

# Seismic Loads

Guide to the Seismic Load Provisions of ASCE 7-16

> Finley A. Charney, Ph.D., P.E. Thomas F. Heausler, P.E., S.E. Justin D. Marshall, Ph.D., P.E.



### Seismic Loads

### Other Titles of Interest

#### ASCE 7 Hazard Tool

Delivers a quick, efficient way to look up key design parameters specified by Standard ASCE/SEI 7-10 and 7-16 through a web-based application that retrieves load data for each of seven hazards, visualizes them on a map, and generates a unified report of results. (ASCE 2016) (http://ascetools.online)

#### Minimum Design Loads and Associated Criteria for Buildings and Other Structures, ASCE/SEI 7-16

Provides requirements for general structural design and includes means for determining dead, live, soil, flood, wind, snow, rain, atmospheric ice, and earthquake loads and their combinations that are suitable for inclusion in building codes and other documents. A detailed commentary of explanatory and supplementary information is included. (ASCE 2016) (ISBN 978-0-7844-1424-8)

#### Significant Changes to the Minimum Design Load Provisions of ASCE 7-16

by GARY CHOCK, P.E., D.CE.; S. K. GHOSH, PH.D.; MICHAEL O'ROURKE, PH.D., P.E.; AND T. ERIC STAFFORD, P.E.

Describes the revisions to the minimum design load requirements set forth in Standard ASCE/SEI 7-16. (ASCE Press 2018) (ISBN 978-0-7844-1457-6)

#### Seismic Loads: Guide to the Seismic Load Provisions of ASCE 7-10

BY FINLEY A. CHARNEY, PH.D., P.E.

Provides clear explanations of the seismic design provisions contained in Standard ASCE/SEI 7-10. (ASCE Press 2015) (ISBN 978-0-7844-1352-4)

#### Seismic Evaluation and Retrofit of Existing Buildings, ASCE/SEI 41-17

Describes deficiency-based and systematic procedures that use performance-based principles to evaluate and retrofit existing buildings to withstand the effects of earthquakes. (ASCE 2017) (ISBN 978-0-7844-1485-9)

#### Earthquake Protection of Building Equipment and Systems: Bridging the Implementation Gap

BY JEFFREY A. GATSCHER, GARY L. MCGAVIN, AND PHILIP J. CALDWELL

Presents a framework for applying the latest earthquake engineering research to the nonstructural elements of individual building projects, concentrating on mechanical and electrical systems. (ASCE Press 2012) (ISBN 978-0-7844-1152-0)

### Seismic Loads

Guide to the Seismic Load Provisions of ASCE 7-16

Finley A. Charney, Ph.D., P.E. Thomas F. Heausler, P.E., S.E. Justin D. Marshall, Ph.D., P.E.



#### Library of Congress Cataloging-in-Publication Data

 $Names: \ Charney, \ Finley \ Allan, \ author. \ | \ Heausler, \ Thomas \ F., \ author. \ | \ Marshall, \ Justin \ D, \ author. \ Title: \ Seismic \ loads: \ guide \ to \ the \ seismic \ provisions \ of \ ASCE \ 7-16 / \ Finley \ A. \ Charney, \ Ph.D., \ P.E., \ Normalized \ Marshall, \ Seismic \ Seismic$ 

Thomas F. Heausler, P.E., S.E., Justin D. Marshall, Ph.D., P.E.

Other titles: Seismic loads (2020)

Description: Reston, Virginia : American Society of Civil Engineers, 2020. | Includes bibliographical references and index. | Summary: "Authors Charney, Heausler, and Marshall provide clear, authoritative explanations of the seismic design provisions contained in Minimum Design Loads and Associated Criteria for Buildings and Other Structures, Standard ASCE/SEI 7-16"– Provided by publisher.

Identifiers: LCCN 2019051180 | ISBN 9780784415504 (print) | ISBN 9780784482704 (pdf) | ISBN 9780784482728 (epub)

Subjects: LCSH: Earthquake resistant design–Standards. | Earthquake resistant design–Case studies.

Classification: LCC TA658.44 .C3824 2020 | DDC 624.1/762021873-dc23 LC record available at https://lccn.loc.gov/2019051180

Published by American Society of Civil Engineers 1801 Alexander Bell Drive Reston, Virginia 20191-4382 www.asce.org/bookstore | ascelibrary.org

Any statements expressed in these materials are those of the individual authors and do not necessarily represent the views of ASCE, which takes no responsibility for any statement made herein. No reference made in this publication to any specific method, product, process, or service constitutes or implies an endorsement, recommendation, or warranty thereof by ASCE. The materials are for general information only and do not represent a standard of ASCE, nor are they intended as a reference in purchase specifications, contracts, regulations, statutes, or any other legal document. ASCE makes no representation or warranty of any kind, whether express or implied, concerning the accuracy, completeness, suitability, or utility of any information, apparatus, product, or process discussed in this publication, and assumes no liability therefor. The information contained in these materials should not be used without first securing competent advice with respect to its suitability for any general or specific application. Anyone utilizing such information assumes all liability arising from such use, including but not limited to infringement of any patent or patents.

ASCE and American Society of Civil Engineers-Registered in US Patent and Trademark Office.

*Photocopies and permissions.* Permission to photocopy or reproduce material from ASCE publications can be requested by sending an email to permissions@asce.org or by locating a title in the ASCE Library (http://ascelibrary.org) and using the "Permissions" link.

Errata: Errata, if any, can be found at https://doi.org/10.1061/9780784415504.

Copyright © 2020 by the American Society of Civil Engineers. All Rights Reserved. ISBN 978-0-7844-1550-4 (print) ISBN 978-0-7844-8270-4 (PDF) ISBN 978-0-7844-8272-8 (ePub) Manufactured in the United States of America.

26 25 24 23 22 21 20 1 2 3 4 5

### Contents

Preface xi

Abbreviations and Symbols xv

Table of Conversion Factors xvii

Chapter 1	<b>Overview of the ASCE 7 Seismic Load Provisions</b> 1
	1.1 Intent of the Seismic Load Provisions 1
	1.2 Brief History of ASCE 7 Seismic Load Provisions $2$
	1.3 Overview of the Update Process for ASCE 7 5
	1.4 Significant Changes in ASCE 7-16 Relative to ASCE 7-10 7
Chapter 2	Risk Category 9
	2.1 Overview 9
	2.2 Examples 11
Chapter 3	Determining Ground Motion Parameters 17
	3.1 Examples 21
	3.2 Using the ASCE 7 Hazard Tool 23
Chapter 4	Site Class Procedure for Seismic Design 27
	4.1 Gathering Data 28
	4.2 Site Class Determination 28
	4.3 Site Classification Example <i>31</i>
	4.4 Comments on Site Classification 33
Chapter 5	Developing an Elastic Response Spectrum 35
	5.1 Development of an Elastic Vertical Response Spectrum 39
Chapter 6	Importance Factor and Seismic Design Category 41
	6.1 Seismic Importance Factor $I_e$ 41
	6.2 Seismic Design Category 43

#### Chapter 7 Selection of Structural Systems 47

- 7.1 Structural Configuration Issues 50
- 7.2 Bearing Wall Systems 50
- 7.3 Dual Systems 52
- 7.4 Coupled Reinforced Concrete Shear Wall Systems 54
- 7.5 Cantilevered Column Systems 55
- 7.6 Steel Frame Systems Not Specifically Detailed for Seismic Resistance 55
- 7.7 Alternate and Nonconforming Systems 56

#### Chapter 8 Combinations of Lateral Load Resisting Systems 57

8.1 Combinations of Framing Systems in the Same Direction or in Different Directions 58

8.2 Combinations of Structural Systems in the Vertical Direction 62

8.3 Computing Approximate Periods of Vibration for Combined Systems 64

8.4 Vertical Combination When the Lower Section Is Stiff Relative to the Upper Portion 65

#### Chapter 9 Diaphragm Flexibility 67

9.1 Example Classification of Diaphragm Flexibility Using Section 12.3.1.3 69

9.2 Accidental Torsion in Systems with Semirigid Diaphragms 72

#### Chapter 10 Horizontal Structural Irregularities 75

- 10.1 Torsional Irregularities (Types 1a and 1b) 75
- 10.2 Reentrant Corner Irregularity (Type 2) 80
- 10.3 Diaphragm Discontinuity Irregularity (Type 3) 81
- 10.4 Out-of-Plane Offset Irregularity (Type 4) 83
- 10.5 Nonparallel System Irregularity (Type 5) 85
- 10.6 Consequences of Horizontal Irregularities 85

#### Chapter 11 Vertical Structural Irregularities 87

- 11.1 Soft Story (Stiffness) Irregularities (Types 1a and 1b) 87
- 11.2 Weight (Mass) Irregularity (Type 2) 92
- 11.3 Vertical Geometric Irregularity (Type 3) 93

11.4 In-Plane Discontinuity in Vertical Lateral Force-Resisting Element Irregularity (Type 4) 93

11.5 Discontinuity in Lateral Strength–Weak Story Irregularity (Types 5a and 5b) 94

11.6 Consequences of Vertical Irregularities 97

#### Chapter 12 Redundancy Factor 99

#### Chapter 13 Load Combinations 105

13.1 Basic Load Combinations 106

13.2 Special Seismic Load Combinations, Including the Overstrength Factor 111

#### Chapter 14 Selection of Structural Analysis Procedures 113

- 14.1 Selection of Structural Analysis Procedures 114
- 14.2 Examples for Computing  $T_S$  and Comparing to 3.5  $T_S$  115
- 14.3 Structural Analysis Considerations 117

#### Chapter 15 Structural Modeling Requirements 119

15.1 Overview of Mathematical Modeling Requirements 119

#### Chapter 16 Effective Seismic Weight (Mass) 125

16.1 Example 1: 4-Story Book Warehouse and Office Building in Burlington, Vermont 125
16.2 Example 2: Low-Rise Industrial Building 133

#### Chapter 17 Period of Vibration 135

17.1 Approximate Fundamental Period T<sub>a</sub> 135
17.2 Computing T<sub>a</sub> for Masonry and Concrete Shear Wall Structures 141
17.3 Periods of Vibration for Three-Dimensional Systems 143

17.4 Differences Between  $C_u T_a$  and  $T_{\text{computed}}$  146

#### Chapter 18 Description and Use of the Equivalent Lateral Force Procedure 147

18.1 Overview of the ELF Procedure 148
18.2 Use of the ELF Procedure for Purposes Other than Final Design 153

#### Chapter 19 Drift and P-delta Effects 157

- 19.1 Example Building 160
- 19.2 P-delta Effects 164
- 19.3 Back-Calculation of Stability Ratios when P-delta Effects are Included in Analysis  $\ 166$
- 19.4 Computation of Actual Story Overstrength 168

Chapter 20	Accidental Torsion and Amplification of Accidental Torsion 171
	20.1 Application of Accidental Torsion in Systems with Relatively Flexible Semirigid Diaphragms <i>178</i>
	20.2 Application of Accidental Torsion and Torsional Amplification in Modal Response Spectrum and Linear Response History Analysis 179
Chapter 21	Equivalent Lateral Force Analysis 185
	21.1 8-Story Building 186
	21.2 Two-Stage ELF Procedure According to Section 12.2.3.2 <i>198</i>
Chapter 22	Modal Response Spectrum Analysis 205
	22.1 Overview <i>206</i>
	22.2 Response Spectrum Used for Analysis 207
	22.3 System Modeling 208
	22.4 Modal Properties 208
	22.5 Number of Modes to Include in the Analysis and Modal Combination Procedure 209
	22.6 Initial Scaling of Results (Determining Modal Response Parameters) 211
	22.7 Analysis Results 211
	22.8 Determination of Force Results 214
Chapter 23	Linear Response History Analysis 221
	23.1 Overview <i>222</i>
	23.2 Response Spectrum Used for Analysis 223
	23.3 System Modeling 224
	23.4 Modal Properties 224
	23.5 Number of Modes to Include in the Analysis and Modal
	Combination Procedure 225
	23.6 Ground Motion Selection and Modification 225
	23.7 Analysis Results 234
Chapter 24	Comparison of Computed Response Using ELF, MRS, and LRH Analysis 249
	24.1 Inelastic Story Drift Comparisons 249
	24.2 Elastic Base Shear Comparisons 251
Chapter 25	Nonlinear Response History Analysis 261
	25.1 Development Process <i>263</i>

25.2 Overview of the ASCE 7-16 Chapter 16 Provisions 264

#### Chapter 26 Diaphragms and Collectors 269

#### Chapter 27 Nonstructural Components 277

27.1 Example of Empirical Method for 4-Story Reinforced Concrete Building 280
27.2 Development and Use of Floor Response Spectra 287

27.3 1% Damping 292

## Chapter 28 Nonbuilding Structures 293 28.1 Example 1: Pipe Rack 295 28.2 Example 2: Large Equipment Structures on a Pile Supported Mat 306

#### Chapter 29 Complete Seismic Load Analysis of Simple Building 309

- 29.1 Simple Building Details 309
- 29.2 Seismic Design 310
- 29.3 Accidental Torsion 312
- 29.4 Member and Connection Checks 314

#### Chapter 30 Frequently Asked Questions 321

I. Questions Covering General Issues 321

II. Questions Covering Design Issues 324

III. Questions Covering Structural Analysis Issues 329

#### Appendix A Overview of Modal Response History and Modal Response Spectrum Analysis 345

- A.1 Overview of the MRS Procedure 346
- A.2 Overview of the Modal Response History Procedure 347
- A.3 Unified Approach 348
- A.4 Direct Response History Analysis 348
- A.5 Advantages of Response History Analysis 348

#### Appendix B 8-Story Building Case Study Structure 351

References 361 Index 365 About the Authors 373