Practical Guide to SEISMIC RESTRAINT

Second Edition

James R. Tauby
Richard Lloyd



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About the Authors

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Richard J. Lloyd is manager of Mason Industries' engineering office in California. He holds a Bachelor of Science in Engineering from California State University at Northridge. He led Mason engineering teams in inspecting earthquake-damaged equipment installations, analyzing failures, and designing retrofits. He is a coauthor of the California Office of Statewide Health Planning and Development (OSHPD) Pre-Approval OPA-0349 "Mason Industries Seismic Restraint Guidelines for Suspended Piping, Ductwork and Electrical Systems," which he used to design and supervise the installation of seismic bracing systems on many projects. He is currently a member of the Earthquake Engineering Institute (EERI), International Code Council (ICC), Applied Technology Council (ATC), and American Society of Civil Engineering (ASCE), where he participated in the development of ASCE 7-10 (Chapter 13). He has also participated in shake table testing of equipment mounted on vibration isolation systems for equipment certification. His most recent involvement in research projects includes designing vibration isolation, seismic restraints, and piping flexible connectors for the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) "Full-Scale Structural and Nonstructural Building System Performance During Earthquakes & Post-Earthquake Fire", the large-scale shake table test of a structure with mechanical, electrical, and plumbing nonstructural components.

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Preface

There have been many interesting developments in the design of mechanical, plumbing, and electrical systems for earthquakes since publication of the first edition of this manual in 1999. Information from these developments has been used to revise some parts of this book and to add new material of interest to design engineers, contractors, owners, code enforcement agencies, and equipment manufacturers.

Included in Chapter 2 of this second edition are updated summaries of the 2009 International Building Code® (IBC®) and the American Society of Civil Engineers' (ASCE) Standard ASCE 7-10 design requirements. Also included is a summary of additional requirements from the 2010 California Building Code (CBC). In all cases, the focus on differential system displacement is highlighted.

There are updates to the specification considerations, seismic restraint devices and connection methods, and equations for seismic wind force determination along with examples. There is also a chapter that includes photographs of correct and incorrect methods for installation of mechanical, electrical, and plumbing equipment and piping.

An important addition is the information on equipment certification in Chapter 4. In the first edition, this chapter was limited to a discussion of equipment ruggedness from a nuclear industry study and some information on shipping fragility and test methods. This information has for the most part been deleted. A summary of industry standard fragility levels has been retained as a useful general reference. But the additional information on equipment shake table testing and equipment certification may be of particular value to equipment manufacturers, who may be struggling with meeting equipment certification requirements and confused over the options of analysis, testing, or experience data.

Although the testing and analysis of equipment is important, current equipment certification standards do not address piping connections. In an earthquake, the piping connected to equipment can be subject to differential displacement, straining and rupturing vulnerable piping connections. Broken piping connections were to blame for many instances of equipment shutdown in an earthquake. Accordingly, new codes require system design to accommodate differential displacements. This second edition includes valuable new information on the advantages of different types of flexible connectors, the importance of proper connector orientation, and the need for flexible connector testing to develop accurate stiffness at operating pressure.

In Chapter 5 of the first edition, we noted that concrete anchor values were easily obtainable from ICBO reports where, with a few adjustments for spacing and edge distance, most

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engineers could comfortably select anchor bolts. Since that time, we have learned of the critical importance of cracked-concrete testing of anchors and complex calculations to determine various anchor failure modes. Included in the second edition are illustrations and descriptions of anchors with cracked-concrete testing and a table of allowable loads for reference.

We believe this guide remains pertinent for the design engineer, installing contractors, code officials, local inspectors, and others who are interested in seismic and wind restraint design. Although this publication is considered a design guide, it should be understood that the information it presents reflects our understanding of the current code requirements and generally accepted good engineering practices. The responsibility for satisfying local codes and regulations still remains with the design professional.

Jim Tauby
Rich Lloyd
November 2011

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As with any publication, there are people and organizations that deserve to be thanked for their assistance. This publication is no different. The very first person we would like to thank is former ASHRAE President, Terry Townsend. Terry was the inspiration to ASHRAE Technical committee TC 2.7 Seismic and Wind Restraint to begin the process to have this publication written. Terry has helped coach us through this and other ASHRAE projects throughout the years. To say this publication would have not been possible without his guidance is an understatement.

We would like to thank ASHRAE Technical Committee TC 2.7. Their editing skills of the first edition and technical guidance for both editions of this publication were invaluable.

We would like to thank our original co-authors of the first edition, Todd Noce and Joep Tunnissen. They contributed to several chapters and helped edit the first edition.

We were extremely lucky to have Norm Mason edit this manual. Norm Mason gave the first ASHRAE talk on the design of Seismic Restraints in San Francisco in the early 1970s. This manual and the industry as a whole is an extension of that talk.

Most importantly, we would like to thank our wives, Maureen Tauby and Ellen Lloyd, for their support and understanding. Without their understanding and allowances into our personal time, this publication would not have been possible.

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1 Fundamentals of Earthquakes

An earthquake is simply defined as shaking of the ground. This shaking can cause irreparable damage to natural and human-made structures. It has been known to change the course of rivers, cause landslides down into valleys, and create tsunamis that engulf islands. There are three natural and one human-made cause for earthquakes.

COLLAPSE EARTHQUAKES

Collapse earthquakes are the least common of the natural causes. They are caused by the sudden fall of the roof of an underground cavern or mine. Earthquakes that are caused by a landslide are also grouped into the collapse category.

VOLCANIC EARTHQUAKES

These are earthquakes that are caused by volcanic activity. Their large explosive eruptions can produce shock waves that form earthquakes. Volcanoes are usually formed on the edges of the tectonic plates and are linked, therefore, to the final natural cause, the tectonic earthquake.

TECTONIC EARTHQUAKES

This is the most common earthquake. The shifting or slipping of one tectonic plate edge adjacent to another causes most tectonic earthquakes. This slipping could be minor, as in a tremor, or major, as in a full earthquake.

EXPLOSIVE EARTHQUAKES

These are human-made quakes that are usually caused by underground nuclear explosions.

PLATES

Plates (or tectonic plates) are the outermost rock layers and cover the entire surface of the Earth. The major tectonic plates are shown in Figure 1-1. The plates themselves are relatively stable in their interiors but are unstable where they contact adjacent plates. The constant moving of the plates, as they try to slip past or under one another, can cause violent earthquakes. Most earthquakes occur at faults along the plates.

FAULTS

A fault is an offset in a geological structure. Inactive faults are faults that have not been active for thousands of years. They are well documented and their abrupt strata changes are easily identifiable. Active faults, on the other hand, move constantly, producing stress and eventually giving rise to earthquakes. Active faults are also documented, with new faults being discovered after each seismic event.

There are three basic fault types, as seen in Figure 1-2. The first is a normal fault. A normal fault is a vertical displacement, where one side slips downward, at an angle from 0° to 90° away from the other side. The second is a reverse fault, which is also a vertical displacement, where one side slides up past the other. Both normal and reverse faults are