Chapter 7 – Part 2
Horizontal Diaphragm Design

2020 NEHRP Provisions Training Materials

Kelly Cobeen S.E., *Wiss Janney Elstner Associates*

FEMA

Building Seismic Safety Council | BSSC

nehrp

2020 NEHRP Provisions Design Examples Document


2020 NEHRP Recommended Seismic Provisions: Design Examples, Training Materials, and Design Flow Charts

FEMA P-2192-V2/November 2021

Volume II: Training Materials

FEMA

nehrp

FEMA Building Seismic Safety Council nehrp

2

What's New in Diaphragm Design Provisions

- ASCE/SEI 7-10
  - Sections 12.10.1 and 12.10.2 - *Traditional Diaphragm Design Method*
- ASCE/SEI 7-16 (2015 *NEHRP Provisions*)
  - Section 12.10.3 - *Alternative Design Provisions* is added
    - Cast-in-place concrete, precast concrete, and wood structural panel diaphragms
- ASCE/SEI 7-22 (2020 *NEHRP Provisions*)
  - Section 12.10.3 – *Alternative Design Provisions* is expanded
    - Bare steel deck, concrete-filled steel deck diaphragms
  - Section 12.10.4 – *Alternative RWFD Provisions* is added

What's New in Diaphragm Design Provisions

- ASCE/SEI 7-16 (2015 *NEHRP Provisions*)
  - Definition of diaphragm transfer forces
  - Amplification of transfer forces by Ω_0 for horizontal structural irregularity type 4
- ASCE/SEI 7-22 (2020 *NEHRP Provisions*)
  - Introduction of special seismic detailing provisions for bare steel deck diaphragms
  - Differentiation of design provisions for diaphragms meeting or not meeting the special seismic detailing provisions

Why Are Diaphragm Design Provisions Changing?

- Driven by research including both testing and numerical studies
- To better reflect diaphragm dynamic response
- To better reflect diaphragm deformation capacity
- Thought to provide better diaphragm performance at the same or potentially lower cost
- More detail later…

Diaphragm Design Presentation Outline – Part 2

- Brief overview of diaphragm seismic design methods
- Example one-story RWFD building with steel deck diaphragm
  - Section 12.10.1 and 12.102 *Traditional Design Method*
  - Section 12.10.4 ***Alternative RWFD Design Method***
  - Comparison of results

Overview of Diaphragm Design - NEHRP Diaphragm Tech Briefs

NIST, NEHRP Seismic Design Technical Brief No. 3, Seismic Design of Cast-in-Place Concrete Diaphragms, Chords and Collectors (2016)

NIST, NEHRP Seismic Design Technical Brief No. 5, Seismic Design of Composite Steel Deck and Concrete-filled Diaphragms (2011)

NIST, NEHRP Seismic Design Technical Brief No. 10, Seismic Design of Wood Light-Frame Structural Diaphragms (2014)

FEMA Building Seismic Safety Council nehrp 7

Overview of Diaphragm Design - NEHRP Diaphragm Tech Briefs

- NIST, 2011. *NEHRP Seismic Design Technical Brief No. 5, Seismic Design of Composite Steel Deck and Concrete-filled Diaphragms* (NIST GRC 11-917-10), National Institute of Standards and Technology, Gaithersburg, MD.
- NIST, 2014. *NEHRP Seismic Design Technical Brief No. 10, Seismic Design of Wood Light-Frame Structural Diaphragm Systems* (NIST GRC 14-917-32), National Institute of Standards and Technology, Gaithersburg, MD.
- NIST, 2016a. *NEHRP Seismic Design Technical Brief No. 12, Seismic Design of Cold-Formed Steel Lateral Load-Resisting Systems* (NIST GRC 16-917-38), National Institute of Standards and Technology, Gaithersburg, MD.
- NIST, 2016b. *NEHRP Seismic Design Technical Brief No. 3, Seismic Design of Cast-in-Place Concrete Diaphragms, Chords and Collectors, Second Edition* (NIST GRC 16-917-42), National Institute of Standards and Technology, Gaithersburg, MD.
- NIST, 2017. *NEHRP Seismic Design Technical Brief No. 12, Seismic Design of Precast Concrete Diaphragms* (NIST GRC 17-917-47), National Institute of Standards and Technology, Gaithersburg, MD.

FEMA Building Seismic Safety Council nehrp 8

Diaphragm Seismic Design Methods

1. Section 12.10.1 and 12.10.2 ***Traditional Design Method***
2. Section 12.10.3 ***Alternative Design Method***
3. Section 12.10.4 ***Alternative "RWFD" Design Method***:
   - *Alternative Diaphragm Design Provisions for One-Story Structures with Flexible Diaphragms and Rigid Vertical Elements*

- Scope: Diaphragms, Chords and Collectors
  - Design forces
  - In some instances, detailing

FEMA Building Seismic Safety Council nehrp 9

Diaphragm Seismic Design Methods

Method and ASCE/SEI 7-22 Section	Number of Stories Permitted	Diaphragm Systems Included	Comments
Traditional Sections 12.10.1 and 12.10.2	Any	All	▪ Not permitted for precast concrete diaphragms in SDC C through F ▪ Diaphragm design forces are determined using seismic design parameters (R, Ω_0, and C_d) for the vertical SFRS

FEMA Building Seismic Safety Council nehrp 10

Diaphragm Seismic Design Methods

Method and ASCE/SEI 7-22 Section	Number of Stories Permitted	Diaphragm Systems Included	Comments
Alternative Section 12.10.3	Any	▪ Cast-in-place concrete ▪ Precast concrete ▪ Wood structural panel ▪ Bare steel deck ▪ Concrete-filled metal deck	▪ Required for precast concrete diaphragms in SDC C through F, providing improved seismic performance ▪ Optional for other diaphragm types ▪ Better reflects vertical distribution of diaphragm forces ▪ R_s diaphragm design force reduction factor better reflects effect of diaphragm ductility and displacement capacity on diaphragm seismic forces ▪ Forces in collectors and their connections to vertical elements are amplified by 1.5 in place of Ω_0

FEMA Building Seismic Safety Council nehrp

Diaphragm Seismic Design Methods

Method and ASCE/SEI 7-22 Section	Number of Stories Permitted	Diaphragm Systems Included	Comments
Alternative RWFD Section 12.10.4	One Story	▪ Wood structural panel ▪ Bare steel deck ▪ Diaphragm must meet scoping limitations of ASCE/SEI 7-22 Section 12.10.4.1	▪ Primarily intended for buildings with diaphragm spans of 100 feet or greater ▪ New T_{diaph}, R_{diaph}, $\Omega_{0\text{-diaph}}$, and $C_{d\text{-diaph}}$, better reflect response of RWFD building type ▪ Provides better performance with the same or reduced construction cost

FEMA Building Seismic Safety Council nehrp

Diaphragm Seismic Design Methods

- Advantages of using Section 12.10.3 Alternative Design Provisions:
  - Better reflects vertical distribution of diaphragm forces
  - Better reflects effect of diaphragm ductility and displacement capacity
  - May result in lower seismic demands
- Advantages of using Section 12.10.4 Alternative RWFD Method;
  - Better reflects seismic response of RWFD buildings
  - May result in lower seismic demands
  - Is anticipated to result in better performance
- When will the Section 12.10.1 and 12.10.2 Traditional Method result in lower design forces?
  - Bare steel deck diaphragms not meeting the AISI S400 special seismic detailing provisions
  - Other

Introduction to Section 12.10.4 Alternative RWFD Design Method

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

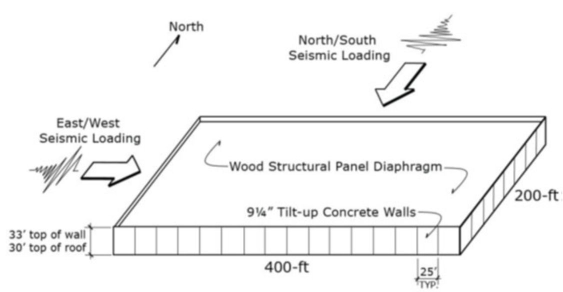
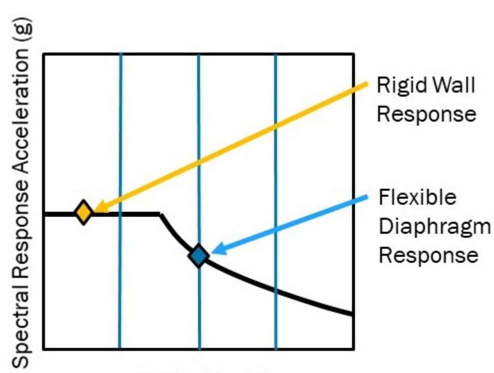


Figure Credit: FEMA, FEMA P-1026 (2014)



Introduction to Section 12.10.4 Alternative RWFD Design Method

Studies Behind Alternative RWFD Design Method:

- FEMA, 2021. *Seismic Design of Rigid Wall-Flexible Diaphragm Buildings: An Alternate Procedure* (FEMA P-1026), Federal Emergency Management Agency, Washington, DC
- Koliou, M., Filiatrault, A., Kelly, D., and Lawson, J., 2015a. "Buildings with Rigid Walls and Flexible Diaphragms I: Evaluation of Current U.S. Seismic Provisions," *Journal of Structural Engineering*, American Society of Civil Engineers, Reston, VA.
- Koliou, M., Filiatrault, A., Kelly, D., and Lawson, J., 2015b. "Buildings with Rigid Walls and Flexible Diaphragms II: Evaluation of a New Seismic Design Approach Based on Distributed Diaphragm Yielding," *Journal of Structural Engineering*, American Society of Civil Engineers, Reston, VA.
- Schafer, 2019. *Research on the Seismic Performance of Rigid Wall Flexible Diaphragm Buildings with Bare Steel Deck Diaphragms*, CFSRC Report 2019-2.

Introduction to Section 12.10.4 Alternative RWFD Design Method

Design to encourage distributed inelastic behavior for improved seismic performance

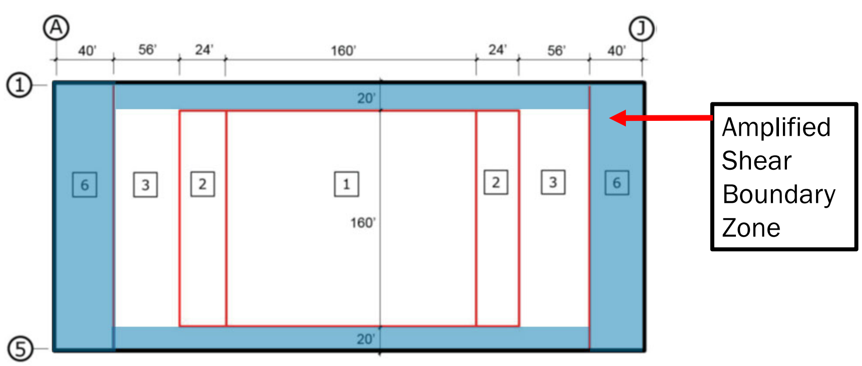
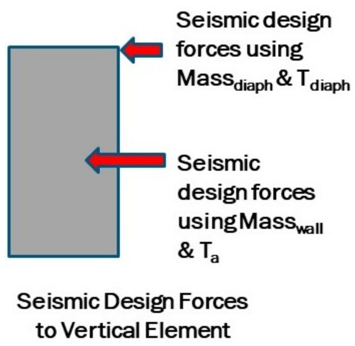
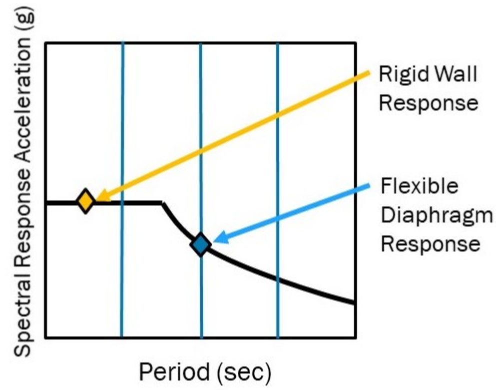


Figure Based on FEMA, FEMA P-1026 (2014)

Introduction to Section 12.10.4 Alternative RWFD Design Method

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





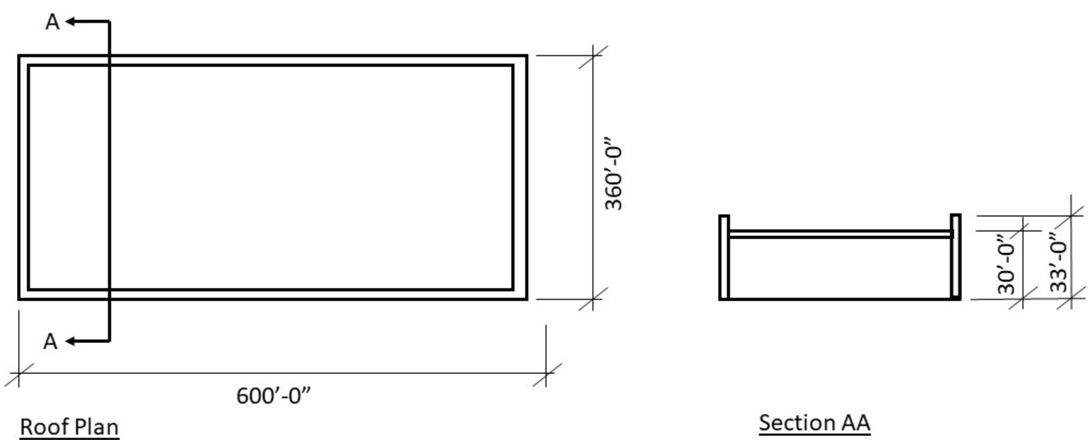
Example One-Story RWFD Building with Bare Steel Deck Diaphragm

Diaphragm Design Presentation Outline – Part 2

- Example one-story RWFD building with steel deck diaphragm
  - Section 12.10.1 and 12.102 *Traditional Design Method*
  - Section 12.10.4 *Alternative RWFD Design Method*
  - Comparison of results

FEMA Building Seismic Safety Council nehrp 19

Example One-Story RWFD Building with Steel Deck Diaphragm



FEMA Building Seismic Safety Council nehrp 20

Example One-Story RWFD Building with Steel Deck Diaphragm

Building Configuration

- One story
- I_e = 1.0
- Mean roof height = 30 feet
- Length = 600 feet
- Width = 360 feet
- S_{DS} = 1.0, S_{D1} = 0.50 (ASCE/SEI 7-22 Section 11.4.4)
- Bare steel deck diaphragm
- Intermediate precast concrete shear walls - R=4, Ω_0=2.5, C_d=4

Example One-Story RWFD Building with Steel Deck Diaphragm

The system includes a bare steel deck diaphragm supported on open-web steel joists and girders. The perimeter walls are 9-1/4-inch-thick tilt-up concrete walls, with a mean roof height of 30 feet, and a parapet above the roof of 3 feet.

For purposes of design, the diaphragm will be categorized as flexible:

- When using Section 12.10.1 and 12.10.2 provisions, Section 12.3.1.1 permits the combination of bare steel deck and concrete walls to be idealized as flexible.
- When using Section 12.10.4, diaphragms meeting the applicable limitations of Section 12.10.4.1 are automatically considered flexible and able to use the flexible diaphragm-based provisions of Section 12.10.4.

Example One-Story RWFD Building with Steel Deck Diaphragm

Step 1 - Weight for Seismic Analysis

Roof D = 20 psf

Wall D = 116 psf

Wall seismic weight tributary to roof:

w = 116 (33)(33/2)/30 = 2,105 plf

Seismic weight – Roof: 0.02 ksf (600 ft) (360 ft)	= 4,320 kips
Longitudinal walls: (2.105 klf)(600 ft)(2 sides)	= 2,526 kips
Transverse walls: (2.105 klf)(360 ft)(2 sides)	= 1,516 kips
TOTAL	= 8,362 kips acting at roof

FEMA Building Seismic Safety Council nehrp

Example One-Story RWFD Building with Steel Deck Diaphragm

Step 1 - Diaphragm Weight, w_{px}, at the Roof

w_{px} = Total seismic weight – weight of the walls resisting seismic forces

= 8,362 – 1,516 = 6,846 kips (for seismic forces in transverse direction)

= 8,362 – 2,526 = 5,836 kips (for seismic forces in longitudinal direction)

FEMA Building Seismic Safety Council nehrp

Example One-Story RWFD Building with Steel Deck Diaphragm

Step 2 - Base Shear

$T_a = C_t h_n^x = 0.020(30)^{0.75}$ =0.26 sec (ASCE/SEI 7-22 Eq. 12.8-7)

$$C_s = \frac{S_{DS}}{R/I_e} = \frac{1.0}{4/1.0} = 0.250$$ (ASCE/SEI 7-22 Eq. 12.8-2)

C_s need not exceed:

$$C_s = \frac{S_{D1}}{T(R)/I_e} = \frac{0.50}{0.26(4)/1.0} = 0.481$$ (ASCE/SEI 7-22 Eq. 12.8-3)

Base Shear $V = C_s W$ = (0.250)(8,362) = 2,090 kips (ASCE/SEI 7-22 Eq. 12.8-1)

FEMA Building Seismic Safety Council nehrp

Example One-Story RWFD Building with Steel Deck Diaphragm

Traditional Design Method (12.10.1 & 12.10.2)

FEMA Building Seismic Safety Council nehrp

Traditional Design Method

Step 4 - Strength Level diaphragm design force:

$$F_{px} = \frac{\sum_{i=x}^{n} F_i}{\sum_{i=x}^{n} w_i} w_{px}$$ (ASCE/SEI 7-22 Eq. 12.10-1)

For a single-story building, $F_{px} = C_s\ (w_{px})$

$F_{px} = C_s\ (w_{px})$

= 0.25 (6,846) = 1,712 kips (transverse direction)

= 0.25 (5,836) = 1,459 kips (longitudinal direction)

Traditional Design Method

The minimum value of F_{px} is:

$F_{px} = 0.2 S_{DS} I_e w_{px}$ (ASCE/SEI 7-22 Eq. 12.10-2)

= 0.2(1.0)(1.0)(6,846) = 1,369 kips (transverse direction)

= 0.2(1.0)(1.0)(5,836) = 1,167 kips (longitudinal direction)

The maximum value of F_{px} is:

$F_{px} = 0.4 S_{DS} I_e w_{px}$ (ASCE/SEI 7-22 Eq. 12.10-3)

= 0.4(1.0) (1.0)(6,846) = 2,738 kips (transverse direction)

= 0.4(1.0) (1.0)(5,836) = 2,334 kips (longitudinal direction)

Traditional Design Method

Step 4 - Governing diaphragm design force

F_{px} = 1,712 kips (transverse direction)
F_{px} = 1,459 kips (longitudinal direction)

FEMA Building Seismic Safety Council nehrp 29

Traditional Design Method

Step 6 - Diaphragm Design for Shear

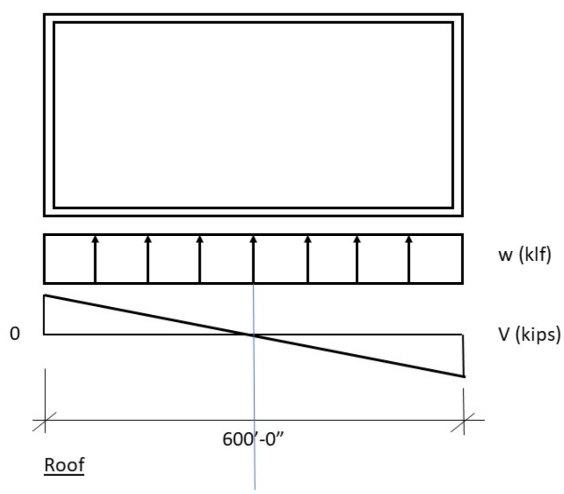
The diaphragm is design for shear using F_{px} forces. The following illustrates shear calculations for the transverse direction.

For transverse roof diaphragm forces:

w = 1,712 kips / 600 ft = 2.85 klf

V = 2.85 klf (600 ft / 2) = 856 kips

v = 856 kips / 360 ft = 2.37 klf maximum at end of diaphragm span



FEMA Building Seismic Safety Council nehrp 30

Traditional Design Method

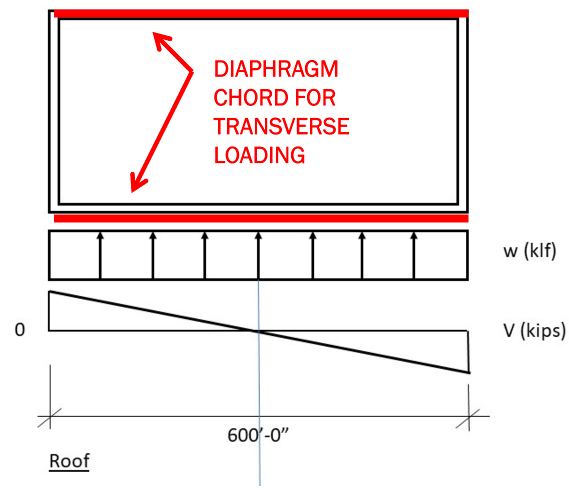
Step 6 - Diaphragm Design for Flexure

For transverse roof diaphragm forces:

w = 1,712 kips / 600 ft = 2.85 klf

M = 2.85 klf (600 ft)^2 / 8 = 128,250 kip-ft

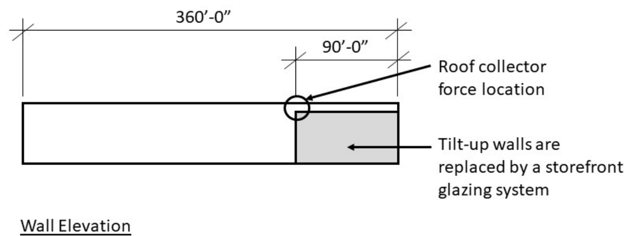
Chord T/C = 128,250 kip-ft / 360 ft = 356 kips maximum at diaphragm mid-span



31

Traditional Design Method

Step 7 - Diaphragm Collector Design with Seismic Forces Amplified by Ω_0



The collector force is calculated based on the maximum transverse diaphragm shear, amplified by Ω_0:

- T/C = 2.37 klf (90 ft) (2.5) = 533 kips

32

Traditional Design Method

Step 8 - Deflection and Drift Limitations.

- All applicable ASCE/SEI 7-22 deflection and drift checks are to be completed. It is important that this include a check that the gravity system can accommodate the mid-span deflection of the roof diaphragm, and the P-D stability of the tilt-up wall panels when subject to the diaphragm deflection.
- See the commentary to the ASCE/SEI 7-22 Section 12.10.4 provisions for further discussion of these checks

Example One-Story RWFD Building with Steel Deck Diaphragm

Alternative RWFD Design Method (12.10.4)

Meeting AISI S400 Special Seismic Detailing Requirements

Diaphragm Seismic Design Methods

- Advantages of using Section 12.10.3 Alternative Design Provisions:
  - Better reflects vertical distribution of diaphragm forces
  - Better reflects affect of diaphragm ductility and displacement capacity
  - May result in lower seismic demands
- Advantages of using Section 12.10.4 Alternative RWFD Method;
  - Better reflects seismic response of RWFD buildings
  - May result in lower seismic demands
  - Is anticipated to result in better performance
- When will the Section 12.10.1 and 12.10.2 Traditional Method result in lower design forces?
  - Bare steel deck diaphragms not meeting the AISI S400 special seismic detailing provisions
  - Other

Alternative RWFD Design Method (NOT Meeting Special Seismic Detailing Requirements, 12.10.4)

Preview of Diaphragm Force Equation

$$F_{px} = C_{s-diaph}(w_{px})$$ (ASCE/SEI 7-22Eq. 12.10-15)

$$C_{s-diaph} = \frac{S_{DS}}{R_{diaph}/I_e}$$ (ASCE/SEI 7-22Eq. 12.10-16a)

$$C_{s-diaph} = \frac{S_{D1}}{T_{diaph}(R_{diaph})/I_e}$$ (ASCE/SEI 7-22 Eq. 12.10-16b)

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)

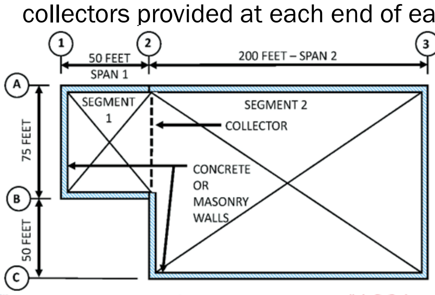
Step 1 - Check ASCE/SEI 7-22 Section 12.10.4.1 Scoping Limitations

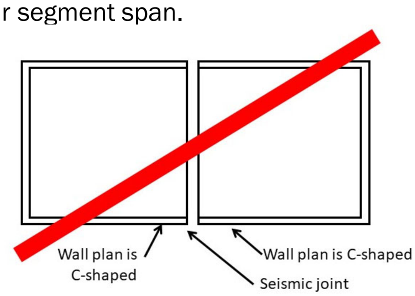
The following are the scoping limitations that must be checked. If the building conforms to all scoping limitations, it is eligible to use the ASCE/SEI 7-22 Section 12.10.4 procedure.

1. All portions of the diaphragm shall be designed using the provisions of this section in both orthogonal directions.
2. The diaphragm shall consist of either a) a wood structural panel diaphragm designed in accordance with AWC SDPWS and fastened to wood framing members or wood nailers with sheathing nailing in accordance with the AWC SDPWS Section 4.2 nominal shear capacity tables, or b) a bare (untopped) steel deck diaphragm meeting the requirements of AISI S400 and AISI S310 .
3. Toppings of concrete or similar materials that affect diaphragm strength or stiffness shall not be placed over the wood structural panel or bare steel deck diaphragm.

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)

4. The diaphragm shall not contain horizontal structural irregularities, as specified in ASCE/SEI 7-22 Table 12.3-1, except that Horizontal Structural Irregularity Type 2 (reentrant corner irregularity) is permitted.
5. The diaphragm shall be rectangular in shape or shall be divisible into rectangular segments for purpose of seismic design, with vertical elements of the seismic force-resisting system or collectors provided at each end of each rectangular segment span.





Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)

6. The vertical elements of the seismic force-resisting system shall be limited to one or more of the following: concrete shear walls, precast concrete shear walls, masonry shear walls, steel concentrically braced frames, steel and concrete composite braced frames, or steel and concrete composite shear walls.
7. The vertical elements of the seismic force-resisting system shall be designed in accordance with ASCE/SEI 7-22 Section 12.8, except that they shall be permitted to be designed using the two-stage analysis procedure of ASCE/SEI 7-22 Section 12.2.3.2.2, where applicable.

The example building conforms to all of these limitations and can be designed in accordance with ASCE/SEI 7-22 Section 12.10.4.

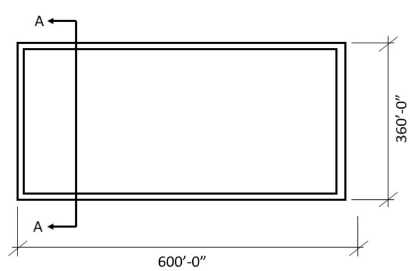
FEMA Building Seismic Safety Council nehrp

39

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 2 - Break roof diaphragm into a series of rectangular segments for purposes of design with each segment spanning to vertical elements or a collector .

- Because the example building is rectangular in plan and shear walls are located at the building perimeter, a single rectangular segment extending for the full building plan (600 ft by 360 ft) will be used.



Roof Plan

FEMA Building Seismic Safety Council nehrp

40

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 3 - Determine W_{px}.

W_{px} was determined in previous slides to be:

6,846 kips (transverse forces)

5,836 kips (longitudinal forces)

FEMA Building Seismic Safety Council nehrp 41

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 4 - Determine R_{diaph}

Section 12.10.4.2.1:

R_{diaph} = 4.5 for bare steel deck diaphragms that meet the special seismic detailing requirements of AISI S400 Section F3.5.1.

R_{dipah} = Response modification coefficient for design of diaphragm using the alternative diaphragm design method of Section 12.10.4

R_{diaph} = 4.5 for bare steel deck diaphragms that meet the special seismic detailing requirements for AISI S400

R_{diaph}= 1.5 for all other bare steel deck diaphragms

FEMA Building Seismic Safety Council nehrp 42

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements AISI S400 Section F3.5.1)

Item	Prescriptive Requirements
1	The steel deck panel type shall be 36 in. (914 mm) wide, 1.5 in. (38.1 mm) deep, wide rib, 6 in. (152 mm) pitch (WR) deck.
2	The steel deck base steel thickness shall be greater than or equal to 0.0295 in. (0.749 mm) and less than or equal to 0.0598 in. (1.52 mm).
3	The steel deck material shall conform to Section A.3.1.1 of AISI S100 [CSA S136].
4	The structural connection between the steel deck and the supporting steel member (with minimum thickness of 1/8 in. (3.18 mm)) shall be limited to mechanical connectors qualified in accordance with AISI S400 Section F3.5.1.1.

FEMA Building Seismic Safety Council nehrp 43

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements AISI S400 Section F3.5.1)

Item	Prescriptive Requirements
5	The structural connection perpendicular to the steel deck ribs shall be no less than a 36/4 pattern (12 in. (305 mm) on center) and no more than a 36/9 pattern (6 in. (152mm) on center) with double fasteners in the last panel rib.
6	The structural connection parallel to the steel deck ribs shall be spaced no less than 3 in. (76.2 mm) and no more than 24 in. (610 mm) and shall not be greater than the sidelap connection spacing.
7	The sidelap connection between steel deck shall be limited to #10, #12, or #14 screws sized such that shear in the screws is not the controlling limit state, or connectors qualified in accordance with AISI S400 Section F3.5.1.2.

FEMA Building Seismic Safety Council nehrp 44

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements AISI S400 Section F3.5.1)

Item	Prescriptive Requirements
8	The sidelap connection shall be spaced no less than 6 in. (152 mm) and no more than 24 in. (610 mm).

Impact of Prescriptive Requirements:
- Requires mechanical fasteners
- Welded connections not permitted under prescriptive requirements

Other AISI methods:
- Qualification by testing – AISI S400 Section F3.5.2.1
- Principles of mechanics – AISI S400 Section F3.5.2.2

FEMA Building Seismic Safety Council nehrp

45

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 5- Determine T_{diaph}

- $T_{diaph} = 0.001 L_{diaph}$ for bare steel deck diaphragms (ASCE/SEI 7-22 Section 12.10.4.2.1)
- T_{diaph} = 0.001 (600) = 0.60 s (transverse forces)
- T_{diaph}= 0.001 (360) = 0.36 s (longitudinal forces)

FEMA Building Seismic Safety Council nehrp

46

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 6 - Determine $C_{s\text{-}diaph}$

For transverse forces:

$$C_{s-diaph} = \frac{S_{DS}}{R_{diaph}/I_e} = \frac{1.0}{4.5/1.0} = 0.222$$

(ASCE/SEI 7-22 Eq. 12.10-16a)

But need not exceed

$$C_{s-diaph} = \frac{S_{D1}}{T_{diaph}(R_{diaph})/I_e} = \frac{0.50}{0.60(4.5)/1.0} = 0.185$$

(ASCE/SEI 7-22 Eq. 12.10-16b)

Use $C_{s\text{-}diaph}$ = 0.185 transverse

FEMA Building Seismic Safety Council nehrp

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)

For longitudinal forces:

$$C_{s-diaph} = \frac{S_{DS}}{R_{diaph}/I_e} = \frac{1.0}{4.5/1.0} = 0.222$$

(ASCE/SEI 7-22 Eq. 12.10-16a)

But need not exceed:

$$C_{s-diaph} = \frac{S_{D1}}{T_{diaph}(R_{diaph})/I_e} = \frac{0.50}{0.36(4.5)/1.0} = 0.309$$

(ASCE/SEI 7-22Eq. 12.10-16b)

Use $C_{s\text{-}diaph}$ = 0.222 longitudinal

FEMA Building Seismic Safety Council nehrp

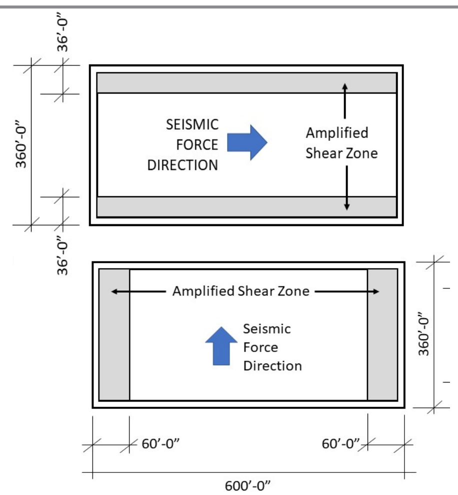
Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 7 - Determine diaphragm design force, F_{px}

- $F_{px} = C_{s\text{-}diaph} (w_{px})$ (ASCE/SEI 7-22 Eq.12.10-15)
- F_{px} = 0.185 (6,846) = 1,266 kips transverse
- F_{px} = 0.222 (5,836) = 1,296 kips longitudinal

Note that unlike the ASCE/SEI 7-22 Section 12.10.1 and 12.10.2 traditional method and the Section 12.10.3 alternative method, for the Section 12.10.4 alternative RWFD method there is no lower bound for diaphragm seismic design forces.

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)



Step 8 - Determine amplified shear and extent of amplified shear boundary zone

- Because the diaphragm span in both directions is greater than 100 ft., an amplified shear zone will be located at each end of the diaphragm span and extend for ten percent of the diaphragm span. The extent of the amplified shear zones are:
- 0.10 (600) = 60 ft each end for transverse forces
- 0.10 (360) = 36 ft each end for longitudinal forces.

If diaphragm span were 100 ft. or less, amplified shear zone would apply to the entire diaphragm area.

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)

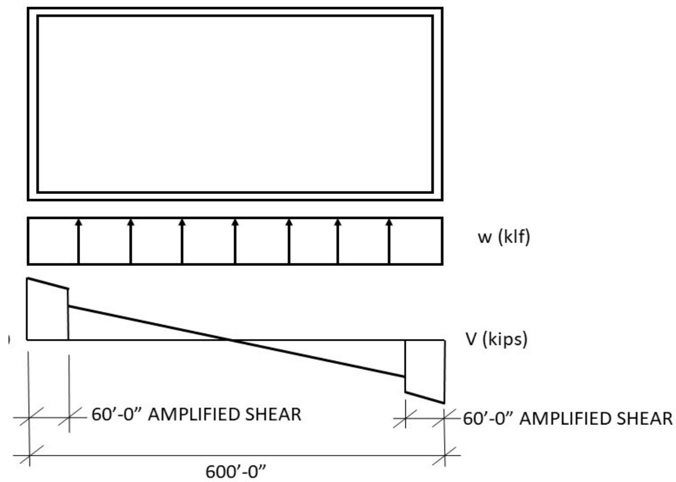
Step 9 - Diaphragm Design for Shear

The diaphragm is designed for shear using F_{px} forces. The following illustrates shear calculations for the transverse direction.

For transverse roof diaphragm forces:

- w = 1,266 kips / 600 ft = 2.11 klf
- V = 2.11 klf (600 ft / 2) = 633 kips
- v = 633 kips / 360 ft = 1.76 klf maximum at end of diaphragm span WITHOUT shear amplification
- v = 1.76 klf (1.5) = 2.64 klf maximum at end of diaphragm span WITH shear amplification

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)



Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 9 - Diaphragm Design for Flexure –Chord Forces

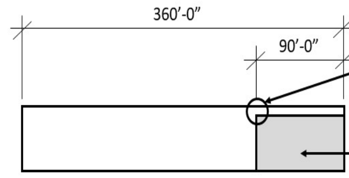
For transverse roof diaphragm forces, the chord force is calculated using F_{px} forces without amplification:

- w = 1,266 kips / 600 ft = 2.11 klf
- M = 2.11 klf (600 ft)^2 / 8 = 94,950 kip-ft
- Chord T/C = 94,950 kip-ft / 360 ft = 264 kips maximum at diaphragm mid-span

FEMA Building Seismic Safety Council nehrp 53

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 10 - Determine collector forces in accordance with ASCE/SEI 7-22 Section 12.10.4.2.4. Collector forces are to be based on F_{px} forces WITHOUT the 1.5 amplification factor BUT multiplied by $\Omega_{0\text{-diaph}}$.



Wall Elevation

- Per ASCE/SEI 7-22 Section 12.10.4.2.4, the collector force is calculated based on the maximum transverse diaphragm shear WITHOUT amplification, multiplied by $\Omega_{0\text{-diaph}}$:
- T/C = 1.76 klf (90 ft) (2.0) = 317 kips

FEMA Building Seismic Safety Council nehrp 54

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 11 - Check applicable ASCE/SEI 7-22 deflection and drift limitations.

- Where required by ASCE/SEI 7-22, determine $C_{d\text{-}diaph}$ and diaphragm deflections in accordance with ASCE/SEI 7-22 Section 12.10.4.2.5. All applicable ASCE/SEI 7-22 deflection and drift checks are to be completed. It is important that this includes a check that the gravity system can accommodate the mid-span deflection of the roof diaphragm, and the P-D stability of the tilt-up wall panels when subject to the diaphragm deflection.
- See the commentary to the ASCE/SEI 7-22 Section 12.10.4 provisions for further discussion of these checks

Example One-Story RWFD Building with Steel Deck Diaphragm

Alternative RWFD Design Method (12.10.4)

NOT Meeting AISI S400 Special Seismic Detailing Requirements

Alternative RWFD Design Method (NOT Meeting Special Seismic Detailing Requirements, 12.10.4)

- This example building has a bare steel deck diaphragm that is welded instead of using mechanical fasteners. The diaphragm does not meet the special seismic detailing requirements of AISI S400 Section F3.5.1.

Alternative RWFD Design Method (NOT Meeting Special Seismic Detailing Requirements, 12.10.4)

<u>Step 1 - Check ASCE/SEI 7-22 Section 12.10.1.1 Scoping Limitations</u>

- The following are the scoping limitations that must be checked. If the building conforms with all scoping limitations, it is eligible to use the ASCE/SEI 7-22 Section 12.10.4 procedure.

1. All portions of the diaphragm shall be designed using the provisions of this section in both orthogonal directions.
2. The diaphragm shall consist of either a) a wood structural panel diaphragm designed in accordance with AWC SDPWS and fastened to wood framing members or wood nailers with sheathing nailing in accordance with the AWC SDPWS Section 4.2 nominal shear capacity tables, or b) a bare (untopped) steel deck diaphragm meeting the requirements of AISI S400 and AISI S310.

Alternative RWFD Design Method (NOT Meeting Special Seismic Detailing Requirements, 12.10.4)

3. Toppings of concrete or similar materials that affect diaphragm strength or stiffness shall not be placed over the wood structural panel or bare steel deck diaphragm.
4. The diaphragm shall not contain horizontal structural irregularities, as specified in ASCE/SEI 7-22 Table 12.3-1, except that Horizontal Structural Irregularity Type 2 (reentrant corner irregularity) is permitted.
5. The diaphragm shall be rectangular in shape or shall be divisible into rectangular segments for purpose of seismic design, with vertical elements of the seismic force-resisting system or collectors provided at each end of each rectangular segment span.

Alternative RWFD Design Method (NOT Meeting Special Seismic Detailing Requirements, 12.10.4)

6. The vertical elements of the seismic force-resisting system shall be limited to one or more of the following: concrete shear walls, precast concrete shear walls, masonry shear walls, steel concentrically braced frames, steel and concrete composite braced frames, or steel and concrete composite shear walls.
7. The vertical elements of the seismic force-resisting system shall be designed in accordance with ASCE/SEI 7-22 Section 12.8, except that they shall be permitted to be designed using the two-stage analysis procedure of ASCE/SEI 7-22 Section 12.2.3.2.2, where applicable.

Alternative RWFD Design Method (NOT Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 2 - Break roof diaphragm into a series of rectangular segments for purposes of design with each segment spanning to vertical elements or a collector.

- Because the example building is rectangular in plan and shear walls are located at the building perimeter, one rectangular segment extending for the full building plan will be used.

Step 3 - Determine w_{px}.

- W_{px} was determined in Example Section 7.7.1 to be:
- 6,846 kips (transverse forces)
- 5,836 kips (longitudinal forces)

FEMA Building Seismic Safety Council nehrp 61

Alternative RWFD Design Method (NOT Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 4 - Determine R_{diaph}

- R_{diaph} = 1.5 for bare steel deck diaphragms NOT meeting the special seismic detailing requirements for AISI S400

Step 5 - Determine T_{diaph}

- $T_{diaph} = 0.001L_{diaph}$ for bare steel deck diaphragms (ASCE/SEI 7-22 Section 12.10.4.2.1)
- T_{diaph} = 0.001 s/ft (600 ft) = 0.60 s (transverse forces)
- T_{diaph}= 0.001 s/ft (360 ft) = 0.36 s (longitudinal forces)

FEMA Building Seismic Safety Council nehrp 62

Alternative RWFD Design Method (NOT Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 6 - Determine $C_{s\text{-}diaph}$

For transverse forces:

$$C_{s-diaph} = \frac{S_{DS}}{R_{diaph}/I_e} = \frac{1.0}{1.5/1.0} = 0.667$$

(ASCE/SEI 7-22Eq. 12.10-16a)

But need not exceed

$$C_{s-diaph} = \frac{S_{D1}}{T_{diaph}(R_{diaph})/I_e} = \frac{0.50}{0.60(1.5)/1.0} = 0.555$$

(ASCE/SEI 7-22 Eq. 12.10-16b)

- Use $C_{s\text{-}diaph}$ = 0.555 transverse

Alternative RWFD Design Method (NOT Meeting Special Seismic Detailing Requirements, 12.10.4)

For longitudinal forces:

$$C_{s-diaph} = \frac{S_{DS}}{R_{diaph}/I_e} = \frac{1.0}{1.5/1.0} = 0.667$$

(ASCE/SEI 7-22 Eq. 12.10-16a)

But need not exceed:

$$C_{s-diaph} = \frac{S_{D1}}{T_{diaph}(R_{diaph})/I_e} = \frac{0.50}{0.36(1.5)/1.0} = 0.926$$

(ASCE/SEI 7-22 Eq. 12.10-16b)

- Use $C_{s\text{-}diaph}$ = 0.667 longitudinal

Alternative RWFD Design Method (NOT Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 7 -Determine diaphragm design force, F_{px}

- $F_{px} = C_{s\text{-}diaph}\,(w_{px})$ (ASCE/SEI 7-22 Eq. 12.10-15)
- F_{px} = 0.555 (6,846) = 3,800 kips transverse
- F_{px} = 0.667 (5,836) = 3,893 kips longitudinal

FEMA Building Seismic Safety Council nehrp

Alternative RWFD Design Method (NOT Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 8 - Determine amplified shear and extent of amplified shear boundary zone

- Because the diaphragm span in both directions is greater than 100 ft., an amplified shear zone will be located at each end of the diaphragm span and extend for ten percent of the diaphragm span. The extent of the amplified shear zones are:
- 0.10 (600 ft) = 60 ft each end for transverse forces
- 0.10 (360 ft) = 36 ft each end for longitudinal forces.

FEMA Building Seismic Safety Council nehrp

Alternative RWFD Design Method (NOT Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 9 - Diaphragm Design for Shear

The diaphragm is designed for shear using F_{px} Forces. The following illustrates shear calculations for the transverse direction.

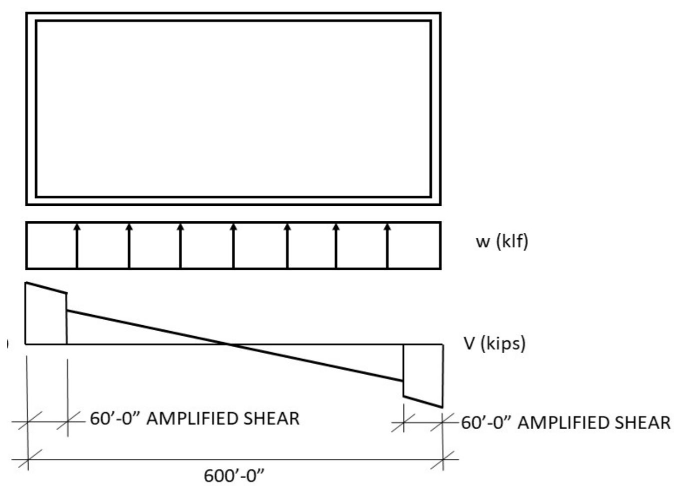
For transverse roof diaphragm forces:

- *w* = 3,800 kips / 600 ft = 6.33 klf
- *V* = 6.33 klf (600 ft / 2) = 1,900 kips
- *v* = 1,900 kips / 360 ft = 5.28 klf maximum at end of diaphragm span WITHOUT shear amplification
- *v* = 5.28 klf (1.5) = 7.92 klf maximum at end of diaphragm span WITH shear amplification

FEMA Building Seismic Safety Council nehrp

67

Alternative RWFD Design Method (Meeting Special Seismic Detailing Requirements, 12.10.4)



FEMA Building Seismic Safety Council nehrp

68

Alternative RWFD Design Method (NOT Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 9 - Diaphragm Design for Flexure – Chord Forces

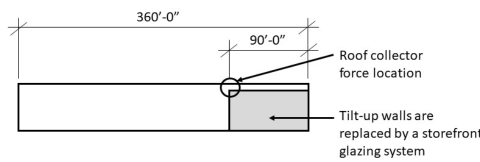
- For transverse roof diaphragm forces the chord force is calculated using F_{px} forces without amplification:
- w = 3,800 kips / 600 ft = 6.33 klf
- M = 6.33 klf (600 ft)^2 / 8 = 284,850 kip-ft
- Chord T/C = 284,850 kip-ft / 360 ft = 791 kips maximum at diaphragm mid-span

FEMA Building Seismic Safety Council nehrp

69

Alternative RWFD Design Method (NOT Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 10 - Determine collector forces in accordance with ASCE/SEI 7-22 Section 12.10.4.2.4. Collector forces are to be based on F_{px} forces WITHOUT the 1.5 amplification factor, multiplied by $W_{0\text{-diaph}}$., however $\Omega_{0\text{-diaph}}$ need not be taken as greater than R_{diaph}.



Wall Elevation

- Per ASCE/SEI 7-22 Section 12.10.4.2.4, the collector force is calculated based on the maximum transverse diaphragm shear WITHOUT amplification, multiplied by $W_{0\text{-diaph}}$, however $W_{0\text{-diaph}}$ need not be taken as greater than R_{diaph}
- T/C = 5.28 klf (90 ft) (1.5) = 713 kips

FEMA Building Seismic Safety Council nehrp

70

Alternative RWFD Design Method (NOT Meeting Special Seismic Detailing Requirements, 12.10.4)

Step 11 - Check applicable ASCE/SEI 7-22 deflection and drift limitations.

- Where required by ASCE/SEI 7-22, determine $C_{d\text{-}diaph}$ and diaphragm deflections in accordance with ASCE/SEI 7-22 Section 12.10.4.2.5. All applicable ASCE/SEI 7-22 deflection and drift checks are to be completed. It is important that this include a check that the gravity system can accommodate the mid-span deflection of the roof diaphragm, and the P-D stability of the tilt-up wall panels when subject to the diaphragm deflection.
- See the commentary to the ASCE/SEI 7-22 Section 12.10.4 provisions for further discussion of these checks

FEMA Building Seismic Safety Council nehrp

71

Example One-Story RWFD Building with Steel Deck Diaphragm

Comparison of Methods

FEMA Building Seismic Safety Council nehrp

72

Comparison of Design Methods

Table 7.7-1: Comparison of Traditional and Alternative RWFD Design Forces

Diaphragm Design Method	Special Seismic Detailing met?	Transverse			Longitudinal		
		F_{px} (kips)	v_{px} (plf)	v_{px} amplified shear zone (plf)	F_{px} (kips)	v_{px} (plf)	v_{px} amplified shear zone (plf)
Traditional ASCE/SEI 7-22 Section 12.10.1 and 12.10.2	NA	1,712	2,370	NA	1,459	1,220	NA
Alternative RWFD ASCE/SEI 7-22 Section 12.10.4	Yes	1,266	1,760	2,640	1,296	1,080	1,620
Alternative RWFD ASCE/SEI 7-22 Section 12.10.4	No	3,800	5,280	7,920	3,893	3,240	4,870

FEMA Building Seismic Safety Council nehrp

Comparison of Design Methods

Table 7.7-2: Comparison of Traditional and Alternative RWFD Collector Forces

Diaphragm Design Method	Special Seismic Detailing met?	Chord Force *T/C* (kips)	Collector Force *T/C* (kips)
Traditional ASCE/SEI 7-22 Section 12.10.1 and 12.10.2	NA	356	533
Alternative RWFD ASCE/SEI 7-22 Section 12.10.4	Yes	264	317
Alternative RWFD ASCE/SEI 7-22 Section 12.10.4	No	791	713

1.0 kip = 4.45 kN, 1.0 ft = 0.3048 m, 1.0 ft-kip = 1.36 kN-m

FEMA Building Seismic Safety Council nehrp

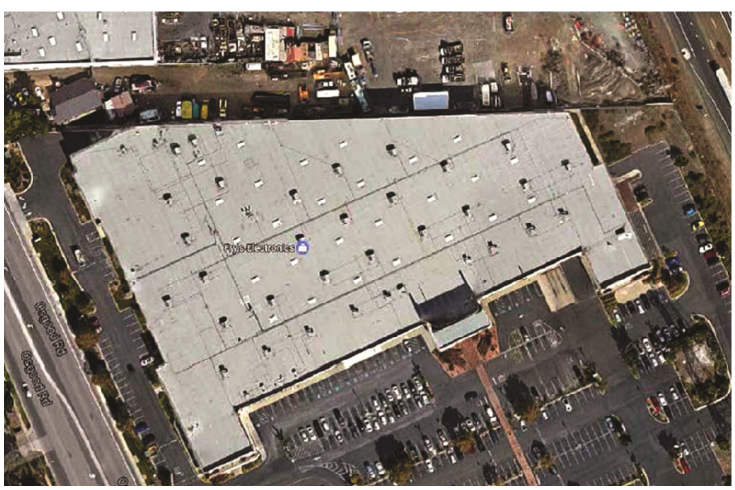
Part 2 - Closing Comments

Questions

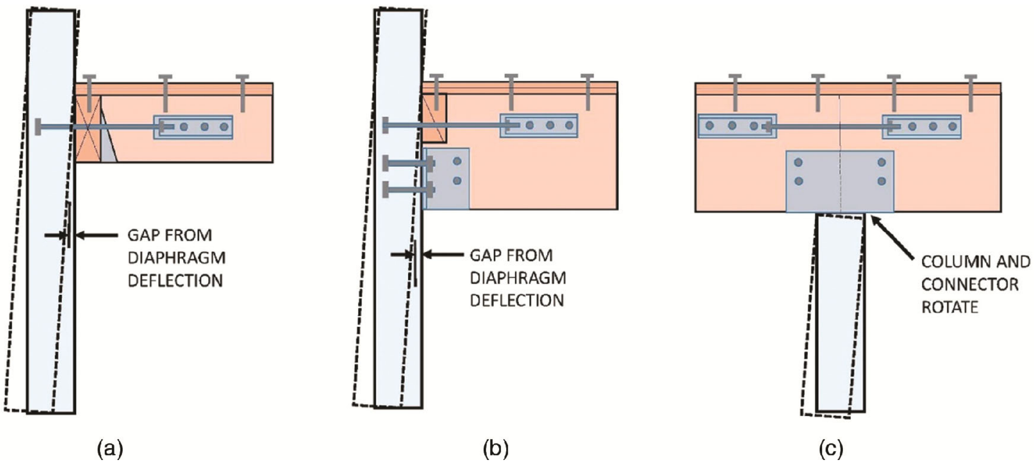
DISCLAIMER

- NOTICE: Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of the Federal Emergency Management Agency. Additionally, neither FEMA, nor any of its employees make any warranty, expressed or implied, nor assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, product or process included in this publication.
- The opinions expressed herein regarding the requirements of the *NEHRP Recommended Seismic Provisions*, the referenced standards, and the building codes are not to be used for design purposes. Rather the user should consult the jurisdiction's building official who has the authority to render interpretation of the code.
- This set of training materials is intended to remain complete in its entirety even if used by other presenters. If the training materials are excerpted in part for use in other presentations, we ask users to provide a reference/citation to this document and related chapter authors and acknowledge the possibility of incomplete interpretation if only part of the material is used.

Building Geometry Where Section 12.10.3 Cannot Be Used



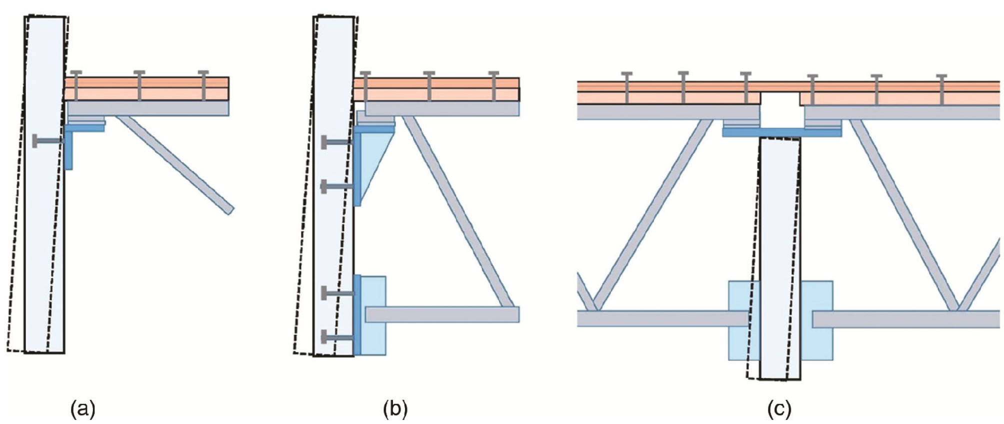
Diaphragm Deflection Considerations – Wood Diaphragm



FEMA Building Seismic Safety Council nehrp

79

Diaphragm Deflection Considerations – Steel Open-Web Joists



FEMA Building Seismic Safety Council nehrp

80