Part 1, Appendix A: Detailed Summary of Reinforced Concrete Punctured Shear Wall Studies

A.1 Introduction

As described in Part 1, Chapter 1, the Working Group 1, Linear effort focused on refinements and improvements to the linear procedure limitation provision ASCE/SEI 41. This involved a number of case study efforts. The main effort focused on studies involving a reinforced concrete shear wall building. This Appendix A1 provides a more detailed summary of the punctured reinforced concrete shear wall building case studies. It includes a description of the prototype buildings, the linear and nonlinear models, and results from investigation of the weak story irregularity limitation of ASCE/SEI 41-17 Section 7.3.1.1 which prohibits use of linear analysis methods if there is a weak story irregularity and if the DCR of any wall pier exceeds the lesser of 3.0 and the *m*-factor for the component action. There are three key questions:

- How closely do the results of the linear analyses match those of the nonlinear analyses?
- Does the limitation provision appropriately prevent a situation where the linear results would be overly unconservative?
- How do the results from ASCE/SEI 41-17 compare with ASCE/SEI 7-16 (ASCE, 2017)?

Conclusions are provided, as well as proposed next steps.

A.2 Reinforced Concrete Shear Wall Building Description

A.2.1 Source of Building Geometry: SEAW and FEMA P-2006 Case Studies

The existing building that was selected for this investigation is a reinforced concrete shear wall building built in the 1960s and designed in accordance with the 1961 Uniform Building Code (ICBO, 1961). It has been modified from the concrete shear wall design example in FEMA P-2006, *Example Application Guide for ASCE/SEI 41-13 Seismic Evaluation and Retrofit of Existing Buildings with Additional Commentary for ASCE/SEI 41-17* (FEMA, 2018). The FEMA P-2006 example was adapted from a presentation for the Structural Engineers Association of Washington (SEAW).

A.2.2 Overall Building Description and Geometry

The building has six 20-ft bays in the east-west longitudinal direction and three 20-ft bays in the north-south transverse direction. The baseline story height is 14 ft, but it is subject to change for parametric studies. The building does not have a basement. The building is used as an office building, and the Risk Category is II. The building is categorized as Type C2 (Concrete Shear Walls with Stiff Diaphragms) according to Table 3-1 of ASCE/SEI 41-17.

A.2.3 Structural Elements

The existing floor system consists of 4” non-prestressed concrete slab supported by joists in east-west direction and beams in the north-south direction. The floor system is supported by rectangular reinforced concrete columns, and the columns bear on isolated square spread footings. The existing lateral force-resisting system is composed of perforated reinforced concrete shear walls supported by strip footings.

A.2.4 Material Properties

The nominal (lower-bound) and expected grades of the *existing* materials of the building are:

- Existing concrete: f'_{cL} = 2,500 psi, f'_{cE} = 1.5(f'_{cL}) = 3,750 psi
- Existing reinforcing steel: f_{yL} = 40,000 psi, f_{yE} = 1.25(f_{yL}) = 50,000 psi

The nominal (lower-bound) and expected grades of *retrofit* materials are:

- New concrete: f'_{cL} = 5,000 psi, f'_{cE} = 1.3(f'_{cL}) = 6,500 psi

  (The factor to translate lower-bound or design concrete strength to expected compressive strength for new concrete is not specifically addressed in ASCE/SEI 41-17. A factor of 1.3 is chosen for this purpose, as recommended by ACI 319-19 Appendix A, Table A.9.1. ASCE/SEI 41-17 Table 10-1 applies to existing materials.)

- New reinforcing steel: f_{yL} = 60,000 psi, f_{yE} = 1.25(f_{yL}) = 75,000 psi

No retrofit materials are used in this case study.

A.2.5 Applied Loads

The uniform floor and roof loads are:

- Roof live load: 20 psf
- Floor live load: 125 psf (due to office light storage loads).

- Floor dead load (self-weight plus superimposed dead load) is not specified herein but is varied for the parametric studies, and the final seismic weight per level is summarized in tables for each study.

The building site is not subject to any geologic hazard such as liquefaction, lateral spreading, slope failure or tsunami.

Figure A-1 and Figure A-2 illustrate the building floor plan and south / north elevation. The floor plan remains the same for different building variants, but the elevation is subject to change for the building variants used in parametric studies. Only the east-west direction loading is being studied, and thus north-south oriented shear walls are not included in the model.

For each case described in Section 4, the geometry of the shear walls, story height and seismic story weight will be varied to meet the intended structural and loading conditions of the case study.

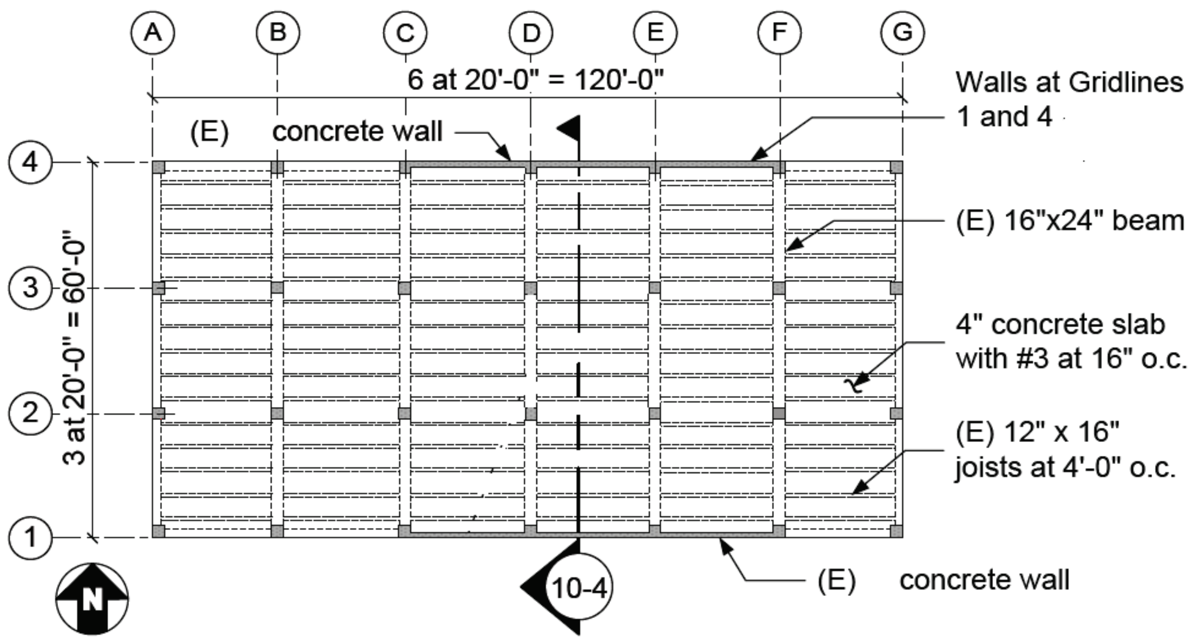


Figure A-1. Floor plan of prototype buildings.

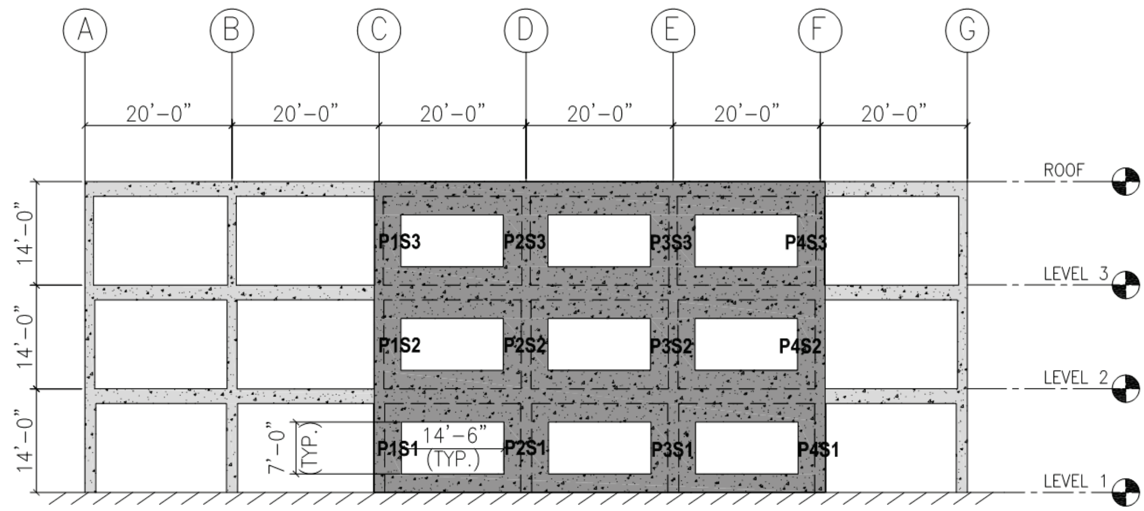


Figure A-2. Example south and north elevation of three-story prototype building.

A.3 Structural Models and Analysis Procedures

A.3.1 Linear Static and Linear Dynamic Procedures

Linear structural models for the prototype buildings have been created using ETABS following the provisions in Section 7.2.3 and Chapter 10 of ASCE/SEI 41-17. Some of the characteristics of the models are listed as follows:

- The structural models are three-dimensional.
- Section 7.2.3.3 of ASCE/SEI 41-17 states that the total initial lateral stiffness of secondary components, i.e., gravity-carrying frame, shall not exceed 25% of the total initial lateral stiffness of the primary components. Accordingly, the percentage of lateral loads resisted by the primary components has been checked to make sure that less than 25% of the total lateral loads are resisted by the secondary components.
- Expected material properties are assigned to structural components in the model.
- Effective sectional stiffness has been assigned to structural components according to Table 10-5 of ASCE/SEI 41-17 and other applicable specifications such as ACI 318-14 (ACI, 2014).
- Rigid diaphragms are used.
- Pinned supports are assigned to the base of shear walls. No soil-structure interaction effect is being considered at this stage.
- P-Delta effects are included.
- Gravity loads are uniformly distributed over the diaphragms.

- Seismic mass of floors is uniformly distributed over the diaphragms.
- Accidental torsional effects are checked per Section 7.2.3.2 of ASCE/SEI 41-17 and Section 12.8.4.2 of ASCE/SEI 7-16 and included if it turns out to be required.
- Load combinations for ASCE/SEI 41-17 are per Section 7.2.2 for linear analysis which includes:
  - $1.1D + 1.1 \times (0.25L) + 1.0E = 1.1D + 0.275L + 1.0E$, where L is the unreduced design live load from ASCE/SEI 7
  - $0.9D + 1.0E$

Linear static and response spectrum analysis have been performed according to the linear static procedure (LSP) and linear dynamic procedure (LDP) outlined in Section 7.4 of ASCE/SEI 41-17. The equivalent lateral force procedure and modal response spectrum analysis outlined in ASCE/SEI 7-16 have also been studied. Some features of the analysis are listed as follows

- Response spectra are scaled to reach the desired seismic load level.
- Seismic loads are parallel to the east-west direction of interest.

The following images illustrate the general layout of the ETABS finite element models that have been studied.

For simplicity, detailed comparisons focused on the LSP runs, and they are summarized in this appendix. LDP analyses are not summarized.

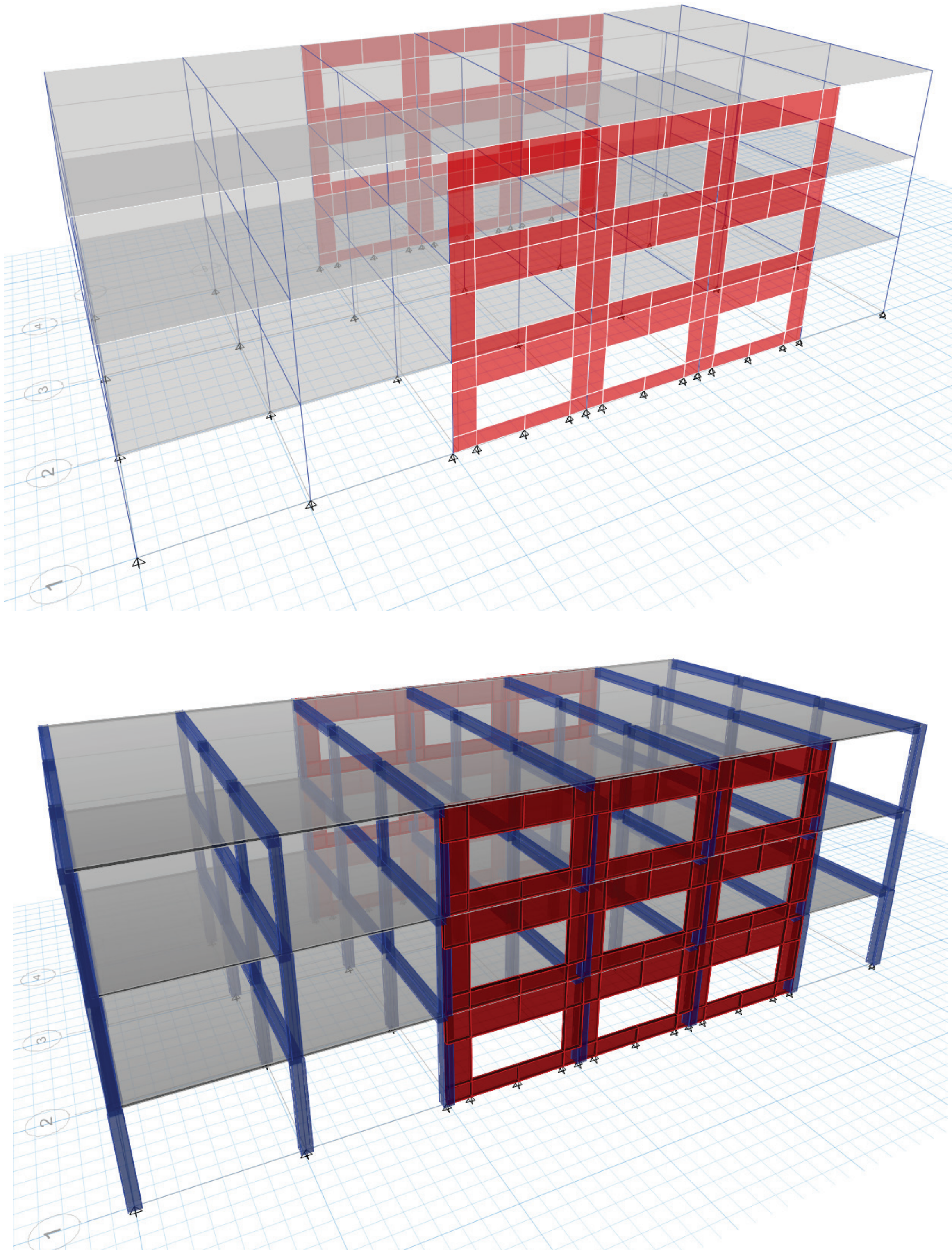


Figure A-3. Three-dimensional views of the ETABS model showing the shell elements in planar and extruded versions.

A.3.2 Nonlinear Static and Nonlinear Dynamic Procedures

Nonlinear structural models have been created using PERFORM-3D Version 7.0.0 following the provisions in Section 7.2.3 and Chapter 10 of ASCE/SEI 41-17. Some of the characteristics of the models are listed as follows:

- The structural models are three-dimensional.
- According to Section 7.2.3.3 of ASCE/SEI 41-17, both primary and secondary components, i.e., shear walls, diaphragms, and columns, are included in the model.
- Uniaxial stress-strain relations of reinforcing steel and concrete materials are created for implementing fiber-discretized sections.
- Fiber-discretized sections for capturing inelastic axial-flexural interactions are assigned to selected wall piers. Columns embedded in the walls have been incorporated into the fiber sections.
- Shear stress-strain relations have been determined according to Table 10-20 of ASCE/SEI 41-17 and assigned to selected wall piers and spandrels.
- Rigid diaphragms are used. Gravity columns are included to help capture P-Delta effects.
- Pinned supports are assigned to the base of shear walls and columns. No soil-structure interaction effects are being considered at this stage.
- P-Delta effects are considered.
- Gravity loads are applied to the top of columns according to the tributary area.
- Lateral seismic floor mass is lumped at the master node of the rigid floor constraint.
- Accidental torsional effects were checked.
- A linear elastic gravity analysis is conducted prior to any nonlinear seismic analysis and the gravity loads at the end of the gravity analysis remain constant in the seismic analysis.
- Seismic displacements are applied parallel to the east-west direction of interest.
- Vertical seismic effects are not considered.
- The load combination for ASCE/SEI 41-17 is per Section 7.2.2 for nonlinear analysis which is:
    - $1.0D + 0.25L + 1.0E$, where L is the unreduced design live load from ASCE/SEI 7
- Nonlinear static pushover analysis is conducted per the nonlinear static procedure (NSP) outlined in Section 7.4 of ASCE/SEI 41-17.

- For the NSP, response spectra are scaled to reach the desired seismic demand.
- For the nonlinear dynamic procedure (NDP), nonlinear response history analysis (NRHA) is performed according to Section 7.4 of ASCE/SEI 41-17.
- For the NDP, earthquake ground motions are scaled to reach the desired seismic demand.

The following Figure A1-4 illustrates the general layout of the PERFORM-3D finite element models that have been studied.

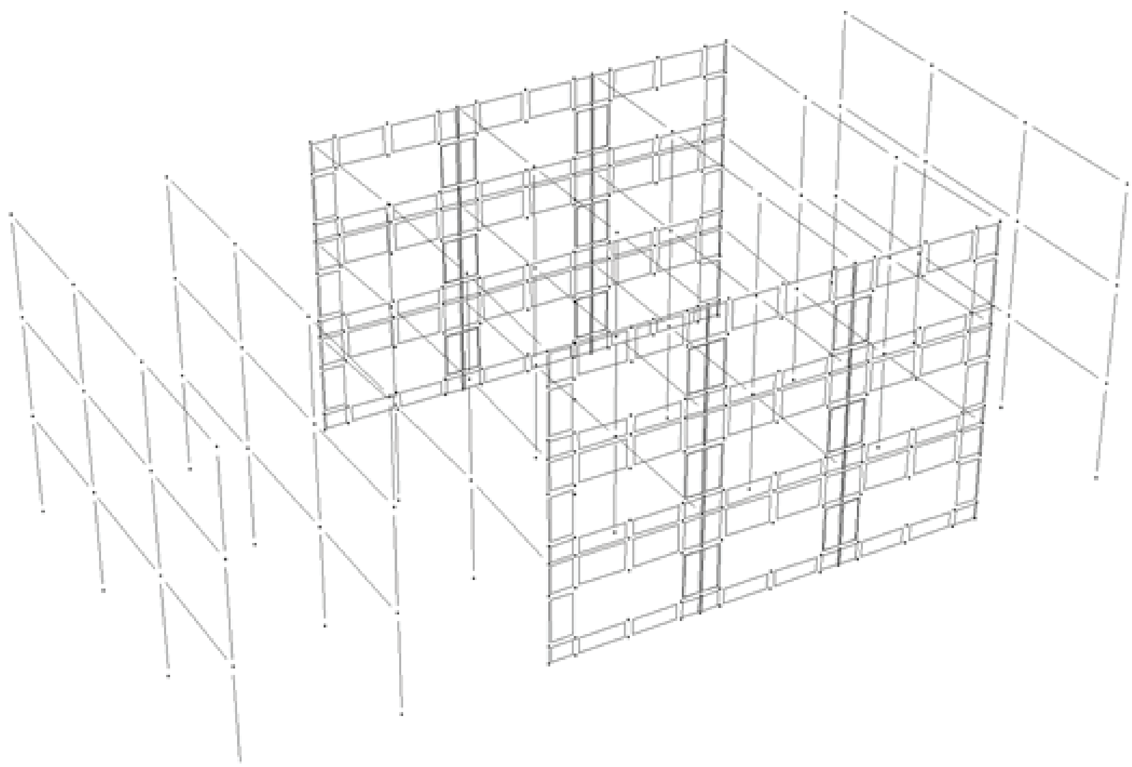


Figure A-4. Three-dimensional view of the PERFORM-3D model.

During the first phase of the study, a typical seismic demand in coastal California outside the near field zone for short-period buildings (S_S = 1.0 at BSE-1N and S_S = 1.5 at BSE-2N) were used for the LSP, NSP, and NDP analyses. This level of seismic shaking was such that the buildings showed insufficient capacity in all three procedures. For this reason, a reduced demand was selected for the new phase of the project. A value of S_S = 0.667 was selected for the BSE-1N level and S_S = 1.0 for the BSE-2N level. Lower demand was expected to help achieve more pronounced results between procedures. The value of S_a = 0.67 was used for the Design Earthquake level demand for ASCE/SEI 7-16. In order to make sure the building is representative of 1960s design, it was also evaluated using the 1961 Uniform Building Code using Z = 1.0 and K = 1.0. For NRHA, the ground motions of the first phase were scaled down by multiplying their accelerations by 2/3.

Since the first phase did not show differences between the LSP, NSP, and NDP procedures, first phase results are not useful in exploring differences, and they are not summarized here. Instead, results for the second phase S_S = 0.67 at BSE-1N and S_S = 1.0 at BSE-2N are summarized. In addition, due to large volume of information, results are only presented in this appendix for shear demands and capacities, rather than moment demands. The main Part 1, Chapter 1 report contains short summaries of key results for the S_S = 1.0 at BSE-1N and S_S = 1.5 at BSE-2N case study, and maximum moment DCRs for both case studies.

A.4 Weak Story Irregularity Studies

A.4.1 ASCE/SEI 41-17 Provisions

Section 7.3.1.1.3 of ASCE/SEI 41-17 defines the “weak story” vertical irregularity based on the average DCR between two stories: “a weak story irregularity shall be considered to exist in any direction of the building if the ratio of the average shear DCR for elements in any story to that of an adjacent story in the same direction exceeds 125%.” Section 7.3.1.1 states that if a component DCR exceeds the lesser of 3.0 and the *m*-factor for the component action and any irregularity is present, then linear procedures shall not be used.

The definition of “weak story” in Section 7.3.1.1.3 of ASCE/SEI 41-17 could be too stringent for some common building types. A very common and simple example would be when a two-story shear wall building with the same wall piers at each story is subjected to an inverted triangular seismic load, the average shear DCR for wall piers in Story 1 is 150% of that in Story 2 and, thus, a “weak story” is identified. By comparison, in ASCE/SEI 7-16, the weak story definition is where the “story lateral strength is less than 80% of the story above,” and the extreme weak story is where “the story lateral strength is less than 65% of the story above.” In this two-story example, with the same story strength at each story, there is no weak story per ASCE/SEI 7-16.

In the presence of the “weak story” irregularity, if the DCR of any wall pier exceeds the lesser of 3.0 the *m*-factor for the component action, linear procedures shall not be used.

Examining the limitation on use of linear procedures in the presence of weak story irregularity will help identify the accuracy of this limitation and possibly broaden the range of buildings that can be evaluated using linear procedures.

A.4.2 Analysis Plan

Comparisons between linear and nonlinear analyses were performed using a linear model and a detailed nonlinear structural model that captures the governing damage/failure mode of the wall piers (shear or flexure). The Acceptance Ratios of wall piers are compared between the linear and nonlinear procedures to check the accuracy of linear procedures.

The analysis plan for examining the weak story irregularity is as follows.

- Three-story reinforced concrete shear wall buildings with different perforated perimeter walls are being studied. For each building, the walls on Gridlines 1 and 4 are identical. The perforated perimeter walls have been designed in the following three patterns:
- Pattern 1: Same wall piers at all three stories, as shown in Figure A-5;
- Pattern 2: Tall first story, as shown in Figure A-6; and
- Pattern 3: Wider wall piers on upper stories, as shown in Figure A-7. Only linear and nonlinear static procedure analyses were explored for Pattern 3. Given the results from Patterns 1 and 2, it was found that there was no need to do nonlinear response history analysis of Pattern 3.
- Create linear and nonlinear building models and conduct linear static, linear dynamic, nonlinear static, and nonlinear response history analyses.
- Compare Acceptance Ratios of wall piers between linear and nonlinear procedures.

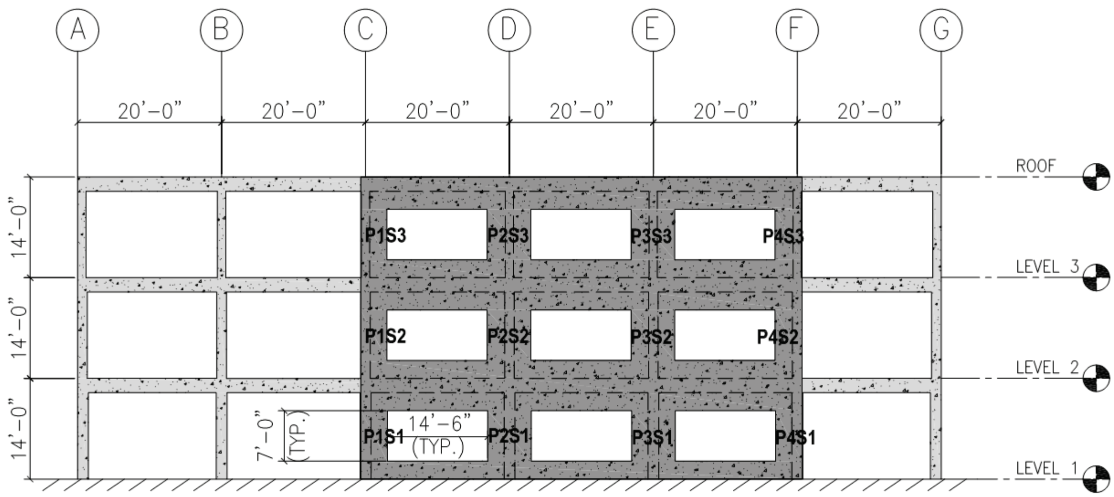


Figure A-5a. Shear Wall Pattern No. 1.

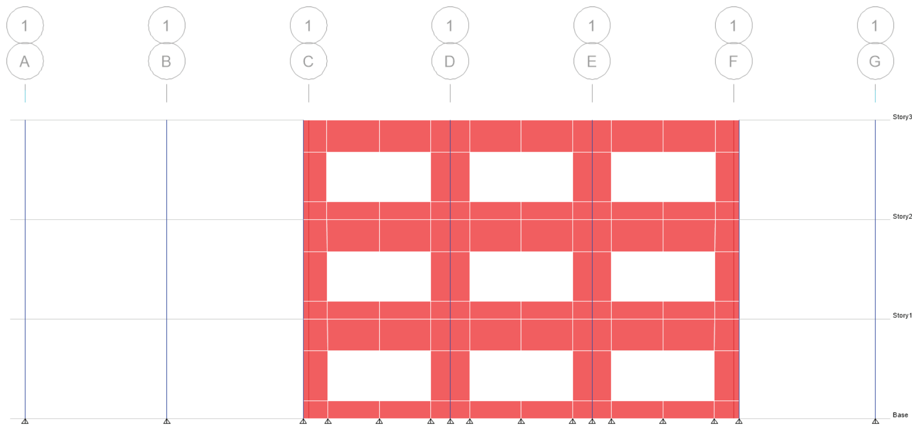


Figure A-5b. ETABS model for Shear Wall Pattern No. 1.

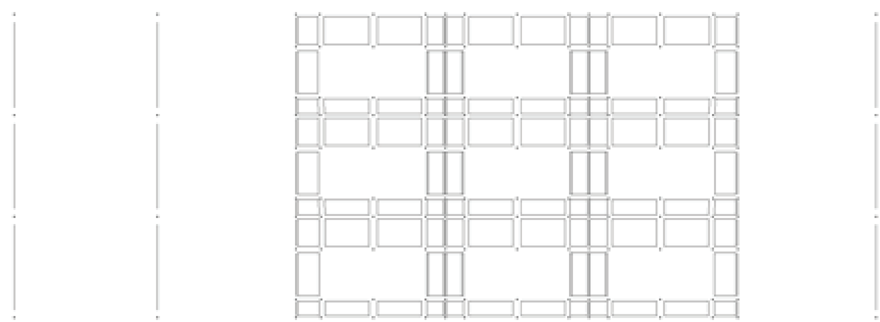


Figure A-5c. PERFORM-3D model for Shear Wall Pattern No. 1.

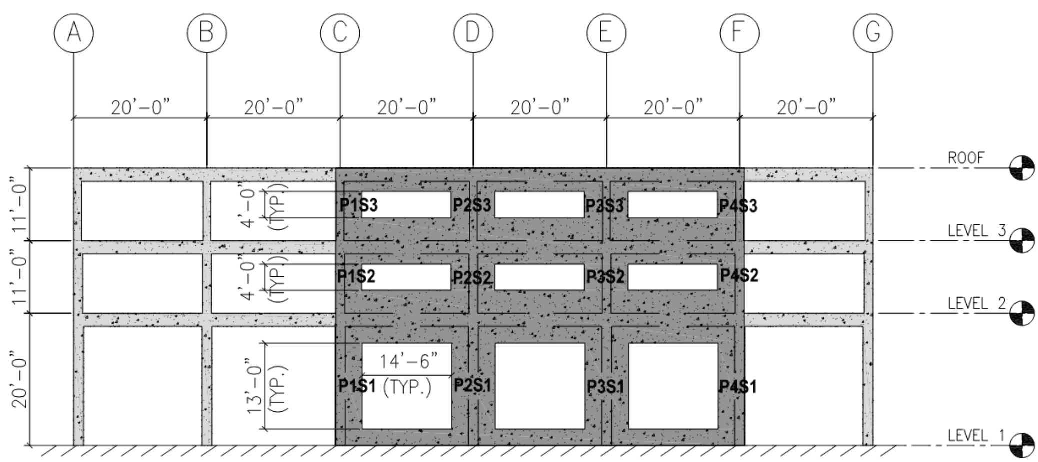


Figure A-6a. Shear Wall Pattern No. 2.

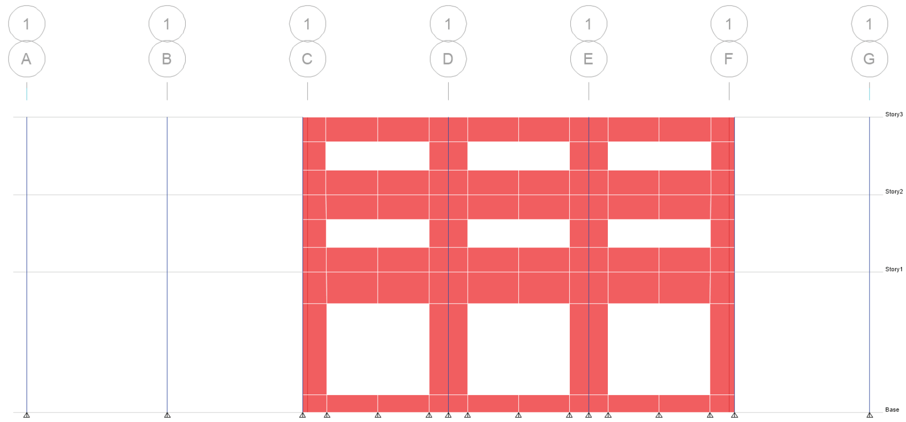


Figure A-6b. ETABS Model for Shear Wall Pattern No. 2.

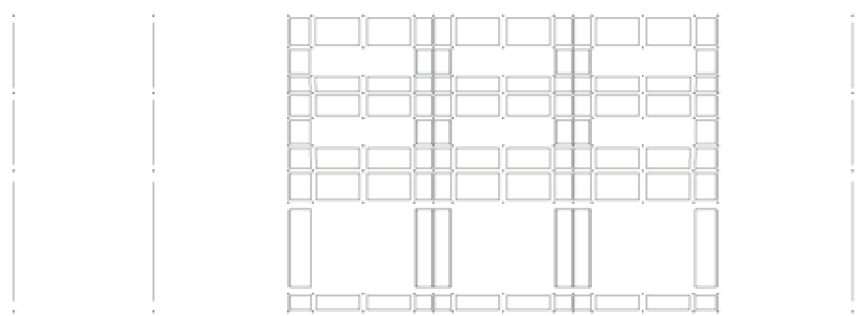


Figure A-6c. PERFORM-3D Model for Shear Wall Pattern No. 2.

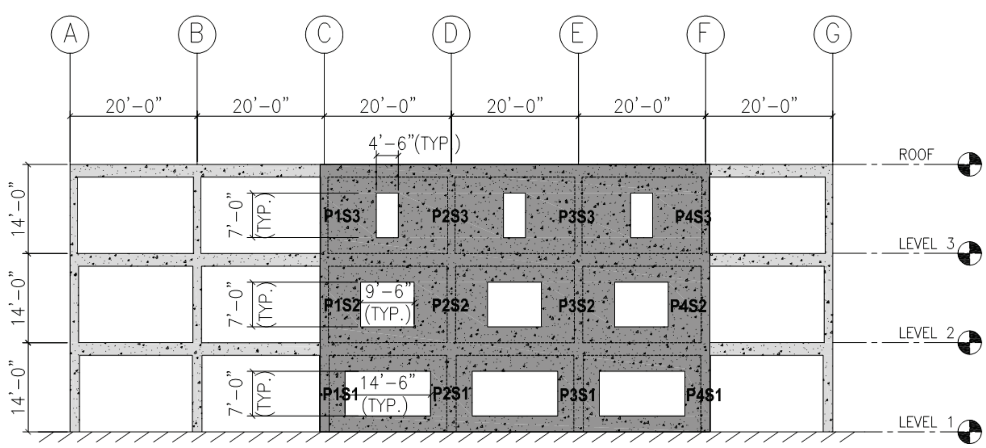


Figure A-7a. Shear Wall Pattern No. 3.

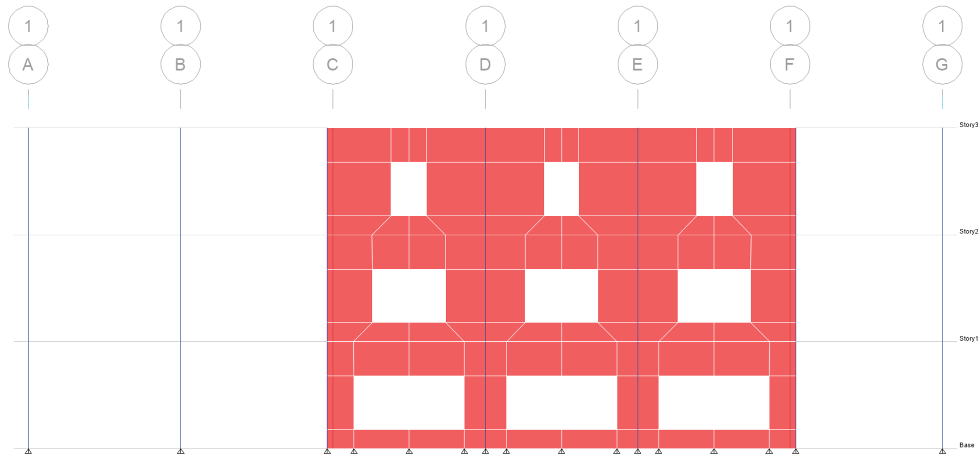


Figure A-7b ETABS Model for Shear Wall Pattern No. 3.

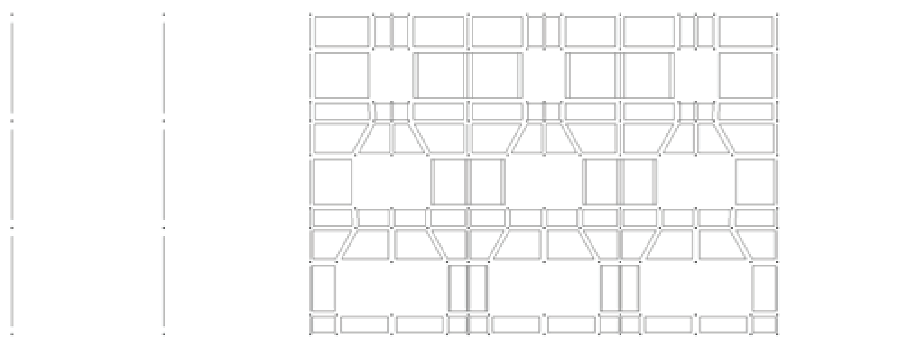


Figure A-7c PERFORM-3D Model for Shear Wall Pattern No. 3.

A.4.3 Details of Models and Analysis

Some key design parameters of shear wall patterns No. 1 to 3 are listed in Table A-1 to Table A-3, respectively. The 1961 UBC requires a minimum horizontal reinforcing ratio of $\rho = 0.0025$. This is larger than the value of $\rho = 0.0015$ in ASCE/SEI 7-16 Section 10.7.2.2 which specifies that walls with lower values shall be considered force-controlled. #4 bars at 9 in. o.c. were used in the 8 in. wall which gives a value of $\rho = 0.0028$.

Table A-1: Design Parameters of Shear Wall Pattern No. 1 (as shown in Figure A-5)

Story	Seismic Story Weight[1]	Story Height	Wall Thickness	Reinforcing Steel[2]	Shear Reinf. Ratio	Pier Width (in.)				Pier Clear Height (in.)			
	(kips)	(ft)	(in.)			P1	P2	P3	P4	P1	P2	P3	P4
3	800	14	8	One layer of #4@9" o.c., each way	0.0028	40	66	66	40	84	84	84	84
2	900	14	8			41	66	66	41	84	84	84	84
1	900	14	8			42	66	66	42	84	84	84	84

1 Seismic story force is shared by two shear walls with the same pattern at Gridlines 1 and 4.
2 Development of reinforcements is assumed to be adequate.

Table A-2: Design Parameters of Shear Wall Pattern No. 2 (as shown in Figure A-6)

Story	Seismic Story Weight[1]	Story Height	Wall Thickness	Reinforcing Steel[2]	Shear Reinf. Ratio	Pier Width (in.)				Pier Clear Height (in.)			
	(kips)	(ft)	(in.)			P1	P2	P3	P4	P1	P2	P3	P4
3	800	14	8	One layer of #4@9" o.c., each way	0.0028	40	66	66	40	48	48	48	48
2	900	14	8			41	66	66	41	48	48	48	48
1	900	14	8			42	66	66	42	156	156	156	156

1 Seismic story force is shared by two shear walls with the same pattern at Gridlines 1 and 4.
2 Development of reinforcements is assumed to be adequate.

Table A-3 Design Parameters of Shear Wall Pattern No. 3 (as shown in Figure A-7)

Story	Seismic Story Weight[1]	Story Height	Wall Thickness	Reinforcing Steel[2]	Shear Reinf. Ratio	Pier Width (in.)				Pier Clear Height (in.)			
	(kips)	(ft)	(in.)			P1	P2	P3	P4	P1	P2	P3	P4
3	800	14	8	One layer of #4@9" o.c., each way	0.0028	100	186	186	100	84	84	84	84
2	900	14	8			71	126	126	71	84	84	84	84
1	900	14	8			42	66	66	42	84	84	84	84

1 Seismic story force is shared by two shear walls with the same pattern at Gridlines 1 and 4.
2 Development of reinforcements is assumed to be adequate.

A.4.4 Shear Wall Pattern 1

A.4.4.1 UBC 1961 ACCEPTANCE RATIOS

Table A1-4 shows the derivation of allowable stress demand (ASD) story forces. Table A1-5 shows key properties for each pier, including the ASD demand-to-capacity ratio. In keeping with the terminology used in FEMA P-2006, the "Acceptance Ratio" will be used to compare results between different methods. For the UBC, this is the traditional demand-to-capacity ratio, which for shear is the allowable stress design ratio V_E / V_{allow}. Per Table A1-5, the maximum Acceptance Ratio is 0.57, and it occurs at the first story.

Table A-4: Calculation of Seismic Story Force per UBC 1961

<table>
<tr><th>Story</th><th>Seismic weight (k)</th><th>Seismic height (ft)</th><th>Z</th><th>K</th><th>H (ft)</th><th>D (ft)</th><th>T (s)</th><th>C</th><th>$V = ZKCW$ (k)</th><th>H_x (ft)</th><th>F_x (k)</th><th>F_{story} (k)</th></tr>
<tr><td>3</td><td>800</td><td>14</td><td rowspan="3">1.0</td><td rowspan="3">1.0</td><td rowspan="3">42</td><td rowspan="3">120</td><td rowspan="3">0.19</td><td rowspan="3">0.09</td><td rowspan="3">225</td><td>42</td><td>106</td><td>106</td></tr>
<tr><td>2</td><td>900</td><td>14</td><td>28</td><td>80</td><td>186</td></tr>
<tr><td>1</td><td>900</td><td>14</td><td>14</td><td>40</td><td>225</td></tr>
<tr><td>Total</td><td>2,600</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>225</td><td></td></tr>
</table>

Table A-5: Check of Wall Pier Capacity per UBC 1961

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	f_{allow} (psi)	V_{allow} (k)	V_E (k)	V_E/V_{allow}
3	P1S3	40	84	8	125	40	8	0.21
	P2S3	66	84	8	125	66	18	0.28
	P3S3	66	84	8	125	66	18	0.28
	P4S3	40	84	8	125	40	8	0.21
2	P1S2	41	84	8	125	41	15	0.36
	P2S2	66	84	8	125	66	31	0.47
	P3S2	66	84	8	125	66	31	0.47
	P4S2	41	84	8	125	41	15	0.36
1	P1S1	42	84	8	125	42	19	0.44
	P2S1	66	84	8	125	66	38	**0.57**
	P3S1	66	84	8	125	66	38	**0.57**
	P4S1	42	84	8	125	42	19	0.44

A.4.4.2 ASCE/SEI 7-16 ACCEPTANCE RATIOS

Table A-6 shows the derivation of factored story forces per ASCE/SEI 7-16. For ASCE/SEI 7-16, the Acceptance Ratio is the traditional demand-to-capacity ratio, which for shear is the factored ratio $V_u / \Phi V_n$. Per Table A-7, the maximum Acceptance Ratio is 1.08, and it occurs at the first story. Acceptance Ratios over 1.0 are shaded in red.

Table A-6 Calculation of Story Shear for Pattern 1 per ASCE/SEI 7-16

Story	Seismic Weight (k)	Seismic Height (ft)	k	S_{DS}	R	I_e	C_s	V (k)	h_x (ft)	C_v	F_x (k)	F_{story} (k)
3	800	14	1						42	0.47	163	163
2	900	14	1	0.667	5	1.0	0.1	347	28	0.35	122	285
1	900	14	1						14	0.18	61	347
Total	2,600										347	

Table A-7 Check of Wall Pier Capacity per ASCE/SEI 7-16 (1.4*D* + 1.0*L* + 1.0*E*)

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	ϕV_n (k)	V_u (k)	$V_u/\phi V_n$
3	P1S3	40	84	8	32	11	0.34
	P2S3	66	84	8	54	35	0.65
	P3S3	66	84	8	54	31	0.59
	P4S3	40	84	8	32	17	0.52
2	P1S2	41	84	8	33	20	0.61
	P2S2	66	84	8	54	53	0.99
	P3S2	66	84	8	54	50	0.94
	P4S2	41	84	8	33	30	0.89
1	P1S1	42	84	8	34	26	0.78
	P2S1	66	84	8	54	58	1.08
	P3S1	66	84	8	54	56	1.05
	P4S1	42	84	8	34	33	0.98

A.4.4.3 ASCE/SEI 41-17 LSP ACCEPTANCE RATIOS AND LIMITATIONS

Table A-8 shows the derivation of story forces per the ASCE/SEI 41-17 LSP. Table A-9 and Table A-11 show that at both the BSE-1N and BSE-2N hazard levels, the limitation restrictions are not triggered since neither the weak story check nor the average DCR exceeds the allowable *m*-factor. However, a soft story is identified, and the limitation is triggered. For the ASCE/SEI 41-17 LSP, the Acceptance Ratio for shear is the ratio $V_{UD} / \kappa m V_{CE}$. Per Table A-10 and Table A-12, the maximum Acceptance Ratios are 0.89 and 1.07 for the BSE-1N and BSE-2N hazard levels, respectively. These maxima occur at the first story.

Table A-8: Calculation of Story Shear for Pattern 1 per ASCE/SEI 41-17

Story	Seismic Weight (k)	Story Height (ft)	k	C_1C_2	C_m	S_a	V (k)	h_x (ft)	C_v	F_x (k)	F_{story} (k)
3	800	14	1					42	0.47	718	**718**
2	900	14	1	1.1	0.8	0.667	1,525	28	0.35	538	**1,256**
1	900	14	1					14	0.18	269	**1,525**
Total	2,600									1,525	

Table A-9: Check of Weak and Soft Story Irregularities for Pattern 1 per ASCE/SEI 41-17 at BSE-1N

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	DCR	*m*-factor (k)	Average Shear DCR	Ratio of Average DCR Between this Story and Story Above	Weak Story?	Limit Use of Linear Procedures?	Story Drift Ratio	Soft story and Limit Use of Linear Static Procedure?
3	P1S3	40	84	8	0.8	2.5	1.0	N/A	N/A	NO	0.09%	NO
	P2S3	66	84	8	1.1	2.5				NO		
	P3S3	66	84	8	1.1	2.5				NO		
	P4S3	40	84	8	0.8	2.5				NO		
2	P1S2	41	84	8	1.5	2.5	1.7	1.70	YES	NO	0.13%	YES
	P2S2	66	84	8	1.9	2.5				NO		
	P3S2	66	84	8	1.9	2.5				NO		
	P4S2	41	84	8	1.5	2.0				NO		

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	DCR	*m*-factor (k)	Average Shear DCR	Ratio of Average DCR Between this Story and Story Above	Weak Story?	Limit Use of Linear Procedures?	Story Drift Ratio	Soft story and Limit Use of Linear Static Procedure?
1	P1S1	42	84	8	1.8	2.5	2.0	1.16	NO	NO	0.12%	NO
	P2S1	66	84	8	2.1	2.5				NO		
	P3S1	66	84	8	1.8	2.5				NO		
	P4S1	42	84	8	2.1	2.0				NO		

Table A-10: Check of Wall Piers via LSP of ASCE/SEI 41-17 for Pattern 1

BSE-1N, 0.9*D* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	V_{CE} (k)	V_{UD} (k)	m_{LS} (Shear)	$\kappa m_{LS} V_{CE}$	Acceptance Ratio $V_{UD} / \kappa m_{LS} V_{CE}$
3	P1S3	40	84	8	67	53	2.5	167	0.32
	P2S3	66	84	8	110	125	2.5	276	0.45
	P3S3	66	84	8	110	123	2.5	276	0.45
	P4S3	40	84	8	67	56	2.5	167	0.33
2	P1S2	41	84	8	69	100	2.5	171	0.58
	P2S2	66	84	8	110	206	2.5	276	0.75
	P3S2	66	84	8	110	205	2.5	276	0.74
	P4S2	41	84	8	69	103	2.0	137	0.75
1	P1S1	42	84	8	70	123	2.5	176	0.70
	P2S1	66	84	8	110	235	2.5	276	0.85
	P3S1	66	84	8	110	235	2.5	276	0.85
	P4S1	42	84	8	70	126	2.0	141	0.89

Table A-10: Check of Wall Piers via LSP of ASCE/SEI 41-17 for Pattern 1 (continued)

BSE-1N, 1.1*D* + 0.275*L* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	V_{CE} (k)	V_{UD} (k)	m_{LS} (Shear)	$km_{LS}V_{CE}$	Acceptance Ratio $V_{UD}/\ \kappa m_{LS}V_{CE}$
3	P1S3	40	84	8	67	53	2.5	167	0.31
	P2S3	66	84	8	110	126	2.5	276	0.46
	P3S3	66	84	8	110	123	2.5	276	0.45
	P4S3	40	84	8	67	56	2.5	167	0.34
2	P1S2	41	84	8	69	99	2.5	171	0.58
	P2S2	66	84	8	110	207	2.5	276	0.75
	P3S2	66	84	8	110	205	2.5	276	0.74
	P4S2	41	84	8	69	104	2	137	0.76
1	P1S1	42	84	8	70	122	2.5	176	0.70
	P2S1	66	84	8	110	236	2.5	276	0.85
	P3S1	66	84	8	110	235	2.5	276	0.85
	P4S1	42	84	8	70	126	2	141	0.90

Table A-11: Check of Weak and Soft Story Irregularities for Pattern 1 per ASCE/SEI 41-17 at BSE-2N

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	DCR	Average Shear DCR	Ratio of Average DCR Between this Story and Story Above	Weak Story?	Limit Use of Linear Procedures?	Story Drift Ratio	Soft story and Limit Use of Linear Static Procedure?
3	P1S3	40	84	8	1.2	1.5	N/A	N/A	NO	0.13%	NO
	P2S3	66	84	8	1.7				NO		
	P3S3	66	84	8	1.7				NO		
	P4S3	40	84	8	1.2				NO		
2	P1S2	41	84	8	2.2	2.6	1.70	YES	NO	0.20%	YES
	P2S2	66	84	8	2.8				NO		
	P3S2	66	84	8	2.8				NO		
	P4S2	41	84	8	2.2				NO		
1	P1S1	42	84	8	2.7	3.0	1.16	NO	NO	0.18%	NO
	P2S1	66	84	8	3.2				NO		
	P3S1	66	84	8	3.2				NO		
	P4S1	42	84	8	2.7				NO		

Table A-12: Check of Wall Piers via LSP of ASCE/SEI 41-17 for Pattern 1

BSE-2N, 0.9*D* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	$f'_{cE} l_w d_w$ (k)	$P/f'_{cE} l_w d_w$ (k)	m_{CP}	$k m_{CP} V_{CE}$	Acceptance Ratio $V_{UD} / \kappa m_{LS} V_{CE}$
3	P1S3	40	84	8	1200	0.00	3	201	0.40
	P2S3	66	84	8	1980	0.00	3	331	0.56
	P3S3	66	84	8	1980	0.01	3	331	0.56
	P4S3	40	84	8	1200	0.05	3	201	0.41
2	P1S2	41	84	8	1230	0.00	3	206	0.73
	P2S2	66	84	8	1980	0.00	3	331	0.93
	P3S2	66	84	8	1980	0.02	3	331	0.93
	P4S2	41	84	8	1230	0.10	3	206	0.75
1	P1S1	42	84	8	1260	0.00	3	211	0.88
	P2S1	66	84	8	1980	0.00	3	331	1.07
	P3S1	66	84	8	1980	0.02	3	331	1.06
	P4S1	42	84	8	1260	0.07	3	211	0.89

Table A-12: Check of Wall Piers via LSP of ASCE/SEI 41-17 for Pattern 1 (continued)

BSE-2N, 1.1*D* + 0.275*L* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	$f'_{cE}l_wd_w$ (k)	$P/f'_{cE}l_wd_w$ (k)	m_{CP}	$km_{CP}V_{CE}$	Acceptance Ratio $V_{UD}/km_{LS}V_{CE}$
3	P1S3	40	84	8	1200	0.00	3	201	0.40
	P2S3	66	84	8	1980	0.00	3	331	0.57
	P3S3	66	84	8	1980	0.01	3	331	0.56
	P4S3	40	84	8	1200	0.05	3	201	0.42
2	P1S2	41	84	8	1230	0.00	3	206	0.73
	P2S2	66	84	8	1980	0.00	3	331	0.93
	P3S2	66	84	8	1980	0.03	3	331	0.93
	P4S2	41	84	8	1230	0.10	3	206	0.75
1	P1S1	42	84	8	1260	0.00	3	211	0.88
	P2S1	66	84	8	1980	0.01	3	331	1.07
	P3S1	66	84	8	1980	0.03	3	331	1.06
	P4S1	42	84	8	1260	0.08	3	211	0.89

A.4.4.4 ASCE/SEI 41-17 NSP ACCEPTANCE RATIOS AND LIMITATIONS

Figure A-8 shows the target displacements at the roof for Pattern 1. At the BSE-1N seismic hazard level, the target displacement is 0.74”. At the BSE-2N level, it is 1.50”.

For the ASCE/SEI 41-17 NSP, the Acceptance Ratio for shear is the ratio of the shear strain at the target displacement divided by the target strain per ASCE/SEI 41-17. Per Table A1-13, at the BSE-1N hazard level and the Life Safety Building Performance Level, the highest Acceptance Ratio is at the first story where the strain at the target displacement is 0.32% and the limit is 0.75% (for Pier 4) for an Acceptance Ratio of 0.43. At the BSE-2N level, the Acceptance Ratio is much higher at 2.92.

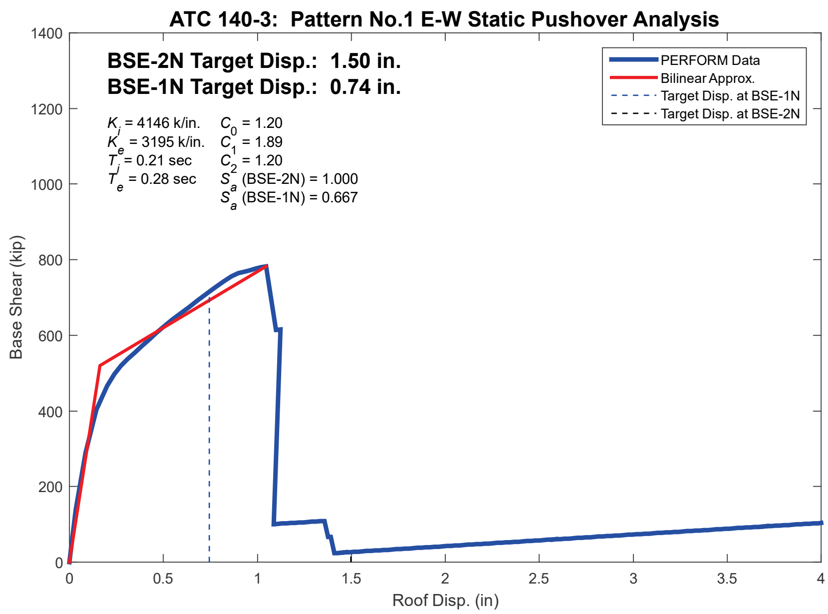


Figure A-8 Target displacements for Shear Wall Pattern No. 1.

Table A-13: Check of Wall Piers via Nonlinear Static Procedure (NSP) of ASCE/SEI 41-17 for Pattern 1

BSE-1N, 1.0*D* + 0.25*L* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	Shear Strain at Target Disp.	Axial at Target Disp. (k)	Target Strain Limit for LS	Acceptance Ratio
3	P1S3	40	84	8	0.00%	-11	1.50%	0.00
	P2S3	66	84	8	0.01%	-8	1.50%	0.00
	P3S3	66	84	8	0.01%	-34	1.50%	0.01
	P4S3	40	84	8	0.00%	-46	1.50%	0.00
2	P1S2	41	84	8	0.09%	1	1.50%	0.06
	P2S2	66	84	8	0.18%	-28	1.50%	0.12
	P3S2	66	84	8	0.21%	-64	1.50%	0.14
	P4S2	41	84	8	0.17%	-139	0.75%	0.23
1	P1S1	42	84	8	0.23%	41	1.50%	0.15
	P2S1	66	84	8	0.33%	-67	1.50%	0.22
	P3S1	66	84	8	0.34%	-81	1.50%	0.23
	P4S1	42	84	8	0.32%	-251	0.75%	0.43

Table A-13: Check of Wall Piers via Nonlinear Static Procedure (NSP) of ASCE/SEI 41-17 for Pattern 1 (continued)

BSE-2N, 1.0*D* + 0.25*L* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	Shear Strain at Target Disp.	Axial at Target Disp. (k)	Target Strain Limit for LS	Acceptance Ratio
3	P1S3	40	84	8	0.00%	-29	2.00%	0.00
	P2S3	66	84	8	0.00%	-15	2.00%	0.00
	P3S3	66	84	8	0.02%	-24	2.00%	0.01
	P4S3	40	84	8	0.00%	-28	2.00%	0.00
2	P1S2	41	84	8	0.15%	-46	2.00%	0.07
	P2S2	66	84	8	0.26%	-63	2.00%	0.13
	P3S2	66	84	8	0.29%	-55	2.00%	0.15
	P4S2	41	84	8	0.25%	-59	2.00%	0.13
1	P1S1	42	84	8	2.53%	-55	2.00%	1.26
	P2S1	66	84	8	2.24%	-125	1.00%	2.24
	P3S1	66	84	8	2.30%	-81	2.00%	1.15
	P4S1	42	84	8	2.92%	-88	1.00%	2.92

A.4.4.5 ASCE/SEI 41-17 NDP ACCEPTANCE RATIOS AND LIMITATIONS

The following tables summarizes the results obtained from the Nonlinear Dynamic Procedure for both hazard levels, BSE-1N and BSE-2N. The maximum Acceptance Ratio within all piers of story 1 are presented here. To facilitate the collection and analysis of the results, the shear strain was measured only at the middle of the pier and the flexural rotation was measured at the top and bottom. Table A-14 and Table A-15 and show the results for Pattern 1 at BSE-1N and BSE-2N, respectively. In these tables, the Acceptance Ratio for shear strain and flexural rotation are indicated for each of the 11 ground motions of the sets. The average values are shown at the last line of the table and the maximum of the Acceptance Ratios per ground motion in Column 6.

Table A-14: Pattern 1 Acceptance Ratio at BSE-1N

EQ	Name	Acceptance Ratio				Comments
		Shear	Rotation Top	Rotation Bottom	Max	
1	Imperial Valley	0.14	0.14	0.14	0.14	Analysis finished
2	Loma Prieta	13.62	0.29	0.34	13.62	All piers at Story 1 reached LS limit state in shear
3	Northridge, Sylmar CSE	42.71	0.26	0.34	42.71	All piers at Story 1 reached LS limit state in shear
4	Northridge, Sylmar OVM	14.92	0.09	0.11	14.92	All piers at Story 1 reached LS limit state in shear
5	Chi Chi TCU079	25.48	0.26	0.36	25.48	All piers at Story 1 reached LS limit state in shear
6	Chi Chi TCU122	0.12	0.13	0.14	0.14	Analysis finished
7	Duzce	1.33	0.29	0.30	1.33	P1 to P3 reached LS limit state in shear
8	Chetsu 65010	0.31	0.14	0.17	0.31	Analysis finished
9	Chetsu 65025	0.18	0.11	0.14	0.18	Analysis finished
10	Mexico, Chihuahua	0.14	0.12	0.13	0.14	Analysis finished
11	Mexico, Ejido Saltillo	0.09	0.12	0.13	0.13	Analysis finished
AVERAGE:		9.01	0.18	0.21	9.01	

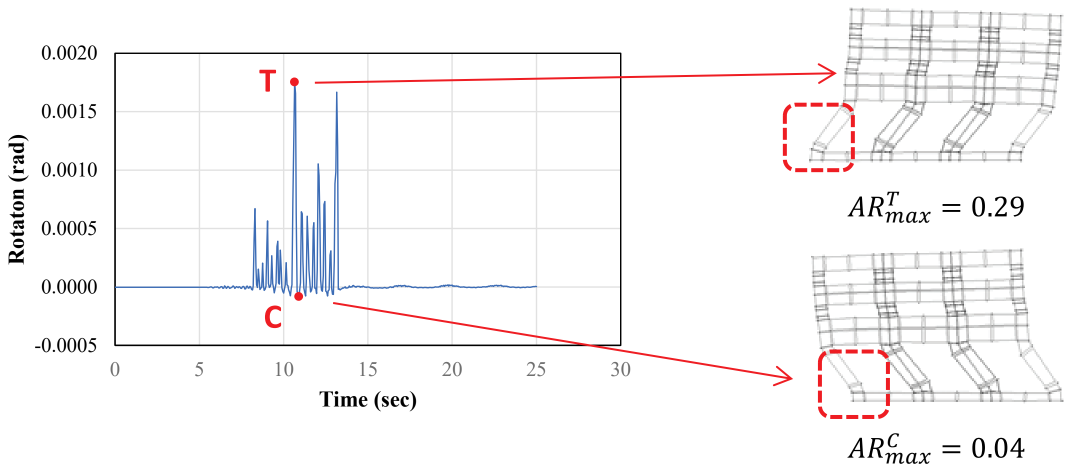
Table A-15: Pattern 1 Acceptance Ratio at BSE-2N

EQ	Name	Acceptance Ratio				Comments
		Shear	Rotation Top	Rotation Bottom	Max	
1	Imperial Valley	0.19	0.09	0.09	0.19	Analysis finished
2	Loma Prieta	18.53	0.17	0.17	18.53	All piers at Story 1 reached CP limit state in shear
3	Northridge, Sylmar CSE	36.19	0.18	0.15	36.19	All piers at Story 1 and 2 reached LS limit state in shear
4	Northridge, Sylmar OVM	14.27	0.13	0.14	14.27	All piers at Story 1 reached CP limit state in shear
5	Chi Chi TCU079	15.59	0.17	0.15	15.59	All piers at Story 1 reached CP limit state in shear
6	Chi Chi TCU122	0.15	0.08	0.08	0.15	Analysis finished
7	Duzce	16.42	0.14	0.14	16.42	All piers at Story 1 reached CP limit state in shear
8	Chetsu 65010	0.33	0.13	0.14	0.33	Analysis finished
9	Chetsu 65025	0.17	0.07	0.08	0.17	Analysis finished
10	Mexico, Chihuahua	0.15	0.08	0.08	0.15	Analysis finished
11	Mexico, Ejido Saltillo	0.12	0.08	0.07	0.12	Analysis finished
AVERAGE:		9.28	0.12	0.12	9.28	

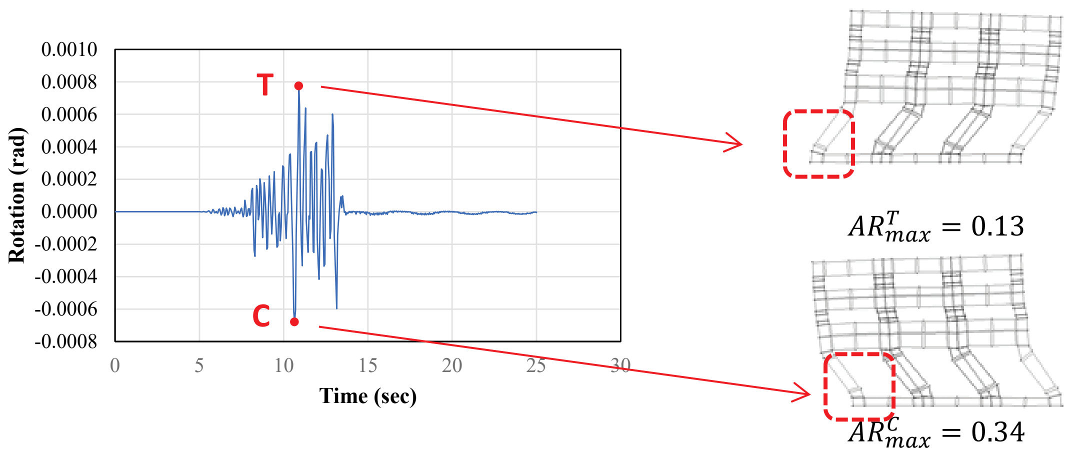
The Acceptance Ratios were calculated dividing the maximum deformation experienced in the pier (deformation demand) by the deformation capacity per ASCE/SEI 41-17. The red numbers represent the cases where the Acceptance Ratio is greater than the allowable deformation per ASCE/SEI 41-17. The selected criterion used in PERFORM-3D to stop the analysis was a maximum story drift of 4%. The reason to select that criterion in lieu of a maximum allowable deformation associated with Acceptance Ratio (in shear or flexure) was to allow the building to deform as much as possible to evaluate the level of damage in each pier at the end of the ground motion. After the analysis, no local instability or convergence problem were identified, and all the time steps were applied to the structure under both hazard levels.

As an example, the following figure illustrate the shear deformation time history and the flexural rotation time history at the top and bottom of the pier 1 for Pattern 1 under Loma Prieta ground motion at BSE-1 hazard level. The rotational Acceptance Ratio for the top gage was calculated as follow. Similar calculations were followed to calculate the rest of Acceptance Ratios.

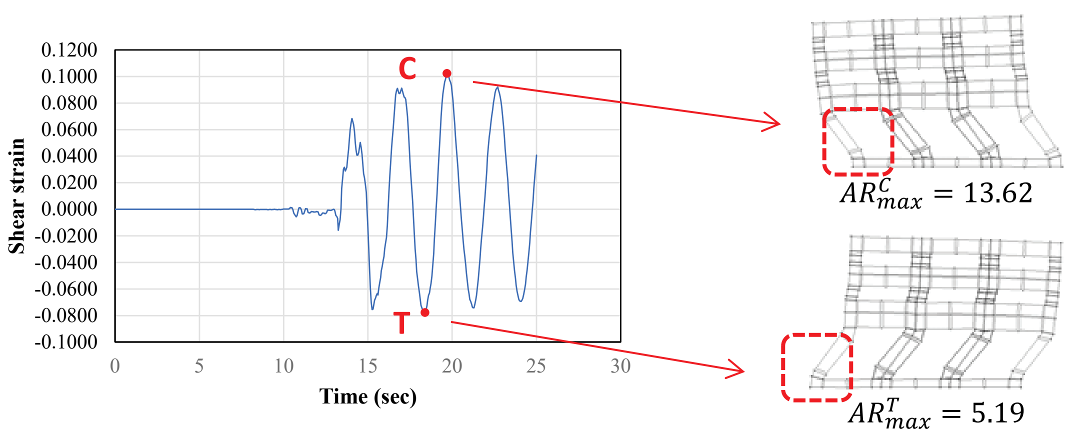
$$AR_{\max}^{C} = \frac{0.00175}{0.006} = 0.29$$



a) Top rotational gage



b) Bottom rotational gage



c) Shear gage

Figure A-9. Nonlinear response history analysis response for Pattern 1 under Loma Prieta earthquake at BSE-1N hazard level.

As can be seen in the tables, Pattern 1 does not have the capacity to withstand the level of shaking imposed by the proposed ground motions. Under both hazard levels, the building piers failed in shear under 5 out of 11 ground motions used. In these cases, all the piers located at Story 1 failed at the same time.

A.4.4.6 FINDINGS

For Pattern 1, the walls are easily adequate for shear demands from the 1961 UBC, with a maximum Acceptance Ratio of 0.57. However, for ASCE/SEI 7-16, they are overstressed at Level 1 with a maximum Acceptance Ratio of 1.08. Thus, the case study building is reasonably representing a 1960s design that would not meet today's demands.

For the ASCE/SEI 41-17 LSP, the maximum Acceptance Ratios are 0.90 and 1.07 at the BSE-1N and BSE-2N hazard levels, respectively. The limitation restrictions are triggered due to the weak story irregularity at the BSE-2N hazard level, and linear procedures are not allowed. For the ASCE/SEI 41-17 NSP, the Acceptance Ratios are 0.43 at the BSE-1N level and 2.92 at the BSE-2N level. Results from the NDP indicate the building does not have enough capacity to withstand the earthquake demand imposed. The building failed in shear under 5 out of 11 of the ground motions used for both hazard levels.

A.4.5 Shear Wall Pattern 2

The following sections summarize the results for the UBC, ASCE/SEI 7-16, and the ASCE/SEI 41-17 LSP, NSP, and NDP for Pattern 2. The same procedures explained in the previous sections were used to calculate the Acceptance Ratios.

A.4.5.1 UBC 1961 ACCEPTANCE RATIOS

Table A-16: Calculation of Seismic Story Force per UBC 1961

Story	Seismic Weight (k)	Seismic Height (ft)	*Z*	*K*	*H* (ft)	*D* (ft)	*T* (s)	*C*	*V* = *ZKCW* (k)	H_x (ft)	F_x (k)	F_{story} (k)
3	800	11	1.0	1.0	42	120	0.19	0.09	**225**	42	95	95
2	900	11								31	79	174
1	900	20								20	51	225
Total	2,600										225	

Table A-17: Check of Wall Pier Capacity per UBC 1961

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	f_{allow} (psi)	V_{allow} (k)	V_e (k)	V_e/V_{allow}
3	P1S3	40	48	8	125	40	6	0.16
	P2S3	66	48	8	125	66	18	0.27
	P3S3	66	48	8	125	66	18	0.27
	P4S3	40	48	8	125	40	6	0.16
2	P1S2	41	48	8	125	41	12	0.29
	P2S2	66	48	8	125	66	32	0.48
	P3S2	66	48	8	125	66	32	0.48
	P4S2	41	48	8	125	41	12	0.29
1	P1S1	42	156	8	125	42	21	0.49
	P2S1	66	156	8	125	66	36	0.54
	P3S1	66	156	8	125	66	36	0.54
	P4S1	42	156	8	125	42	21	0.49

A.4.5.2 ASCE/SEI 7-16 ACCEPTANCE RATIOS

Table A-18: Calculation of Story Shear for Pattern 2 per ASCE/SEI 7-16

Story	Seismic Weight (k)	Seismic Height (ft)	k	S_{DS}	R	I_e	C_s	V (k)	h_x (ft)	C_v	F_x (k)	F_{story} (k)	k_{story} (k/in.)
3	800	11	1						42	0.42	147	147	22,690
2	900	11	1	0.67	5	1.0	0.1	**347**	31	0.35	122	268	22,690
1	900	20	1						20	0.23	78	347	8,299
Total	2,600										347		

Table A-19: Check of Wall Pier Capacity per ASCE/SEI 7-16 (1.40*D* + 1.0*L* + 1.0*E*)

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	ϕV_n (k)	V_u (k)	$V_u/\phi V_n$
3	P1S3	40	48	8	32	8	0.24
	P2S3	66	48	8	54	33	0.62
	P3S3	66	48	8	54	29	0.55
	P4S3	40	48	8	32	17	0.52
2	P1S2	41	48	8	33	17	0.52
	P2S2	66	48	8	54	53	0.98
	P3S2	66	48	8	54	49	0.91
	P4S2	41	48	8	33	27	0.82
1	P1S1	42	156	8	34	29	0.85
	P2S1	66	156	8	54	58	1.09
	P3S1	66	156	8	54	57	1.06
	P4S1	42	156	8	34	35	1.02

A.4.5.3 ASCE/SEI 41-17 LSP ACCEPTANCE RATIOS AND LIMITATIONS

Table A-20: Calculation of Story Shear for Pattern 2 per ASCE/SEI 41-17

Story	Seismic Weight (k)	Seismic Height (ft)	k	C_1C_2	C_m	S_a	V (k)	h_x (ft)	C_v	F_x (k)	F_{story} (k)
3	800	11	1	1.1	0.8	0.67	1525	42	0.42	645	645
2	900	11	1					31	0.35	535	1,180
1	900	20	1					20	0.23	345	1,525
Total	2,600									1,525	

Table A-21: Check of Weak and Soft Story Irregularities for Pattern 2 per ASCE/SEI 41-17 at BSE-1N

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	DCR	*m*-factor	Average Shear DCR	Ratio of Average DCR Between this Story and Story Above	Weak Story?	Limit Use of Linear Procedures?	Story Drift Ratio	Soft Story and Limit Use of Linear Static Procedure?
3	P1S3	40	48	8	0.7	2.5	0.9	N/A	N/A	NO	0.06%	NO
	P2S3	66	48	8	1.0	2.5				NO		
	P3S3	66	48	8	1.0	2.5				NO		
	P4S3	40	48	8	0.7	2.5				NO		
2	P1S2	41	48	8	1.3	2.5	1.6	1.77	YES	NO	0.09%	NO
	P2S2	66	48	8	1.8	2.5				NO		
	P3S2	66	48	8	1.8	2.5				NO		
	P4S2	41	48	8	1.3	2.5				NO		
1	P1S1	42	156	8	1.9	2.5	2.1	1.29	NO	NO	0.24%	YES
	P2S1	66	156	8	2.2	2.5				NO		
	P3S1	66	156	8	2.2	2.5				NO		
	P4S1	42	156	8	1.9	2.5				NO		

Table A-22: Check of Wall Piers via LSP of ASCE/SEI 41-17 for Pattern 2

BSE-1N, 0.9*D* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	V_{CE} (k)	V_{UD} (k)	m_{LS}	$\kappa m_{LS} V_{CE}$	Acceptance Ratio $V_{UD}/\kappa m_{LS} V_{CE}$
3	P1S3	40	48	8	67	44	2.5	167	0.26
	P2S3	66	48	8	110	113	2.5	276	0.41
	P3S3	66	48	8	110	111	2.5	276	0.40
	P4S3	40	48	8	67	49	2.5	167	0.29
2	P1S2	41	48	8	69	86	2.5	171	0.50
	P2S2	66	48	8	110	195	2.5	276	0.71
	P3S2	66	48	8	110	194	2.5	276	0.70
	P4S2	41	48	8	69	90	2	137	0.65
1	P1S1	42	156	8	70	132	2.5	176	0.75
	P2S1	66	156	8	110	240	2.5	276	0.87
	P3S1	66	156	8	110	239	2.5	276	0.87
	P4S1	42	156	8	70	134	2	141	0.96

Table A-22: Check of Wall Piers via LSP of ASCE/SEI 41-17 for Pattern 2 (Continued)

BSE-1N, 1.1*D* + 0.275*L* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	V_{CE} (k)	V_{UD} (k)	m_{LS}	$\kappa m_{LS} V_{CE}$	Acceptance Ratio $V_{UD} / \kappa m_{LS} V_{CE}$
3	P1S3	40	48	8	67	43	2.5	167	0.26
	P2S3	66	48	8	110	114	2.5	276	0.41
	P3S3	66	48	8	110	111	2.5	276	0.40
	P4S3	40	48	8	67	50	2.5	167	0.30
2	P1S2	41	48	8	69	85	2.5	171	0.50
	P2S2	66	48	8	110	196	2.5	276	0.71
	P3S2	66	48	8	110	194	2.5	276	0.70
	P4S2	41	48	8	69	91	2	137	0.66
1	P1S1	42	156	8	70	132	2.5	176	0.75
	P2S1	66	156	8	110	240	2.5	276	0.87
	P3S1	66	156	8	110	239	2.5	276	0.87
	P4S1	42	156	8	70	135	2	141	0.96

Table A-23: Check of Weak and Soft Story Irregularities for Pattern 2 per ASCE/SEI 41-17 at BSE-2N

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	DCR	*m*-factor	Average Shear DCR	Ratio of Average DCR Between this Story and Story Above	Weak Story?	Limit Use of linear procedures?	Story Drift Ratio	Soft Story and Limit use of Linear Static Procedure?
3	P1S3	40	48	8	1.0	3.0	1.4	N/A	N/A	NO	0.09%	NO
	P2S3	66	48	8	1.5	3.0				NO		
	P3S3	66	48	8	1.5	3.0				NO		
	P4S3	40	48	8	1.0	3.0				NO		
2	P1S2	41	48	8	1.9	3.0	2.4	1.77	YES	NO	0.14%	NO
	P2S2	66	48	8	2.6	3.0				NO		
	P3S2	66	48	8	2.6	3.0				NO		
	P4S2	41	48	8	1.9	3.0				NO		
1	P1S1	42	156	8	2.8	3.0	3.1	1.29	YES	NO	0.37%	YES
	P2S1	66	156	8	3.2	3.0				YES		
	P3S1	66	156	8	3.2	3.0				YES		
	P4S1	42	156	8	2.8	3.0				NO		

Table A-24: Check of Wall Piers via LSP of ASCE/SEI 41-17 for Pattern 2

BSE-2N, 0.9*D* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	V_{CE} (k)	V_{UD} (k)	m_{CP}	$km_{CP}V_{CE}$	Acceptance Ratio $V_{UD}/km_{CP}V_{CE}$
3	P1S3	40	48	8	67	67	3	201	0.33
	P2S3	66	48	8	110	168	3	331	0.51
	P3S3	66	48	8	110	166	3	331	0.50
	P4S3	40	48	8	67	72	3	201	0.36
2	P1S2	41	48	8	69	130	3	206	0.63
	P2S2	66	48	8	110	292	3	331	0.88
	P3S2	66	156	8	110	290	3	331	0.88
	P4S2	41	156	8	69	134	3	206	0.65
1	P1S1	42	156	8	70	199	3	211	0.94
	P2S1	66	156	8	110	359	3	331	1.08
	P3S1	66	0	8	110	358	3	331	1.08
	P4S1	42	0	8	70	201	3	211	0.95

Table A-24: Check of Wall Piers via LSP of ASCE/SEI 41-17 for Pattern 2 (Continued)

BSE-2N, 1.1*D* + 0.275*L* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	V_{CE} (k)	V_{UD} (k)	m_{CP}	$\kappa m_{CP} V_{CE}$	Acceptance Ratio $V_{UD}/\ \kappa m_{CP} V_{CE}$
3	P1S3	40	48	8	67	67	3	201	0.33
	P2S3	66	48	8	110	169	3	331	0.51
	P3S3	66	48	8	110	166	3	331	0.50
	P4S3	40	48	8	67	73	3	201	0.36
2	P1S2	41	48	8	69	129	3	206	0.63
	P2S2	66	48	8	110	293	3	331	0.88
	P3S2	66	156	8	110	291	3	331	0.88
	P4S2	41	156	8	69	135	3	206	0.65
1	P1S1	42	156	8	70	198	3	211	0.94
	P2S1	66	156	8	110	359	3	331	1.08
	P3S1	66	0	8	110	358	3	331	1.08
	P4S1	42	0	8	70	202	3	211	0.96

A.4.5.4 ASCE/SEI 41-17 NSP ACCEPTANCE RATIOS AND LIMITATIONS

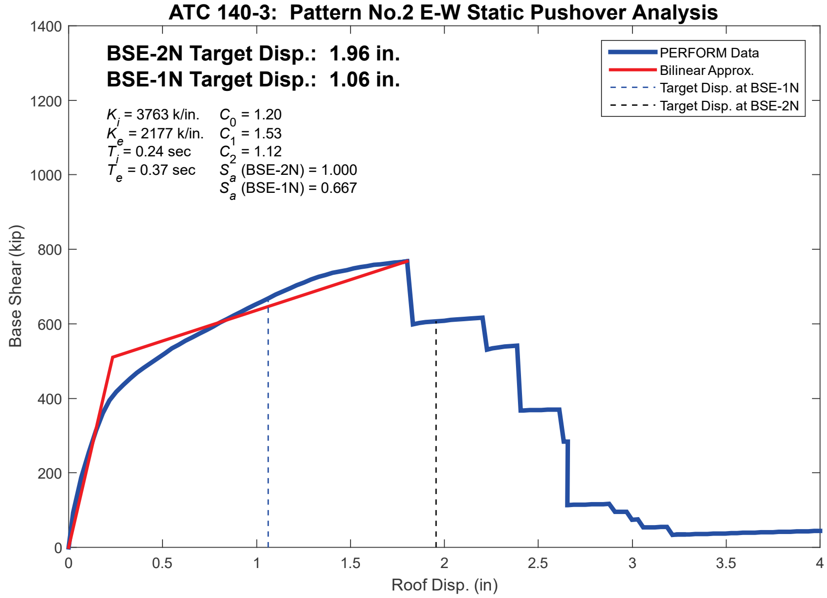


Figure A-10 Target displacements for Shear Wall Pattern No. 2.

Table A-25: Check of Wall Piers via Nonlinear Static Procedure (NSP) of ASCE/SEI 41-17 for Pattern 2

BSE-1N, 1.0*D* + 0.25*L* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	Shear Strain at Target Disp.	Axial at Target Disp. (k)	Target Strain Limit for LS	Acceptance Ratio
3	P1S3	40	48	8	0.01%	-12	1.50%	0.00
	P2S3	66	48	8	0.01%	-14	1.50%	0.00
	P3S3	66	48	8	0.00%	-48	1.50%	0.00
	P4S3	40	48	8	0.00%	-29	1.50%	0.00
2	P1S2	41	48	8	0.10%	-13	1.50%	0.06
	P2S2	66	48	8	0.13%	-43	1.50%	0.09
	P3S2	66	48	8	0.13%	-92	1.50%	0.09
	P4S2	41	48	8	0.01%	-91	0.75%	0.01
1	P1S1	42	156	8	0.17%	23	1.50%	0.11
	P2S1	66	156	8	0.23%	-75	1.50%	0.15
	P3S1	66	156	8	0.27%	-108	0.75%	0.36
	P4S1	42	156	8	0.31%	-214	0.75%	0.42

Table A-25: Check of Wall Piers via Nonlinear Static Procedure (NSP) of ASCE/SEI 41-17 for Pattern 2 (Continued)

BSE-2N, 1.0*D* + 0.25*L* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	Shear Strain at Target Disp.	Axial at Target Disp. (k)	Target Strain Limit for CP	Acceptance Ratio
3	P1S3	40	48	8	0.00%	-20	2.00%	0.00
	P2S3	66	48	8	0.01%	-15	2.00%	0.01
	P3S3	66	48	8	0.01%	-38	2.00%	0.00
	P4S3	40	48	8	0.00%	-34	2.00%	0.00
2	P1S2	41	48	8	0.21%	-22	2.00%	0.10
	P2S2	66	48	8	0.22%	-50	2.00%	0.11
	P3S2	66	48	8	0.25%	-79	2.00%	0.12
	P4S2	41	48	8	0.20%	-96	1.00%	0.20
1	P1S1	42	156	8	0.30%	19	2.00%	0.15
	P2S1	66	156	8	0.56%	-76	2.00%	0.28
	P3S1	66	156	8	0.74%	-170	1.00%	0.74
	P4S1	42	156	8	1.17%	-157	1.00%	1.17

A.4.5.5 ASCE/SEI 41-17 NDP ACCEPTANCE RATIOS AND LIMITATIONS

Table A-26: Pattern 2 Acceptance Ratio at BSE-1N

EQ	Name	Acceptance Ratio				Comments
		Shear	Rotation Top	Rotation Bottom	Max	
1	Imperial Valley	0.23	0.75	0.83	0.83	Analysis finished
2	Loma Prieta	0.99	1.72	2.06	2.06	All piers at story 1 reached LS limit state in flexure
3	Northridge, Sylmar CSE	0.90	1.64	2.02	2.02	Pie 2 to P4 at story 1 reached LS limit state in flexure
4	Northridge, Sylmar OVM	4.07	1.73	1.87	4.07	All piers at story 1 reached LS limit state in shear
5	Chi Chi TCU079	2.38	1.92	2.14	2.38	All piers at story 1 reached LS limit state in flexure.
6	Chi Chi TCU122	0.16	0.68	0.75	0.75	Analysis finished
7	Duzce	0.56	1.58	1.72	1.72	All piers at story 1 reached LS limit state in flexure
8	Chetsu 65010	0.48	1.38	1.56	1.56	Analysis finished
9	Chetsu 65025	0.13	0.64	0.72	0.72	Analysis finished
10	Mexico, Chihuahua	0.14	0.65	0.71	0.71	Analysis finished
11	Mexico, Ejido Saltillo	0.13	0.64	0.72	0.72	Analysis finished
AVERAGE		0.93	1.21	1.37	1.37	

Table A-27: Pattern 2 Acceptance Ratio at BSE-2N

EQ	Name	Acceptance Ratio				Comments
		Shear	Rotation Top	Rotation Bottom	Max	
1	Imperial Valley	0.21	0.49	0.54	0.54	Analysis finished
2	Loma Prieta	3.49	1.06	1.02	3.49	All piers at story 1 reached CP limit state in shear
3	Northridge, Sylmar CSE	11.41	1.05	1.00	11.41	All piers at story 1 reached CP limit state in shear
4	Northridge, Sylmar OVM	6.33	0.64	0.74	6.33	All piers at story 1 reached CP limit state in shear
5	Chi Chi TCU079	6.27	1.07	0.96	6.27	All piers at story 1 reached CP limit state in shear
6	Chi Chi TCU122	0.14	0.43	0.42	0.43	Analysis finished
7	Duzce	0.71	0.97	1.07	1.07	Analysis finished
8	Chetsu 65010	6.78	0.95	1.02	6.78	All piers at story 1 reached CP limit state in shear
9	Chetsu 65025	0.16	0.39	0.45	0.45	Analysis finished
10	Mexico, Chihuahua	0.19	0.50	0.47	0.50	Analysis finished
11	Mexico, Ejido Saltillo	0.12	0.36	0.39	0.39	Analysis finished
AVERAGE:		3.26	0.72	0.74	3.26	

A.4.5.5 FINDINGS

For Pattern 2, the walls are easily adequate for shear demands from the 1961 UBC, with a maximum Acceptance Ratio of 0.54. However, for ASCE/SEI 7-16, they are overstressed at Levels 1 with maximum Acceptance Ratios of 1.09. As before, the building analyzed represent a 1960s building that will fail under modern building code demand.

For the ASCE/SEI 41-17 LSP, the maximum Acceptance Ratio is 0.96 and 1.08 for BSE-1N and BSE-2N hazard levels, respectively. Once again, the linear procedure limitation provision restrictions are triggered, and linear procedures are not allowed. For the ASCE/SEI 41-17 NSP, the Acceptance Ratios are 0.42 at the BSE-1N level and 1.17 at the BSE-2N level. Results from the NDP indicate the building does not have enough capacity to withstand the earthquake demand imposed. The building failed in shear under 2 and 5 out of 11 of the ground motions used for BSE-1N and BSE-2N, respectively. The building piers failed in moment under 6 and 4 out of 11 of the ground motions used for BSE-1N and BSE-2N, respectively.

A.4.6 Shear Wall Pattern 3

A.4.6.1 UBC 1961 ACCEPTANCE RATIOS

Table A-28: Calculation of Seismic Story Force per UBC 1961

Story	Seismic Weight	Seismic Height	*Z*	*K*	*H*	*D*	*T*	*C*	*I=ZKCW*	h_x	F_x	F_{story}
	(k)	(ft)			(ft)	(ft)	(s)		(k)	(ft)	(k)	(k)
3	800	14							42	106	106	42
2	900	14	1.0	1.0	42	120	0.19	0.09	225	28	80	186
1	900	14							14	40	225	14
Total	2,600									225		

Table A-29: Check of Wall Pier Capacity per UBC 1961

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	f_{allow} (psi)	v_{allow} (k)	V_E (k)	V_E/v_{allow}
3	P1S3	100	84	8	125	100	5	0.05
	P2S3	186	84	8	125	186	22	0.12
	P3S3	186	84	8	125	186	22	0.12
	P4S3	100	84	8	125	100	5	0.05
2	P1S2	71	84	8	125	71	11	0.15
	P2S2	126	84	8	125	126	36	0.28
	P3S2	126	84	8	125	126	36	0.28
	P4S2	71	84	8	125	71	11	0.15
1	P1S1	42	84	8	125	42	19	0.44
	P2S1	66	84	8	125	66	38	0.57
	P3S1	66	84	8	125	66	38	0.57
	P4S1	42	84	8	125	42	19	0.44

A.4.6.2 ASCE/SEI 7-16 ACCEPTANCE RATIOS

Table A-30: Calculation of Story Shear for Pattern 3 per ASCE/SEI 7-16

Story	Seismic Weight (k)	Seismic Height (ft)	k	S_{DS}	R	I_e	C_s	V (k)	h_x (ft)	C_v	F_x (k)	F_{story} (k)	k_{story} (k/in.)
3	800	11	1						42	0.42	147	147	22,690
2	900	11	1	0.67	5	1.0	0.1	**347**	31	0.35	122	268	22,690
1	900	20	1						20	0.23	78	347	8,299
Total	2,600										347		

Table A-31: Check of Wall Pier Capacity per ASCE/SEI 7-16 (1.40 D + 1.0 L + 1.0 E)

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	ϕV_n (k)	V_u (k)	$V_u/\phi V_n$
3	P1S3	100	84	8	81	12	0.14
	P2S3	186	84	8	151	42	0.28
	P3S3	186	84	8	151	35	0.23
	P4S3	100	84	8	81	14	0.17
2	P1S2	71	84	8	58	17	0.30
	P2S2	126	84	8	102	58	0.57
	P3S2	126	84	8	102	53	0.52
	P4S2	71	84	8	58	33	0.57
1	P1S1	42	84	8	34	26	0.76
	P2S1	66	84	8	54	56	1.05
	P3S1	66	84	8	54	55	1.02
	P4S1	42	84	8	34	35	1.04

A.4.6.3 ASCE/SEI 41-17 LSP ACCEPTANCE RATIOS AND LIMITATIONS

Table A-32: Calculation of Story Shear for Pattern 3 per ASCE/SEI 41-17

Story	Seismic Weight	Seismic Height	k	C_1C_2	C_m	S_a	V	h_x	C_v	F_x	F_{story}
	(k)	(ft)					(k)	(k)		(k)	(k)
3	800	11	1					42	0.42	645	645
2	900	11	1	1.1	0.8	0.67	1525	31	0.35	535	1,180
1	900	20	1					20	0.23	345	1,525
Total	2,600									1,525	

Table A-33: Check of Weak and Soft Story Irregularities for Pattern 3 per ASCE/SEI 41-17 for BSE-1N

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	DCR	*m*-factor	Average Shear DCR	Ratio of Average DCR Between this Story and Story Above	Limit Use of Linear Procedures?	Story Drift Ratio	Soft story and Limit use of Linear Static Procedure?
3	P1S3	100	84	8	0.3	2.5	0.4	N/A	NO	0.02%	NO
	P2S3	186	84	8	0.4	2.5			NO		
	P3S3	186	84	8	0.4	2.5			NO		
	P4S3	100	84	8	0.3	2.5			NO		
2	P1S2	71	84	8	0.8	2.5	1.0	2.46	NO	0.06%	YES
	P2S2	126	84	8	1.0	2.5			NO		
	P3S2	126	84	8	1.0	2.5			NO		
	P4S2	71	84	8	0.8	2.5			NO		
1	P1S1	42	84	8	1.8	2.5	2.0	2.09	NO	0.11%	YES
	P2S1	66	84	8	2.1	2.5			NO		
	P3S1	66	84	8	2.1	2.5			NO		
	P4S1	42	84	8	1.8	2.5			NO		

Table A-34: Check of Wall Piers via LSP of ASCE/SEI 41-17 for Pattern 3 for BSE-1N

BSE-1N, 0.9*D* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	V_{CE} (k)	V_{UD} (k)	m_{LS}	$\kappa m_{CP} V_{CE}$	Acceptance Ratio $V_{UD} / \kappa m_{LS} V_{CE}$
3	P1S3	100	84	8	167	46	2.5	418	0.11
	P2S3	186	84	8	311	136	2.5	778	0.17
	P3S3	186	84	8	311	133	2.5	778	0.17
	P4S3	100	84	8	167	47	2.5	418	0.11
2	P1S2	71	84	8	119	96	2.5	297	0.32
	P2S2	126	84	8	211	215	2.5	527	0.41
	P3S2	126	84	8	211	213	2.5	527	0.40
	P4S2	71	84	8	119	102	2.5	297	0.34
1	P1S1	42	84	8	70	125	2.5	176	0.71
	P2S1	66	84	8	110	231	2.5	276	0.84
	P3S1	66	84	8	110	230	2.5	276	0.83
	P4S1	42	84	8	70	129	2	141	0.92

Table A-34 (Continued)

BSE-1N, 1.1*D* + 1.1*L* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	V_{CE} (k)	V_{UD} (k)	m_{LS}	$\kappa m_{CP} V_{CE}$	Acceptance Ratio $V_{UD} / \kappa m_{LS} V_{CE}$
3	P1S3	100	84	8	167	46	2.5	418	0.11
	P2S3	186	84	8	311	137	2.5	778	0.18
	P3S3	186	84	8	311	133	2.5	778	0.17
	P4S3	100	84	8	167	48	2.5	418	0.11
2	P1S2	71	84	8	119	94	2.5	297	0.32
	P2S2	126	84	8	211	216	2.5	527	0.41
	P3S2	126	84	8	211	213	2.5	527	0.40
	P4S2	71	84	8	119	104	2.5	297	0.35
1	P1S1	42	84	8	70	125	2.5	176	0.71
	P2S1	66	84	8	110	231	2.5	276	0.84
	P3S1	66	84	8	110	230	2.5	276	0.83
	P4S1	42	84	8	70	130	2	141	0.93

Table A-35 Check of Weak and Soft Story Irregularities for Pattern 3 per ASCE/SEI 41-17 for BSE-2N

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	DCR	*m*-factor	Average Shear DCR	Ratio of Average DCR Between this Story and Story Above	Limit Use of Linear Procedures?	Story Drift Ratio	Soft story and Limit use of Linear Static Procedure?
3	P1S3	100	84	8	0.4	3.0	0.6	N/A	NO	0.04%	NO
	P2S3	186	84	8	0.6	3.0			NO		
	P3S3	186	84	8	0.6	3.0			NO		
	P4S3	100	84	8	0.4	3.0			NO		
2	P1S2	71	84	8	1.2	3.0	1.4	2.46	NO	0.08%	YES
	P2S2	126	84	8	1.5	3.0			NO		
	P3S2	126	84	8	1.5	3.0			NO		
	P4S2	71	84	8	1.2	3.0			NO		
1	P1S1	42	84	8	2.7	3.0	3.0	2.09	NO	0.17%	YES
	P2S1	66	84	8	3.1	3.0			YES		
	P3S1	66	84	8	3.1	3.0			YES		
	P4S1	42	84	8	2.7	3.0			NO		

Table A-36 Check of Wall Piers via LSP of ASCE/SEI 41-17 for Pattern 3 for BSE-2N

BSE-2N, 0.9*D* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	V_{CE} (k)	V_{UD} (k)	m_{CP}	$\kappa m_{CP} V_{CE}$	Acceptance Ratio $V_{UD} / \kappa m_{CP} V_{CE}$
3	P1S3	100	84	8	167	70	3	502	0.14
	P2S3	186	84	8	311	202	3	933	0.22
	P3S3	186	84	8	311	199	3	933	0.21
	P4S3	100	84	8	167	71	3	502	0.14
2	P1S2	71	84	8	119	145	3	356	0.41
	P2S2	126	84	8	211	321	3	632	0.51
	P3S2	126	84	8	211	319	3	632	0.50
	P4S2	71	84	8	119	151	3	356	0.43
1	P1S1	42	84	8	70	189	3	211	0.90
	P2S1	66	84	8	110	346	3	331	1.04
	P3S1	66	84	8	110	345	3	331	1.04
	P4S1	42	84	8	70	193	3	211	0.92

Table A-36 (Continued)

BSE-2N, 1.1*D* + 1.1*L* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	V_{CE} (k)	V_{UD} (k)	m_{CP}	$\kappa m_{CP} V_{CE}$	Acceptance Ratio $V_{UD} / \kappa m_{CP} V_{CE}$
3	P1S3	100	84	8	167	70	3	502	0.14
	P2S3	186	84	8	311	203	3	933	0.22
	P3S3	186	84	8	311	199	3	933	0.21
	P4S3	100	84	8	167	71	3	502	0.14
2	P1S2	71	84	8	119	144	3	356	0.40
	P2S2	126	84	8	211	322	3	632	0.51
	P3S2	126	84	8	211	319	3	632	0.50
	P4S2	71	84	8	119	153	3	356	0.43
1	P1S1	42	84	8	70	188	3	211	0.89
	P2S1	66	84	8	110	346	3	331	1.05
	P3S1	66	84	8	110	345	3	331	1.04
	P4S1	42	84	8	70	194	3	211	0.92

A.4.6.4 ASCE/SEI41-17 NSP ACCEPTANCE RATIOS AND LIMITATIONS

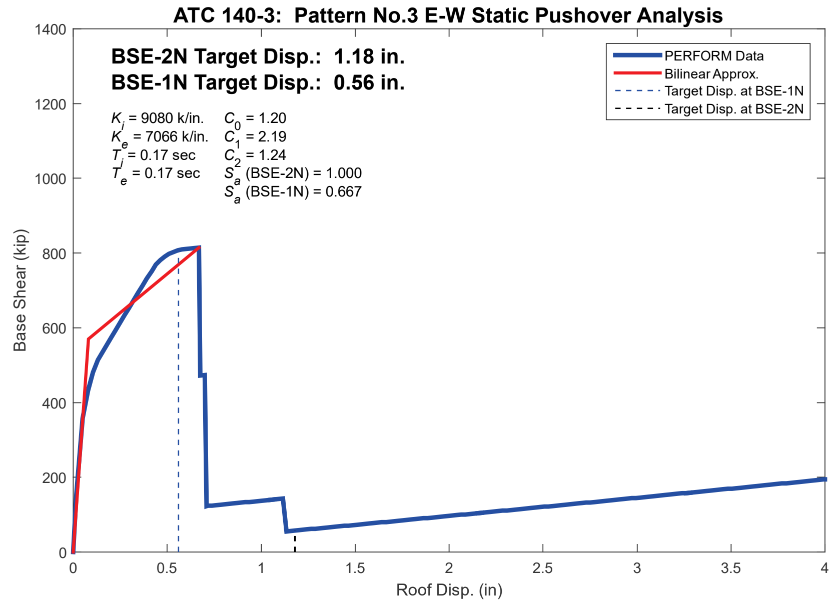


Figure A1-11 Target displacements for Shear Wall Pattern No. 3.

Table A-37 Check of Wall Piers via Nonlinear Static Procedure (NSP) of ASCE/SEI 41-17 for Pattern 3

BSE-1N, 1.0*D* + 0.25*L* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	Shear Strain at Target Disp.	Axial at Target Disp. (k)	Target Strain Limit for LS	Acceptance Ratio
3	P1S3	100	84	8	0.00%	-48	1.50%	0.00
	P2S3	186	84	8	0.00%	-25	1.50%	0.00
	P3S3	186	84	8	0.00%	-11	1.50%	0.00
	P4S3	100	84	8	0.00%	-14	1.50%	0.00
2	P1S2	71	84	8	0.01%	-138	0.75%	0.01
	P2S2	126	84	8	0.01%	-63	1.50%	0.01
	P3S2	126	84	8	0.00%	-16	1.50%	0.00
	P4S2	71	84	8	0.00%	-11	1.50%	0.00
1	P1S1	42	84	8	0.50%	-189	0.75%	0.66
	P2S1	66	84	8	0.62%	-87	1.50%	0.41
	P3S1	66	84	8	0.59%	-41	1.50%	0.39
	P4S1	42	84	8	0.39%	-36	1.50%	0.26

Table A-37 (Continued)

BSE-2N, 1.0*D* + 0.25*L* + 1.0*E*

Story	Pier	l_w (in.)	H_w (in.)	h_w (in.)	Shear Strain at Target Disp.	Axial at Target Disp. (k)	Target Strain Limit for CP	Acceptance Ratio
3	P1S3	100	84	8	0.00%	-22	2.00%	0.00
	P2S3	186	84	8	0.00%	-24	2.00%	0.00
	P3S3	186	84	8	0.00%	-21	2.00%	0.00
	P4S3	100	84	8	0.00%	-16	2.00%	0.00
2	P1S2	71	84	8	0.00%	-46	2.00%	0.00
	P2S2	126	84	8	0.01%	-55	2.00%	0.01
	P3S2	126	84	8	0.00%	-50	2.00%	0.00
	P4S2	71	84	8	0.00%	-29	2.00%	0.00
1	P1S1	42	84	8	2.13%	-53	2.00%	1.07
	P2S1	66	84	8	2.13%	-71	2.00%	1.07
	P3S1	66	84	8	2.12%	-69	2.00%	1.06
	P4S1	42	84	8	0.50%	-43	2.00%	0.25

A.4.6.5 FINDINGS

For Pattern 3, the walls are easily adequate for shear demands from the 1961 UBC, with a maximum Acceptance Ratio of 0.57. However, for ASCE/SEI 7-16, they are overstressed at Level 1 with a maximum Acceptance Ratio of 1.05.

For the ASCE/SEI 41-17 LSP, the maximum Acceptance Ratio is 0.93 and 1.05 for both BSE-1N and BSE-2N hazard levels. The linear procedure limitation provision restrictions are triggered, and linear procedures are not allowed. For the ASCE/SEI41-17 NSP, the Acceptance Ratios are 0.66 at the BSE-1N level and 1.07 at the BSE-2N level.

A.5 Conclusions

A.5.1 Summary of Findings

The findings of the three building patterns that have been studied can be summarized below:

- All three building patterns that have been studied show adequate performance under the UBC 1961 provisions with Acceptance Ratios less than 0.60.
- All three building patterns are overstressed for the ASCE/SEI 7-16 loads with a maximum Acceptance Ratio of 1.08 at Story 1.
- All three building patterns show adequate Acceptance Ratios for the ASCE/SEI 41-17 LSP loads under the BSE-1N seismic hazard level, but they are overstressed at the BSE-2N seismic hazard level, with worst case Acceptance Ratios of 0.96 and 1.08, respectively.
- The linear procedure limitation provision restrictions are triggered for all three patterns, such that linear procedures are not permitted.
- When checked for ASCE/SEI 41-17 NSP, similar results were obtained in all the buildings studied. A maximum Acceptance Ratio of 0.66 was obtained at the lower hazard level. When the seismic demand increase, all three buildings are overstressed with a maximum Acceptance Ratio of 2.92 was calculated.
- For NDP, the Pattern 1 and Pattern 2 buildings both failed to provide enough shear capacity at both hazard levels. Pattern 1 failed in shear at 5 out of 11 ground motions at BSE-1N and BSE-2N. At the BSE-1N hazard level, Pattern 2 failed in shear under 2 ground motions and in flexure under 6 ground motions. At the BSE-2N hazard level, the building failed in shear and flexure under 5 and 4 ground motions, respectively.
- For both Patterns 1 and 2, the LSP results are close to meeting the performance objective, but the NDP results show the building does meet the objective. Thus, the linear procedure limitation provision result of not permitted is appropriate because it prevents a misleading, unconservative conclusion from being drawn based on the LSP.

A.5.2 Issues and Conclusions

The three building patterns produced inconsistent findings and conclusions regarding the limitations that are being examined.

A.5.2.1 BUILDING PATTERN 1

For Building Pattern 1, the following conclusions have been obtained, as shown in Table A1-38.

- It is unclear whether ASCE/SEI 7-16 can predict the Acceptance Ratio for ASCE/SEI 41-17 NSP. At the BSE-1N hazard level, there is a large discrepancy between the results of the two methods with 1.08 from ASCE/SEI 7-16 and 0.43 from ASCE/SEI 41-17, whereas at the BSE-2N hazard level, NSP predict a greater Acceptance Ratio, with values of 1.50 and 2.92, respectively.
- Looking at the Acceptance Ratios produced by the ASCE/SEI 41-17 LSP and NSP procedures, a similar conclusion can be reached. A large discrepancy was found between both methods at both hazard levels. Acceptance Ratios of 0.90 and 0.43 were obtained at the BSE-1N hazard level for LSP and NSP, respectively. When comparing values at the BSE-2N hazard level, the ratios were 1.07 and 2.92. At the lower hazard level, both methods predict acceptable behavior of the building, whereas the contrary was observed at the BSE-2N hazard level.
- No conclusion can be made from the NDP results obtained since the building does not have enough capacity at both the BSE-1N and BSE-2N hazard levels.
- The intent of the limitation provisions is presumably to prevent using less conservative results from the presumably less accurate linear procedures when the results from the nonlinear procedures are more conservative. Answering the question of whether the limitation of LSP is appropriate, it appears that at BSE-1N level the LSP is more conservative than the NSP, with Acceptance Ratios of 0.90 and 0.43 respectively, and thus the limitation is not appropriate regardless of the fact both methods predict acceptable behavior of the building. Contrary to that, at a BSE-2N hazard level, the opposite holds true, since the Acceptance Ratios are 1.07 and 2.92 for the LSP and NSP respectively, and thus the limitation is appropriate, although the Acceptance Ratios at this hazard level are considerably different between themselves.

Table A-38: Building Pattern 1 Summary

Code	Acceptance Ratio	ASCE/SEI 7-16 Bounds NSP?	LSP Bounds NSP?	ASCE/SEI 7-16 Bounds NDP	LSP Bounds NDP	LSP Permitted?	Limitation Provision is Appropriate?
1961 UBC	0.57	--	--	--	--	--	--
ASCE/SEI 7-16	1.08	--	--	--	--	--	--
LSP, BSE-1N	0.90	--	--	--	--	Not Permitted	No
LSP, BSE-2N	1.07	--	--	--	--	Not Permitted	Yes
NSP, BSE-1N	0.43	Yes: 1.08 > 0.43	Yes: 0.90 > 0.43	--	--	--	Too conservative
NSP, BSE-2N	2.92	No: 1.08 < 2.92	No: 1.07 < 2.92	--	--	--	Yes
NDP, BSE-1N	Fail	--	--	No	No	--	Yes
NDP, BSE-2N	Fail	--	--	No	No	--	Yes

A.5.2.2 BUILDING PATTERN 2

For Building Pattern 2, the following conclusions have been obtained as shown in Table A1-39.

- We observe that in this building pattern the provisions of ASCE/SEI 7-16 cannot predict the building performance under ASCE/SEI 41-17 NSP, as the Acceptance Ratio of 1.02 that is obtained from ASCE/SEI 7-16 is far from 0.42 and 1.17 Acceptance Ratios from NSP.

- Similarly, the ASCE/SEI 41-17 LSP does not predict the NSP Acceptance Ratios at the BSE-1N hazard level since there is a significant difference in the results (1.02 vs 0.42). More consistent Acceptance Ratios were obtained at the BSE-2N hazard level (1.02 vs 1.08).

- The limitation provision for the LSP is appropriate in this case for the BSE-1N hazard level contrary to what was observed at the BSE-2N hazard level. The Acceptance Ratios that were obtained from the LSP are much higher compared to the NSP at the lower hazard levels and thus more conservative.

- Similar to Pattern 1, no conclusion can be reached from the NDP results.

Table A-39: Building Pattern 2 Summary

Code	Acceptance Ratio	ASCE/SEI 7-16 Bounds NSP?	LSP Bounds NSP?	ASCE/SEI 7-16 Bounds NDP	LSP Bounds NDP	LSP Permitted?	Limitation Provision is Appropriate?
1961 UBC	0.57	--	--	--	--	--	--
ASCE/SEI 7-16	1.02	--	--	--	--	--	--
LSP, BSE-1N	0.96	--	--	--	--	Not Permitted	No
LSP, BSE-2N	1.08	--	--	--	--	Not Permitted	Yes
NSP, BSE-1N	0.42	Yes: 1.02 > 0.43	Yes: 0.96 > 0.42	--	--	--	Too conservative
NSP, BSE-2N	1.17	No: 1.02 < 1.17	No: 1.08 < 1.17	--	--	--	Yes
NDP, BSE-1N	Fail	--	--	No	No	--	Yes
NDP, BSE-2N	Fail	--	--	No	No	--	Yes

A.5.2.3 BUILDING PATTERN 3

For Building Pattern 3, the following conclusions have been obtained, as shown in Table A1-40.

- Similar to Pattern 1, it is observed that it is unclear whether ASCE/SEI 7-16 can predict the Acceptance Ratio for ASCE/SEI 41 NSP. At the BSE-1N hazard level, there a large discrepancy between the results of the two methods, whereas at the BSE-2N hazard level they are reasonably close.

- Looking at the Acceptance Ratios produced by the ASCE/SEI 41 LSP and NSP procedures, the LSP can reasonably predict the Acceptance Ratio for NSP at the BSE-2N hazard level; however, a discrepancy when comparing values at the BSE-1N hazard level is observed.

- Answering the question of whether the linear procedure limitation of LSP is appropriate, it appears that at the BSE-1N hazard level the LSP is more conservative than the NSP, and thus the limitation is not appropriate. Contrary to that, at a BSE-2N hazard level, the opposite holds true, and thus the limitation appears appropriate.

- NDP analyses were not conducted for Building Pattern 3.

Table A-40: Building Pattern 3 Summary

Code	Acceptance Ratio	ASCE/SEI 7-16 Bounds NSP?	LSP Bounds NSP?	LSP Permitted?	Limitation Provision is Appropriate?
1961 UBC	0.57	--	--	--	--
ASCE/SEI 7-16	1.04	--	--	--	--
LSP, BSE-1N	0.93	--	--	Not Permitted	--
LSP, BSE-2N	1.04	--	--	Not Permitted	--
NSP, BSE-1N	0.66	Yes: 1.04 > 0.66	Yes: 0.93 > 0.66	--	Too conservative
NSP, BSE-2N	1.07	No: 1.04 < 1.07	No: 1.04 < 1.07	--	Yes

A.5.2.4 CLOSING

The WG1 case studies summarized above formed a portion of the analysis used to evaluate the ASCE/SEI 41-17 linear limitation provisions. See Part 1, Chapter 1 for a broader perspective incorporating other case studies and research, as well as the resulting code change proposal and rationale.

A.7 References

ACI, 2014, *Building Code Requirements for Structural Concrete and Commentary*, ACI 318-14, American Concrete Institute.

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FEMA, 2018, *Example Application Guide for ASCE/SEI 41-13 Seismic Evaluation and Retrofit of Existing Buildings with Additional Commentary for ASCE/SEI 41-17*, FEMA P-2006 Report, prepared by the Applied Technology Council for the Federal Emergency Management Agency, Washington, D.C.

ICBO, 1961, 1961 Uniform Building Code, Volume 1, International Conference of Building Officials, Los Angeles, California.