrete structures inside and outside the containment system.

CHAPTER 2—MATERIALS

2.1—Cement

Cements conforming to ASTM C150/C150M, which would be suitable for conventional concrete and produce the required physical properties, are suitable for use in heavyweight concrete. Low-alkali cement should be used when alkali-reactive constituents are present in the aggregates, and a moderate- or low-heat cement should be used for massive members in accordance with ACI 301-16 Chapter 8, Mass Concrete. To avoid high and rapid heat of hydration and resultant cracking, it is advisable not to use Type III cement or accelerators in heavyweight concrete mixtures, unless the concrete temperature is controlled by specially designed refrigeration systems. Blended hydraulic cements meeting the requirements of ASTM C595/C595M may also be used in place of portland cement. However, blended hydraulic cements should be employed only if their use does not reduce the density of the concrete below the minimum acceptable density or other property for the specific application or structure. Storage of cementitious materials should be in accordance with ACI 304R.

2.2—Aggregates

The practice of evaluating normalweight aggregates for producing durable concrete is applicable to heavyweight aggregates as well. Because of the manner in which the