ACI 350.3-06

Seismic Design of Liquid-Containing Concrete Structures and Commentary (ACI 350.3-06)

An ACI Standard

Reported by ACI Committee 350

American Concrete Institute®

American Concrete Institute®
Advancing concrete knowledge

Seismic Design of Liquid-Containing Concrete Structures and Commentary

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.

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.

Order information: ACI documents are available in print, by download, on CD-ROM, 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
38800 Country Club Drive
Farmington Hills, MI 48331
U.S.A.
Phone: 248-848-3700
Fax: 248-848-3701

www.concrete.org

Seismic Design of Liquid-Containing Concrete Structures and Commentary (ACI 350.3-06)

AN ACI STANDARD

REPORTED BY ACI COMMITTEE 350

Environmental Engineering Concrete Structures

Satish K. Sachdev
Chair

Jon B. Ardahl
Vice Chair

John W. Baker
Secretary

Walter N. Bennett	Carl A. Gentry*	Dennis C. Kohl	Jerry Parnes
Lucian I. Bogdan	Gautam Ghosh*	Nicholas A. Legatos†	Andrew R. Philip
Steven R. Close	Charles S. Hanskat	Ramon E. Lucero*	Narayan M. Prachand
Patrick J. Creegan*	Keith W. Jacobson	Andrew R. Minogue‡	Risto Protic*
Ashok K. Dhingra*	Dov Kaminetzky	Lawrence G. Mrazek*	William C. Sherman*
Robert E. Doyle	M. Reza Kianoush*	Javeed A. Munshi*	Lawrence M. Tabat*
Anthony L. Felder	David G. Kittridge		

Subcommittee Members

Iyad M. Alsamsam	Daniel J. McCarthy
Clifford T. Early, Jr.	Carl H. Moon
Paul Hedli	G. Scott Riggs
Jerry A. Holland	John F. Seidensticker
Lawrence E. Kaiser	Paul J. St. John
Salvatore Marques	Paul Zoltanetzky, Jr.

Consulting Members

William Irwin
Terry Patzias
Lawrence Valentine

*Members of Seismic Provisions Subcommittee.
†Seismic Provisions Subcommittee Chair.
‡Seismic Provisions Subcommittee Secretary.

Seismic Design of Liquid-Containing Concrete Structures and Commentary (ACI 350.3-06)

REPORTED BY ACI COMMITTEE 350

This standard prescribes procedures for the seismic analysis and design of liquid-containing concrete structures. These procedures address the loading side of seismic design and are intended to complement ACI 350-06, Section 1.1.8 and Chapter 21.

Keywords: circular tanks; concrete tanks; convective component; earthquake resistance; environmental concrete structures; impulsive component; liquid-containing structures; rectangular tanks; seismic resistance; sloshing; storage tanks.

INTRODUCTION

The following paragraphs highlight the development of this standard and its evolution to the present format:

From the time it embarked on the task of developing an ACI 318-dependent code, ACI Committee 350 decided to expand on and supplement Chapter 21, "Special Provisions for Seismic Design," to provide a set of thorough and comprehensive procedures for the seismic analysis and design of all types of liquid-containing environmental concrete structures. The committee's decision was influenced by the recognition that liquid-containing structures are unique structures whose seismic design is not adequately covered by the leading national codes and standards. A seismic design subcommittee was appointed with the charge to implement the committee's decision.

The seismic subcommittee's work was guided by two main objectives:

1. To produce a self-contained set of procedures that would enable a practicing engineer to perform a full seismic analysis and design of a liquid-containing structure. This meant that these procedures should cover both aspects of seismic design: the "loading side" (namely the determination of the seismic loads based on the mapped maximum considered earthquake spectral response accelerations at short periods (S_s) and 1 second (S_1) obtained from the Seismic Ground Motion maps [Fig. 22-1 through 22-14 of ASCE 7-05, Chapter 22] and the geometry of the structure); and the "resistance side" (the detailed design of the structure in accordance with the provisions of ACI 350, so as to resist those loads safely); and

2. To establish the scope of the new procedures consistent with the overall scope of ACI 350. This required the inclusion of all types of tanks—rectangular, as well as circular; and reinforced concrete, as well as prestressed.

(Note: While there are currently at least two national standards that provide detailed procedures for the seismic analysis and design of liquid-containing structures (ANSI/AWWA 1995a,b), these are limited to circular, prestressed concrete tanks only).

As the loading side of seismic design is outside the scope of ACI 318, Chapter 21, it was decided to maintain this practice in ACI 350 as well. Accordingly, the basic scope, format, and mandatory language of Chapter 21 of ACI 318 were retained with only enough revisions to adapt the chapter to environmental engineering structures. Provisions similar to Section 1.1.8 of ACI 318 are included in ACI 350. This approach offers at least two advantages:

1. It allows ACI 350 to maintain ACI 318's practice of limiting its seismic design provisions to the resistance side only; and

2. It makes it easier to update these seismic provisions so as to keep up with the frequent changes and improvements in the field of seismic hazard analysis and evaluation.

ACI 350.3-06 supersedes 350.3-01 and became effective on July 3, 2006.

The seismic force levels and *R*-factors included in this standard provide results at strength levels, such as those included for seismic design in the 2003 International Building Code (IBC), particularly the applicable connection provisions of 2003 IBC, as referenced in ASCE 7-02. When comparing these provisions with other documents defining seismic forces at allowable stress levels (for example, the 1994 Uniform Building Code [UBC] or ACI 350.3-01), the seismic forces in this standard should be reduced by the applicable factors to derive comparable forces at allowable stress levels.

The user should note the following general design methods used in this standard, which represent some of the key differences relative to traditional methodologies, such as those described in ASCE (1984):

1. Instead of assuming a rigid tank for which the acceleration is equal to the ground acceleration at all locations, this standard assumes amplification of response due to natural frequency of the tank;
2. This standard includes the response modification factor;
3. Rather than combining impulsive and convective modes by algebraic sum, this standard combines these modes by square-root-sum-of-the-squares;
4. This standard includes the effects of vertical acceleration; and
5. This standard includes an effective mass coefficient, applicable to the mass of the walls.

CONTENTS