IT9 – Diaphragm Issues

Update April 5, 2018

nehrp

FEMA

Building Seismic Safety Council

a council of the National Institute of Building Sciences

Scope

- **Scope 1 - Rigid Wall/ Flexible Diaphragm:** Determine next steps required to progress the rigid wall - flexible diaphragm seismic design methodology of the FEMA P-1026 guideline document to a Part 1 proposal ready for incorporation into ASCE 7. This will include consideration of technical gaps as well as mandatory language. If possible with IT resources, begin next steps.(road maps)
- **Scope 2 – Diaphragm Alternative Design Method - Deriving R_s Factors:** Determine next steps required to fully develop and document the methodology for deriving Rs diaphragm design force reduction factors for the alternative provisions for diaphragm seismic design developed by PUC last cycle. If possible with IT resources, begin next steps.(more likely Part III document,)
- **Overlay** - Incorporate available steel deck diaphragm information into the two items listed above

Scope 1 - RWFD

- **Scope 1 - Rigid Wall/ Flexible Diaphragm:** Determine next steps required to progress the rigid wall - flexible diaphragm seismic design methodology of the FEMA P-1026 guideline document to a Part 1 proposal ready for incorporation into ASCE 7. This will include consideration of technical gaps as well as mandatory language. If possible with IT resources, begin next steps.(road maps)

- Part 1 Proposal - RWFD with wood diaphragm
- Part 1 Proposal - Incorporating steel deck diaphragms
- Part 1 Proposal – Drift due to diaphragm deflection

Scope 1 - Starting Point

- Flexible diaphragm dominates building response
- Two-stage ELF analysis is used to capture this behavior
- Reduced nailing away from diaphragm edge help to distribute yielding and improve performance

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Scope 1 – RWFD Schedule/Milestones

Wood Diaphragm RWFD proposal

- April 2017 - Written proposal to PUC
- July 2017 – PUC Ballot

Steel Diaphragm RWFD proposal

- Steel research still in progress
- April 2018 – Steel presentation at PUC Mtg
- November 2018 – Written proposal to PUC
- March 2019 – PUC ballot

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Scope 1 – Proposal 1: RVEFD

12.10 DIAPHRAGMS, CHORDS AND COLLECTORS

Diaphragms, chords and collectors shall be designed in accordance with Sections 12.10.1 and 12.10.2.

EXCEPTIONS:

1. Precast concrete diaphragms, including chords and collectors, in structures assigned to Seismic Design Category C, D, E or F, shall be designed in accordance with Section 12.10.3
2. Precast concrete diaphragms in Seismic Design Category B, cast-in-place concrete diaphragms and wood-sheathed diaphragms supported by wood diaphragm framing are permitted to be designed in accordance with Section 12.10.3.
3. Diaphragms, chords and collectors in one-story structures that meet the limitations of 12.10.4.1 are permitted to be designed in accordance with Section 12.10.4.

Scope 1 – Proposal 1: RVEFD

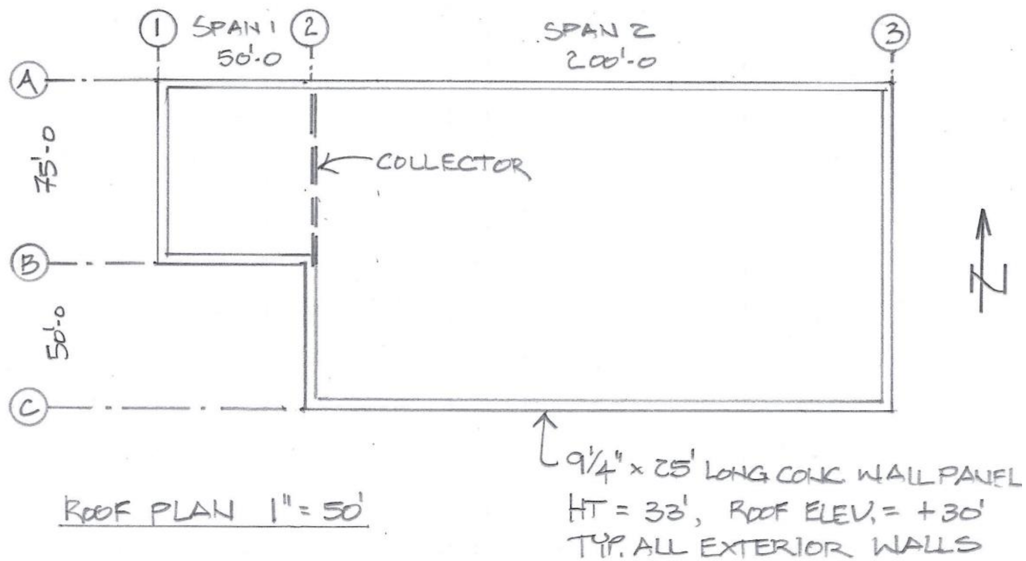
12.10.4 Alternative Diaphragm Design Forces for One-Story Structures with Flexible Diaphragms and Rigid Vertical Elements. Where permitted by Section 12.10 and meeting the limitations of Sec. 12.10.4.1, diaphragm design forces, including design forces for chords, collectors, and their connections (in-plane) to vertical elements, shall be determined in accordance with Sections 12.10.4.2.

12.10.4.1 Limitations. Diaphragms in one-story structures are permitted to be designed in accordance with Section 12.10.4 provided all of the following limitations are met;

1. The diaphragm shall be of wood structural panel sheathing, fastened to wood framing members with sheathing nailing in accordance with SDPWS Section 4.2 Tables.
2. Toppings of concrete or similar rigid materials shall not be placed over the wood structural panel diaphragm.
3. The diaphragm shall not contain horizontal structural irregularities, as specified in Table 12.3-1, except that Horizontal Structural Irregularity Type 2 is permitted.
4. The diaphragm shall be rectangular in shape or shall be divisible into rectangular segments for purpose of seismic design, with vertical elements or collectors provided at each edge of each rectangular segment.
5. The vertical elements of the seismic force-resisting system shall be limited to one or more of the following: concrete shear walls, masonry shear walls, steel concentrically braces frames, steel and concrete composite braced frames, or steel and concrete composite shear walls.

Scope 1 – Proposal 1: RVEFD

12.10.4.2 Design. Diaphragms, including chords and collectors and their connections to vertical elements, shall be designed in two orthogonal directions to resist the in-plane design seismic forces determined in accordance with Section 12.10.4.2. Multi-span diaphragms and diaphragms that are not rectangular in shape shall be divided into rectangular segments for purposes of design in accordance with this section, with lateral support provided at each edge of each diaphragm segment by either a vertical element or a collector element.



Scope 1 – Proposal 1: RVEFD

12.10.4.2.1 Seismic Design Forces. The diaphragm seismic design force, $F_{p\text{-}diaph}$, shall be determined in accordance with Eq. 12.10-15.

$$F_{p\text{-}diaph} = C_{s\text{-}diaph} * W_{diaph} \qquad (12.10\text{-}15)$$

Where

W_{diaph} = the mass tributary to the diaphragm for purposes of seismic design.

$$C_{s\text{-}diaph} = \frac{S_{DS}}{R_{diaph}/I_e} \qquad (12.10\text{-}16a)$$

But need not be greater than:

$$C_{s\text{-}diaph} = \frac{S_{D1}}{T_{diaph} * (R_{diaph}/I_e)} \qquad (12.10\text{-}16b)$$

Where

S_{DS} = the design spectral response parameter in the short period range as determined from Section 11.4.5 or 11.4.8.

R_{diaph} = 4.5

I_e = the Importance Factor determined in accordance with Section 11.5.1.

T_{diaph} = 0.002 L_f, determined for each rectangular segment of the diaphragm in each orthogonal direction, and

L_f = the span in feet of the horizontal diaphragm or diaphragm segment being considered, measured between vertical elements or chords that provide support to the diaphragm or diaphragm segment.

Scope 1 – Proposal 1: RVEFD

12.10.4.2.2 Diaphragm Shears. Diaphragm design shears shall be computed for each diaphragm or diaphragm segment in accordance with Section 12.10.4.2.1.

Where diaphragm or diaphragm segment span, L_f, is less than 100 feet, the diaphragm design shear shall, for loading perpendicular to the span, be amplified to 1.5 times the diaphragm shear calculated in accordance with section 12.10.4.2.1.

Where the diaphragm or diaphragm segment span L_f, is greater than or equal to 100 feet, the diaphragm design shear shall be amplified to 1.5 times the shear calculated in accordance with Section 12.10.4.2.1 over an amplified shear boundary zone having a minimum width of 10 percent of the diaphragm or diaphragm segment span. An amplified shear boundary zone shall be provided at each side of the diaphragm or diaphragm segment under consideration.

12.10.4.2.3 Diaphragm Chords. Diaphragm chords shall be provided at each edge of each diaphragm or diaphragm segment to resist tension and compression forces resulting from diaphragm moments. Diaphragm chord forces shall be computed in accordance with Section 12.10.4.2.1.

12.10.4.2.4 Collector Elements and Their Connections. Collector elements shall be provided that are capable of transferring the seismic forces originating in other portions of the structure to the vertical elements of the lateral force resisting system. Seismic forces for diaphragm collectors and their connections

Scope 1 – Proposal 1: RVEFD

to vertical elements shall be computed in accordance with Section 12.10.4.2.1. Structures assigned to Seismic Design Categories C through F shall be designed to resist the forces calculated using the seismic load effects including overstrength factor of Section 12.4.3, with diaphragm overstrength factor, $\Omega_{o\text{-}diaph}$, taken as 2.

12.10.4.2.5 Diaphragm Deflection. The elastic diaphragm deflection, $\delta_{e\text{-}diaph}$, shall be computed using seismic design forces in accordance with Section 12.10.4.2.1. The maximum inelastic diaphragm deflection, δ_{diaph}, shall be computed using Eq. 12.15-3.

$$\delta_{diaph} = \frac{C_{d-diaph} * \delta_{e-diaph}}{I_e} \qquad (12.10\text{-}19)$$

where:

$C_{d\text{-}diaph}$ = 4.5.

12.10.4.2.6 Modifications to seismic force-resisting system design. For structures in which the diaphragm design forces are determined in accordance with Section 12.10.4, the following modifications apply.

1. Footnote b to Table 12.2-1 shall not apply
2. The redundancy factor, ρ, for the diaphragm shall be taken as 1.0
3. Section 12.3.3.4 shall not apply.

Scope 1 – Proposal 2: 2-Stage

12.2.3.2 Two-Stage Analysis Procedure

12.2.3.2.1 Vertical combinations of systems. A two-stage equivalent lateral force procedure is permitted to be used for structures that have a flexible upper portion and a rigid lower portion, provided that the design of the structure conforms with all of the following:

a. The stiffness of the lower portion shall be not less than 10 times the stiffness of the upper portion.
b. The period of the entire structure shall not be greater than 1.1 times the period of the upper structure considered as a separate structure supported at the transition from the upper to the lower portion.
c. The upper portion shall be designed as a separate structure suing the appropriate values of R and roe.
d. The lower portion shall be designed as a separate structure using the appropriate values of R and roe. The reactions from the upper portion amplified by the ratio of the R/ρ of the upper portion over the R/ρ of the lower portion. This ratio shall not be less than 1.0.
e. The upper portion is analyzed with the equivalent lateral force or modal response spectrum procedure, and lower portion is analyzed with the equivalent lateral force procedure.

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Scope 1 – Proposal 2: 2-Stage

12.2.3.2.2 One-story structures with flexible diaphragms. A two-stage equivalent lateral force procedure shall be permitted to be used for one-story structures having flexible diaphragms supported by rigid vertical elements of the seismic force-resisting system, provided that all of the following are met:

a. The structure shall meet the requirements of Sec. 12.10.4.
b. Vertical element seismic design forces contributed by the flexible diaphragms shall use $F_{p\text{-}dipah}$ forces, determined in accordance with Sec. 12.10.4.
c. The vertical element reactions from the diaphragms shall be amplified by the ratio of R_{diaph} divided by R/ρ of the seismic force-resisting system. This ratio shall not be taken as less than 1.0.
d. The vertical element seismic design forces contributed by the in-plane rigid vertical elements shall be determined in accordance with Sec. 12.8.

Scope 1 – Proposal 1 & 2

Question: Do we proceed with wood diaphragm based proposals now?

Scope 2 – Development of R_s

- **Scope 2 – Diaphragm Alternative Design Method - Deriving R_s Factors:** Determine next steps required to fully develop and document the methodology for deriving Rs diaphragm design force reduction factors for the alternative provisions for diaphragm seismic design developed by PUC last cycle. If possible with IT resources, begin next steps.(more likely Part III document,)

- Part 3 Proposal – Recommendations for development of diaphragm design force reduction factor, R_s

Scope 2 – Development of R_s Schedule/Milestones

- Continue following steel research
- April 2018 – Steel presentation to PUC
- November 2018 ? – Written proposal to PUC
- March 2019 ? – PUC ballot

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Steel Research Collaboration

1. 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.

Steel Research Collaboration

2. 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.

End

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 or Jerome Hajjar may attend meetings in Ben's place.

Corresponding Members

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