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The Structural Engineers Association of California (SEAOC) is a professional association of four regional member organizations (Southern California, Northern California, San Diego, and Central California). SEAOC represents the structural engineering community in California. This document is published in keeping with SEAOC's stated mission:

> Empower our members and Member Organizations to advance the people, practice, and position of structural engineering.

Editor

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Suggestions for Improvement

Comments and suggestions for improvements are welcome and should be sent to the following:

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Errata Notification

SEAOC has made a substantial effort to ensure that the information in this document is accurate. In the event that corrections or clarifications are needed, these will be posted on the SEAOC website at www.seaoc.org and on the ICC website at www.iccsafe.org.

SEAOC, at its sole discretion, may issue written errata.

Table of Contents

Preface to the 2021 *IBC SEAOC Structural/Seismic Design Manual*

The *IBC SEAOC Structural/Seismic Design Manual*, throughout its many editions, has served the purpose of illustrating good seismic design and the correct application of building-code provisions. The manual has bridged the gap between the discursive treatment of topics in the *SEAOC Blue Book* (*Recommended Lateral Force Requirements and Commentary*) and real-world decisions that designers face in their practice.

The examples illustrate code-compliant designs engineered to achieve good performance under severe seismic loading. In some cases simply complying with building-code requirements does not ensure good seismic response. This manual takes the approach of exceeding the minimum code requirements in such cases, with discussion of the reasons for doing so.

This edition comprises four volumes:

- Volume 1: Code Application Examples
- Volume 2: Examples for Light-Frame, Tilt-Up, and Masonry Buildings
- Volume 3: Examples for Concrete Buildings
- Volume 4: Examples for Steel-Framed Buildings

In general, the provisions for developing the design base shear, distributing the base-shear-forces vertically and horizontally, checking for irregularities, etc., are illustrated in Volume 1. The other volumes contain more extensive design examples that address the requirements of the material standards (for example, ACI 318 and AISC 341) that are adopted by the IBC. Building design examples do not illustrate many of the items addressed in Volume 1 in order to permit the inclusion of less-redundant content.

Each volume has been produced by a small group of authors under the direction of a manager. The managers have assembled reviewers to ensure coordination with other SEAOC work and publications, most notably the *Blue Book*, as well as numerical accuracy.

This manual can serve as a valuable tool for engineers seeking to design buildings and building components for good seismic response.

Rafael Sabelli and Katy Briggs
Project Managers

Preface to Volume 3

Volume 3 of the 2021 *IBC SEAOC Structural/Seismic Design Manual* illustrates the design requirements for reinforced concrete shear wall and moment-frame seismic systems, parking garages, foundation systems, and diaphragm and collectors.

The design examples in this volume are governed by standards developed by the American Concrete Institute (ACI) in ACI 318, Building Code Requirements for Structural Concrete, and by modifications to that document included in the 2021 IBC. The design examples in this volume approach the solution based on the ductility expectations for the system/component and based on the desired seismic response. In most examples there are several mechanisms that can be utilized to achieve the desired ductility and required resistance, and in each example the author has chosen the appropriate option. The alternatives and the reasons for not choosing them are discussed where applicable.

The examples follow the recommendations provided in the *SEAOC Blue Book* and other SEAOC recommendations. They are intended to assist designers in developing structures and components of structures that achieve good seismic performance. This manual is not intended to be a building code, nor is it intended to provide an exhaustive list of all detailing and design approaches.

Seven of the design examples have been included in past editions of this manual and are updated in this edition: reinforced concrete shear wall, reinforced concrete shear wall with coupling beams, reinforced concrete special moment frame, reinforced concrete parking garage, pile foundation, pile foundations at a special moment resisting frame, and design of concrete diaphragm and collector. A new example for the design of a reinforced concrete ductile coupled wall system has been added to this volume. This new design example utilizes a system that is introduced in ASCE 7-22.

Katy Briggs
Volume 3 Manager

Acknowledgments

Volume 3 of the 2021 *IBC SEAOC Structural/Seismic Design Manual* was written by a group of highly qualified structural engineers, chosen for their knowledge and experience with structural engineering practice and seismic design. The authors are

Joe Maffei, S.E., Ph.D., Maffei Structural Engineering—Examples 1 and 2
Joe is an expert on the seismic evaluation, design, and retrofitting of structures. He has directed a range of projects, including those using innovative solutions and advanced methods of evaluation. Joe has received awards including a Fulbright Fellowship to New Zealand, where he completed his Ph.D. degree, and a postdoctoral scholarship to Japan. He served as Director for EERI and SEAONC, and in 2015 he was elected as a fellow of SEAOC. The American Society of Civil Engineers and the American Concrete Institute have appointed Joe to committees writing structural code provisions. www.maffei-structure.com

Karl Telleen, S.E., Maffei Structural Engineering—Examples 1 and 2
Karl has 19 years of experience, including seismic evaluation and retrofit of concrete and steel buildings, design and peer review of new structures, and wind and seismic analysis of solar arrays. He completed a Fulbright Fellowship in Switzerland in 2010, and he was selected as an EERI Housner Fellow in 2017. Karl served as Director and Treasurer of SEAONC, and he co-authored papers in the journals Earthquake Spectra, Concrete International, and the ASCE Journal of Structural Engineering.
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Martin has 13 years of research experience in structural engineering, including structural fire engineering and seismic evaluation of existing concrete and steel buildings. He holds a Ph.D. from ETH Zurich, Switzerland, and was awarded a Postdoctoral Research Fellowship of the Swiss National Science Foundation that he completed at the Pacific Earthquake Engineering Research Center at UC Berkeley. Martin authored papers in several peer-reviewed journals, including the ASCE Journal of Structural Engineering, Construction and Building Materials, and ACI Materials Journal.

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Jon has 40 years of experience as a structural design and consulting engineer in Northern California. His practice has included extensive experience in seismic analysis and evaluation of existing buildings, the design of new construction, and the seismic strengthening and rehabilitation of existing building projects. He is a Past President of the Structural Engineers Association of California and Structural Engineers Association of Northern California, and a Fellow Member of both organizations. His current committee assignments include the ASCE 7-22 Seismic Sub-Committee (SSC), and TC-2 General Provisions task committee of SSC. www.ida-se.com

Mehran Pourzanjani, S.E., F. SEAOC, Senior Principal, Saiful/Bouquet Structural Engineers—Example 3
Mehran has 40 years of experience designing a wide spectrum of structures, from institutional and public buildings to healthcare, regional malls, high-rise structures, and evaluation and strengthening of existing buildings. Mehran has served as the President of SEAOSC and a Board Director for SEAOC. Additionally, he has served as the past-chair of the SEAOC Seismology Committee, a member of ACI 318H Seismic Provisions Sub-Committee, and ASCE 7-22 Seismic Subcommittee's TC-4 group. He continues to serve on SEAOC's Standards Committee. Mehran has participated in university research through codification for the design and seismic performance of concrete elements. Additionally, as the chair of the SEAOC seismology committee, he spearheaded the development and publication of the 2009 *SEAOC Blue Book* and was the main author of the "Reinforced Concrete Structures" section in the book.

Jeremiah LeGrue, S.E., City of Eugene—Example 4
Jeremiah has over 20 years of structural engineering experience. He is a graduate of Oregon State University and Stanford University. Prior to joining the City of Eugene as a Structural Plans Examiner, he worked for 17 years as a consulting structural engineer. His experience includes work as both designer and peer reviewer for new buildings and seismic evaluation and retrofit of existing buildings using both IBC and ASCE 41-based approaches. www.eugene-or.gov

Stephen Harris, S.E., Independent Structural Engineering Consultant—Examples 5 and 6
Stephen Harris has practiced structural engineering for over 35 years. He is a graduate of the University of California at Davis and a registered Structural Engineer in California and Hawaii. His experience includes design of new structures, seismic strengthening of existing structures, design of pile foundation systems, and building code development. He has served as Director and Treasurer of SEAONC.

Badri K. Prasad, S.E., President, OLMM Consulting Engineers—Example 7
Badri has over 30 years of experience leading design teams for the structural engineering of major new buildings, including healthcare facilities, courts, airports, schools, and seismic retrofits. His areas of expertise include the structural design of complex buildings of all types and materials, seismic rehabilitation of existing buildings for enhanced seismic performance, design execution, and project management. He has published and presented papers at several seminars and is also one of the authors of *Guide to the Design of Diaphragms, Chords and Collectors*, published by National Council of Structural Engineers Association (NCSEA). www.olmm.com

Rahul Sharma, P.E., S.E., Project Engineer, Hohbach-Lewin, Inc.—Example 8
Rahul works on the design and analysis of both new and existing buildings. He is passionate about developing complex problem-solving skills and generally takes on challenging projects. Rahul also gets involved in several standard committees such as the ASCE 7 Seismic Subcommittee, the Building Seismic Safety Council's (BSSC) Provision Update Committee (PUC), and the SEAONC and SEAOC Seismology Committee.

Nicolas Rodrigues, P.E., S.E., Principal, Miyamoto International—Peer Reviewer Examples 3 and 8
Nic has enjoyed designing concrete structures for nearly 20 years, in many markets. Most notably, Nic has designed high-rise towers both internationally and domestically, including the tallest concrete-only tower on the west coast. Nic is honored to have served SEOAC as the chair of seismology, and chair of seismology concrete subcommittee, member of ER-ICC committee, and as a contributing author to the *SEAOC Blue Book* and previous *Design Manual* examples. Most recently, Nic volunteered for ACI as a voting member of the 318H subcommittee (Seismic Provisions) for the 2019 ACI code.

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How to Use This Document

Equation numbers in the right-hand margin refer to the one of the standards (e.g., ACI 318, ASCE 7 or IBC). The default standard is given in the heading of each section of each example; equation numbers in that section refer to that standard unless another standard is explicitly cited.

Abbreviations used in the "Code Reference" column are

§ – Section T – Table

F – Figure Eq – Equation