Part I-Offset Diaphragms

Course Description

Lateral force resisting systems in today’s structures are much more complex than they were several decades ago, incorporating multiple horizontal and vertical offsets in the diaphragms, multiple irregularities, and fewer lateral resisting elements. This two part presentation will provide a brief review of the method used to analyze these complex structures. In part 1, topics will include code requirements, how to recognize diaphragm irregularities and discontinuities, how shears are distributed through complex diaphragms, the method of analysis used to solve the transfer of forces across areas of discontinuity, and the analysis of flexible wood sheathed or untopped steel decking diaphragms with horizontal offsets.
Learning Objectives

- **Basic Information**
  Discuss boundary elements, complete lateral resisting load path requirements and related code sections.
- **Examine Common Types of Discontinuities**
  Examine common types of discontinuities and irregularities and discuss how to establish complete lateral load paths across areas of discontinuity.
- **Discuss the Analytical Method of Analysis**
  Review an analytical method used for solving complex diaphragms and shear walls using “Transfer Diaphragms” and the “Visual Shear Transfer Method.”
- **Offset Diaphragms-Examples**
  Review the analysis of flexible offset diaphragms for loading in the transverse and longitudinal directions.

Presentation Assumptions

Flexible wood sheathed or un-topped steel deck diaphragms

The method of analysis is also relevant to internal load path analysis within semi-rigid diaphragms.

- Loads to diaphragms and shear walls
  - Strength level or allowable stress design
  - Wind or seismic forces (UNO).

  The loads are already factored for the appropriate load combination.

Code References:

- ASCE 7-10 “Minimum Design Loads for Buildings and Other Structures”
- 2012 IBC

Design references:

- The Analysis of Irregular Shaped Structures: Diaphragms and Shear Walls- Malone, Rice
- Design of Wood Structures- Breyer, Fridley, Pollock, Cobeen
- SEAOC Seismic Design Manual, Volume 2
- Wood Engineering and Construction Handbook-Faherty, Williamson
- Guide to the Design of Diaphragms, Chords and Collectors-NCSEA, Mays
**Fundamental Principles:**
A shear wall is a location where diaphragm forces are resisted (supported), and therefore defines a diaphragm boundary location.

**Note:** All edges of a diaphragm shall be supported by a boundary element.

- **Diaphragm Boundary Elements:**
  - Chords, drag struts, collectors, shear walls, frames
  - Boundary member locations:
    - Diaphragm and shear wall perimeters
    - Interior openings
    - Areas of discontinuities
    - Re-entrant corners.

**Note:** Diaphragm and shear wall sheathing shall not be used to splice boundary elements.

**Collector elements** shall be provided that are capable of transferring forces originating in other portions of the structure to the element providing resistance to those forces.

**Basic Information**
- **Boundary Elements**
- **Complete Load Paths**
- **Method of Analysis**

**Boundary Elements “L” Shaped Buildings-Transverse Loading**
Analysis:
- Design shall be based on a rational analysis
- Complete load path from point of origin to lateral force resisting element (includes members and their connections and splices)
- Openings in shear panels that materially effect their strength shall be fully detailed on the plans and shall have their edges adequately reinforced to transfer all shear stresses.

Complete Continuous Lateral Load Paths

Method of Analysis

The Visual Shear Transfer Method

Basic Information

- Boundary Elements
- Complete Load Paths
- Method of Analysis

Shears Transferred Into Boundary Elements

What does this mean?

ASCE 7-10 section 12.10.1: At diaphragm discontinuities such as openings and re-entrant corners, the design shall assure that the dissipation or transfer of edge (chord) forces combined with other forces in the diaphragm is within shear and tension capacity of the diaphragm.
Introduction to Transfer Diaphragms and Transfer Areas

- **Transfer Diaphragm (sub-diaphragm):** A portion of a larger diaphragm designed to anchor and transfer local forces to primary diaphragm chords/struts of the main diaphragm.
- At discontinuities, such as openings or re-entrant corners, the design shall assure that the dissipation or transfer of edge (chord) forces combined with other forces in the diaphragm is within shear and tension capacity of the diaphragm.
- Framing members, blocking, and connections shall extend into the diaphragm a sufficient distance to develop the force transferred into the diaphragm.

**Shear Distribution Into a Simple Diaphragm**

**The Visual Shear Transfer Method**

**Traditional Method**

**Calculating Collector Forces**

**Transfer Diaphragm Members and Elements**

- **Legend:**
  - Unit shear transferred into boundary element
  - Unit shear acting on diaphragm shearing element
  - Tributary width to left and right wall
  - Tributary width to center wall
  - Support
  - Vsw=325 plf
  - Vsw=487 plf (+/- round off)

- **Formulae:**
  - For shear distribution into the collector:
    - \[ F = \text{support} \]
    - \[ F = 13000 \text{ lb} \]
    - \[ F = 487(20) \text{ lb} \]
    - \[ F = 975(10) \text{ lb} \]
    - \[ W(\text{plf}) = 325 \text{ plf} \]
    - \[ W(\text{plf}) = 487 \text{ plf} \]
    - \[ Vsw(\text{plf}) = 1462 \text{ plf} \]
    - \[ Vnet = 487 \text{ plf} \]

- **Support:**
  - 10' Support
  - 29250 lb
  - 20' Support
  - 13000 lb
  - 80' Support
  - 16250 lb

- **Collector force:**
  - \[ F = 975(10) \text{ lb} \]
  - \[ F = 487(20) \text{ lb} \]
  - \[ Vsw = 1462 \text{ plf} \]
  - \[ Vnet = 487 \text{ plf} \]

- **Visual Shear Transfer Method:** (method used in later examples)
Basic Procedure
Method by Edward F. Diekmann

Basic Shear Diagram at transfer diaphragm

Chord

Vnet=+300 -(75)= -225 plf
Vnet =+225 -(75)= +150 plf
Vnet =+300 -(250)= +550 plf
Vnet =+225 +(250)= +475 plf

No outside force is changing the basic diaphragm shear in this area

Transfer Diaphragm Shears
Analogous to a beam with a concentrated load.

Basic diaphragm shear
TD shears

Net shear

+250 plf
Vc

LTD

F(total)= F1+F2+F3+F4

Net direction of shears transferred onto collector

Shear left=+550-225= +325 plf
Shear right=+475-150=+325 plf

Cont. tie strap over bearing perp. to grain?

Collector force distribution

Example of Partial Strut/Collector

Collector force=area of shear diagram

Transfer Area

No gaps allowed. Diaphragm sheathing is not allowed to transfer strut/collector tension or compression forces.

Bearing perp. to grain?

Collector

F(total)= F1+F2+F3+F4

Cont. tie strap over bearing perp. to grain?

Bearing perp. to grain?

Shear Distribution Into The Collector

Place the net diaphragm shear on each side of the collector

Place the transfer shears on each side of the collector

Sum shears on collector (based upon direction of shears transferred onto collector).

Shear left:+550-225= +325 plf
Shear right:+475-150=+325 plf

Collector force=area of shear diagram

F(collector)=(325+325)(L collector)

Collector

Dir. of force on collector

Net shear

Note: The net shears will not always be equal.

Resulting net shear diagram on collector

Direction of shear transferred into collector

No outside force is changing the basic diaphragm shear in this area

_ NOTE:_ Collector must extend the full depth of the transfer diaphragm

**Basic Procedure**

*Method by Edward F. Diekmann*

*Basic Shear Diagram at transfer diaphragm*
**Diaphragms with Horizontal Offsets**

Simple Span Transfer Diaphragm
Analogous to a simple span beam with a concentrated load

Propped Cantilever Transfer Diaphragm
Analogous to a propped cantilever beam with a concentrated load

**Example 1-Diaphragm with Horizontal End Offset**

Transverse Loading

<table>
<thead>
<tr>
<th>SW 1</th>
<th>SW 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>35°</td>
<td>50°</td>
</tr>
</tbody>
</table>

Discontinuous diaphragm chord

Support 12500 lb

Free body for F2

12500 lb

Collector chord

Collector chord

Diaphragm chord

Diaphragm chord

Net shear

375 plf

Basic diaphragm shear

357.1 plf

Transfer diaphragm shears

214.3 plf

Net TD shears (basic shear +/- transfer diaph. shears)

357.1 plf

-250 plf

Legend

375 plf

Basic diaphragm shear

214.3 plf

Transfer diaphragm shears

250 plf

Net TD shears (basic shear +/- transfer diaph. shears)
Example 2-Diaphragm with Horizontal End Offset

Longitudinal Loading

Check the shear capacity of the nailing along the collector

Boundary locations

Diaphragm Nailing Callouts

Callout all nailing on drawings:
- Standard diaphragm nailing
- Boundary nailing
- Collector nailing

Special nailing along collectors

Sum of shears to collector or highest boundary nailing-greater of

Longitudinal Chord Force Diagrams

Transverse Collector Force Diagrams

Diaph.
CL
Questions?

This concludes

AIA Presentation Part 1- on Offset Diaphragms

R. Terry Malone, P.E., S.E.
Senior Technical Director
WoodWorks.org
Prescott Valley, Arizona

Contact Information:
terrym@woodworks.org

WoodWorks
woodworks.org

Events/Presentation Archives (slide handouts)-free