

An ACI Standard

Design Specification
for Concrete Silos
and Stacking Tubes
for Storing Granular
Materials (ACI 313-16) and
Commentary

Reported by ACI committee 313

ACI 313-16



American Concrete Institute
Always advancing



Design Specification for Concrete Silos and Stacking Tubes for Storing Granular Materials (ACI 313-16) and Commentary

Copyright by the American Concrete Institute, Farmington Hills, MI. All rights reserved. This material may not be reproduced or copied, in whole or part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of ACI.

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 ACI Manual of Concrete Practice (MCP).

American Concrete Institute
2880 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

Design Specification for Concrete Silos and Stacking Tubes for Storing Granular Materials (ACI 313-16) and Commentary

An ACI Standard

Reported by ACI Committee 313

Shahriar Shahriar, Chair

William D. Arockiasamy
William H. Bokhoven
Patrick B. Ebner
Stephen G. Frankosky

Timothy A. Harvey
F. Thomas Johnston
David C. Mattes
Rodney M. Nohr

John E. Sadler
Michael D. Simpson
Bill J. Socha

Consulting Members
Donald Midgley
John M. Rotter
Jonathan G. M. Wood

This Design Specification provides material, design, and construction requirements for concrete silos, stave silos, and stacking tubes for storing granular materials, including design and construction requirements for cast-in-place or precast and conventionally reinforced or post-tensioned silos.

Silos and stacking tubes require design considerations not encountered in building structures. While this Design Specification refers to ACI 318 for several requirements, static and dynamic loading from funnel, mass, concentric, and asymmetric flow in silos; special loadings on stacking tubes; and seismic and hopper bottom design are also included.

Keywords: asymmetric flow; bins; funnel flow; granular materials; hoppers; mass flow; silos.

ACI 313-16 supersedes ACI 313-97, was adopted May 24, 2016, and was published August 2016.

Copyright © 2016, American Concrete Institute.

All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by electronic or mechanical device, printed, written, or oral, or recording for sound or visual reproduction or for use in any knowledge or retrieval system or device, unless permission in writing is obtained from the copyright proprietors.

CONTENTS

Introduction, p. 3

CHAPTER 1—GENERAL , p. 4

- 1.1—Scope , p. 4
- 1.2—Documentation , p. 4
- 1.3—Regulations/inspections , p. 5

CHAPTER 2—NOTATION AND DEFINITIONS , p. 6

- 2.1—Notation , p. 6
- 2.2—Definitions , p. 9

CHAPTER 3—REFERENCE STANDARDS, p. 11**CHAPTER 4—MATERIALS , p. 12**

- 4.1—General, p. 12
- 4.2—Cement and concrete , p. 12
- 4.3—Aggregates, p. 12
- 4.4—Water, p. 12
- 4.5—Admixtures , p. 12
- 4.6—Reinforcement, p. 13
- 4.7—Precast concrete staves, p. 13
- 4.8—Tests of materials , p. 13

CHAPTER 5—CONSTRUCTION REQUIREMENTS , p. 14

- 5.1—General, p. 14
- 5.2—Sampling and testing concrete, p. 14
- 5.3—Details and placement of reinforcement , p. 14
- 5.4—Forms , p. 14
- 5.5—Concrete placing and finishing , p. 14
- 5.6—Concrete protection and curing , p. 15
- 5.7—Lining and coating, p. 16
- 5.8—Tolerances for slipformed and jumpformed structures, p. 16

CHAPTER 6—DESIGN , p. 17

- 6.1—General , p. 17
- 6.2—Details and placement of reinforcement , p. 18
- 6.3—Loads , p. 22
- 6.4—Wall design , p. 32
- 6.5—Hopper design , p. 39
- 6.6—Column design , p. 39
- 6.7—Foundation design , p. 40

CHAPTER 7—CONCRETE STAVE INDUSTRIAL SILOS , p. 42

- 7.1—Scope , p. 42
- 7.2—Coatings , p. 42
- 7.3—Erection tolerances , p. 42
- 7.4—Wall design , p. 43
- 7.5—Hoops for stave silos , p. 46
- 7.6—Concrete stave and stave assembly testing , p. 46

CHAPTER 8—POST-TENSIONED CONCRETE SILOS , p. 50

- 8.1—Scope , p. 50
- 8.2—Post-tensioning systems , p. 50
- 8.3—Tendon systems , p. 50
- 8.4—Bonded tendons , p. 52
- 8.5—Unbonded tendons , p. 52
- 8.6—Post-tensioning ducts , p. 52
- 8.7—Details and location of nonprestressed reinforcement, p. 53
- 8.8—Wall openings, p. 53
- 8.9—Stressing records, p. 54
- 8.10—Design , p. 54
- 8.11—Vertical bending moment and shear due to post-tensioning , p. 55
- 8.12—Tolerances , p. 56

CHAPTER 9—CONCRETE STACKING TUBES , p. 57

- 9.1—Scope , p. 57
- 9.2—General layout , p. 57
- 9.3—Loads , p. 59
- 9.4—Load factors and strength reduction factors , p. 59
- 9.5—Tube wall design, p. 60
- 9.6—Foundation or reclaim tunnel , p. 60

CHAPTER R10—COMMENTARY REFERENCES, p. 61

- Authored documents, p. 61

SPECIFICATION**COMMENTARY****Introduction**

This commentary presents considerations and assumptions in developing provisions of the Design Specification. Initial filling (static) pressures are exerted by the stored material at rest. Flow pressures differ from initial filling pressures, and are exerted by the stored material during flow.

Comments on specific provisions of the Design Specification are made using corresponding chapter and section numbers of the Design Specification. References cited in the commentary are listed in [Chapter R10](#).

Currently in preview, click buy full version

SPECIFICATION

CHAPTER 1—GENERAL

1.1—Scope

This Design Specification covers the design and construction of concrete silos, stave silos, and stacking tubes for storing granular materials.

For the design of these structures, initial filling and flow loading shall be considered. This Design Specification is supplemental to ACI 318-11 for design and ACI 301-10 for construction, where indicated.

1.1.1 Specific inclusions—Industrial stave silos for storage of granular materials are included in these specifications. The application to precast concrete is limited to industrial stave silos. Effect of hot stored material is included in this Design Specification.

1.1.2 Specific exclusions—Silos for storing silage are not included in this Design Specification. This Design Specification does not consider any chemical reaction between the silo reinforced concrete and the stored granular material. Three-dimensional dome structures are not included in this Design Specification.

1.1.3 Hierarchy of standards—Whenever the requirements of this Design Specification are more stringent than the requirements of ACI 318-11, the requirements of this Design Specification shall govern.

1.2—Documentation

1.2.1 Project drawings and specifications for silos shall be prepared under the direct supervision of and bear the seal of the licensed design professional.

1.2.2 Contract documents shall show all features of the work, naming the stored materials assumed in the design and stating their properties, including the size and position of all structural components, connections, and reinforcing steel; the specified concrete strength; and the specified strength or grade of reinforcement and structural steel.

COMMENTARY

CHAPTER R1—GENERAL

R1.1—Scope

Silo failures have alerted licensed design professionals to the inadequacy of designing silos for only static pressures due to stored material at rest. Those failures motivated researchers to study the variations of pressures and flow of materials. Research has established that pressures during withdrawal can be significantly higher (Turitzin 1963; Pieper and Wenzel 1964; Reimbert and Reimbert 1980, 1987) or significantly lower than those present when the material is at rest. The excess (above static pressure) is called overpressure, and the shortfall is called underpressure. One of the causes of overpressure is the switch from active to passive conditions that occurs during material withdrawal (Jenike et al. 1972). Underpressures can occur in a flow channel, and overpressures can occur away from a flow channel at the same level (Colijn and Peschl 1980; Holmes 1972; Bernache 1968). Underpressures combined with overpressures cause circumferential bending of the silo wall. Impact during filling can cause the total pressure to exceed the static pressure. Whereas overpressures and underpressures are generally important in deeper silos, impact loading is usually significant for shallow bins (bunkers) in which large volumes of material are dumped suddenly. Some stored granular materials have sufficient cohesion and unconfined compressive strength to form large arches or cavities during discharge. The collapse of these arches and cavities can develop significant impact loads when the material above strikes the wall or floor. This document does not provide methods for calculation of such loads. The probability of forming arches and cavities can be reduced by using hopper and discharge equipment designs that reflect results from flowability testing of the stored material.

Overpressure, underpressure, or impact should be considered in the structural design of silos if present. Initial filling (static) pressures are exerted by the stored material at rest. Flow pressures differ from initial filling pressures, and are exerted by the stored material during flow.

R1.2—Documentation

Silos and stacking tubes are unusual structures. Many licensed design professionals are unfamiliar with computation of their design loads and with their design and detail requirements. Design computations and the preparation of project drawings and project specifications for silos, bunkers, and stacking tubes should be done under the supervision of a licensed design professional experienced in the design of such structures.

If possible, the properties of the stored materials to be used in the design should be obtained from tests of the actual materials to be stored or from records of tests of similar materials previously stored. Properties assumed in the design should be stated in the contract documents.