Building Seismic Safety Council | BSSC

IMPROVED NONSTRUCTURAL SEISMIC DESIGN FORCE EQUATIONS

John Gillengerten – Chair, IT5 Nonstructural Components

nehrp

FEMA

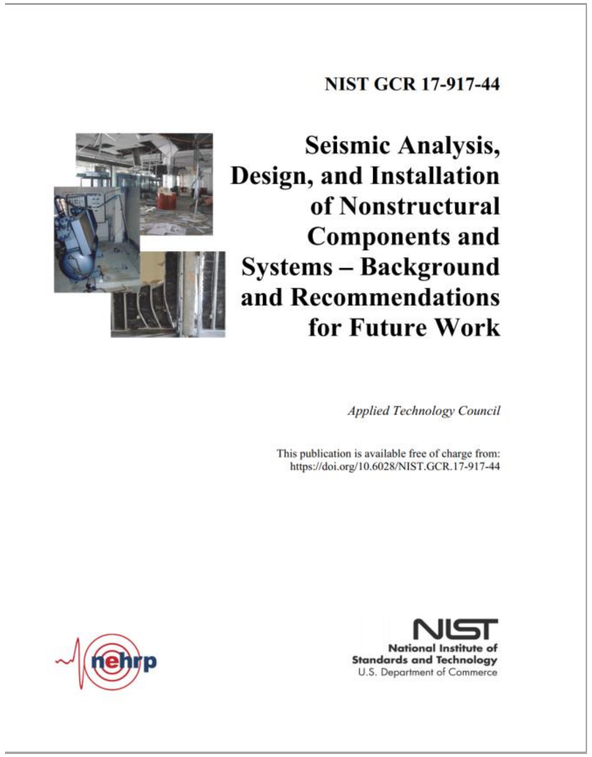
Seismic Design for Nonstructural Components

	1935 UBC Appendix	1961 UBC	1976 UBC	1979 UBC	1997 UBC, ASCE 7-02	2020 NEHRP Equation
Hazard Level	X	X	X	X	X	Same
Site Soil Conditions			X		X	Same
Component Type		X	X	X	X	Revised
Component Strength/Ductility			X	X	X	Revised
Component Importance			X	X	X	Same
Component Flexibility			X	X	X	Revised
Component Anchorage					X	Same
Vertical Location in Structure					X	Revised
Structure SFRS/Period						New

Development of the Revised Force Equations

- In 2013, the National Institute of Standards and Technology (NIST) awarded a NEHRP "Earthquake Structural and Engineering Research" task order contract to the Applied Technology Council (ATC)
- A resulting report, NIST GCR 13-917-23, *Development of NIST Measurement Science R&D Roadmap: Earthquake Risk Reduction in Buildings* identified nonstructural issues as a top priority
- Resulted in the ATC-120 Project

ATC-120 Project Initial Phase


NIST GCR 17-917-44

Seismic Analysis, Design, and Installation of Nonstructural Components and Systems – Background and Recommendations for Future Work

Applied Technology Council

This publication is available free of charge from: https://doi.org/10.6028/NIST.GCR.17-917-44

nehrp

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

- Detailed Reviews of
  - Performance of nonstructural components and systems in past earthquakes,
  - History and evolution of nonstructural seismic design provisions and criteria
  - Current information on research and testing
- Develop recommendations
- Number 1 recommendation - Conduct Holistic Assessment of Current Code Design Approaches

ATC-120 Project Follow-up Phase

NIST GCR 18-917-43

Recommendations for Improved Seismic Performance of Nonstructural Components

Applied Technology Council

This publication is available free of charge from:
https://doi.org/10.6028/NIST.GCR.18-917-43

September 2018

nehrp

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

- A number of topics were studied, including:
  - Reviewed of ASCE/SEI 7-16 nonstructural design provisions
  - Performed analytical investigations to provide a fundamental understanding of the response of nonstructural components to earthquakes, proposed new design equations for horizontal forces
  - Recommended code changes and additional research

Factors Influencing Seismic Design of Nonstructural Components

- Ground shaking intensity, expressed in terms of peak ground acceleration (PGA)
  - Hazard Level
  - Site Conditions
- Component Properties
  - Component period
  - Inherent component damping
  - Component overstrength
  - Ductility (component and/or anchorage)
  - Component Importance
- Vertical location of component within the building or structure supporting the component
- Supporting Structure Properties
  - Building's modal periods
  - Seismic force-resisting system (SFRS)
  - Ductility
  - Inherent damping
  - Configuration (such as plan and vertical irregularities)
  - Floor diaphragm rigidity

Formula Structure

ASCE/SEI 7-16

2020 NEHRP Provisions

PFA/PGA

$$F_p = \frac{0.4 S_{DS} \, a_p}{\frac{R_p}{I_p}} \boxed{\left[1 + 2\frac{z}{h}\right]} W_p$$

$$F_p = 0.4 S_{DS} I_p W_p \boxed{\left[\frac{H_f}{R_\mu}\right]} \boxed{\left[\frac{C_{AR}}{R_{po}}\right]}$$

Resonance, strength and ductility of component

New Design Coefficients

$$F_p = 0.4 S_{DS} I_p W_p \left[\frac{H_f}{R_\mu}\right]\left[\frac{C_{AR}}{R_{po}}\right]$$

- H_f = factor for force amplification as a function of height in the structure;
- R_μ= structure ductility reduction factor;
- C_{AR}= component resonance ductility factor that converts the peak floor or ground acceleration into the peak component acceleration;
- R_{po}= component strength factor.

Force Amplification Factor, H_f

- Function of structure approximate fundamental period T_a and location in structure

$$H_f = 1 + a_1\left(\frac{z}{h}\right) + a_2\left(\frac{z}{h}\right)^{10} \quad \text{or,}$$

$$H_f = 1 + 2.5\left(\frac{z}{h}\right)$$

where $a_1 = \frac{1}{T_a} \le 2.5$

$$a_2 = [1 - (0.4/T_a)^2] \ge 0$$

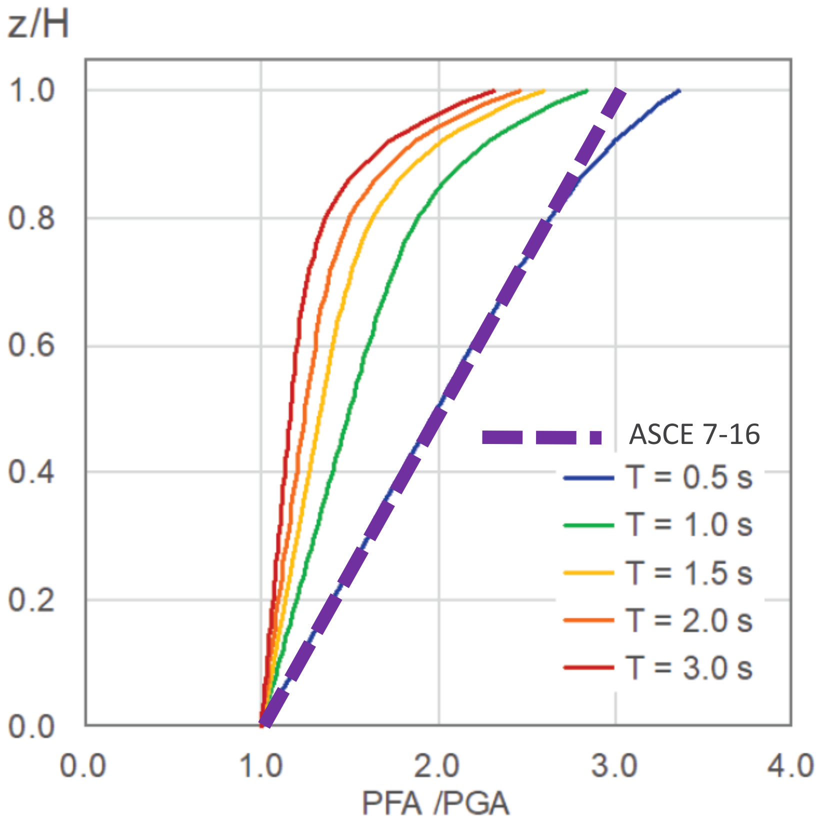


Figure 4-15 Sample equation for PFA/PGA for PCA > 0.9g.

Building global ductility, R_μ

- Increased building ductility generally reduces nonstructural component response.
- This is captured by the variable R_μ

$$R_\mu = (1.1R/\Omega_0)^{1/2} \geq 1.3$$

where R and Ω_0 for the building or supporting structure are obtained from Tables 12.2-1, 15.4-1, and 15,4-2

Building global ductility, R_μ

Values of R_μ (I_e = 1.00)

Ω_0	**R Factor**																	
	0.8	1	1.25	1.5	2	2.5	3	3.25	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8
3							1.30		1.30	1.30	1.30	1.35	1.42	1.48	1.54	1.60		1.71
2.5					1.30	1.30	1.30			1.33		1.48	1.56	1.62	1.69	1.75	1.82	1.88
2			1.30		1.30	1.30	1.30	1.34		1.48		1.66		1.82		1.96		2.10
1.75							1.37											
1.5				1.30			1.48											
1.25			1.30	1.30		1.48												
1	1.30	1.30		1.30														

Lower Bound Cap on R_μ (yellow)

:SDC D and higher, except the following (green)
- Light-frame walls w/shear panels of other materials
- Steel OCBF, IMF
- Cold-formed steel special bolted moment frame
- Cantilever column systems

Treatment of nonbuilding structures

- Nonbuilding structures often utilize ordinary or intermediate lateral systems or are not similar to building systems at all
  - Low values of *R* for nonbuilding structures might have been selected to facilitate adoption in the building standards
  - Low *R* nonbuilding structures have performed well
  - Special systems would be cost-prohibitive
- For nonbuilding structures similar to buildings, the least conservative values of design coefficients (without regard to height limits) can be used for a given LFRS (i.e. intermediate moment frames)
- The calculated period, T may be used in lieu of T_a for the computation of H_f, force amplification with height

Component Design Coefficients

- The focus of the proposal was on including the influence of the supporting structure in the seismic design force equation
- Incorporate the notation for component design coefficients recommended in ATC-120
- Nonstructural components are assigned to one of three categories of component ductility, and whether they are likely to be in resonance

Ductility Category	Assumed Component Ductility, μ_{comp}	Resonance Likely CA/PFA (C_{AR})	
		Supported at or Below Grade Plane	Supported Above Grade Plane by a Structure
Low	1.25	2.0	2.8
Moderate	1.5	1.8	2.2
High	2.0	1.4	1.4

Assignment of C_{AR} and R_{po} Values

- Current design coefficients for nonstructural components are based on engineering judgement
- The new design coefficients for classes of nonstructural components were assigned by IT-5, based on the properties of the components given in ASCE 7-16, using the following assumptions:
  - Components with a_p=1 are classified as unlikely to be in resonance.
  - Components with a_p=2.5 are classified as likely to be in resonance.
  - For components likely to be in resonance, those assigned an R_p=1.5 are classified as low ductility, R_p=2, 2.5, and 3 are classified as having moderate ductility, and those with R_p=4.5 or greater as having high ductility.
  - The component strength factor R_{po} varied from 1.3 to 3, reflecting the level of reserve strengths associated with the component.

Distribution Systems

- Currently, bracing for pipes, ducts, and conduit is designed using the same design coefficients as the distributed system
- In the 2020 Provisions, design of supports and system are considered separately

Rooftop Structures and Equipment Supports

- Design requirements for rooftop structures were expanded
  - Currently no restrictions on design of penthouses and rooftop structures
  - New design coefficients are based on system R values from Chapters 12 or 15
  - Detail design is per Chapters 12 or 15
- Expanded requirements for mechanical and electrical component supports
  - Integral supports (i.e. lugs, saddles, short legs, etc.)
  - Support structures (i.e. braced and moment frames)
  - Platforms (multiple components supported on a single structure)

Changes to Design Practice

- The new equations require knowledge of the LFRS and height of the supporting structure
- Some engineers currently produce designs with little or no information on the structure
  - Default values for R_μ can be used if the structural system is unknown
  - Default formula available for determining H_f is the height of the structure and lateral force-resisting system is unknown
- Practice will evolve if there are substantial advantages for providing the designer with information on the lateral force-resisting system of the structure
- If the information cannot be provided, the design force should be conservative, given the influence of the supporting building on component force demands

Adoption into ASCE/SEI 7-22

- The new procedures for calculation seismic forces for nonstructural components is being incorporated into the next edition of ASCE 7
- A number of enhancements and improvements to the procedures were incorporated into the ASCE 7 version
  - Including the structure importance factor I_e, when computing the building global ductility factor, R_μ
  - Refinement of the design coefficients for high ductility piping systems
  - Improved the correlation between the component resonance ductility factor, C_{AR}, and the anchorage overstrength factor Ω_{0p} for components unlikely to be in resonance

Components at grade

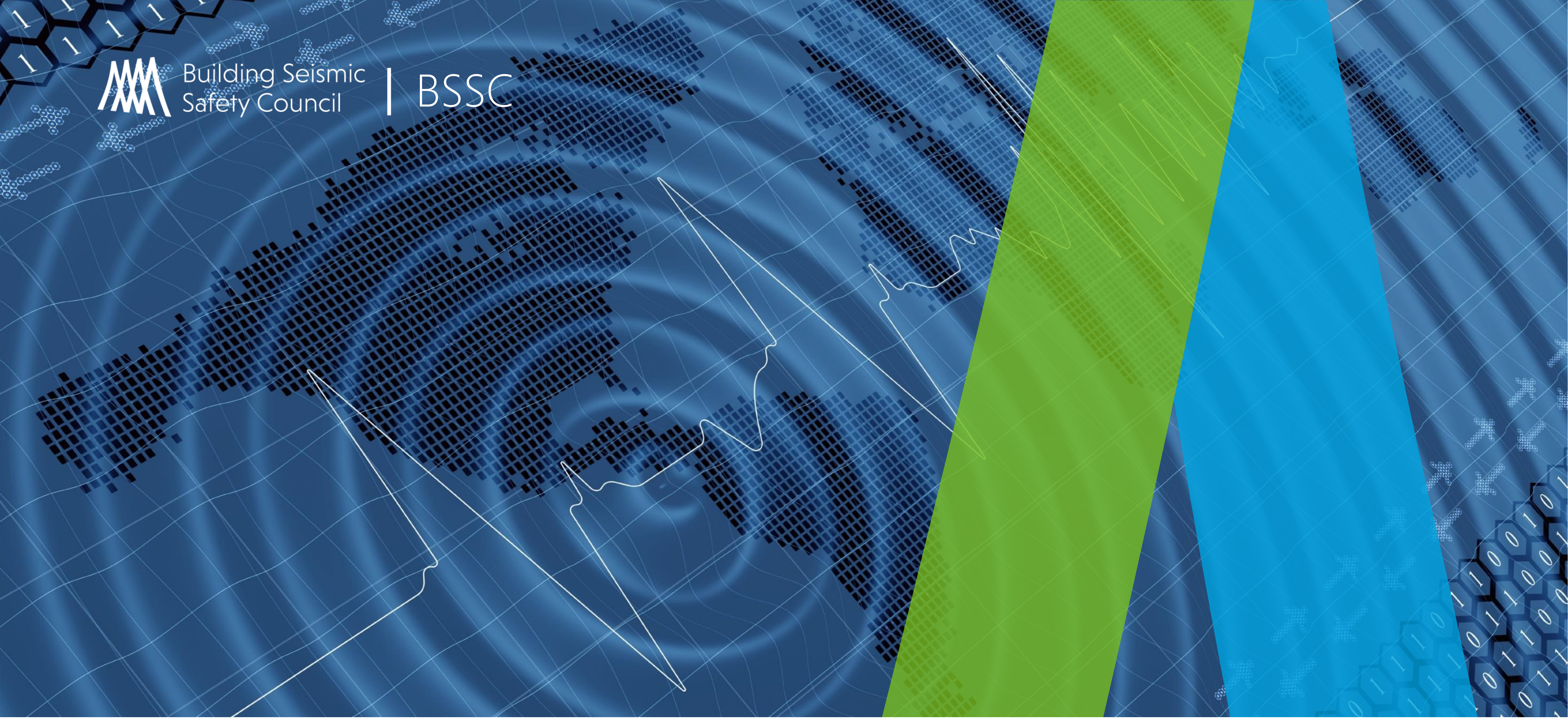
			Current Design Coefficients			Proposed Design Force F_p Normalized to ASCE 7-16 F_p (at Grade)									
No.	New	Description	a_p	R_p	Ω_0	24-sty Steel SMRF	8-sty Steel BRBF	8-sty Special RCSW (Bldg Frame)	2-sty Steel SCBF	2-sty SRMSW (bearing wall)	4-sty Light Frame	6-sty Steel SCBF	6 sty Steel SMRF	2-sty Steel BRBF	6-sty Unknown System
1		Light fixtures, other MEP	1	1.5	1.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2		Access floors, no seismic detailing	1	1.5	2	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78
3		Ceilings, Ext. Walls	1	2.5	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4	X	Int Walls tall light frame	1	2.5	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5		Other Partitions URM	1	1.5	1.5	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78
6		Wet Side HVAC, Electrical	1	2.5	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7		Elevators	1	2.5	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
8		Arch. Rigid Comp.	1	3.5	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
9		Wall Panel Fasteners	1.3	1	1	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
10		Arch. Comp. Low Ductility	2.5	1.5	1.5	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
11		Isolated Comp. Springs	2.5	2	2	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
12		Isolated Comp. Neoprene	2.5	2.5	2	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38
13		Parapets, Ornamentation	2.5	2.5	2	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
14		Egress Stairs Fasteners	2.5	2.5	2.5	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
15		Air Coolers (Fini Fans)	2.5	3	1.5	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
16		Low Ductility Pipes, Ducts	2.5	3	2	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
21		Arch. Comp. High Ductility	2.5	3.5	2.5	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
22		Piping Threaded	2.5	4.5	2	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
23		Other Ducts, Raceways	2.5	6	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
24		Air Side HVAC Equip.	2.5	6	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
25		Ducts, Welded Piping	2.5	9	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
26		ASME B31 Piping Welded	2.5	12	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
27		ASME B31 Piping Threaded	2.5	6	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Items 2, 5, 21, and 22 currently governed by minimum force.   Items 15 and 16 currently 10% over min. force

F_p averaged over all levels of the structure, normalized F_p using ASCE 7-16

			Current Design Coefficients			Proposed Design Force F_p Normalized to ASCE 7-16 F_p (Average of all levels - grade to Roof)									
No.	New	Description	a_p	R_p	Ω_0	24-sty Steel SMRF	8-sty Steel BRBF	8-sty Special RCSW (Bldg Frame)	2-sty Steel SCBF	2-sty SRMSW (bearing wall)	4-sty Light Frame	6-sty Steel SCBF	6 sty Steel SMRF	2-sty Steel BRBF	6-sty Unknown System
1		Light fixtures, other MEP	1	1.5	1.5	0.64	0.66	0.70	0.75	0.85	0.80	0.69	0.66	0.74	0.82
2		Access floors, no seismic detailing	1	1.5	2	1.21	1.35	1.67	1.77	1.97	1.97	1.59	1.44	1.73	2.01
3		Ceilings, Ext. Walls	1	2.5	2	0.89	0.91	0.99	1.03	1.19	1.14	0.97	0.92	1.01	1.18
4	X	Int Walls tall light frame	1	2.5	2	0.90	0.92	1.02	1.07	1.23	1.18	0.99	0.94	1.05	1.23
5		Other Partitions URM	1	1.5	1.5	1.21	1.35	1.67	1.77	1.97	1.97	1.59	1.44	1.73	2.01
6		Wet Side HVAC, Electrical	1	2.5	2	0.89	0.91	0.99	1.03	1.19	1.14	0.97	0.92	1.01	1.18
7		Elevators	1	2.5	2	0.89	0.91	0.99	1.03	1.19	1.14	0.97	0.92	1.01	1.18
8		Arch. Rigid Comp.	1	3.5	2	1.01	1.04	1.15	1.20	1.39	1.34	1.12	1.06	1.17	1.39
9		Wall Panel Fasteners	1.3	1	1	0.67	0.74	0.91	0.98	1.09	1.08	0.87	0.79	0.96	1.10
10		Arch. Comp. Low Ductility	2.5	1.5	1.5	0.53	0.59	0.73	0.80	0.88	0.85	0.69	0.63	0.78	0.87
11		Isolated Comp. Springs	2.5	2	2	0.64	0.70	0.86	0.94	1.07	1.02	0.82	0.75	0.92	1.04
12		Isolated Comp. Neoprene	2.5	2.5	2	0.79	0.88	1.07	1.17	1.33	1.27	1.03	0.93	1.15	1.30
13		Parapets, Ornamentation	2.5	2.5	2	0.69	0.76	0.93	1.02	1.16	1.10	0.89	0.81	1.00	1.15
14		Egress Stairs Fasteners	2.5	2.5	2.5	0.69	0.76	0.93	1.02	1.16	1.10	0.89	0.81	1.00	1.15
15		Air Coolers (Fini Fans)	2.5	3	1.5	0.83	0.91	1.11	1.22	1.39	1.32	1.07	0.97	1.20	1.38
16		Low Ductility Pipes, Ducts	2.5	3	2	0.83	0.91	1.11	1.22	1.39	1.32	1.07	0.97	1.20	1.38
21		Arch. Comp. High Ductility	2.5	3.5	2.5	0.70	0.73	0.86	0.96	1.09	1.01	0.83	0.77	0.95	1.06
22		Piping Threaded	2.5	4.5	2	0.86	0.94	1.17	1.23	1.42	1.40	1.12	1.01	1.21	1.46
23		Other Ducts, Raceways	2.5	6	2	0.87	0.89	0.97	1.01	1.16	1.11	0.95	0.90	0.98	1.15
24		Air Side HVAC Equip.	2.5	6	2	0.88	0.90	0.99	1.04	1.20	1.15	0.96	0.91	1.02	1.20
25		Welded Piping, Ducts	2.5	9	2	0.98	0.98	1.04	1.05	1.14	1.12	1.02	1.00	1.04	1.15
26		ASME B31 Piping Welded	2.5	12	2	1.00	1.00	1.00	1.00	1.02	1.00	1.00	1.00	1.00	1.03
27		ASME B31 Piping Threaded	2.5	6	2	0.84	0.85	0.88	0.89	0.95	0.94	0.87	0.86	0.88	0.96

Building Seismic Safety Council


Building Seismic
Safety Council | BSSC

Building Seismic Safety Council | BSSC

NEW PROVISIONS FOR SEISMIC DESIGN OF DIAPHRAGMS

Kelly Cobeen, Wiss Janney Elstner Associates

nehrp FEMA

Acknowledgements – PUC IT9

Voting members:

Kelly Cobeen	Wiss, Janney, Elstner Associates	Emeryville, CA
John Lawson	Cal Poly San Luis Obispo	San Luis Obispo, CA
S.K. Ghosh	S. K. Ghosh Associates	Palatine, IL
Ben Schafer (1)	Johns Hopkins University	Baltimore, MD
Tom Sabol	Engelkirk & Sabol	Los Angeles, CA
Ron La Plante	California Division of the State Architect	San Diego, CA

(1) Ben Schafer is primary contact and voting member for steel industry research projects. Matt Eatherton and Jerome Hajjar were alternates and active contributors to the work of IT9

Acknowledgements – PUC IT9

Corresponding members:

Andre Filiatrault	SUNY University at Buffalo	Buffalo, NY
Andrew Shuck	WJE	San Francisco, CA
Bill Holmes	Rutherford & Chekene	Oakland, CA
Bonnie Manley	AISI	Norfolk, MA
Christopher Gill	Hilti North America	Plano, TX
Dan Dolan	Washington State University	Pullman, WA
Dave Golden	ASC Steel Deck Div. of ASC Profiles	Sacramento, CA
Jerome (Jerry) Hajjar	Northeastern University	Boston, MA
Maria Koliou	Colorado State University	Fort Collins, CO
Matt Eatherton	Virginia Tech	Blacksburg, VA
Patrick Bodwell	Vulcraft/ Verco Group	Sacramento, CA
Phil Line	American Wood Council	Leesburg, VA
Pouria Bahmani	KPFF Consulting Engineers	Seattle, WA
Robert Tremblay	Polytechnique Montreal	Montreal, Canada
Veronica Cedillos	Applied Technology Council	Redwood City, CA
Steve Hobbs	Vulcraft	Tremonton , UT
Tom Xia	DCI Engineers	Seattle, WA
Walt Schultz	Nucor	Norfolk, NE

Building Seismic Safety Council

nehrp FEMA

3 Diaphragm Seismic Design Methods

Including 2020 NEHRP Provisions and ASCE 7-22

1. Basic Design (Sec. 12.10.1 and 12.10.2)
   a. Can be used for any structure or diaphragm system type EXCEPT precast concrete diaphragms in SDC C and above
2. Alternative Design Provisions for Diaphragms (Sec. 12.10.3)
   a. No limits on structure size or configuration
   b. Limits diaphragm system to those listed in Table 12.10-1 - precast concrete, cast-in-place concrete, wood, bare steel deck diaphragms, concrete filled metal deck systems
3. Alternative Diaphragm Design Provisions for One-Story Structures with Flexible Diaphragms and Rigid Vertical Elements (RWFD, Sec. 12.10.4)
   a. Limits structure size to one story, diaphragm geometry limits apply
   b. Limits structure vertical elements of SFRS to those deemed to be rigid
   c. Limits diaphragm system to wood structural panel on wood framing and bare steel deck

3 Diaphragm Seismic Design Methods

Including 2020 NEHRP Provisions and ASCE 7-22

1. Basic Design (S
   a. Can be used fo … rete diaphragms in SDC C and abo
2. Alternative Des
   a. No limits on st
   b. Limits diaphrag … st-in-place concrete, woo … ms
3. Alternative Dia … with Flexible Diaphragms ar
   a. Limits structure
   b. Limits structure
   c. Limits diaphrag … steel deck

WHY?

- To better recognize:
  - Diaphragm influence on seismic response
  - Diaphragm force demands
  - Diaphragm ductility
- To improve diaphragm and structure seismic performance

2020 Provisions Starting Point

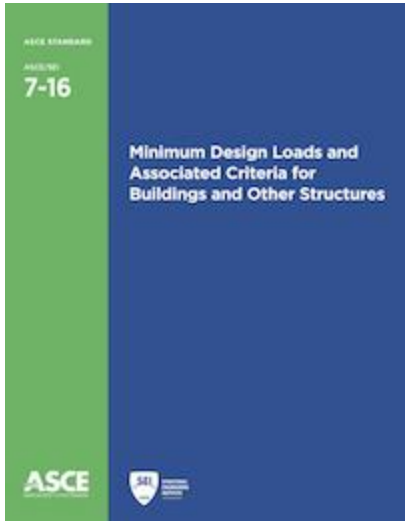
Alternative Design Method

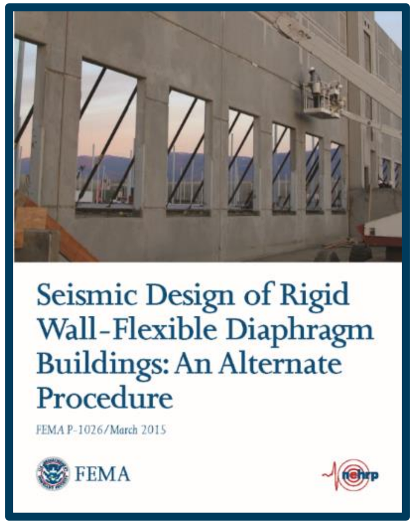
- 2015 NEHRP/ ASCE 7-16
- Extensive Commentary

RWFD

- Simplified Design Program Study (funded by FEMA, administered by BSSC)
- 2015 NEHRP Part 3 Resource Paper
- FEMA P-1026 Guideline Document, published 2015

(Bill Holmes, John Lawson, Dominic Kelly, Maria Koliou + others)





2020 Provisions Steel Research Collaboration

SDII – Steel Diaphragm Innovation Initiative (Eatherton, Hajjar, Easterling, Sabelli)

Advance the seismic performance of steel floor and roof diaphragms utilized in steel buildings through:

- better understanding of diaphragm-structure interaction,
- new design approaches, and
- new three-dimensional modeling tools that provided enhanced capabilities to designers utilizing steel diaphragms in their building systems.

SDII primarily focuses on the seismic design of diaphragms commonly used in steel mid-rise buildings.

2020 Provisions Steel Research Collaboration

RWFD: Advancing Seismic Provisions for Steel Diaphragms in Rigid Wall-Flexible Diaphragm (RWFD) Buildings, with NBM Technologies, Inc.   (Meimand, Torabian, Eatherton, and Schafer)

Objective:
Validate alternative provisions for conventionally designed steel diaphragms in RWFD buildings.

Scope:
Small-scale testing and related efforts to develop an accurate and validated building scale model for NLRH analysis of steel diaphragms in typical RWFD buildings.

Alternative Diaphragm Design Provisions

(Sec. 12.10.3)

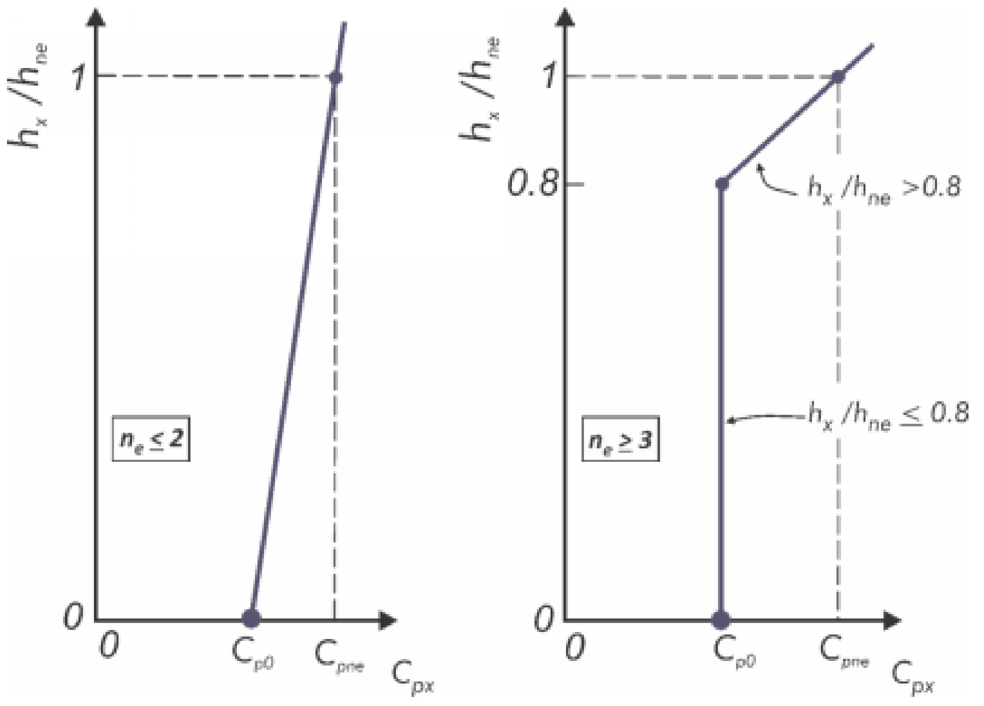


FIGURE 12.10-7 Diaphragm Design Acceleration Coefficient Cpx for Buildings with Non-Uniform Mass Distribution

Alternative Diaphragm Design Provisions
Drivers

Jose Restrepo and Mario Rodriguez collection of analysis and testing data on seismic forces in diaphragms

Multi-University project to develop seismic design methodology for precast concrete diaphragms (Fleishmann et al. 2012)

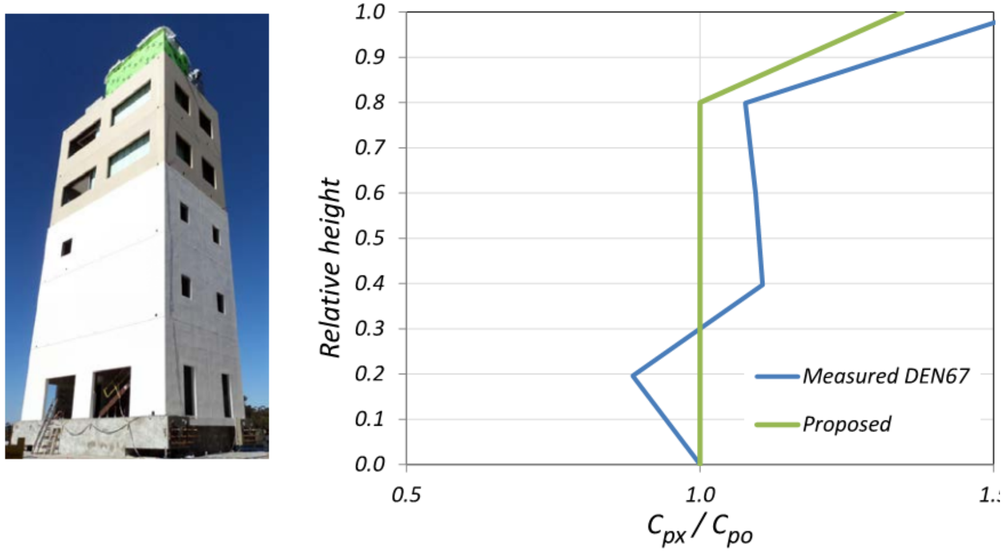


FIGURE 12.10-5 Comparison of Measured Floor Accelerations and Accelerations Predicted by Eq. 12.10-4 for a 5-Story Special MRF Building (Chen et al., 2013)

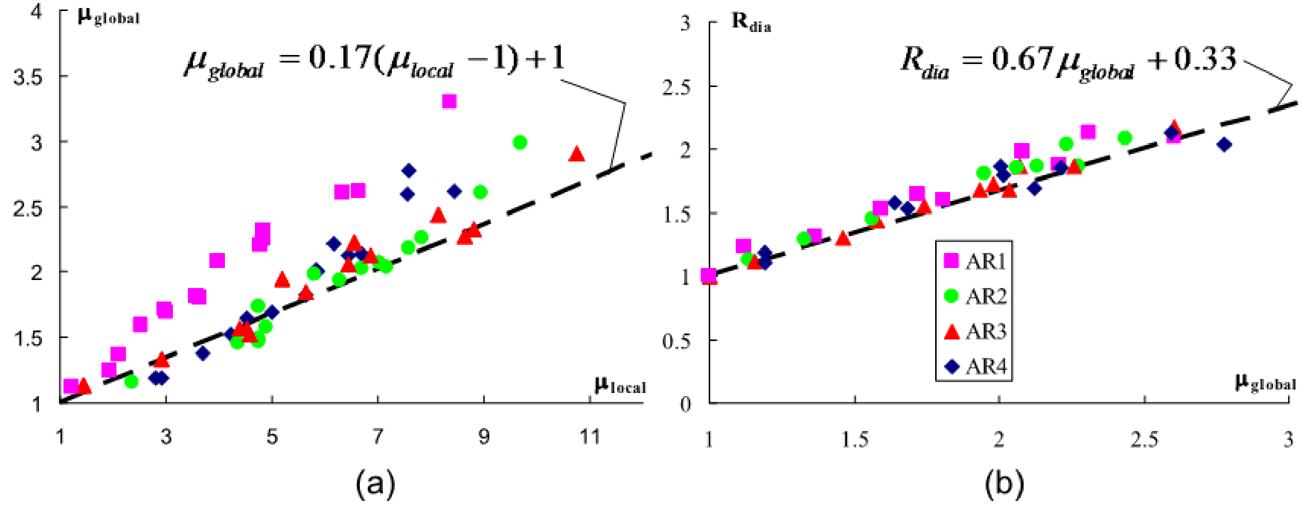


FIGURE C12.10-9 Relationships: (a) μ_{global}-μ_{local} and (b) R_{dia}-μ_{global}

Alternative Diaphragm Design Provisions

Part 1: Introduced new vertical distribution of diaphragm seismic forces for near-elastic diaphragm behavior

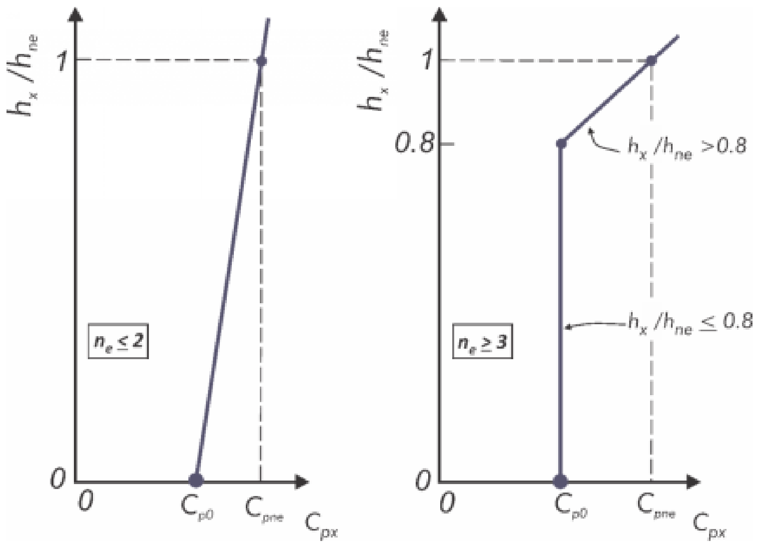


FIGURE 12.10-7 Diaphragm Design Acceleration Coefficient Cpx for Buildings with Non-Uniform Mass Distribution

Part 2: Parameter R_s modifies near-elastic forces based on diaphragm ductility and deformation capacity

$$F_{px} = \frac{C_{px}}{R_s} w_{px}$$

Alternative Diaphragm Design Provisions
(2015 NEHRP ASCE 7-16)

Table 12.10-1 Diaphragm Design Force Reduction Factor, R_s

Diaphragm System		Shear Controlled	Flexure Controlled
Cast-in-place concrete designed in accordance with Section 14.2 and ACI 318	-	1.5	2
Precast concrete designed in accordance with Section 14.2.4 and ACI 318	EDO	0.7	0.7
	BDO	1.0	1.0
	RDO	1.4	1.4
Wood sheathed designed in accordance with Section 14.5 and SDPWS		3.0	NA

Alternative Diaphragm Design Provisions
(Added in 2020 NEHRP and ASCE 7-22)

Table 12.10-1 Diaphragm Design Force Reduction Factor, R_s

Diaphragm System		Shear Controlled	Flexure Controlled
Bare steel deck diaphragm designed in accordance with Section 14.1.5 (Design per AISI S400)	With special seismic detailing	2.5	NA
	Other	1.0	NA
Concrete-filled metal deck diaphragm designed in accordance with Section 14.1.6 (Design per AISC 341)		2.0	NA

Alternative Diaphragm Design Provisions

Bare Steel Deck Diaphragm Background and Basis

- Performance is driven by the performance of the deck profile and interaction with the sidelap and structural connections
- WR roof deck with appropriate connections has adequate ductility and deformation capacity to qualify as special seismic detailing

Alternative Diaphragm Design Provisions

Bare Steel Deck Diaphragm Basis of R_s Derivation

- New cyclic shear (connection level) testing by Schafer and NBM Technologies
- Cantilevered diaphragm tests
- 3D building modeling by Schafer translating local ductility to global ductility
- Use of ATC-19 μ-R relations

Alternative Diaphragm Design Provisions

Concrete Topped Metal Deck Diaphragms Background and Basis

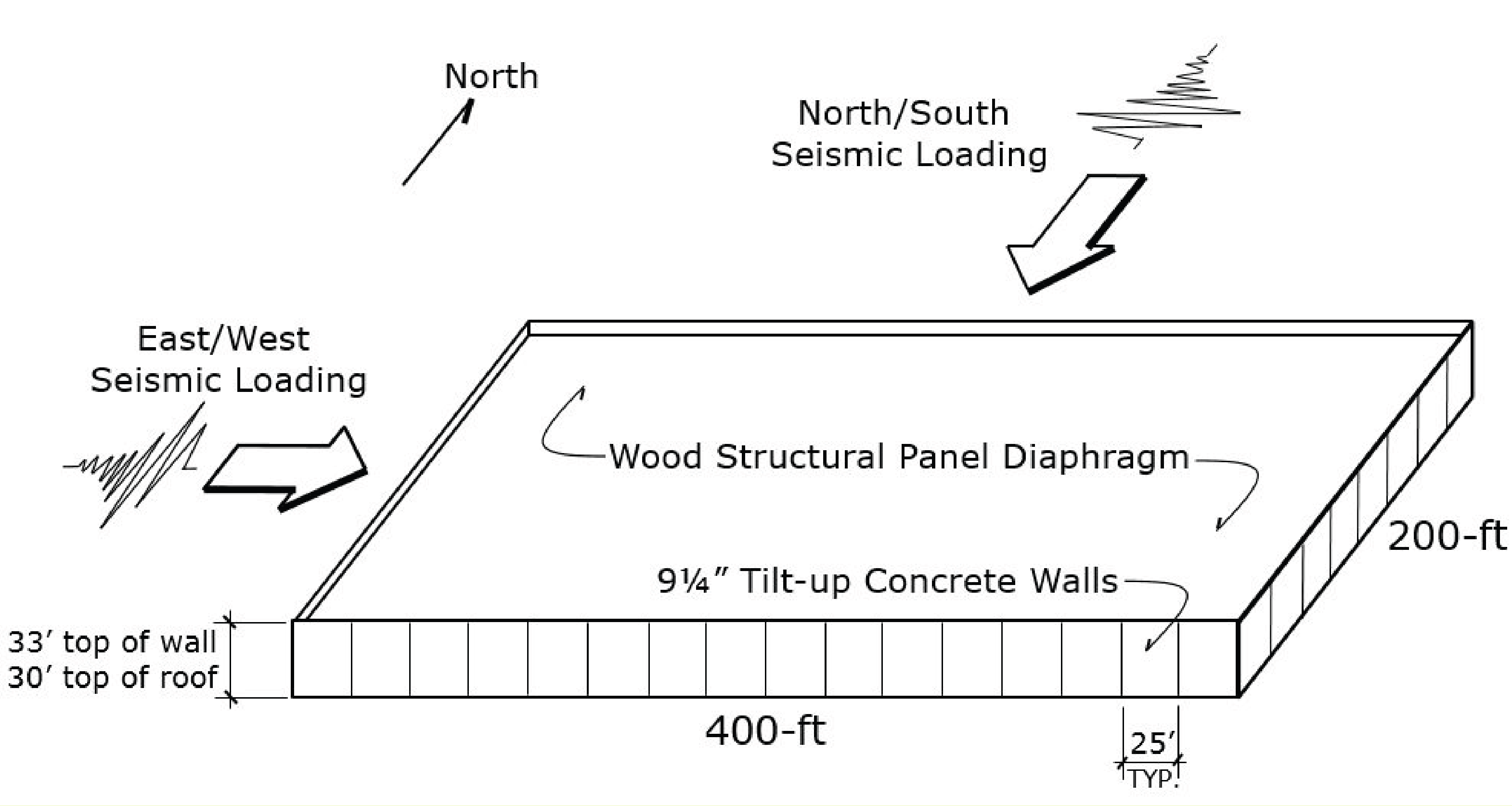
- 2020 NEHRP Part 3 resource paper discusses studies and likely values
- ASCE 7-22 adopted results
- Performance is driven primarily by diagonal cracking in the field of the diaphragm
- Performance can also be driven by shear transfer into collectors and vertical elements

Alternative Diaphragm Design Provisions

Basis of R_s Factor for Concrete Topped Metal Deck Diaphragms

- Derived using method similar to ATC-19 considering overstrength and ductility
- Confirmed with limited FEMA P-695 numerical studies

Rigid-Wall Flexible-Diaphragm (RWFD) Design Provisions

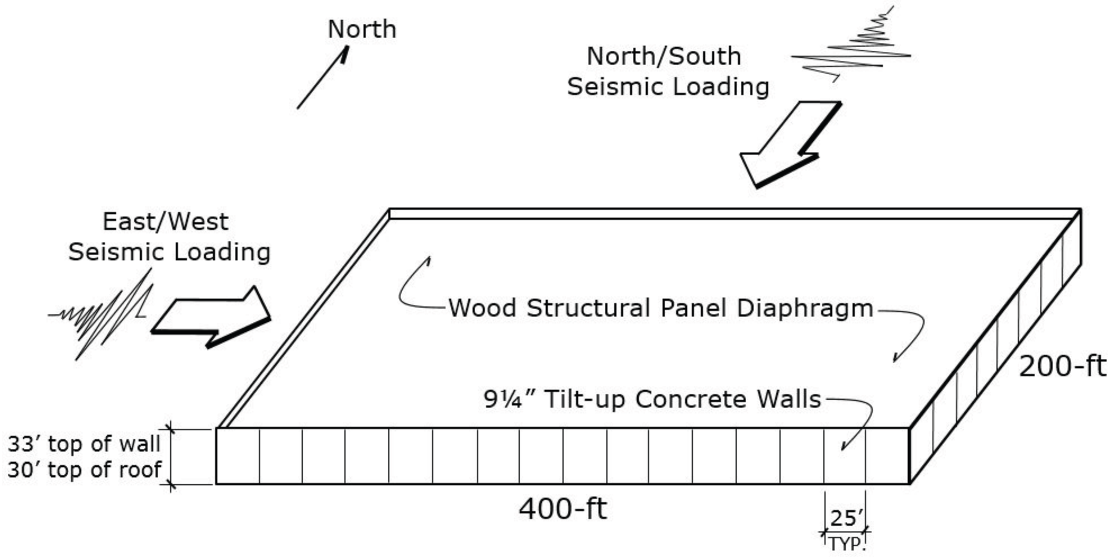


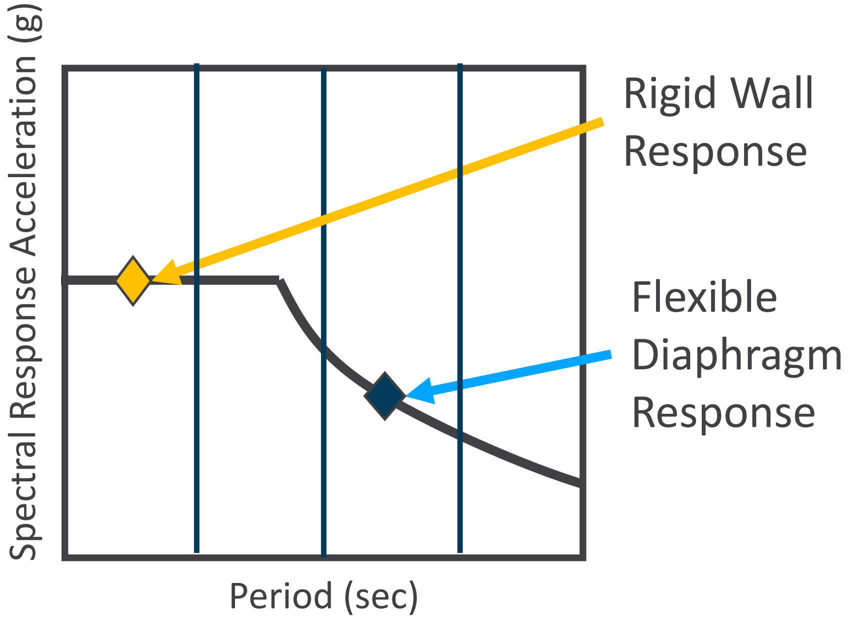
RWFD Incorporation into ASCE 7-22

- New diaphragm design provisions in Section 12.10.4
- New *optional* two-stage approach to vertical element seismic forces in Section 12.2.3.4

RWFD Starting Point

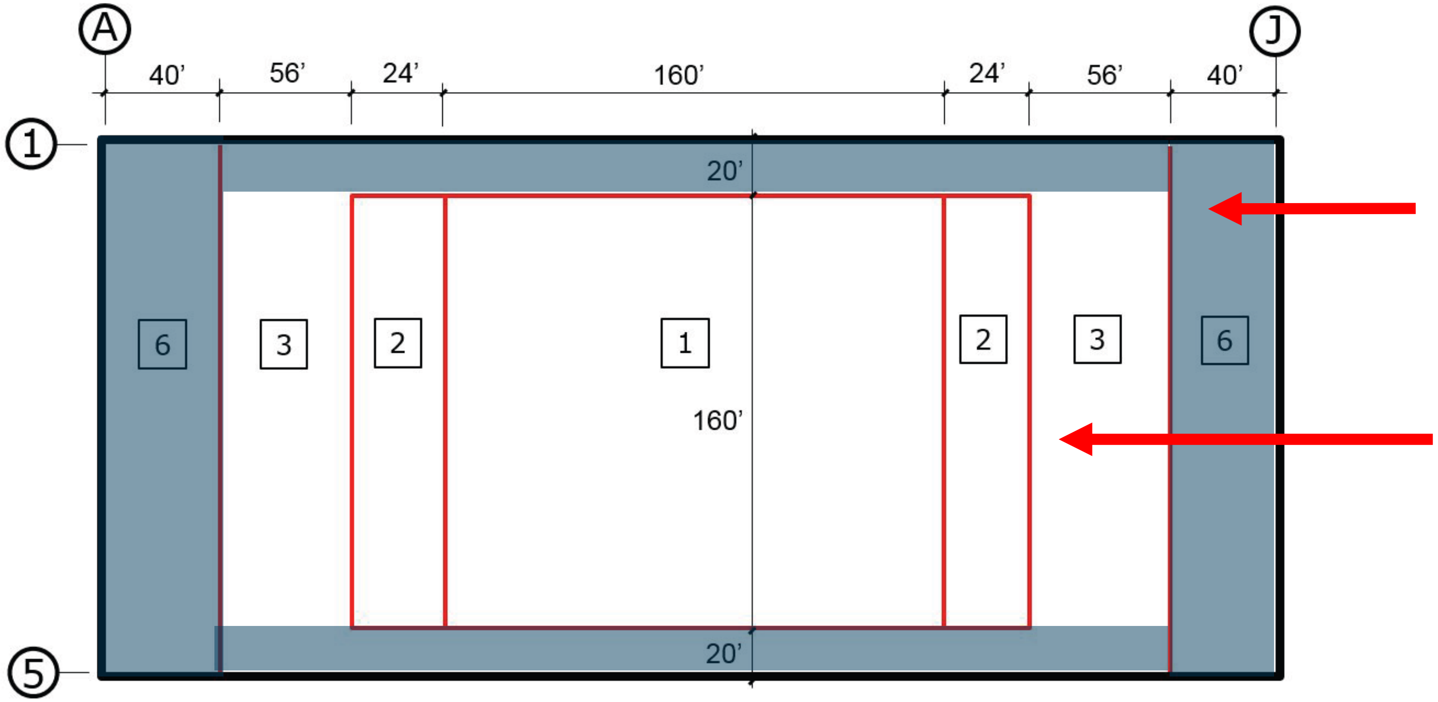
Acknowledge and incorporate actual seismic response of RWFD buildings for diaphragm design





RWFD Starting Point

Design to encourage distributed inelastic behavior for *improved seismic performance*

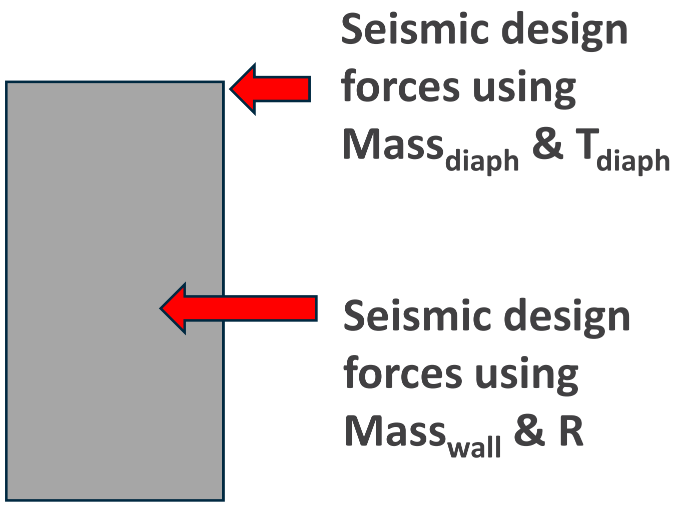


Amplified Shear Boundary Zone

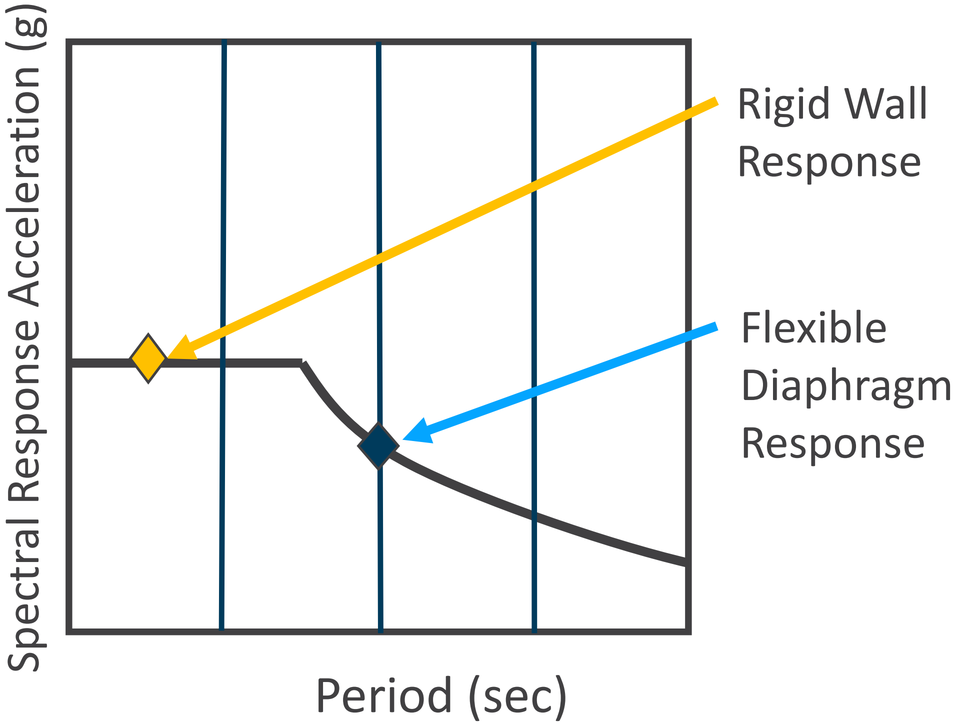
Inelastic behavior is driven away from diaphragm edge and towards interior

RWFD Starting Point

Optional incorporation of actual seismic response of RWFD buildings for vertical elements – 2 stage analysis



Seismic Design Forces to Vertical Element



RWFD Limitations

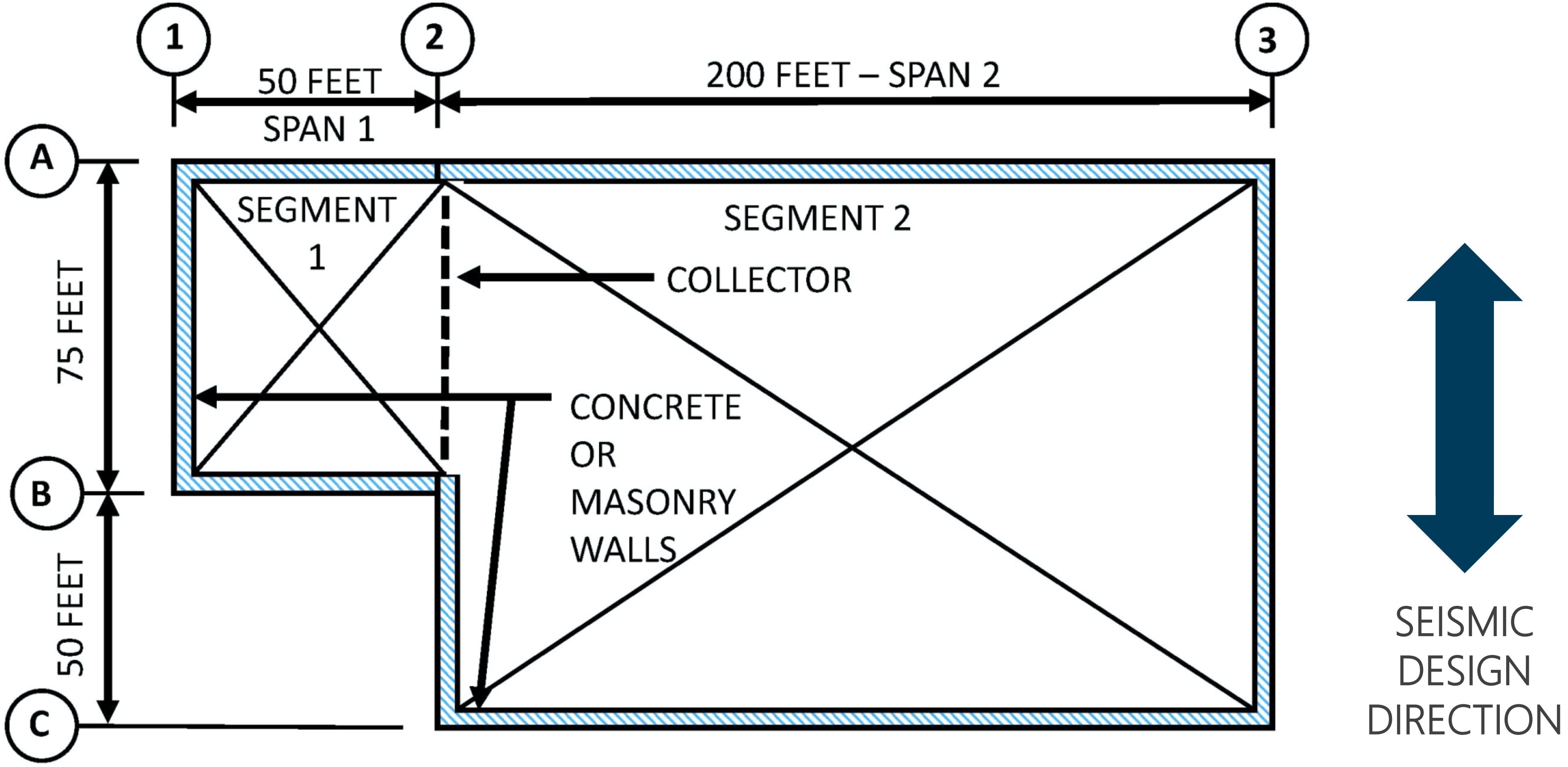
- One-story structures
- All portions of the diaphragm must use RWFD design
- Wood structural panel diaphragms on wood framing or nailers, fastened in accordance with SDPWS tables
- Bare steel deck diaphragms designed in accordance with AISI S400 and AISI S310
- Toppings of concrete or similar not permitted
- Horizontal irregularities prohibited except reentrant corners

RWFD Limitations

- Diaphragm is rectangular or can be divided into rectangles
- Vertical elements permitted are:
  - Concrete, precast concrete or masonry shear walls,
  - Concentrically braced frames,
  - Steel and concrete composite braced frames,
  - Steel and concrete composite shear walls

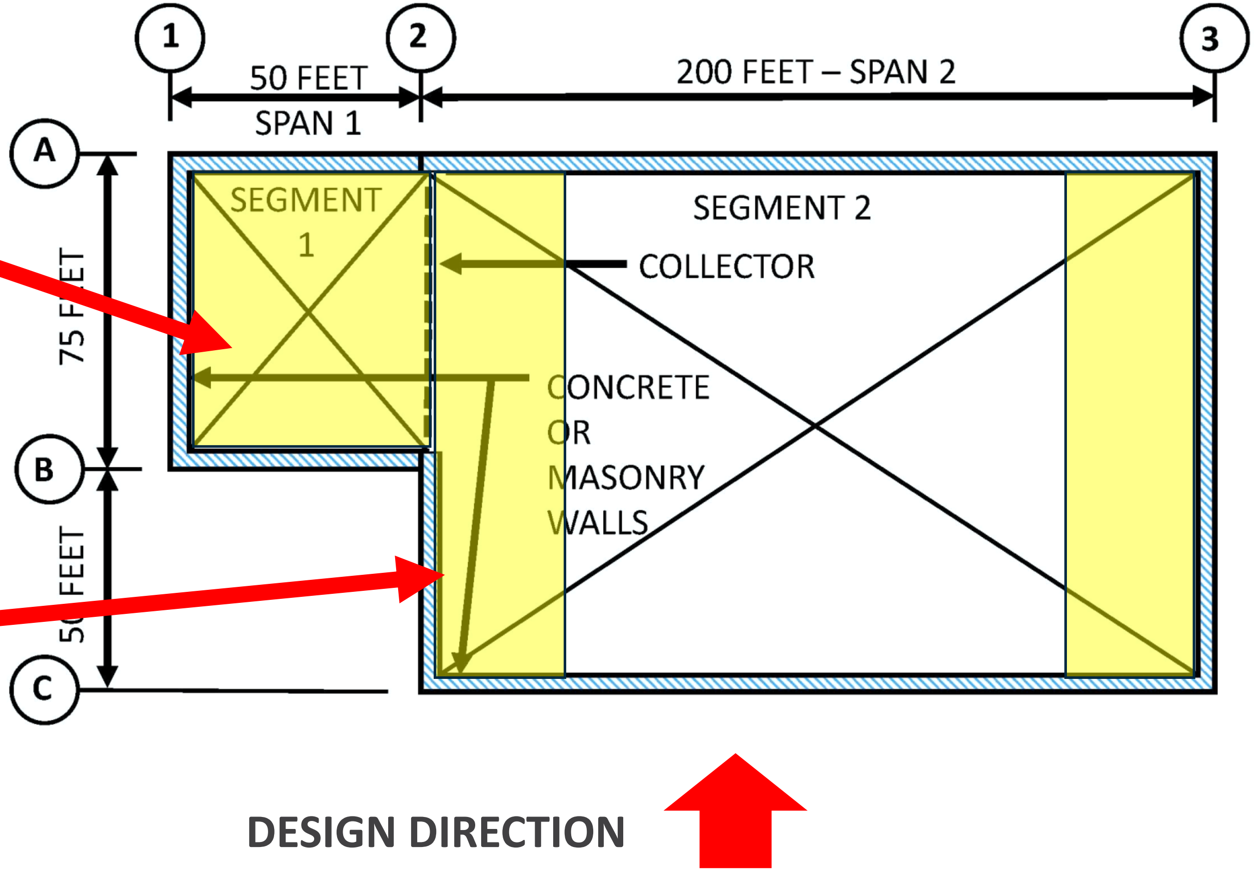
RWFD Limitations

RWFD Limitations

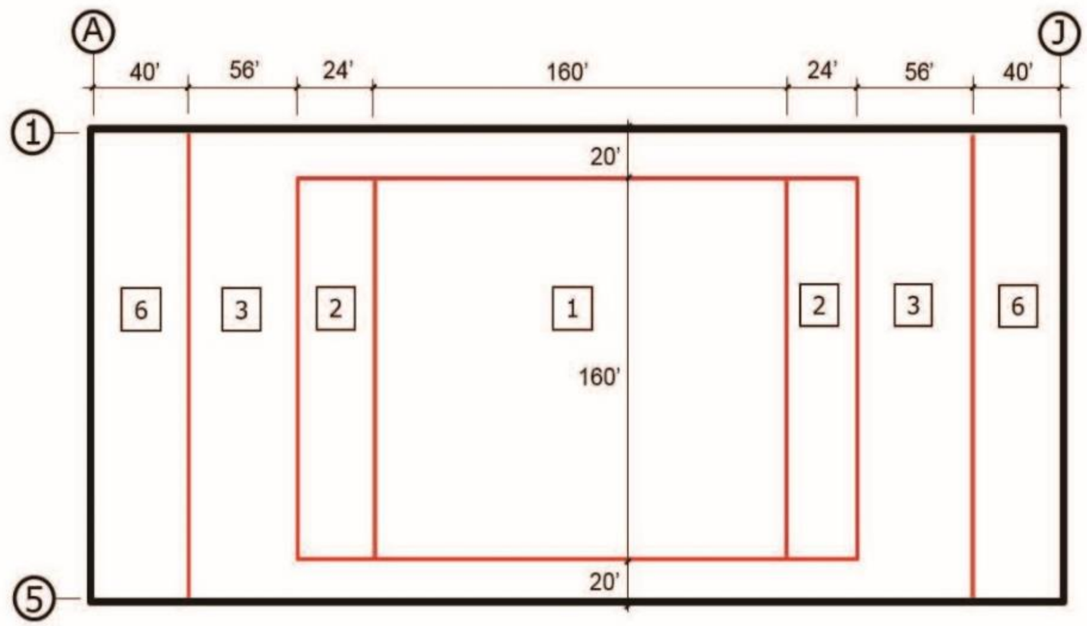


RWFD – Diaphragm Seismic Design Shears

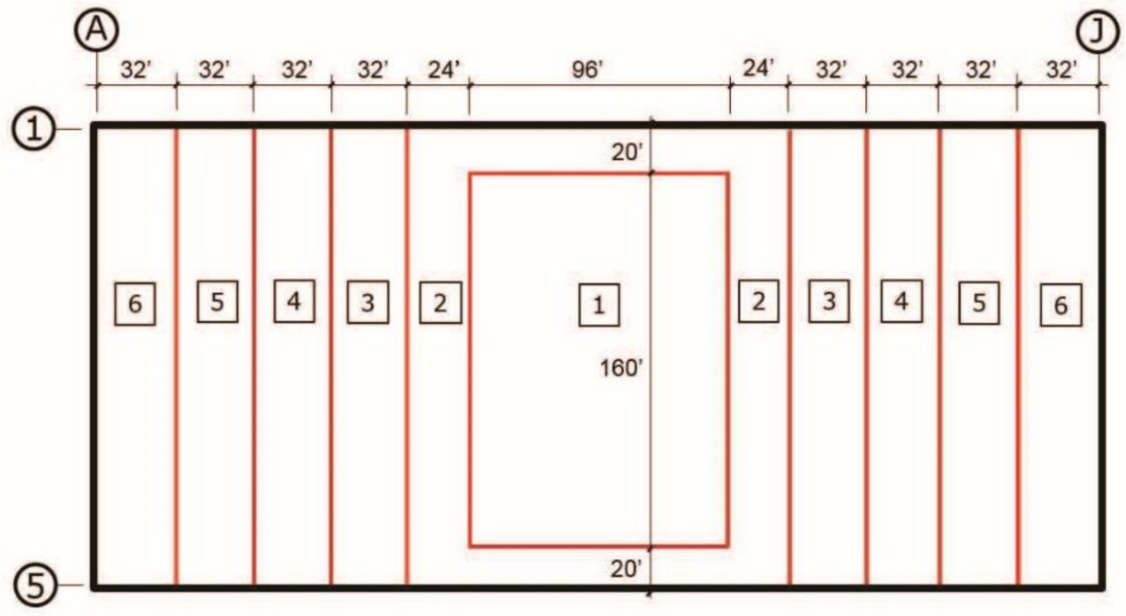
- For L_{diaph} < 100', shear from loading perpendicular to span shall be amplified to 1.5 times Fpx
- For Ldiaph > 100', shear from loading perpendicular shall be amplified to 1.5 times Fpx for amplified shear boundary zone at each end of span for a distance equal to 10% of diaphragm span



RWFD – Example Impact on Wood Roof Diaphragm Design



Shear Nailing Zones - Proposed Design



Shear Nailing Zones - Conventional Design

Figure Credit: FEMA P-1026

RWFD – Diaphragm Seismic Design Forces

$$F_{px} = C_{s\text{-}diaph} * w_{px}$$

$$C_{s\text{-}diaph} = \frac{S_{DS}}{R_{diaph}/I_e}$$

$$C_{s\text{-}diaph} = \frac{S_{D1}}{T_{diaph} * (R_{diaph}/I_e)}$$

RWFD – Diaphragm Seismic Design Forces

R_{diaph}

= 4.5 for wood structural panel diaphragms

= 4.5 for bare steel deck diaphragms that meet the special seismic detailing requirements of AISI S400

= 1.5 for all other bare steel deck diaphragms

T_{diaph}

= 0.002 L_{diaph}, for wood structural panel diaphragms, and

= 0.001 L_{diaph} for profiled steel deck panel diaphragms

Determined for each rectangular segment of the diaphragm in each orthogonal direction [seconds]

RWFD – Diaphragm Seismic Design Forces

$C_{d\text{-}diaph}$

= 3.0 for wood structural panel diaphragms

= 3.0 for bare steel deck diaphragms that meet the special seismic detailing requirements of AISI S400

= 1.5 for all other bare steel deck diaphragms

$\Omega_{0\text{-}diaph}$

= 2

But need not exceed R_{diaph}

RWFD – Diaphragm Chords and Collectors

- Chords are designed using diaphragm F_{px} forces
- Collectors are designed using diaphragm F_{px} forces
- In SDC C to F, collectors and their connections to vertical elements are designed using diaphragm overstrength factor, Ω_0
- Diaphragm overstrength factor need not be combined with the shear amplification of 1.5
- Strength level diaphragm deflection is amplified by $C_{d\text{-}diaph}$

Basis of Methodology – FEMA P-695

NLRHA numerical studies using FEMA P-695 to study probability of collapse in MCE_R as indicator of meeting building code performance target, as documented in FEMA P-1026

- Building footprint range: 100'x100', 200'x400', 400'x 400'
- Heavy and light walls
- High and moderate seismic
- Conventional and proposed new design approach

Archetype ID	Design Configuration				Collapse Margin Parameters				Acceptance Check	
	Building Size	Diaphragm Aspect Ratio	Diaphragm Construction	Seismic SDC	CMR	μ_T	SSF	ACMR	Accept. ACMR	Pass/Fail
Performance Group No. PG-1N (Wood, Large Building, New Design)										
HWL_21_N_OSB_RD4.5-1.5_01	Large	2:1	Wood	D_{max}	2.69	8.44	1.45	3.91	1.73	Pass
HWL_21_N_OSB_RD4.5-1.5_02	Large	2:2	Wood	D_{max}	3.16	8.37	1.45	4.59	1.73	Pass
HWL_21_N_OSB_RD4.5-1.5_03	Large	2:1	Wood	D_{max}	2.65	8.43	1.45	3.84	1.73	Pass
HWL_21_N_OSB_RD4.5-1.5_04	Large	2:1	Wood	D_{max}	3.13	8.35	1.45	4.54	1.73	Pass
HWL_12_N_OSB_RD4.5-1.5_01	Large	1:2	Wood	D_{max}	2.43	8.84	1.34	3.26	1.73	Pass
HWL_12_N_OSB_RD4.5-1.5_02	Large	1:2	Wood	D_{max}	2.45	8.87	1.34	3.29	1.73	Pass
HWL_11_N_OSB_RD4.5-1.5_01	Large	1:1	Wood	D_{max}	2.32	8.34	1.45	3.36	1.73	Pass
HWL_11_N_OSB_RD4.5-1.5_02	Large	1:1	Wood	D_{max}	2.39	8.38	1.45	3.46	2.73	Pass
Mean of Performance Group:					**2.58**	**8.50**	**1.42**	**3.68**	**2.58**	**8.50**
Performance Group No. PG-2N (Wood, Small Building, New Design)										
HWS_21_N_OSB_RD4.5-1.5_01	Small	2:1	Wood	D_{max}	1.80	7.59	1.35	2.43	1.73	Pass
HWS_12_N_OSB_RD4.5-1.5_01	Small	1:2	Wood	D_{max}	1.97	8.15	1.33	2.62	1.73	Pass
HWS_11_N_OSB_RD4.5-1.5_01	Small	1:1	Wood	D_{max}	1.89	8.44	1.33	2.52	1.73	Pass
Mean of Performance Group:					**1.88**	**8.06**	**1.34**	**2.51**	**2.30**	**Pass**
Performance Group No. PG-3N (Wood, Large Building, New Design)										

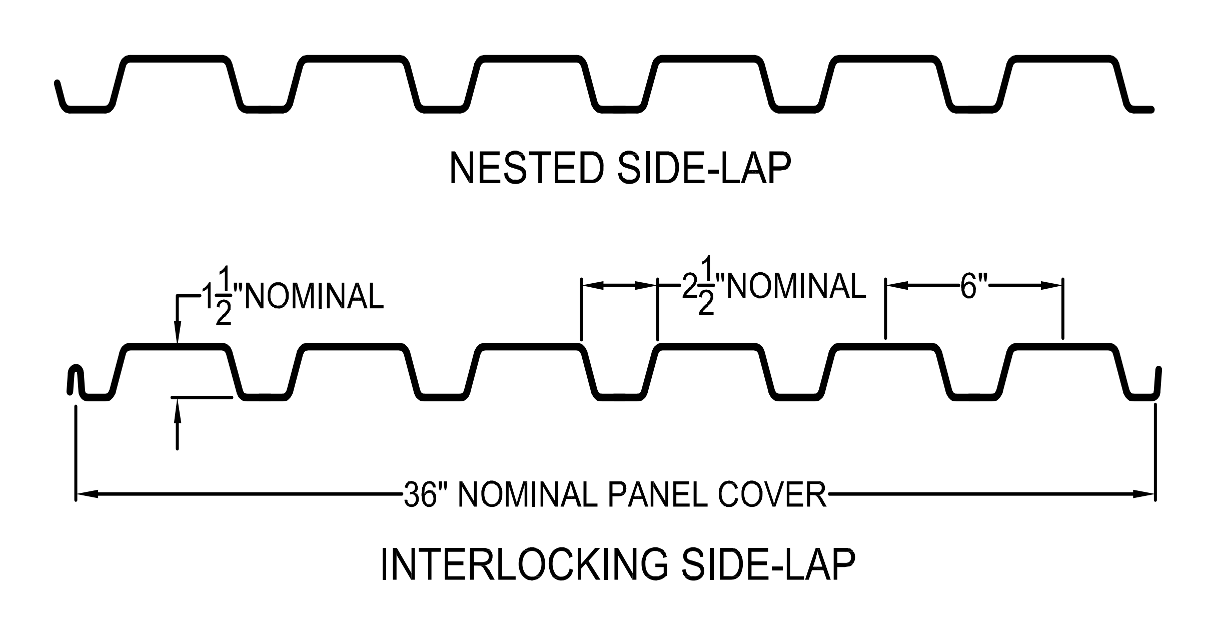
Basis of Methodology – Bare Steel Deck Diaphragms

- NLRHA numerical studies using FEMA P-695. documented in FEMA P-1026

Supplemented by:

- Additional steel studies by Schafer et al.
- Separation of steel deck diaphragms into those with "special seismic detailing" and "all other"

Special Seismic Detailing for Bare Steel Deck Diaphragms



Special Seismic Detailing for Bare Steel Deck Diaphragms

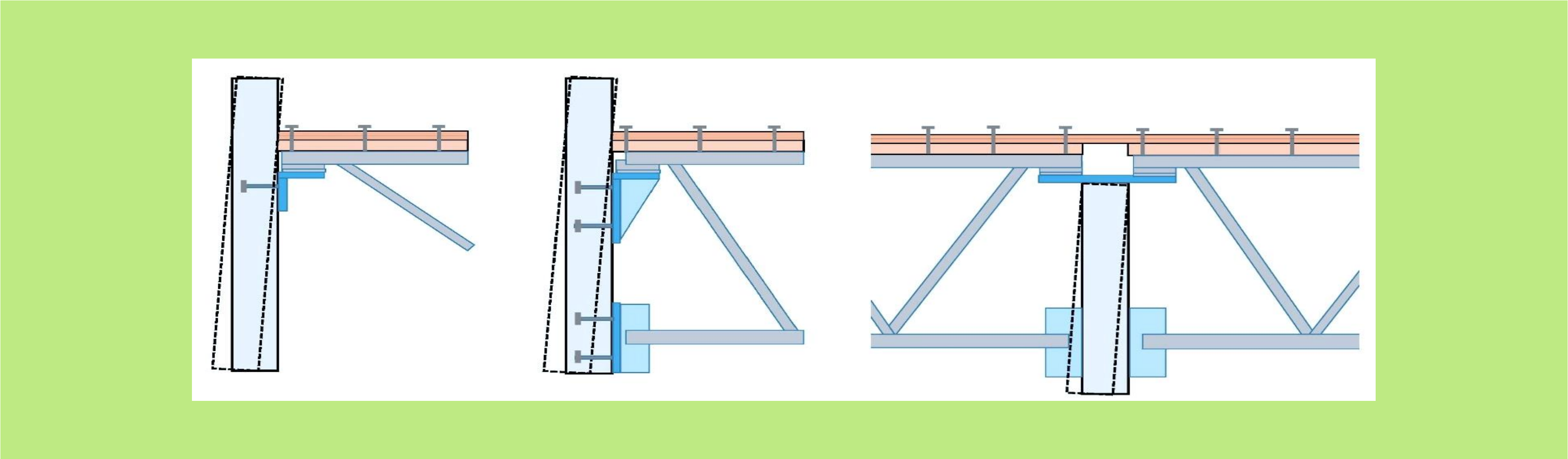
- Required in order to use R_s = 2.5 in Alternative Diaphragm Design Provisions of Sec. 12.10.3
- Required in order to use R_{diaph} = 4.5 in Sec. 12.10.4 RWFD Provisions

Provisions Include

- Prescriptive special seismic detailing - list of 8 requirements, mechanical fasteners only
- Structural Connection Qualification provisions
- Sidelap Connection Qualification provisions
- Special Seismic Qualification by Cantilever Diaphragm Test
- Special Seismic Qualification by Principles of Mechanics

RWFD Other Issues In Commentary

- Calculation of diaphragm deflections
- Wall P-delta stability
- Gravity system accommodation of diaphragm deflection



IT9 Part 3 Resource Papers

- Resource Paper 6 - Diaphragm Design Force Reduction Factor, R_s, for Composite Concrete on Metal Deck Diaphragms
- Resource Paper 7 - Development of Diaphragm Design Force Reduction Factors, R_s
- Resource Paper 8 - Calculation of Diaphragm Deflections Under Seismic Loading

National Institute of BUILDING SCIENCES™
Building Seismic Safety Council