Example Application Guide for ASCE/SEI 41-13, *Seismic Evaluation and Retrofit of Existing Buildings*

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Abstract

FEMA, through the ATC-124 Project series, and with assistance from SEAOC, has sponsored development of an *Example Application Guide* offering guidance on the interpretation and use of ASCE/SEI 41-13. Development is nearing completion, resulting in a set of step-by-step illustrative examples and commentary on issues related to Performance Objectives, data collection, materials testing and knowledge factors, primary versus secondary components, overturning, foundation design, soil-structure interaction, Tier 1 and Tier 2 evaluations, and evaluation and retrofit design of material-specific systems including tilt-up, wood light-frame, steel moment frame, steel braced frame, concrete shear wall, and unreinforced masonry systems.

This paper provides an overview of the topics and examples covered in the *Example Application Guide*; discussion of the approach taken toward organization, presentation, and quality assurance; and a summary of key issues identified in the development of the design examples.

Introduction

For over 30 years, the Federal Emergency Management Agency (FEMA) has had an extensive program to address the seismic safety of existing buildings. This program has led to the development of guidelines and standards for existing buildings that form the basis of current practice for the seismic evaluation and performance-based design of seismic retrofits in the United States.

FEMA engaged the Applied Technology Council (ATC) to develop design guidance for the ASCE/SEI 41-13 consensus standard, *Seismic Evaluation and Retrofit of Existing Buildings* (ASCE, 2014), a need that was identified by the Existing Buildings Committee of the Structural Engineers Association of California (SEAOC) and that aligns with FEMA's desire to replace and improve FEMA 276, *Example Applications of the NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (FEMA, 1997).

The primary objective of the ATC-124 project is to develop a FEMA-supported document, identified as an *Example Application Guide*, that will provide design examples for seismic retrofit and evaluation of buildings using the ASCE/SEI 41 standard. Work includes coordination with the current ASCE Standards Committee on Seismic Retrofit of Existing Buildings.

The ATC-124 project is a three-year effort, with completion expected by the end of 2017. The initial steps in the project included review of sample design example documents and a survey of the industry, including SEAOC members, to identify issues and design guidance needs. This was summarized in Lizundia, et al. (2015). Respondents provided over 100 recommendations. Survey results and recommendations were used to help select the topics that would be included in the *Example Application Guide*.

This paper begins with a description of purpose and target audience for the *Guide* and then reviews the project organization, approach, and presentation strategies. Next, an overview of key topics is given. This is followed by a summary of each of the detailed case study examples. The paper concludes with some highlights of issues identified in the development of the design examples and with general advice on how to best use ASCE/SEI 41-13.

Purpose

The consensus national standard for the seismic evaluation and retrofit of existing buildings, ASCE/SEI 41-13, can be challenging for those unfamiliar with the provisions because its methods are different in many ways from those used in the design of new buildings. The purpose of the *Example Application Guide* is to provide helpful guidance on the interpretation and the use of ASCE/SEI 41-13 through a set of examples that cover key selected topics. The *Guide* covers topics that commonly occur where guidance is believed to be beneficial, with topics effectively organized and presented such that information is easy to find. Commentary accompanies the examples to provide context, rationale, and advice.

The ASCE Standards Committee on Seismic Retrofit of Existing Buildings has developed the next version of the consensus standard, due out by the end of 2017. The *Example Application Guide* includes comments regarding key changes anticipated to occur when ASCE/SEI 41-17 is published. The March 2017 public draft of ASCE/SEI 41-17 was used to identify potential changes. This draft has been approved, and ASCE is making final editorial updates for publication.

The *Guide* does not provide retrofit cost information or detailed information about retrofit techniques. The examples in the *Guide* do not necessarily illustrate the only appropriate methods of design and analysis using ASCE/SEI 41-13. Proper engineering judgment should always be exercised when applying these examples to real projects. Moreover, the ASCE/SEI 41-13 *Example Application Guide* is not meant to establish a minimum standard of care but, instead, presents reasonable approaches to solving practical engineering problems using the ASCE/SEI 41-13 methodology.

Target Audience

The target audience for the *Example Application Guide* is both practicing engineers and building officials who have limited or no experience with ASCE/SEI 41-06 (ASCE, 2007) or ASCE/SEI 41-13 and those engineers and building officials who have used these documents in the past, but have specific questions. It is assumed that the user has seismic design experience and a working knowledge of seismic design concepts. The document includes guidance and examples from locations representing higher and lower seismic hazard levels.

Project Team and Organization

The project organizational structure is shown in Figure 1. A project technical committee leads the development of the *Guide*, with FEMA and SEAOC advisors and a peer review panel providing review and advice. ATC staff members provide project management and document production services. The project team was selected by ATC and FEMA to capture a wide range of skills and expertise. Members of the technical team and peer review panel are active members of the committees that developed both ASCE/SEI 41-13 and the forthcoming ASCE/SEI 41-17.

Project Approach and Development of the Guide

To gain insight into successful strategies for presenting design examples, the project team reviewed relevant sample design example documents. A substantial number of documents were reviewed; they are summarized in Lizundia, et al. (2015). Observations and conclusions from the review included the following.

- *Length:* Providing a detailed example can take a significant amount of text and graphics. For example, in SEAOC (2012), the URM bearing wall building example is 57 pages, and the nonductile concrete moment frame building example is 122 pages. As examples accumulate from the various topics, the overall size of a design guide can grow quite large. FEMA (2012) is over 900 pages long. The SEAOC (2013a-d, 2014) structural/seismic design manual series contains five volumes. The project team initially felt that overly long documents may be less accessible and helpful, but the general consensus of the team and reviewers is that thorough examples are more helpful than summaries. To keep the *Guide* to a manageable length and within the resources available, the document includes only the topics felt to be most helpful, shows a detailed calculation only once and just provides results for similar elements, and provides cross-referencing within the *Guide* rather than repeat the same explanation in detail.

- *Graphics:* Some sample design example documents use closely spaced text. Others utilize a fair number of explanatory sketches and images. The project team concluded the latter approach made for a more readable, more helpful *Guide* and is worth the increase in overall document length. Final figures are still under development, but some examples are provided in this paper.

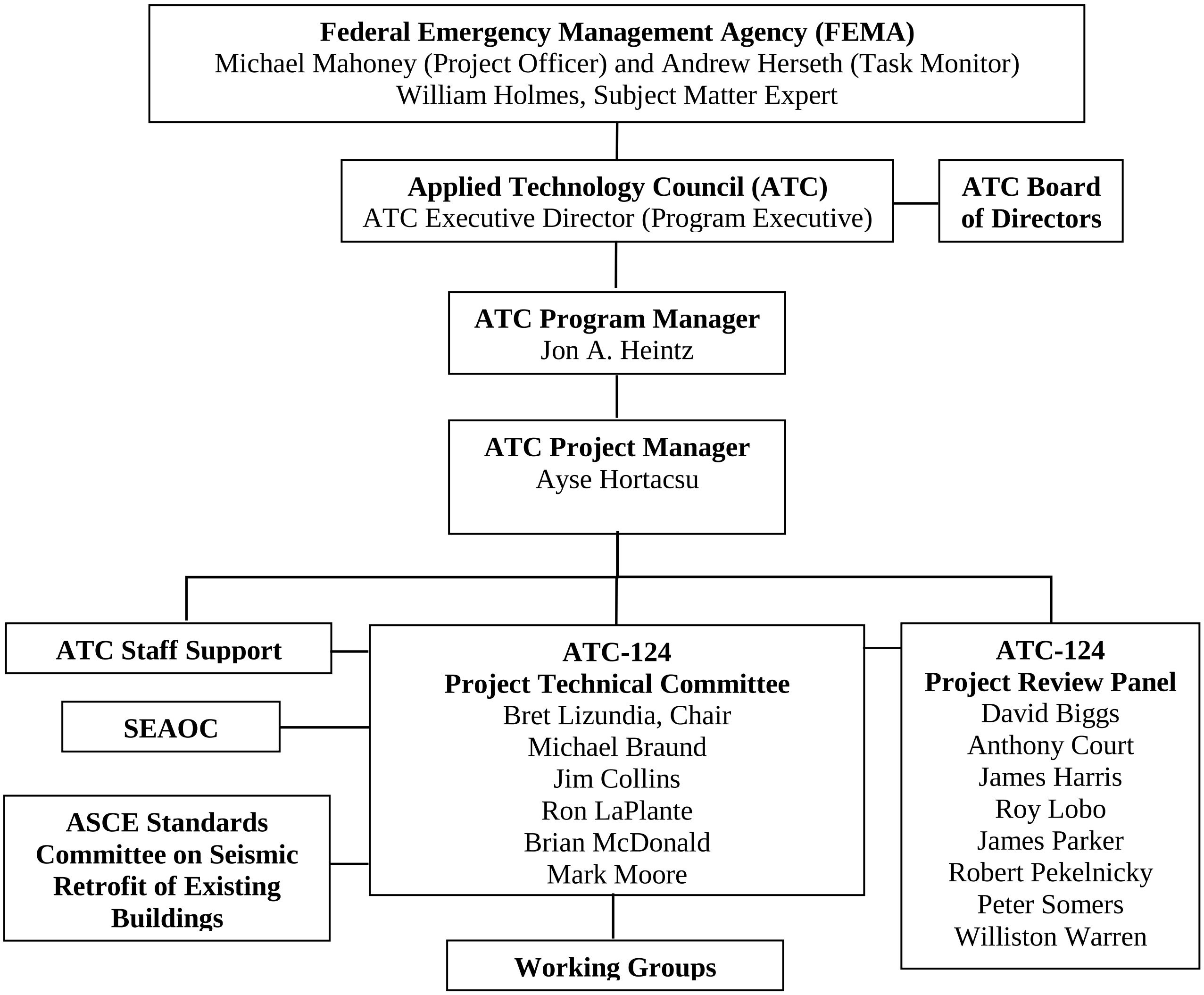

Figure 1. ATC-124 Project Organization Chart

- *Consistency in Example Presentation:* The more successful sample design documents adopt a consistent format for presenting examples that is easy to follow and helps the reader navigate quickly through the document. An outline of what is covered (and what is not) is presented at the beginning of the example so the user need not read through the entire example to find a particular topic. This strategy was adopted in the *Guide*.

- *Topics vs. Full Design Examples:* The SEAOC (2013a-d, 2014) structural/seismic design manual series combines both shorter examples that cover specific topics and more detailed examples for different materials that show evaluation and retrofit of a full building. The project team concluded this was the best approach for use with ASCE/SEI 41-13. As such, the *Guide* has shorter topic examples in the earlier chapters that cover general issues common to most building types, followed by detailed building and material specific examples in the later chapters.

- *Commentary:* Some sample documents provide straightforward, step-by-step examples that follow the reference document provisions, but they do not discuss the meaning of the results or provide tips and shortcuts based on experience. The project team has tried to provide some level of commentary and advice without an excessive amount of additional text or overly controversial and opinionated discussion.

- *Focus Group:* Since the target audience for the *Guide* includes engineers with limited or no experience using ASCE/SEI 41-13, and the authors and reviewers all have substantial experience, a focus group was convened of engineers with seismic experience, but with limited or no ASCE 41 experience. The focus group reviewed a draft of the *Guide*; their charge was not a detailed technical review, but rather an evaluation of document organization and user aids, writing clarity and style, and design example presentation. They provided numerous recommendations that were incorporated into the document to make it easier to use. These included reorganization of sections, reduction in the extent of commentary already found in ASCE/SEI 41-13, clarification of overly long sections, adding example calculations to accompany certain result tabulations, more figures, additional clarifying text in figures, refinements in the margin boxes, and detailed suggestions on specific text.

Presentation Approach

To make the *Example Application Guide* easier to use, a consistent format is taken with each example. Graphics are judiciously used to help illustrate calculations and comments and reduce the reliance on text descriptions. A wide margin layout is employed with boxes in the margin to provide helpful summaries, useful tips and commentary, and indications of key forthcoming changes in the ASCE/SEI 41-17. Figure 2 shows some example margin boxes. Flowcharts and graphics are included, particularly to help the user navigate both the *Guide* and ASCE/SEI 41-13. A detailed index and a cross reference guide are provided to aid in finding specific topics.

Quality Assurance

It is important that the *Guide* not only be informative and easy to use, but also that the examples are accurate. Given the size and detail in the *Guide*, while it is not possible to eliminate all issues, rigorous quality assurance approaches were taken. This included ATC's standard review by staff and by the peer review panel, plus internal review amongst the project team members of one another's work with a lead author and a lead reviewer. It also included independent technical reviews typically by two SEAOC members for each chapter. The SEAOC members were drawn from the Existing Building Committee and Seismology Committee, and they coordinated by Russell Berkowitz.

List of Topics and Examples in the *Guide*

At the time this paper was prepared in July 2017, the final draft for the *Example Application Guide* was being produced. The following topics and examples were included.

- Introduction
  - Purpose
  - Target audience
  - Background on development of ASCE/SEI 41
  - Basic principles of ASCE/SEI 41-13
  - What is not in the document
  - Organization of the document

- Guidance on the Use of ASCE/SEI 41-13
  - ASCE/SEI 41-13 overview
  - Comparison of ASCE/SEI 41-13 and ASCE/SEI 7-10 design principles
  - When should ASCE/SEI 41-13 be used?
  - What is coming in ASCE/SEI 41-17
  - Big picture wisdom and advice

Definition

Unreinforced masonry class: A masonry class is defined by variations in the strength, quality, materials, or condition over a building.

Generally, a class is defined by major variations in one of these properties over a large area.

Useful Tip

The in-plane demand on masonry walls is dependent on the diaphragm strength.

Therefore, the diaphragm capacity and any required diaphragm strengthening should be evaluated before performing the in-plane wall checks.

Note that the trigger for checking in-plane shear maybe revised to use S_{D1} in future editions of ASCE 41.

Figure 2. Sample Definition and Useful Tip Margin Boxes

Commentary

The Special Procedure of ASCE 41 § 15.2 defines wall pier height as the least clear height. The pier height used in the Tier 3 calculation of rocking in Chapter 12 is more complex, depending on the direction of loading.

In addition, the Special Procedure does not make a distinction between interior wall piers and corner piers with flanged returns. For simplicity, only the rectangular portion of the corner pier on the in-plane wall line is used.

Refer to Chapter 12 of this *Example Application Guide* for further discussion of pier height and corner piers using the Tier 3 evaluation.

Figure 3. Sample Commentary Margin Box

- Performance Objectives and Seismic Hazards
  - Performance Objectives and Target Building Performance Levels
  - Seismic hazard
  - Levels of Seismicity
  - Data collection, material testing, as-built information and knowledge factors

- Analysis Procedures and Acceptance Criteria
  - Analysis procedure selection
  - Determination of forces and target displacements
  - Primary vs. secondary elements
  - Force-controlled vs. deformation-controlled actions
  - Overturning
  - Out-of-plane strength of walls
  - Nonstructural components

- Foundations
  - Soil and foundation information and condition assessment
  - Expected foundation capacities and load-deformation characteristics (including bounding soil property uncertainty)
  - Shallow foundation evaluation and retrofit
  - Deep foundation evaluation and retrofit
  - Kinematic interaction and radiation damping soil-structure interaction effects
  - Liquefaction evaluation and mitigation

- Detailed Examples
  - Tier 1 Screening and Tier 2 Deficiency-Based Evaluation and Retrofit. This example uses a tilt-up concrete (PC1) building.
  - Wood tuck-under (W1a) building
  - Pre-Northridge steel moment frame (S1) building
  - Steel braced frame (S2) building
  - Concrete shear wall (C2) building
  - Unreinforced masonry bearing wall (URM) building

For each of the detailed examples, there is a standard presentation approach which includes a description of the building, site seismicity, weight takeoffs, Performance Objective and analysis procedure selection, data collection and material testing, and determination of forces and displacements. The buildings are located in different parts of the United States to present a range of seismicity. The focus is on the linear static procedure (LSP) as this is the most common analysis procedure, although some examples include the linear dynamic procedure (LDP), and the nonlinear static procedure (NSP). Most examples use the Basic Performance Objective for Existing Buildings (BPOE) as this is the most common Performance Objective, but the URM Special Procedure example and an Enhanced Performance Objective for the steel braced frame are included.

Table 1 shows a summary of some information regarding the detailed examples that are planned for the *Guide*. This is followed by a summary of selected information on each of the detailed design examples.

Table 1: Detailed Examples

FEMA Building Type[1]	Risk Category	Location	Level of Seismicity	Performance Objective[2]	Analysis Procedure[3]	Retrofit Procedure
PC1	II	Anaheim, CA	High	BPOE	LSP	Tier 1 and Tier 2 Deficiency-Based
W1a	II	San Jose, CA	High	BPOE	LSP	Tier 3
S1	II	SF Bay Area	High	BPOE	LSP, LDP, NSP	Tier 3
S2	III	Charlotte, NC	Moderate	Enhanced (IO)	LSP	Tier 3
C2	III	Seattle, WA	High	BPOE	LSP, NSP	Tier 3
URM	II	Los Angeles	High	Reduced	Special	Tier 2 Deficiency-Based
URM	II	Los Angeles	High	BPOE	LSP, NSP	Tier 3

Notes:

1. PC1 = Tilt-up concrete shear wall; W1a = Wood multi-story, multi-unit residential (tuck-under); S1 = Steel moment frame, S2 = Steel braced frame, , C2 = Concrete shear wall, URM = Unreinforced masonry bearing wall
2. BPOE = Basic Performance Objective for Existing Building, IO = Immediate Occupancy
3. LSP = Linear Static Procedures; LDP = Linear Dynamic Procedure; NSP = Nonlinear Static Procedure

Tilt-up (PC1) Example

The tilt-up building is located in Anaheim, California. It is a Risk Category II, one-story warehouse designed in 1967. The focus of the example is to provide a detailed description of a Tier 1 screening, including completion of a full set of sample checklists, followed by a Tier 2 Deficiency-Based evaluation and retrofit. The BPOE is the Performance Objective. The Tier 1 screening deficiencies include noncompliant and insufficient quantities of roof-to-wall anchorage; wood ledgers in cross-grain bending; noncompliant crossties in the flexible wood roof diaphragm at girders, purlins and subpurlins; a missing collector at a reentrant corner; and tilt-up wall thicknesses that exceed the permitted height-to-thickness ratio Figure 4 shows a typical perimeter roof-to-wall condition. Figure 5 shows the building geometry; and Figure 6 shows a roof-to-wall tie retrofit.

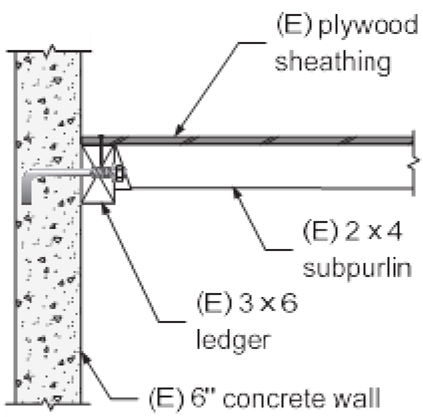

Figure 4: Existing Subpurlin Support at Ledger

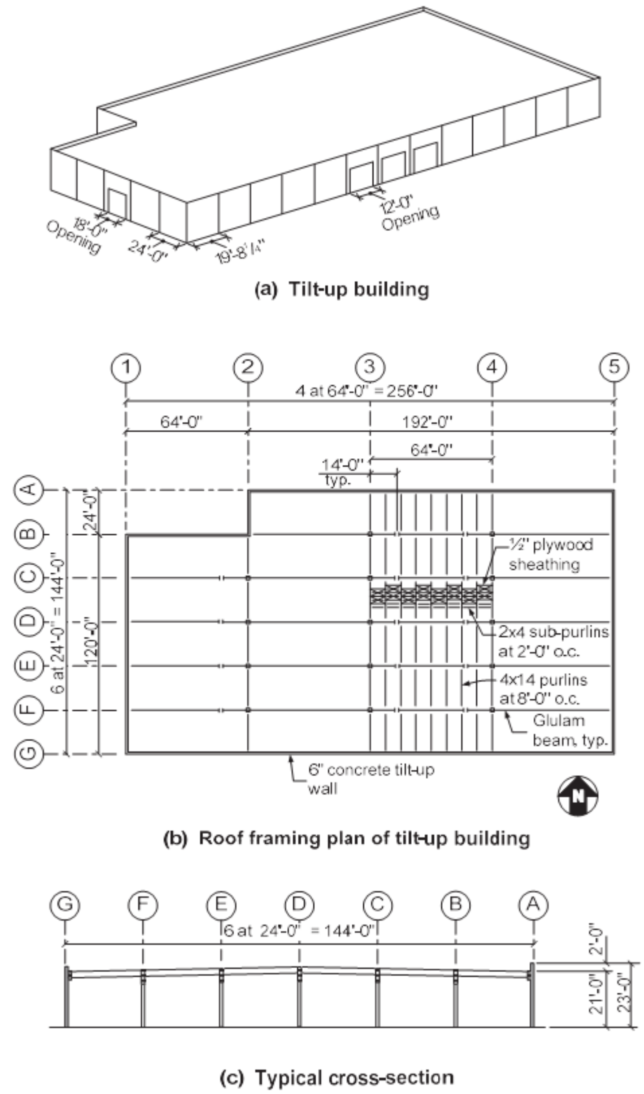

Figure 5: Tilt-up Building Geometry

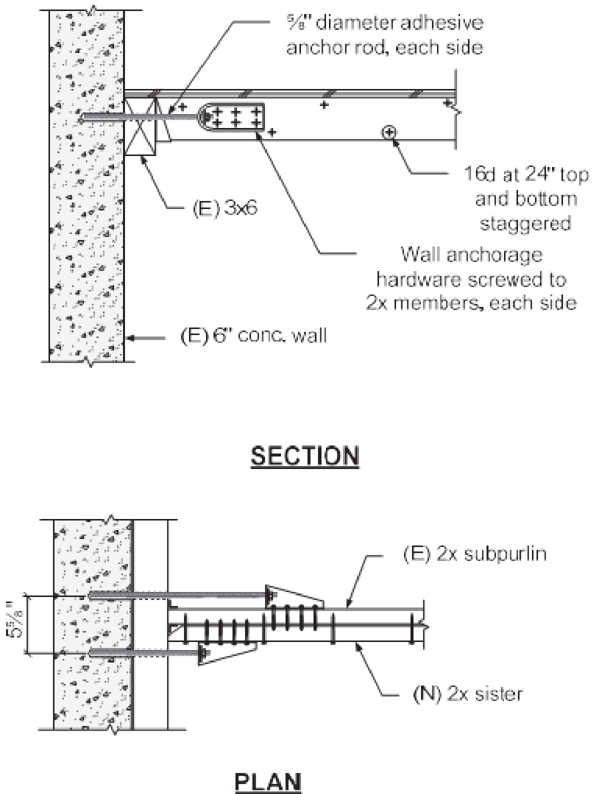

Figure 6: Roof-to-Wall Tie Retrofit

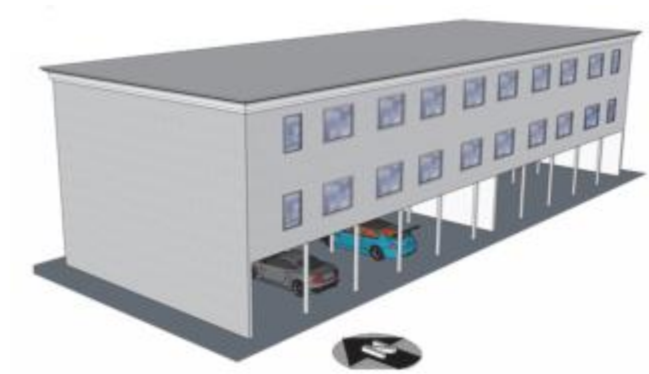

Figure 7: Isometric of the Tuck-under Building

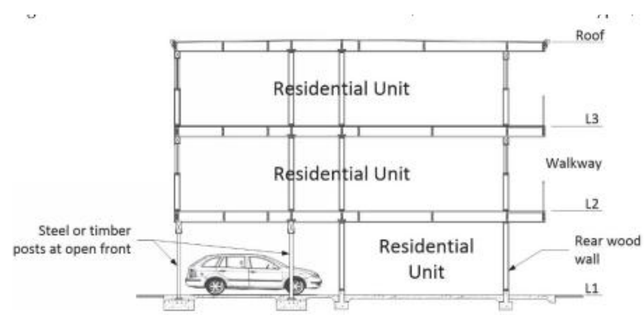

Figure 8: Cross Section

Wood Tuck-under (W1a) Example

The tuck-under building is located in San Jose, California. It is a Risk Category II, three-story apartment building built in the 1960s. The focus of the example is to summarize the Tier 1 screening and identification of the weak story deficiency, and then to provided a detailed Tier 3 evaluation and retrofit of the entire structure. The BPOE is the Performance Objective. The example covers detailed evaluation of shear wall strengths and stiffnesses for the existing structure and the retrofitted building, design of shear wall hold-downs, and design of aspects of a steel moment frame retrofit at the ground story.

Figure 7 shows an isometric of the building, and Figure 8 shows a cross section. Figure 9 shows the existing ground story, and Figure 10 shows the retrofitted ground story with the primary lateral force-resisting elements highlighted.

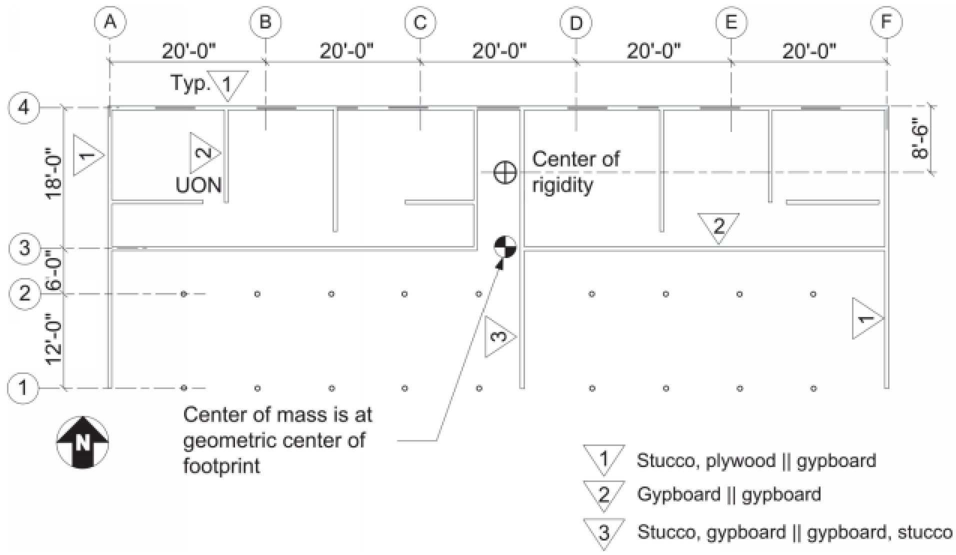

Figure 9: Existing Ground Story

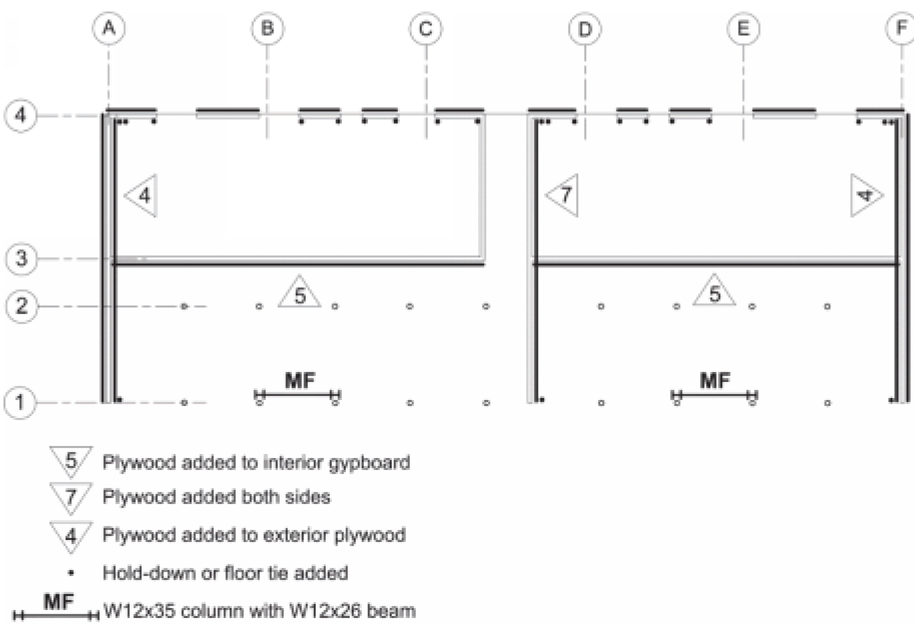

Figure 10: Bottom Story Primary Elements in Retrofit

Pre-Northridge Steel Moment Frame (S1) Example

The steel moment frame building is located in the San Francisco Bay. It is a Risk Category II, four-story office building built in 1985. The focus of the example is on evaluating the moment frame elements including the beam-to-column joints which are typical of buildings designed before code changes that resulted from research into the damage observed in the 1994 Northridge Earthquake. The BPOE is the Performance Objective. Analysis procedures include the LSP, LDP, and NSP.

Figure 11 shows an isometric of the perimeter moment frames. Figure 12 shows a plan of a typical floor. The building has a large off center internal atrium. Figure 13 shows a schematic of a typical beam-to-column connection.

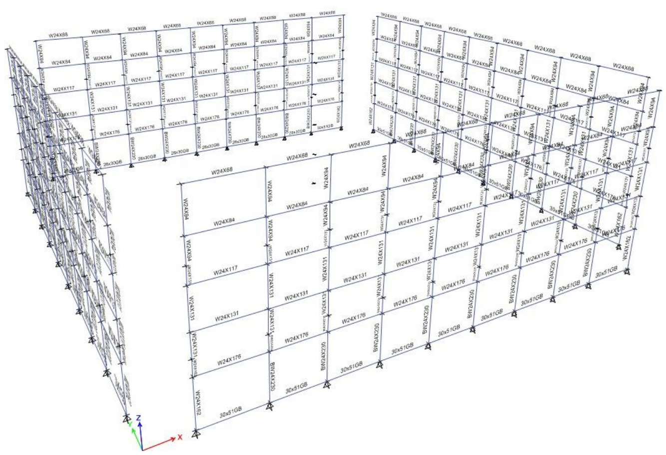

Figure 11: Isometric of Perimeter Moment Frame

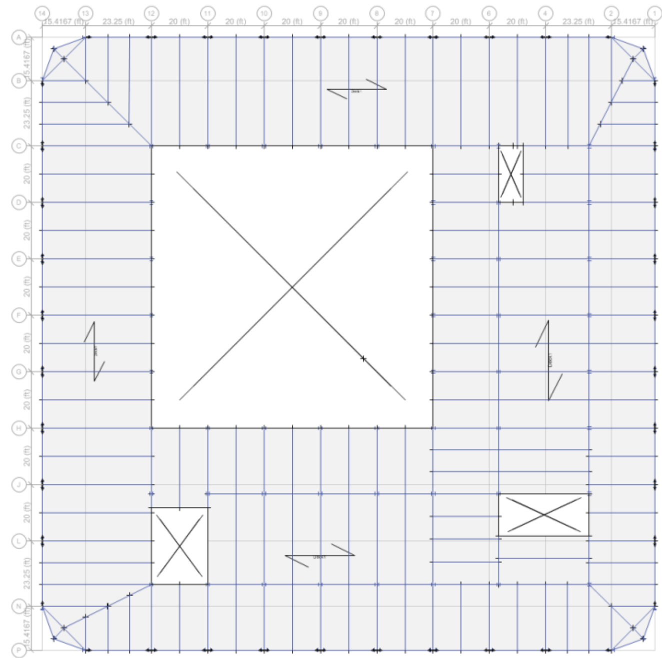

Figure 12: Typical Floor Plan

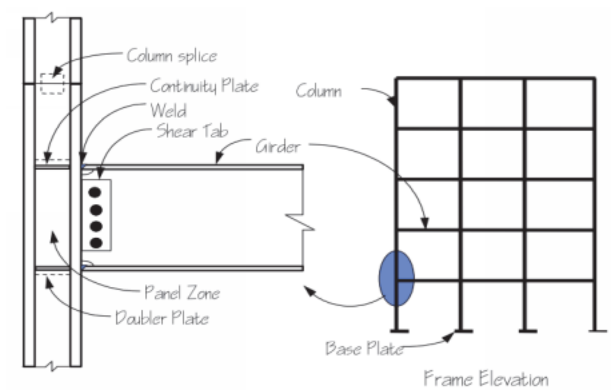

Figure 13: Typical Pre-Northridge WUF Beam-to-Column Connection

Steel Braced Frame (S2) Example

The braced frame building is located in the Charlotte, North Carolina, a region with a moderate Level of Seismicity per ASCE/SEI 41-13. It is a Risk Category II, three-story laboratory building. It was designed to the 1980 edition of Southern Building Code Congress International (SBCCI) Standard Building Code (SBC) with perimeter ordinary concentrically-braced frames. An Enhanced Performance Objective was selected for evaluation which is the Immediate Occupancy Structural Performance Level at the BSE-1N Seismic Hazard Level. The focus of the example is on evaluating the braced frame elements including the brace-to-column joints which are typical of buildings designed before more recent code changes aimed to improve brace ductility and reliability. Evaluation of spread footings under the braces is also covered. The LSP is presented initially, followed by the NSP of one of the building braced bays to compare and contrast the linear and nonlinear behavior of this type of structure with the ASCE/SEI 41-13 modeling and acceptance criteria requirements

Figure 14 shows a typical floor plan. Figure 15 shows a typical braced frame elevation. Figure 16 shows a typical brace-to-beam connection detail.

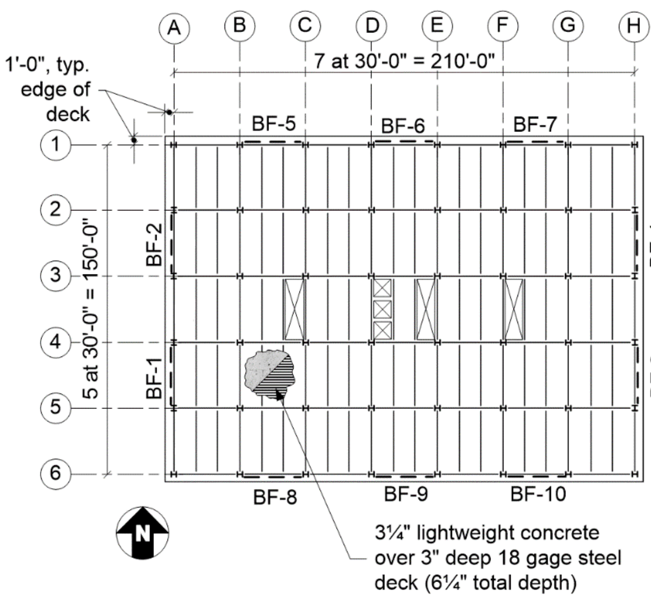

Figure 14: Typical Floor Plan

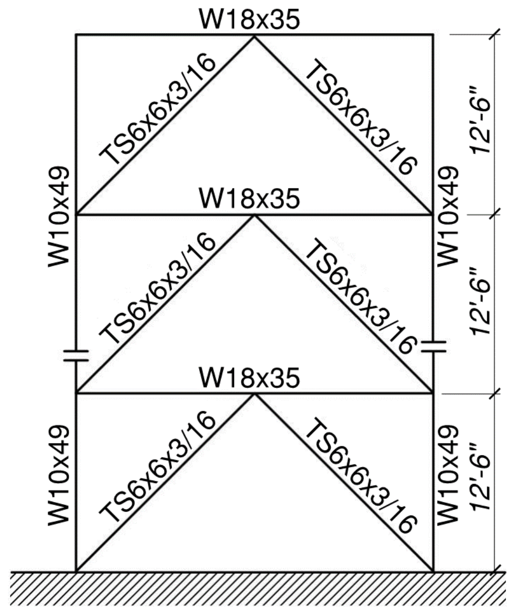

Figure 15: Typical Braced Frame

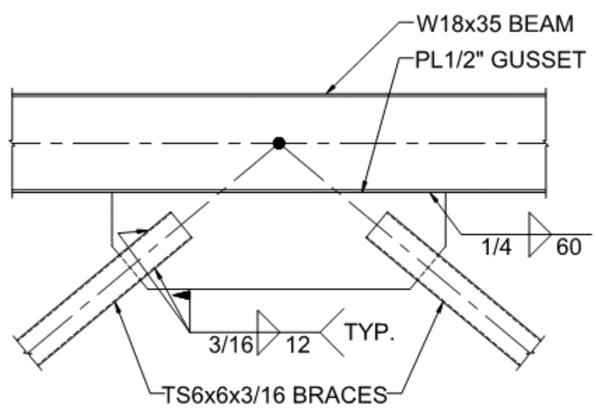

Figure 16: Typical Brace-to-Beam Connection Detail

Concrete Shear Wall (C2) Example

This design example is of a 1950s three-story concrete shear wall building in Seattle, Washington, using the ASCE/SEI 41-13 Tier 3 systematic evaluation procedure with the BPOE as the evaluation and retrofit Performance Objective. It is a Risk Category II office building, with a full basement.

This example shows data collection requirements, evaluation of the lateral force-resisting system with added shear walls, design of fiber-reinforced polymer (FRP) reinforcing at the discontinuous columns and under-reinforced concrete walls, a diaphragm check, collector design where the discontinuous shear wall terminates at the first floor level, and evaluation of compatibility with the non-participating concrete beam/column frame.

The design example is split into two chapters given the size of the presentation. The first chapter covers an LSP evaluation and retrofit. The second chapter covers an NSP evaluation. The NSP evaluation includes both a fixed based model and a flexible base model, and soil structure interaction provisions in ASCE/SEI 41-13 are explored.

Figure 17 shows an isometric of the building, and Figure 18 shows a plan of a typical floor. Figure 19 shows the discontinuous shear wall at the center of the building. Figure 20 shows the computer model used for the NSP evaluation. Figure 21 shows the force-displacement (pushover) curve of the lightly reinforced longitudinal walls on Lines 1 and 4.

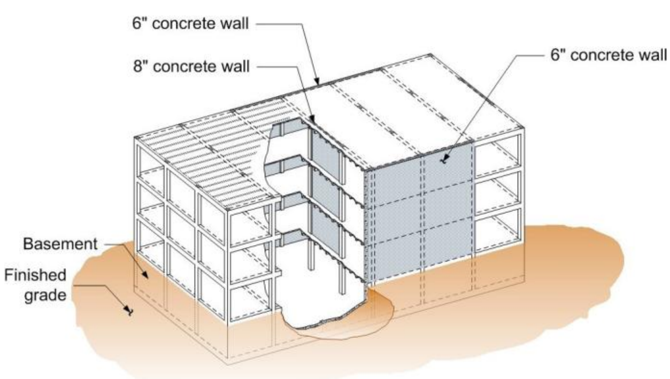

Figure 17: Isometric of Concrete Shear Wall Building

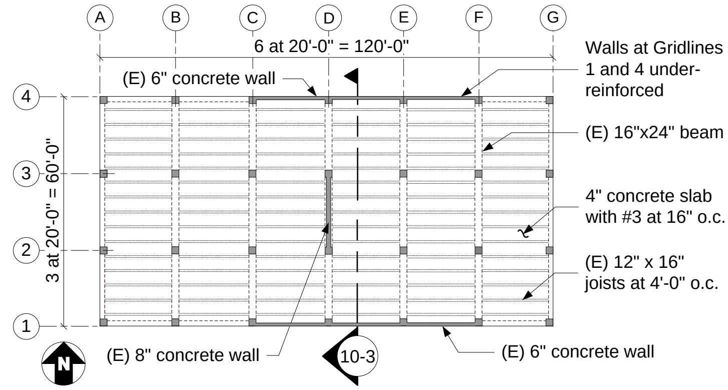

Figure 18: Typical Floor

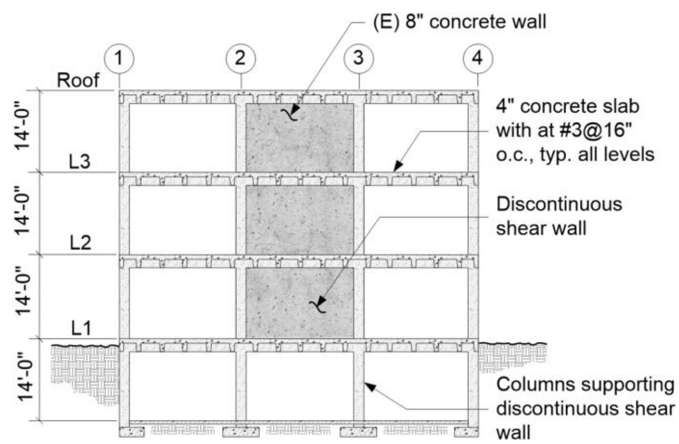

Figure 19: Building Section at Discontinuous Line D Shear Wall

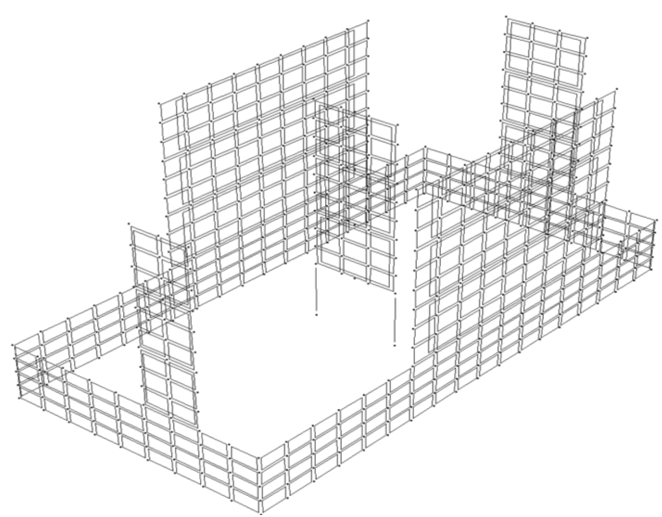

Figure 20: Model for NSP Evaluation

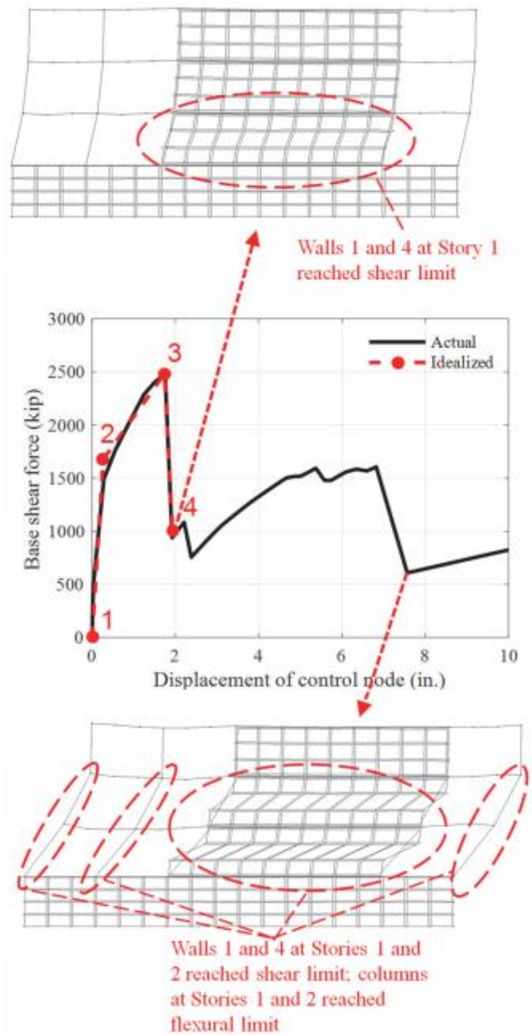

Figure 21: Pushover Curve for Lines 1 and 4

Unreinforced Masonry Bearing Wall (URM) Example

The example building is a two-story, unreinforced masonry bearing wall office building located in Los Angeles. The example building has an assumed construction date of 1920. The example was drawn from the URM bearing wall example in the 2009 *IEBC SEAOC Structural/Seismic Design Manual* (SEAOC, 2012).

The presentation is split into two chapters. The first chapter illustrates the evaluation and retrofit of an unreinforced masonry bearing wall building using the Special Procedure in Chapter 15 of ASCE/SEI 41-13.

Per ASCE/SEI 41-13 Section 15.2.1, the Special Procedure is consistent with other Tier 2 deficiency-based procedures and is permitted for use with the Reduced Performance Objective for Collapse Prevention Performance at the BSE-1E Seismic Hazard Level. The Special Procedure is a stand-alone method, and it does not reference other procedures in ASCE/SEI 41-13. The Special Procedure example includes evaluation of in-plane wall strength, out-of-plane wall strength, diaphragms, and wall-to-diaphragm ties. The example also covers retrofits that include in-plane wall strengthening, out-of-plane wall bracing, and new wall-to-diaphragm shear and tension ties.

The second chapter is uses the Tier 3 provisions of ASCE/SEI 41-13 and the BPOE Performance Objective. The focus is on evaluation of in-plane wall capacity, with comparison of LSP and NSP evaluations as well as the Special Procedure results. The effects of accounting for flanges and the different heights of opening on each side of a URM pier are illustrated.

Figure 22 shows an isometric of the building, and Figure 23 shows plans of the first and second floors. Figure 24 shows a flowchart on how to calculate the in-plane capacity of the masonry walls. This type of flowchart is not contained in ASCE/SEI 41-13.

Figure 22: Isometric of the URM Building

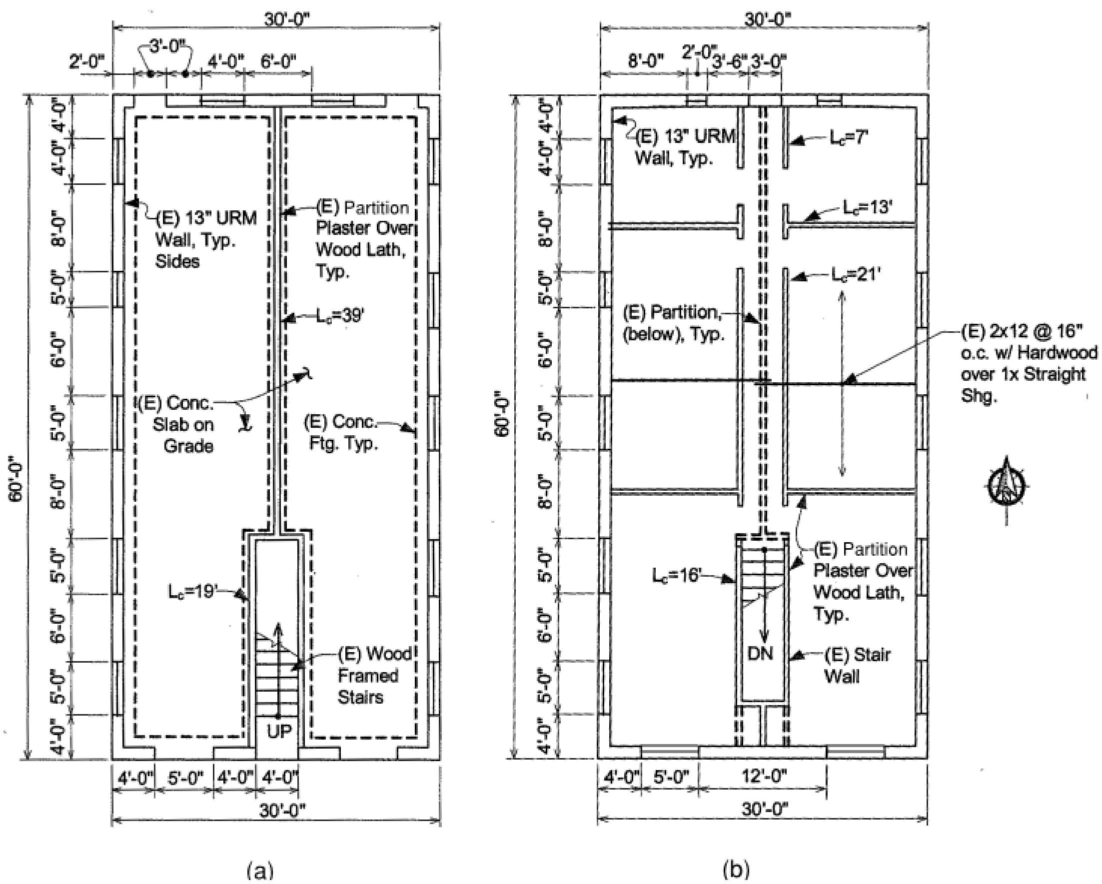

Figure 23: First Floor (a) and Second Floor (b) Plans

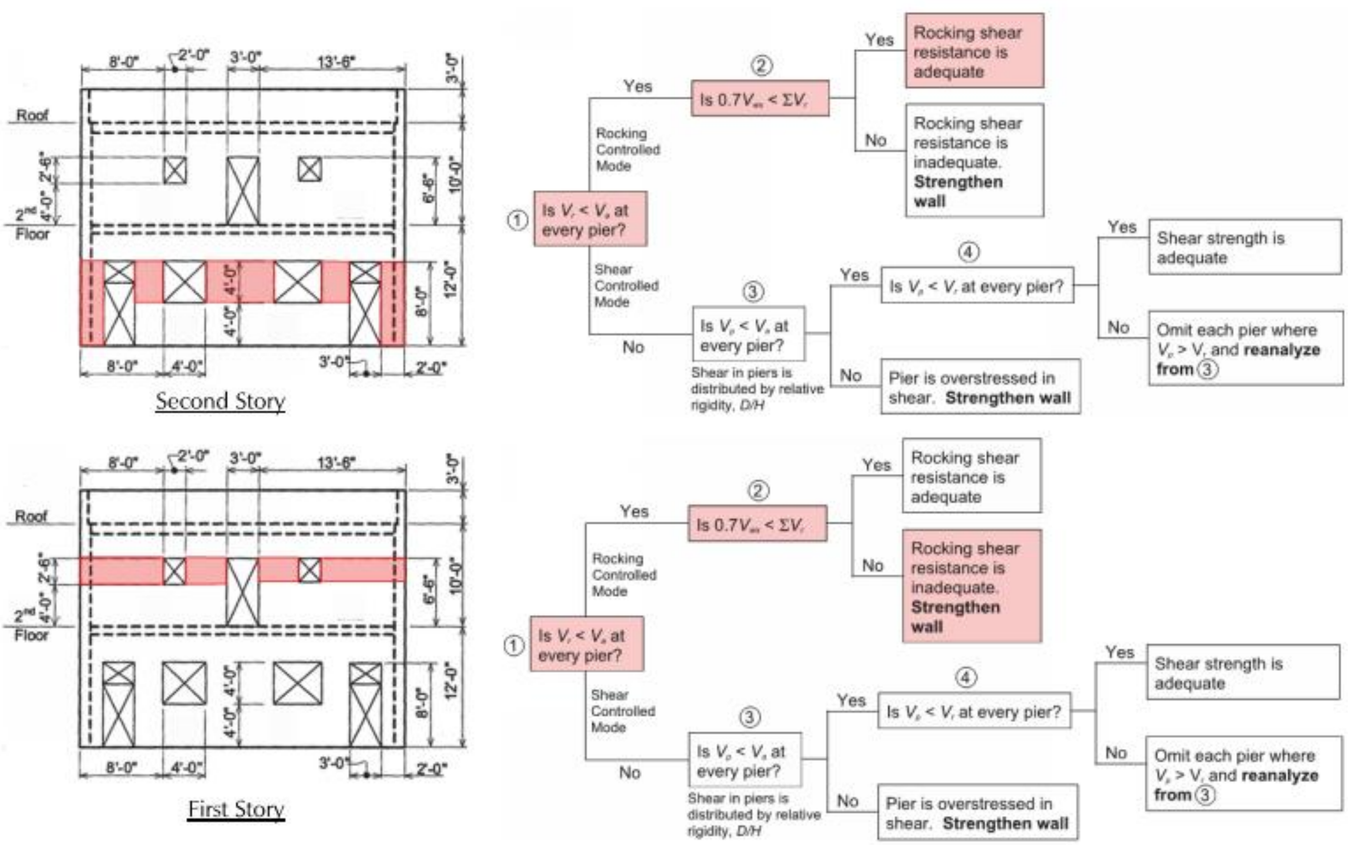

Figure 24: In-Plane Wall Calculation Flowchart

Issues Arising During Development of the Design Guide

During the development of the *Example Application Guide*, the project team had to address a number of issues. Some general highlights of interest include the following.

- *Ambiguous or incomplete provisions:* Occasionally, in trying to complete a design example, the ASCE/SEI 41-13 provisions were found to be ambiguous or incomplete on a particular issue. Such issues were reviewed with the project team and advisors to identify a reasonable set of assumptions. These assumptions are flagged in the *Guide*, usually in a margin text box. In some cases, dialogue between the ATC-124 team and the ASCE committee responsible for updating ASCE 41 will lead to revisions in the forthcoming ASCE/SEI 41-17.

- *Provisions that will change in the forthcoming ASCE/SEI 41-17 update:* The project team was in close communication with the ASCE committee updating ASCE 41. When the forthcoming ASCE/SEI 41-17 update will provide information missing in ASCE/SEI 41-13, the update is used in the design example. When the 41-17 update represents a change, the change (if noteworthy) is flagged, but the ASCE/SEI 41-13 provisions are used.

- *Differences of opinion:* There are some cases were the authors and peer reviewers did not initially agree. Generally, this was resolved by detailed discussion and revision. Substantial effort was made to reach consensus. In a few cases, differences of opinion remain. As noted above, reasonable alternative approaches are possible, and proper engineering judgment should be used.

General Advice

Based on experience with using ASCE/SEI 41-06 and ASCE/SEI 41-13, the *Guide* offers the following general advice, tips, and guidance. Text below is taken largely verbatim from the "Big Picture Wisdom" section of the current July, 2017 draft of the *Example Application Guide*.

- When utilizing ASCE/SEI 41-13 for an evaluation or retrofit, it is important to understand the requirements of the Authority Having Jurisdiction, and any special review requirements.

- ASCE/SEI 41-13 is not always organized in a sequential way, nor were the ASCE/SEI 41-13 provisions holistically developed (with the exception of the URM Special Procedure). An evaluation is performed on a component-by-component basis, which often requires jumping between chapters for analysis provisions, component strengths, and acceptance criteria. In the *Design Guide* examples, the starting point in ASCE/SEI 41-13 and reference sections related to the next steps are indicated.

- Before following the procedures in the standard, ASCE/SEI 41-13 Chapters 1 through 3 including commentaries should be reviewed.

- It is important to read all associated text and table footnotes in the associated chapter in ASCE/SEI 41-13 rather than simply applying the equations. For example, there are many instances where the text and footnotes significantly alter *m*-factors or when certain equations are not applicable.

- ASCE/SEI 41-13 uses displacement-based design. Thus, the inelastic response of a building is all about deformation compatibility and ductility on a component level. The *Guide* provides discussion on displacement-based design and a quantitative comparison between the ASCE/SEI 41-13 approach and the approach used on ASCE/SEI 7-10 for new buildings.

- Understanding component behavior and understanding whether an element is classified as force-controlled or deformation-controlled are essential.

- Obtaining demand-capacity ratios (DCRs) provides an indication of the magnitude and distribution of inelastic demands and is necessary in understanding governing behavior modes for components and systems.

- For nonlinear procedures, reclassification of certain force-controlled actions to deformation-controlled actions is permitted in some cases.

- Boundary conditions in models can make a significant difference in resulting behavior mechanisms and analysis results. Consideration should be given to foundation connections and conditions, as well as soil-structure interaction, when developing models.

- Component checks using the BSE-2N and BSE-2E level seismic hazard almost always control, but in Tier 1 and Tier 2 evaluations, they are not required.

- It may be helpful to check component acceptance criteria for one Structural Performance Level and Seismic Hazard Level and then spot compare with the other Structural Performance Levels and Seismic Hazard Levels under consideration to determine if any can be ruled out by inspection using relative mathematical ratios.

- Even though they may appear straightforward, some equations actually require detailed iteration and parallel calculations to complete. The determination of the target displacement is an example. It requires determination of element DCRs.

- When using the nonlinear analysis procedures, it is not necessary to model everything as a nonlinear element—it is time consuming and misleading. It is worthwhile to develop an initial understanding of the likely elements that will experience nonlinear behavior based on comparative strength and only include those in the model. The assumptions or calculations can be revised after review of initial results.

- Model one gravity column-beam bay for investigating deflection compatibility checks, preferably with high axial load.

- The application of ASCE/SEI 41-13 to light-frame wood construction can be challenging as the methodology requires the determination of the various failure limit states of connections, connection hardware, and the multiple mechanisms in the load path, which are not typically required when designing a new wood structure. Furthermore, ASCE/SEI 41-13 requires metal straps and hold-downs to be evaluated as force-controlled actions which require them to remain essentially elastic, whereas for new structures, these components are typically not designed with the overstrength factor, Ω_o, and are permitted to yield and deform. As a result, these components may not satisfy the ASCE/SEI 41-13 requirements without significant investigation into other failure mechanisms in the load path that may further reduce the demand to these components.

Conclusion

The experience of developing design examples and trying to present the information in an organized, clear manner helped reconfirm that ASCE/SEI 41-13 can be a challenging document, and an *Example Application Guide* can help engineers understand the methodology and provisions more fully. The project team hopes the *Guide* will be a valuable resource for the engineering community.

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