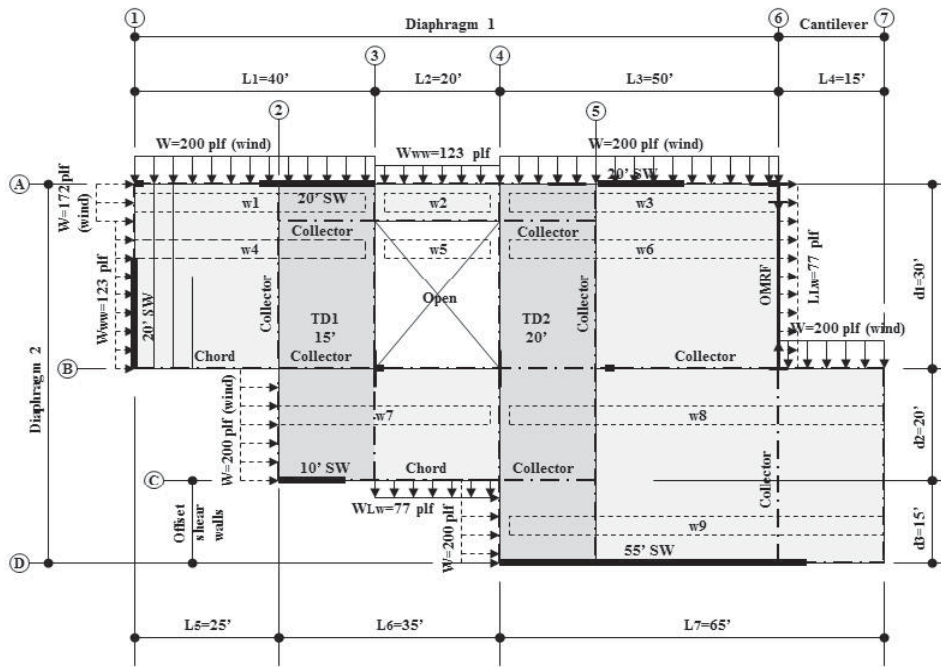


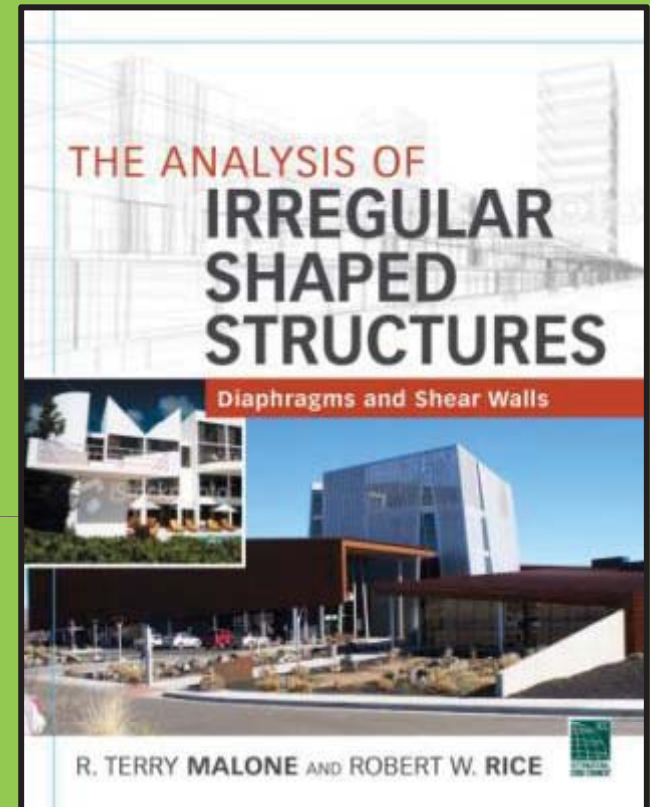


Part 1-Offset Diaphragms



Example-Complex Diaphragm

Based on:



Presentation updated to 2012 IBC, ASCE 7-10
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By: R. Terry Malone, PE, SE
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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 direction.



Presentation Assumptions

Flexible wood sheathed or un-topped steel deck diaphragms

(Also applies to 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

Complete Example with narrative and calculations



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WOOD PRODUCTS COUNCIL

The Analysis of Irregular Shaped Diaphragms


© Tony Mahon, PE, SE • Senior Technical Director • WoodWorks

Several decades ago, the residential and commercial buildings being designed tended to be straightforward, rectangular structures with simple load-out lateral resisting systems. These structures had a minimum number of horizontal and vertical offsets. In contrast, the structural configurations of many modern buildings require complex lateral load paths that incorporate diaphragms at different elevations, multiple re-entrant corners, multiple irregularities and fewer vertical lateral force-resisting elements. It is important to address these design issues and irregularities to ensure complete load paths throughout the structure. However, this doesn't have to be a daunting task.

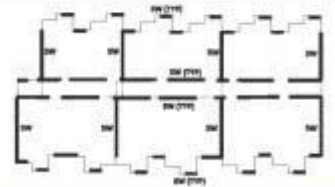
Knowledge regarding the analysis of complex diaphragm layouts varies greatly within engineering and code enforcement communities. In some cases, it has become standard practice to treat all structures as if they were simple rectangular diaphragms, and the absence of continuous load paths, presence of discontinuities, and existing elements such as chases, collectors and drag struts are commonly overlooked. This is largely due to the lack of concrete information on how to design complex diaphragms. While most relevant books and publications provide comprehensive coverage of simple rectangular diaphragms, there is very little guidance on how to analyze and design complex layouts. Further, methods of analysis for simple diaphragms do not easily adapt to the complex layouts in irregularly shaped structures. The purpose of this paper is to bridge that information gap by providing an overview of a method, based on simple statics, which can be used to analyze complex diaphragm structures, while guiding readers to more detailed information through the references.

Principles of Effective Diaphragm Design

Diaphragms, drag chuits, collectors and shear walls function the same way regardless of whether the loads applied to the diaphragm are from wind, seismic, soil or other sources. Principles of engineered design require that complete load paths with adequate strength and stiffness be provided to transfer all forces from the point of origin to the final point of resistance. The 2012 *International Building Code* (IBC) describes this design principle in Section 1604.4, stating:



Massive Construction
Five stories of wood construction plus a wood frame mezzanine over six levels of concrete, two of which are above ground.
© WoodWorks Research, Inc. & Timberlake, LLC. WoodWorks Photography



Typical plan with horizontal offsets in the diaphragm chases and struts.

<http://www.woodworks.org/education-publications/research-papers/#>

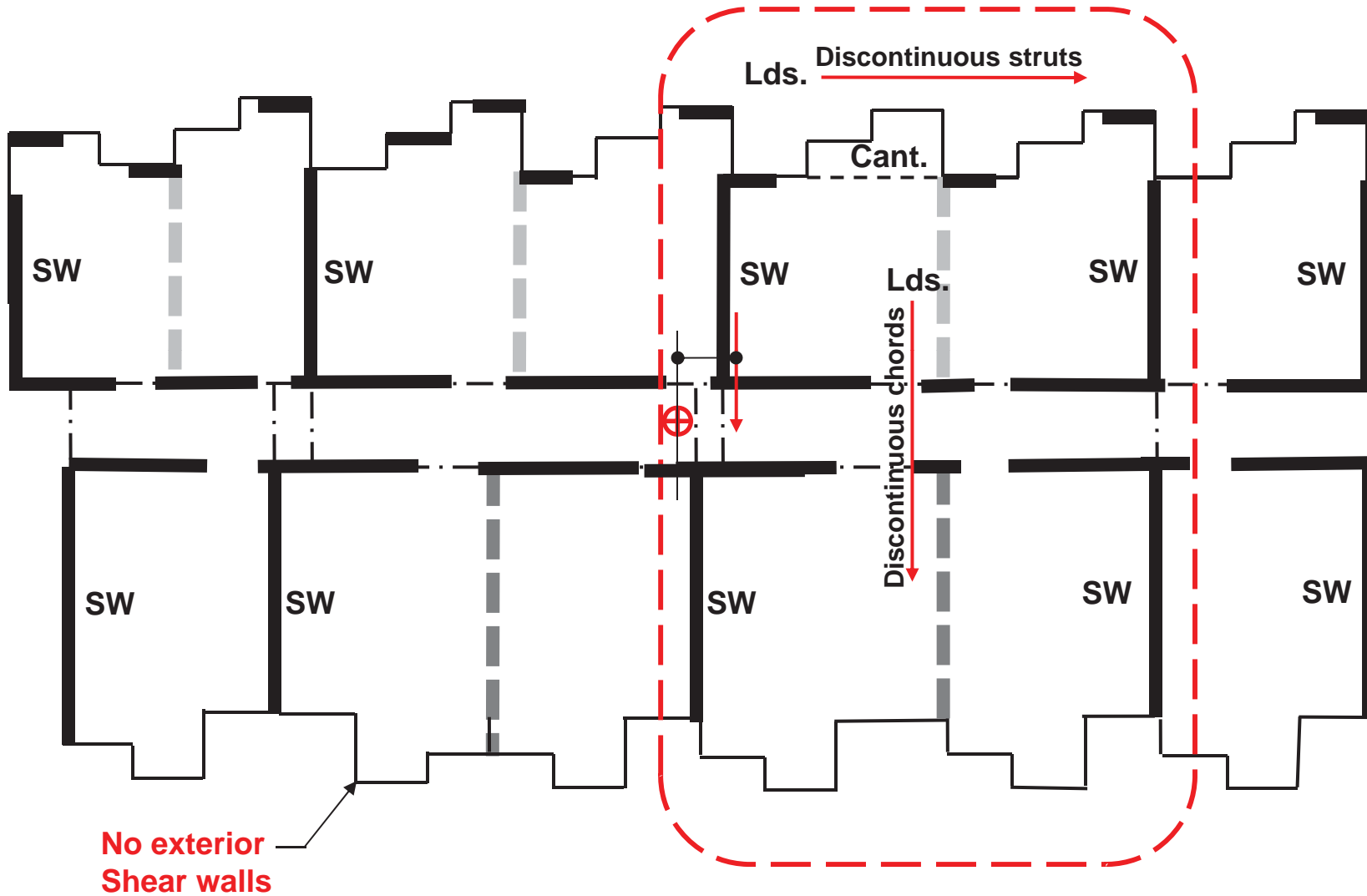
Mid-rise Multi-family



Marselle Condominiums
Structural Engineer engineer: Yu & Trochalakis, PLLC
Photographer: Matt Todd Photographer

**5 stories of wood over 6 stories concrete
(podium) 2 above grade**

Mid-rise Multi-family



Flexible, semi-rigid, or rigid???

**Vertically offset
Diaphragms?**

**Openings in
diaphragm**

**Offsets in the diaphragm
and walls**



Harrington Recovery Center

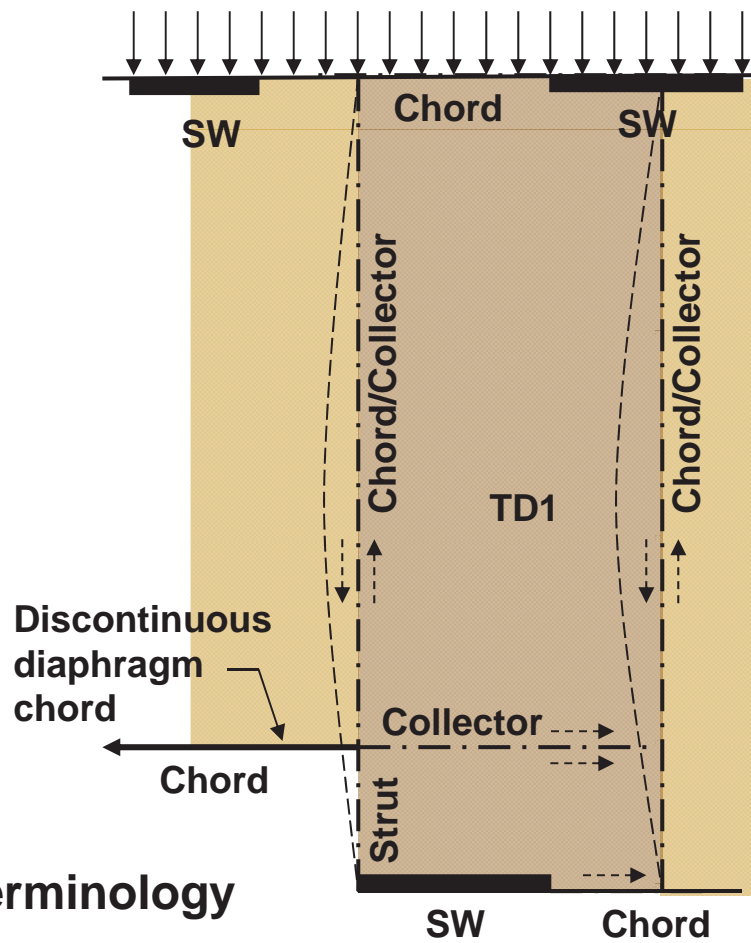
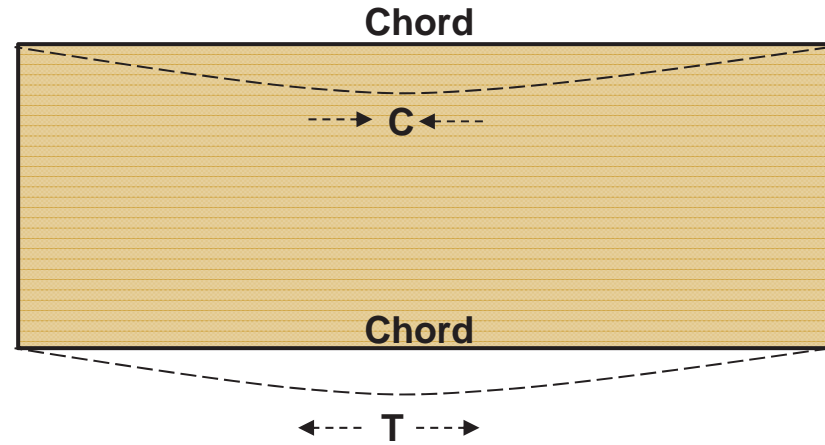
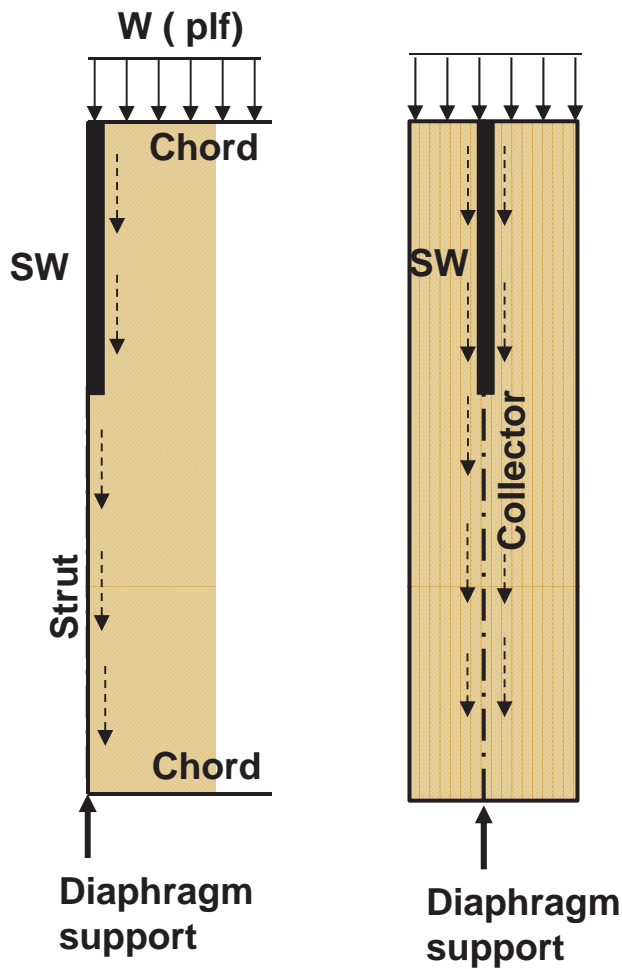
Structural engineer: Pujara Wirth Torke, Inc.

Photographer: Curtis Walz

Basic Information

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





Strut- receives shears from one side only.
Collector- receives shears from both sides.
Chord-perpendicular to the applied load and receives axial tension and compression forces.

Strut, Collector, and Chord- (my) Terminology

Diaphragm Boundary Elements

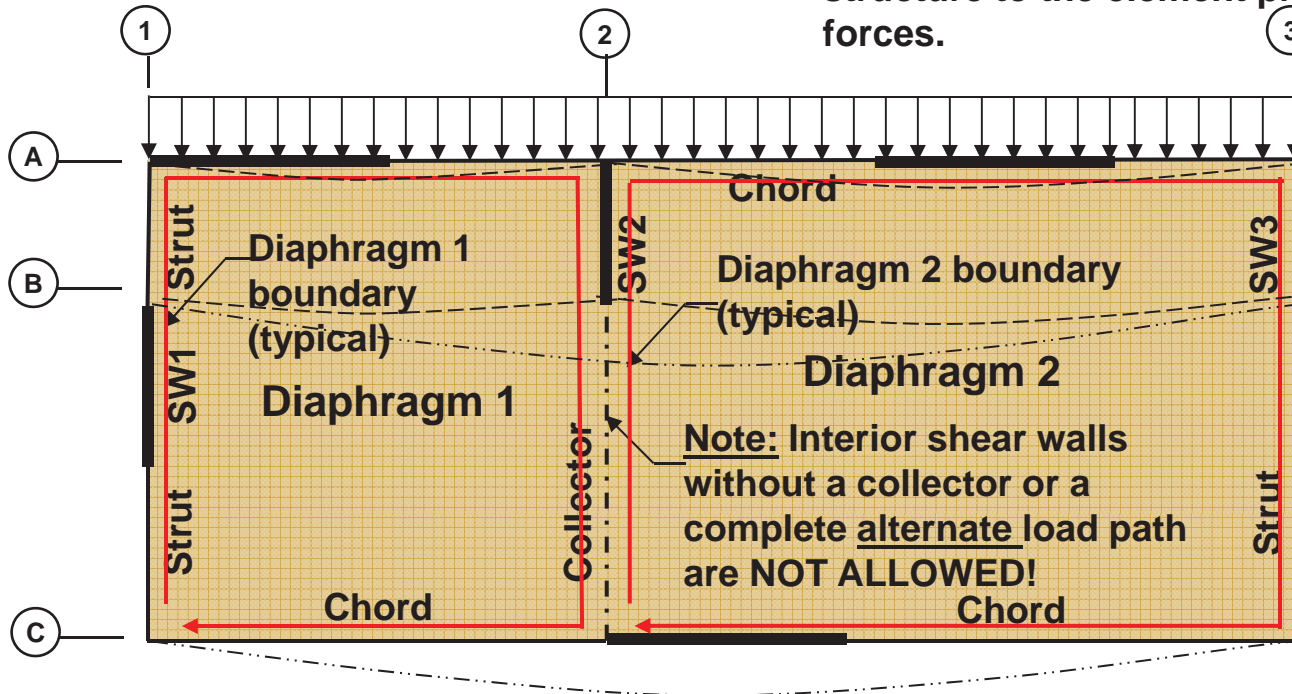
Fundamental Principles:

A shear wall is a location where diaphragm forces are resisted (supported), and therefore defines a diaphragm boundary location.

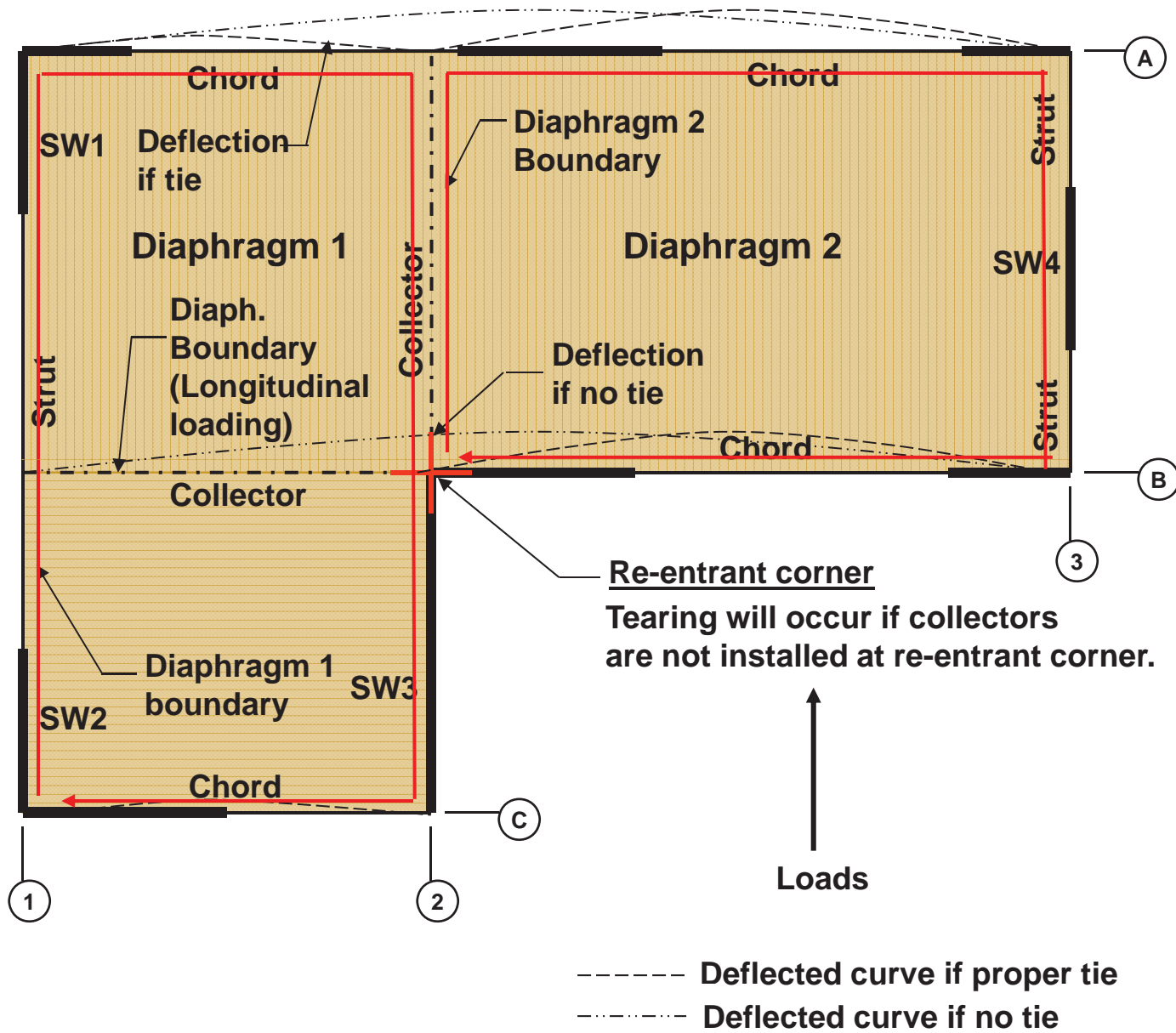
Note: All edges of a diaphragm shall be supported by a boundary element.

• 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.
- 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.



Required for all SDC and wind

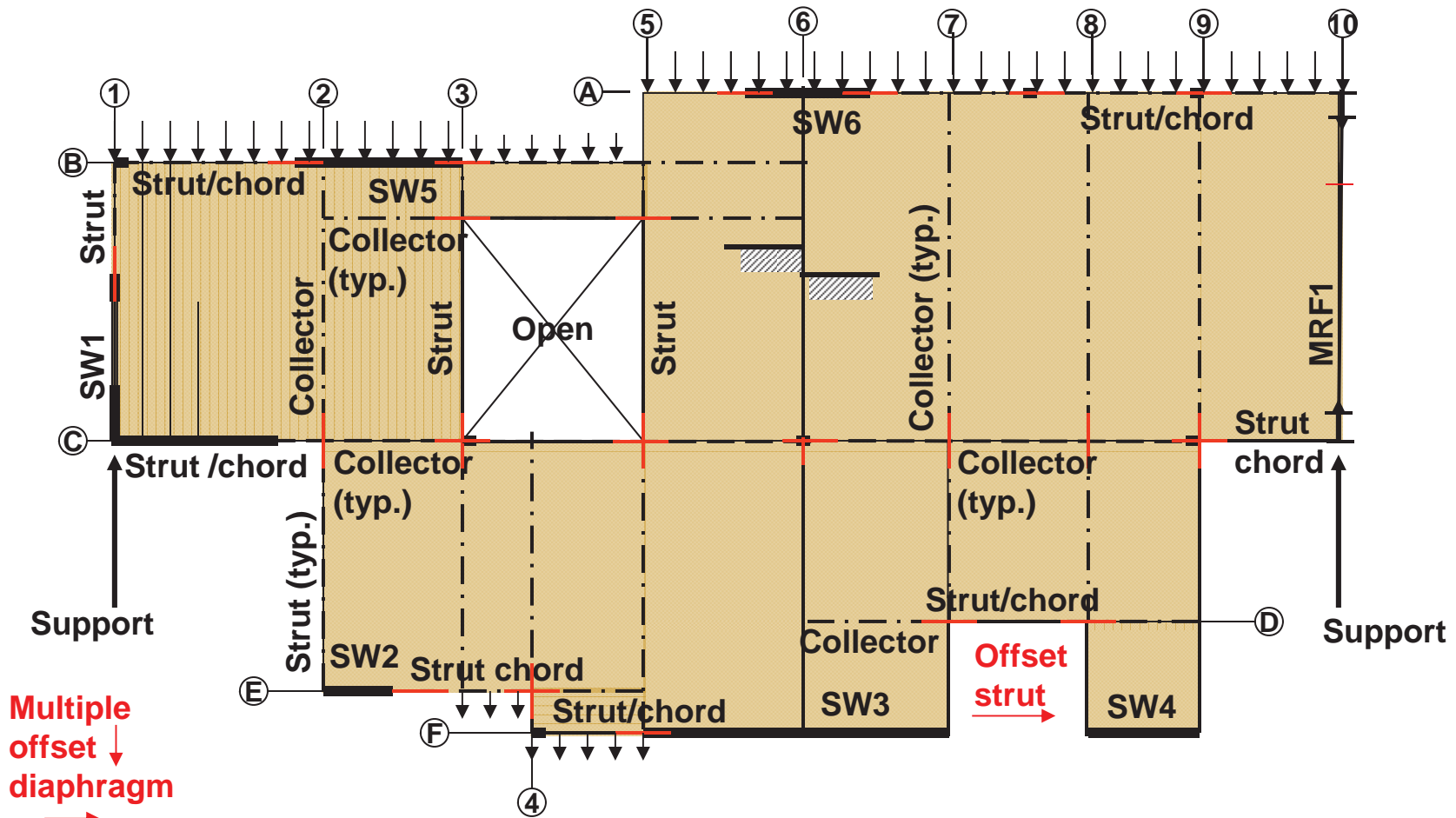


Boundary Elements "L" Shaped Buildings-Transverse Loading

Basic Information

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



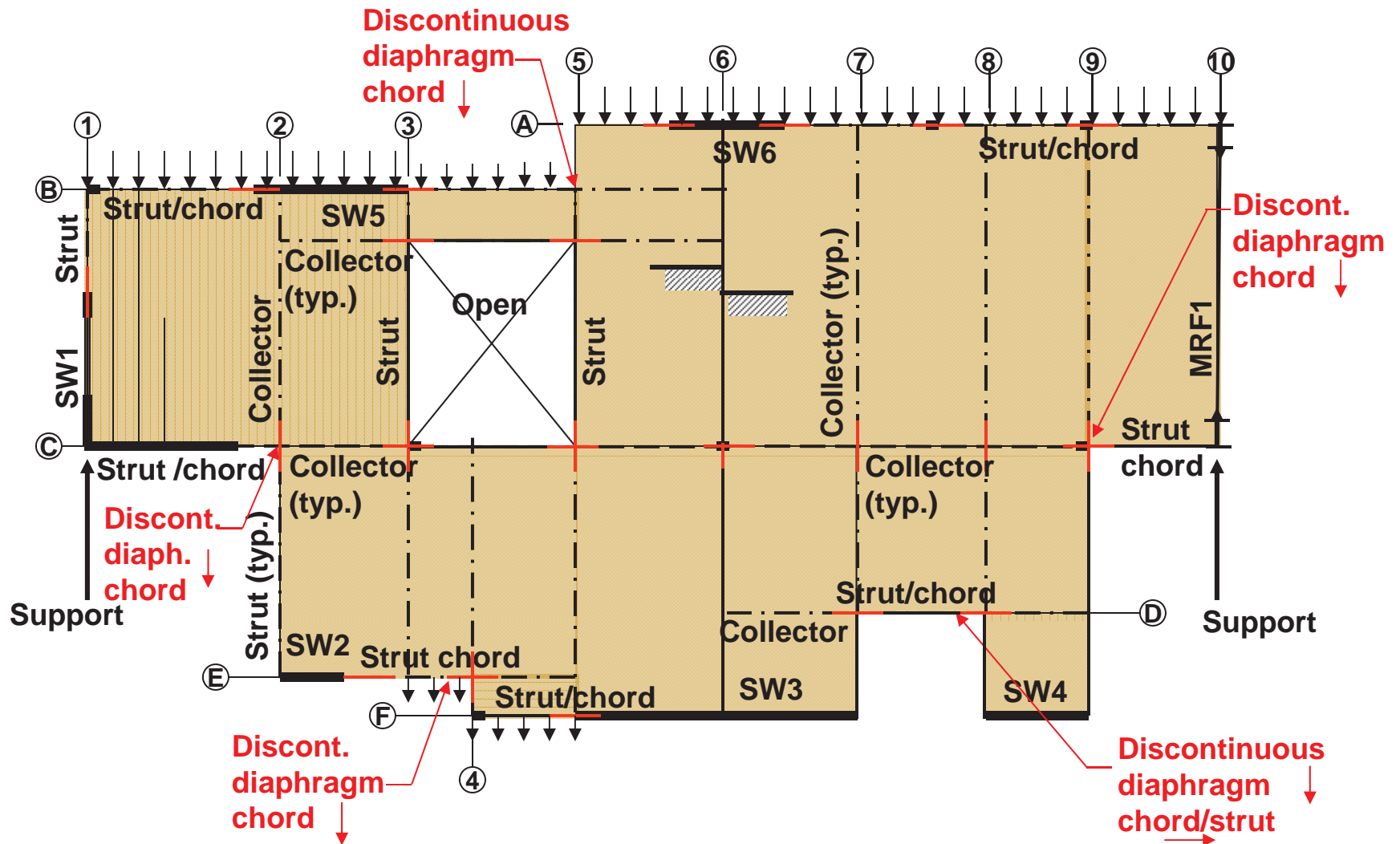


Analysis:

- Design shall be based on a rational analysis
- 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.

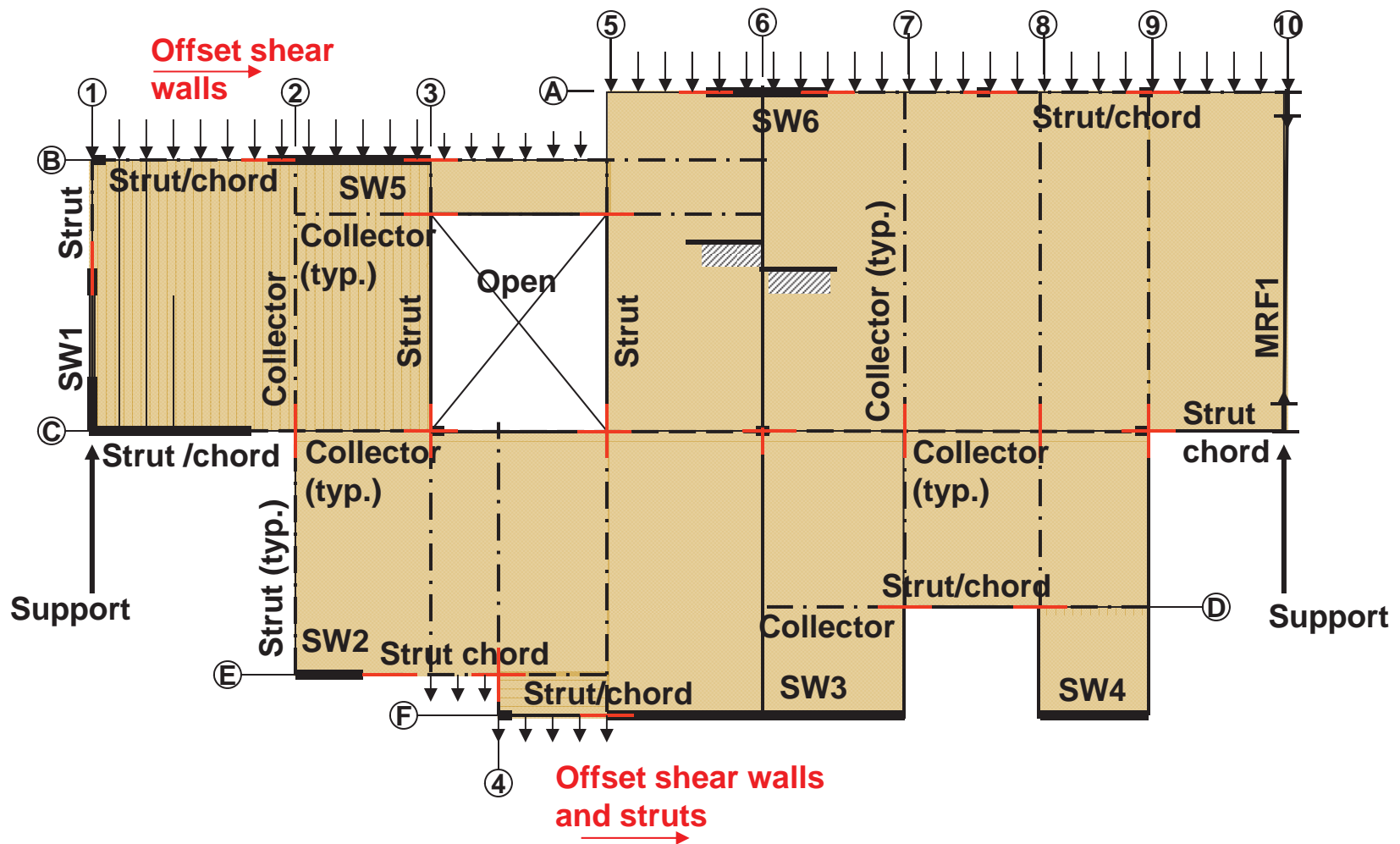
What does this mean?

Complete Continuous Lateral Load Paths



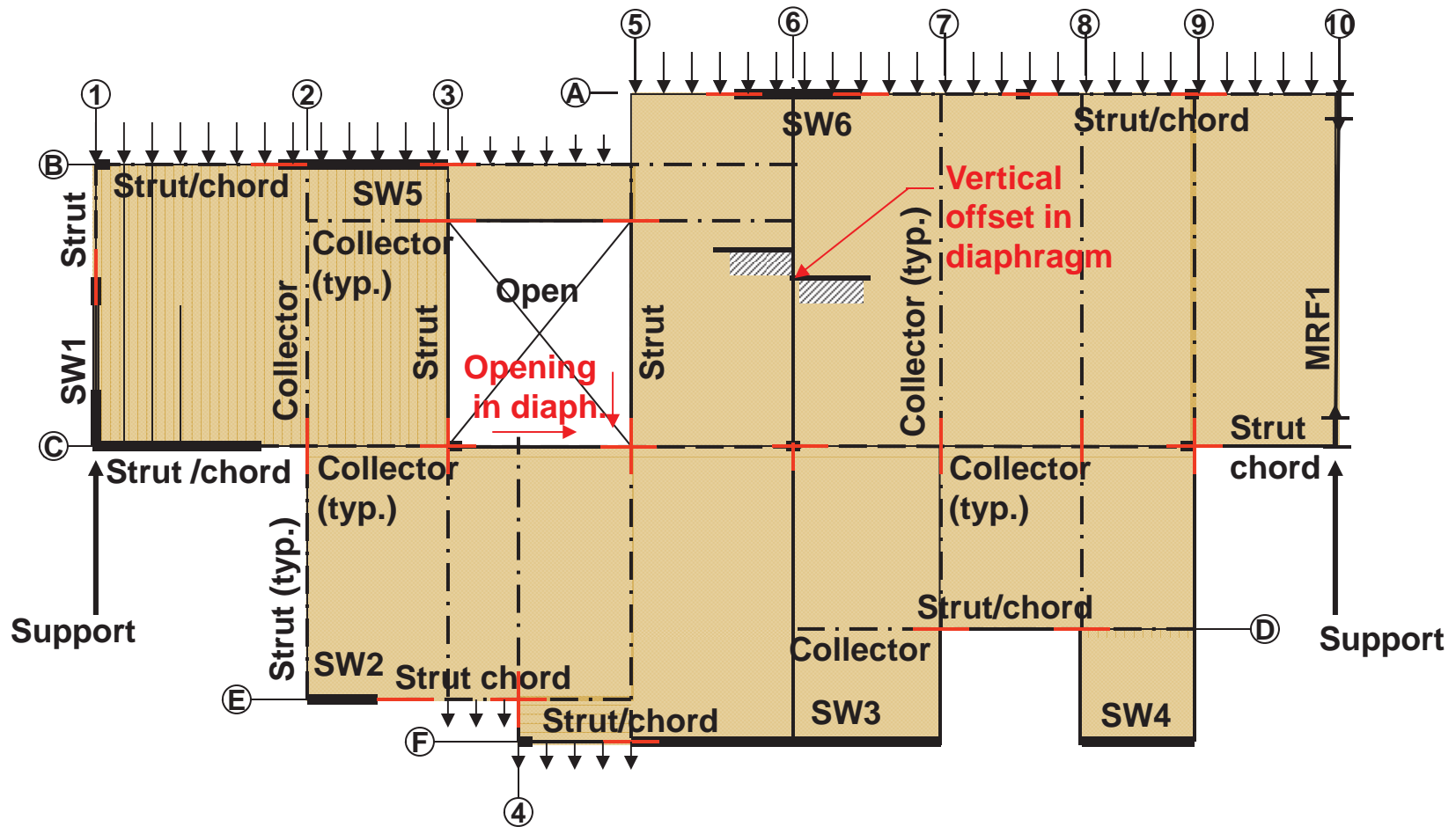
Design: Complete load paths are required including members and their splice connections

Complete Continuous Lateral Load Paths



Design: Complete load paths are required including member and their splice connections

Complete Continuous Lateral Load Paths



Design:

- 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

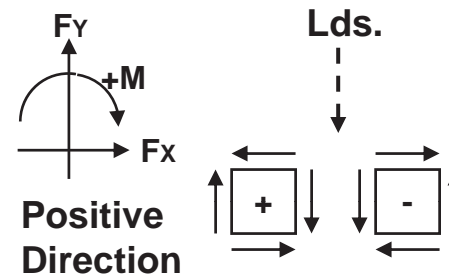
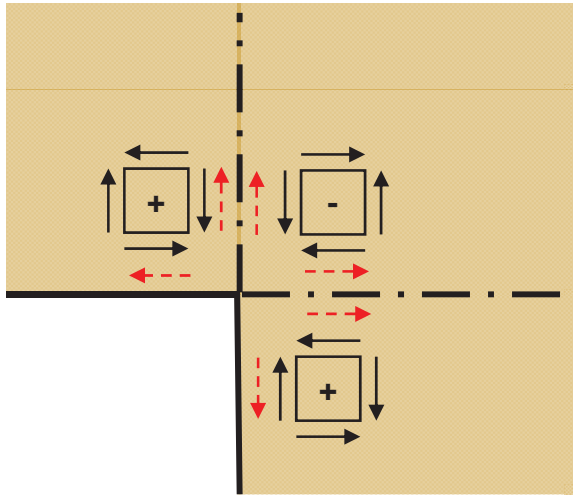
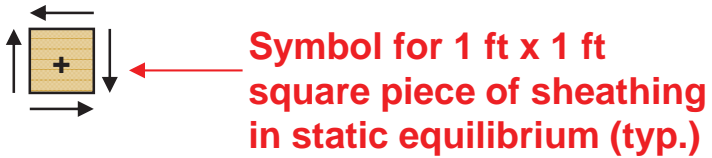
Basic Information

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



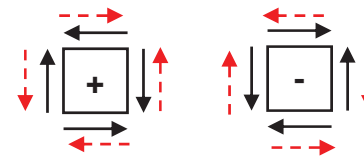
Method of Analysis

The Visual Shear Transfer Method



Transverse Direction (shown)

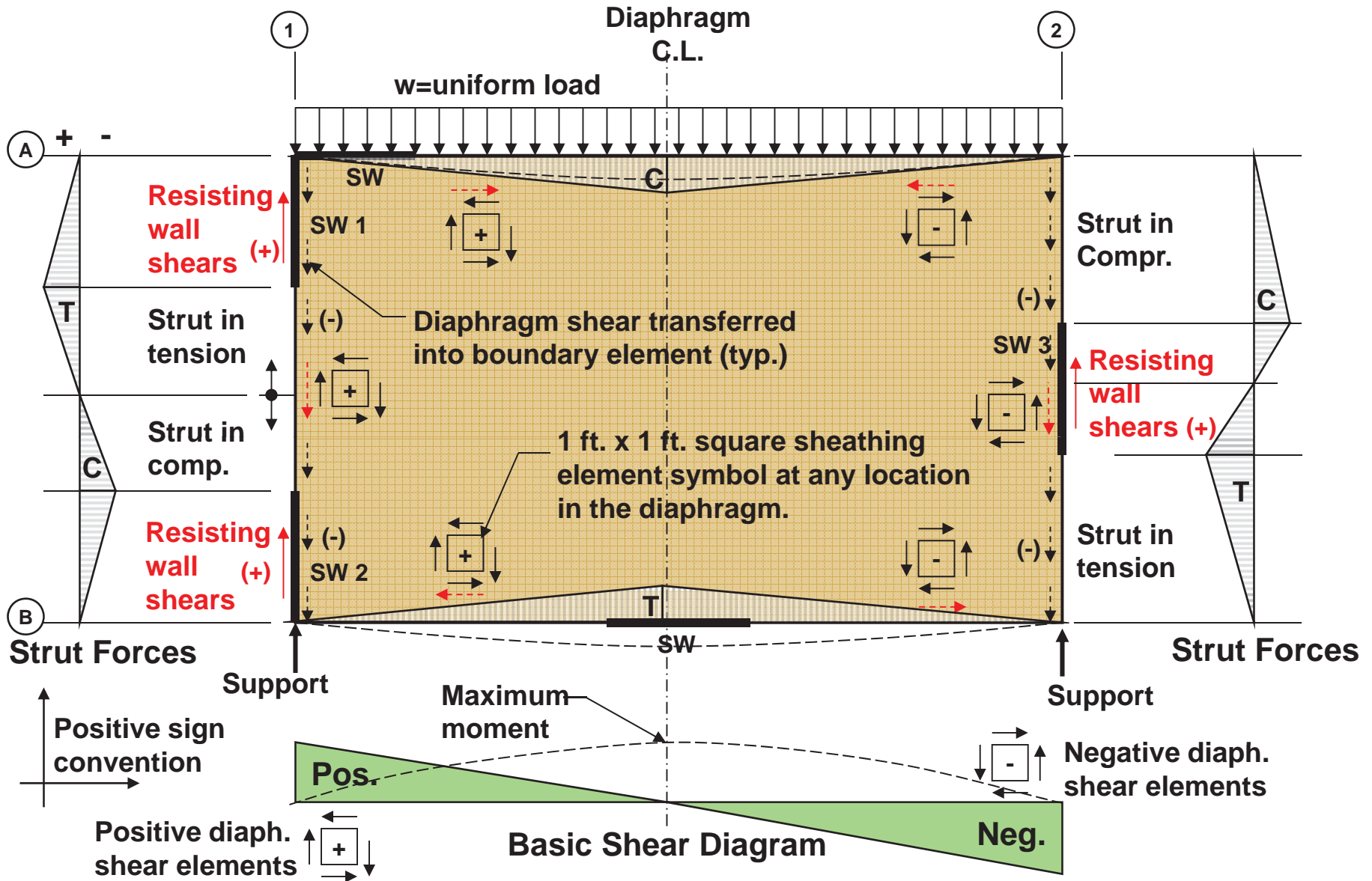
Shears Applied to Sheathing Elements



↑ Unit shear acting on sheathing element (plf)

↑ Unit shear transferred from the sheathing element into the boundary element (plf)

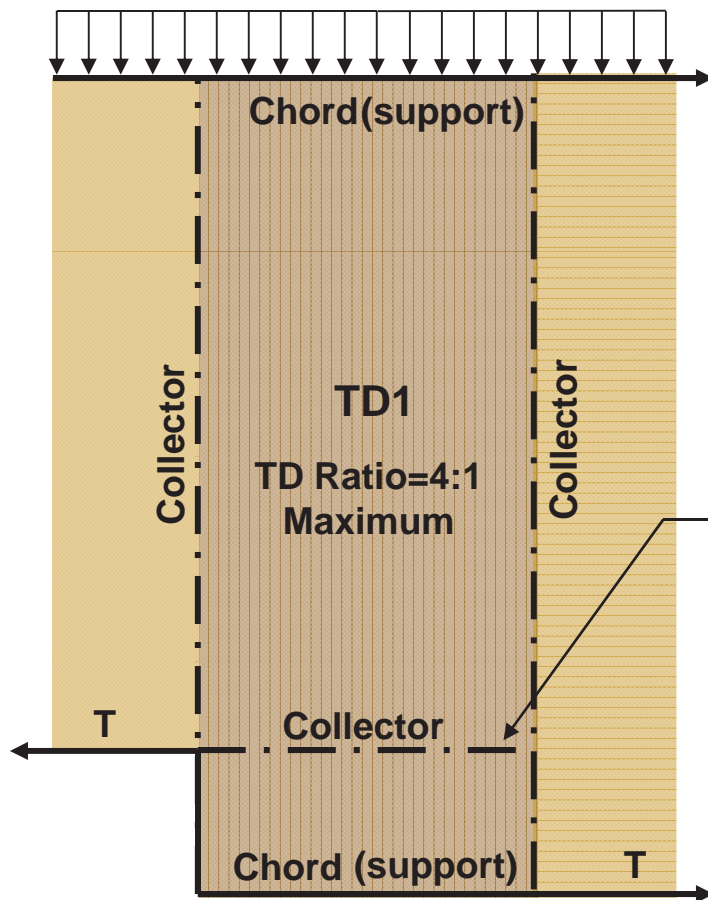
Shears Transferred Into Boundary Elements



All edges of a diaphragm shall be supported by a boundary element (chord, strut, collector) or other vertical lateral force resisting element (shear wall, frame).

Shear Distribution Into a Simple Diaphragm The Visual Shear Transfer Method

Introduction to Transfer Diaphragms and Transfer Areas

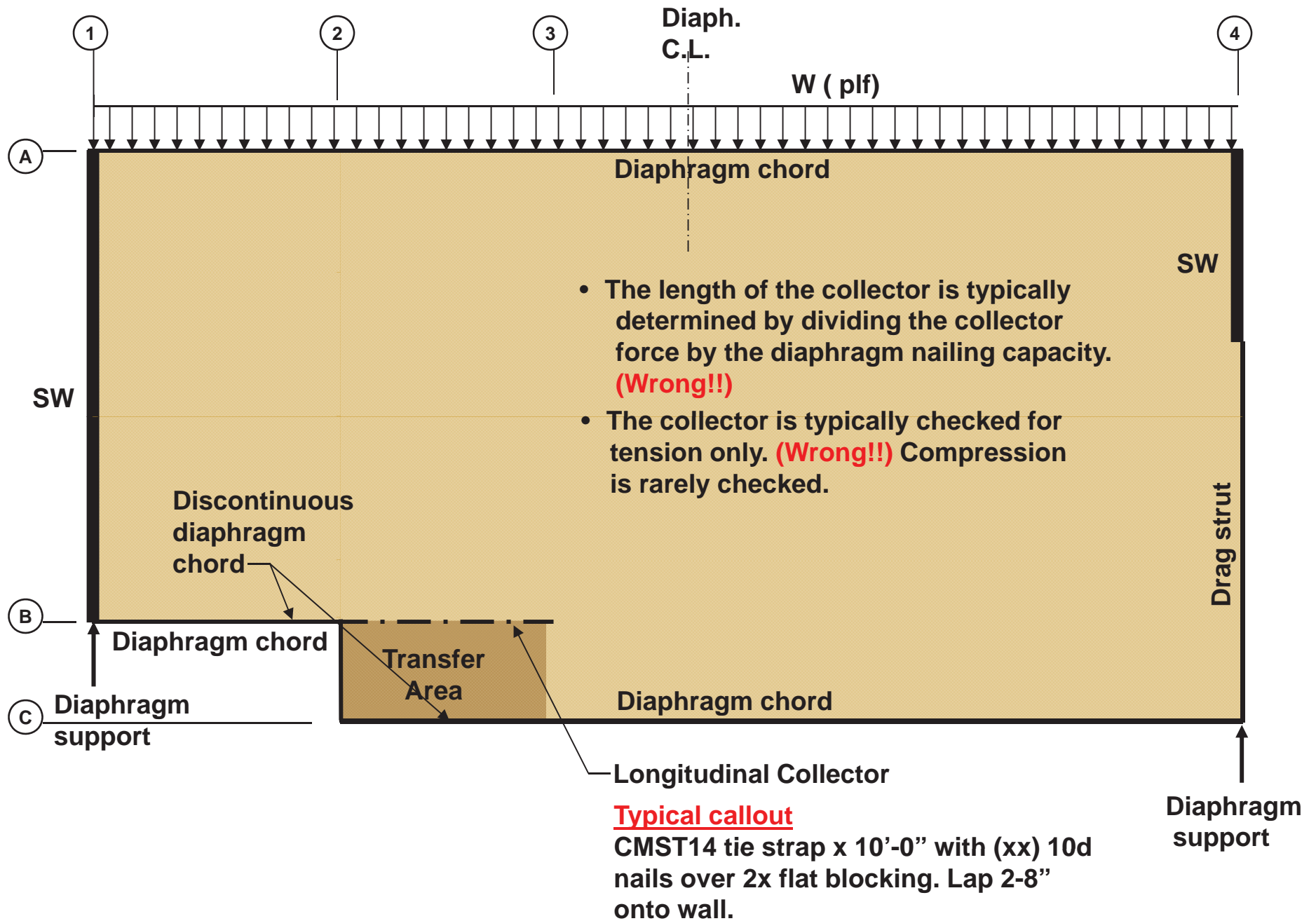


Transfer Diaphragm

- sub-diaphragm
- **Transfers local forces out to primary chords/struts of the main diaphragm.**

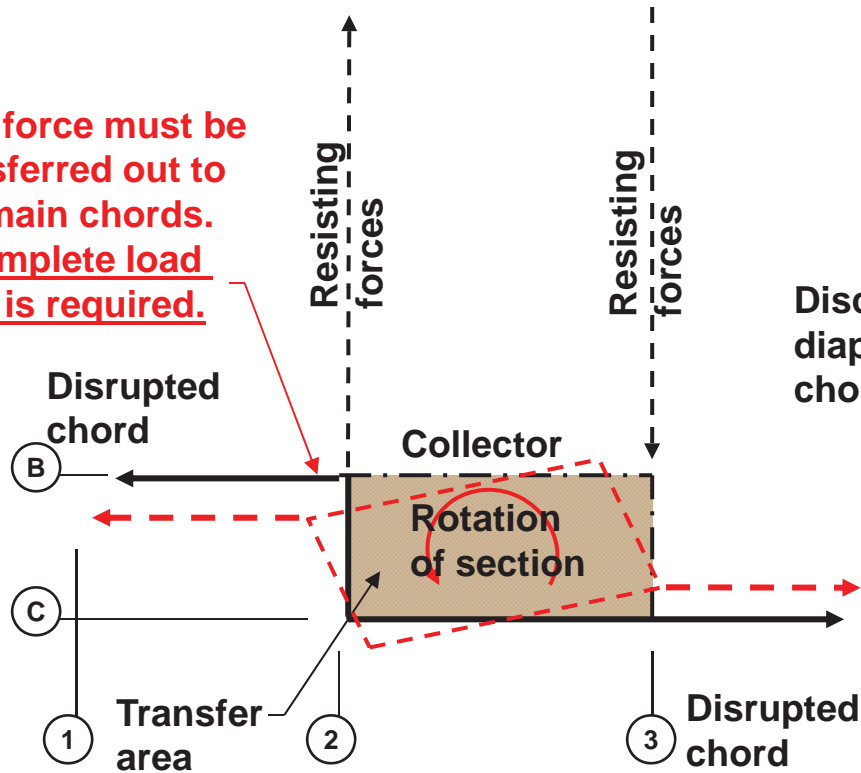
Framing members, blocking, and connections shall extend into the diaphragm a **sufficient distance** to develop the force transferred into the diaphragm.

What does this mean?



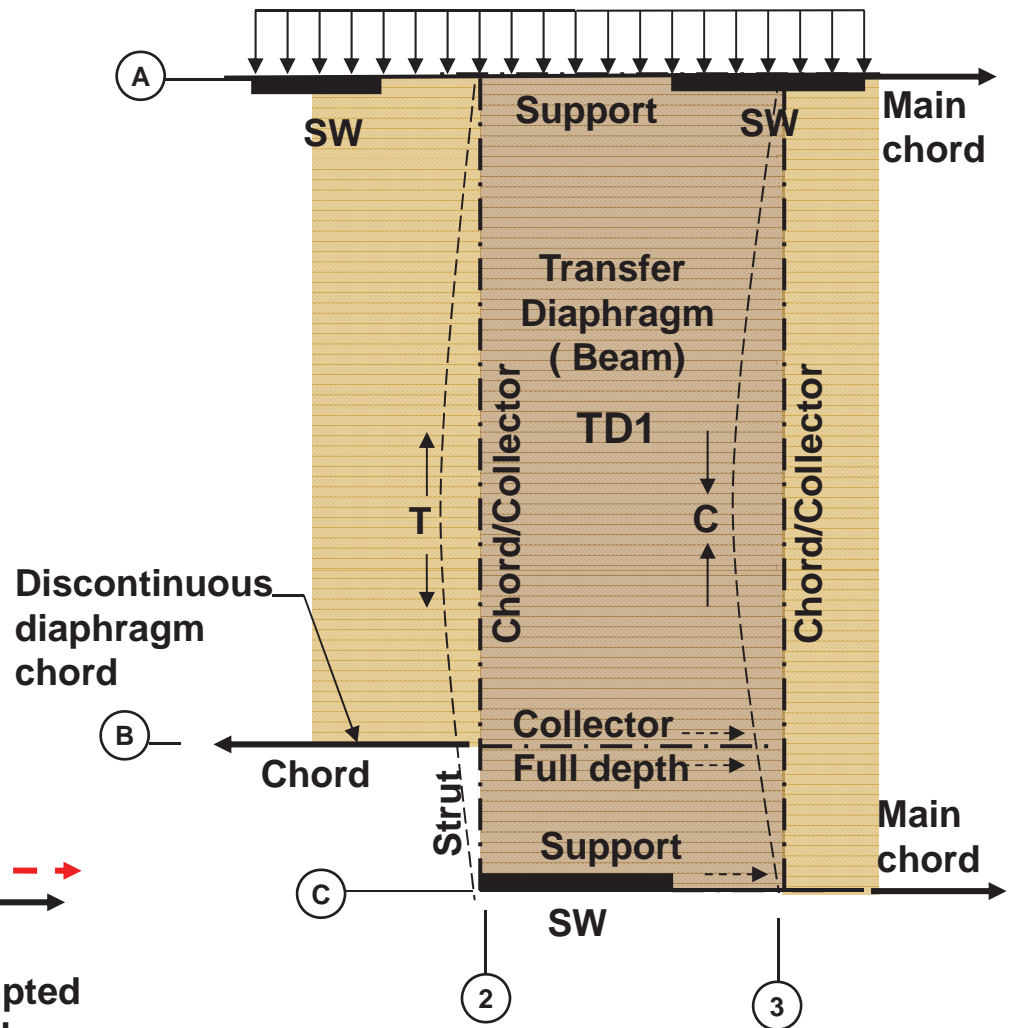
Transfer Diaphragm Members and Elements

This force must be transferred out to the main chords. A complete load path is required.



Transfer area without transverse collectors

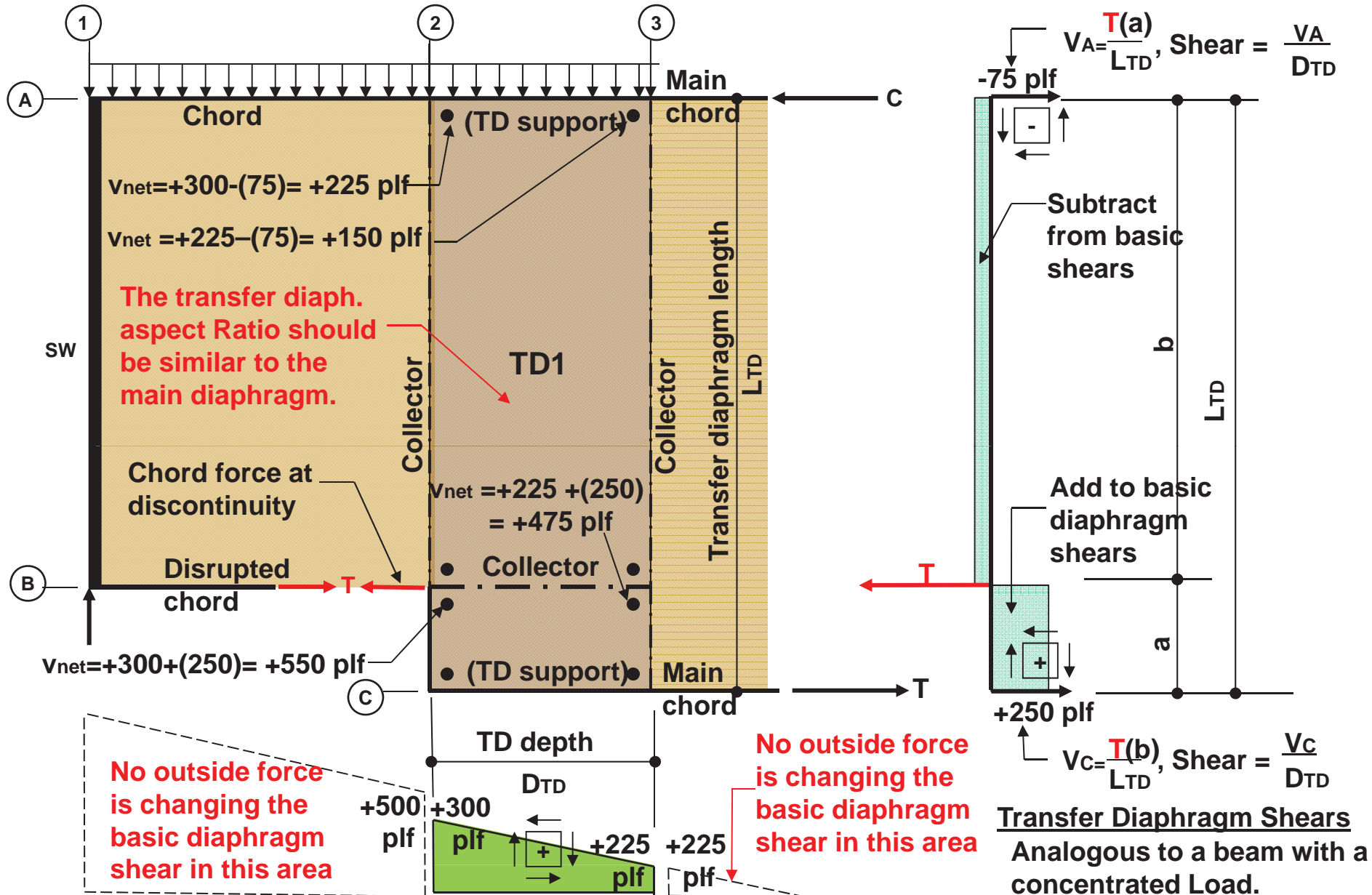
Transfer Mechanism



NOTE:

Collector must extend the full depth of the transfer diaphragm

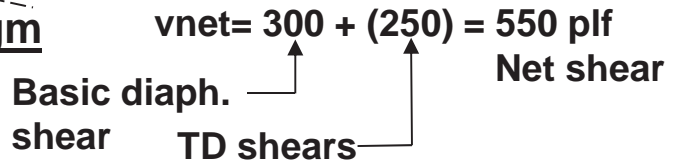
Transfer using beam concept



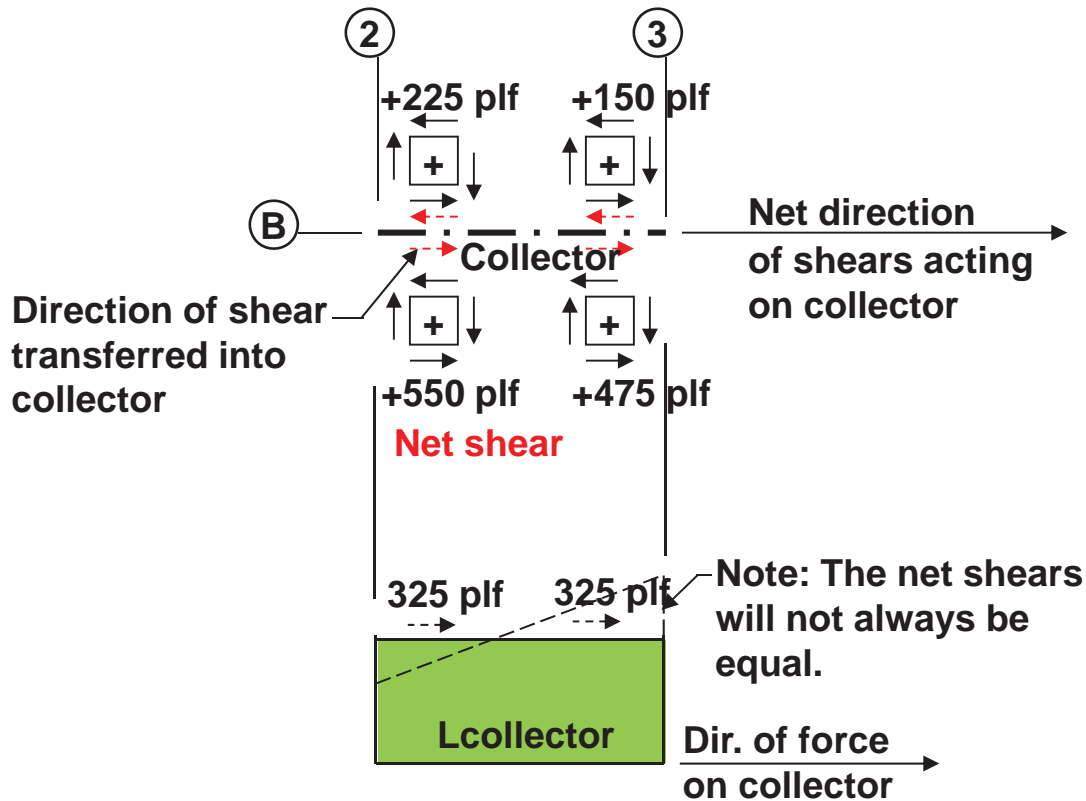
Basic Shear Diagram at transfer diaphragm

Basic Procedure

Method by Edward F. Diekmann



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



Resulting net shear diagram on collector

Shear Distribution Into The Collector

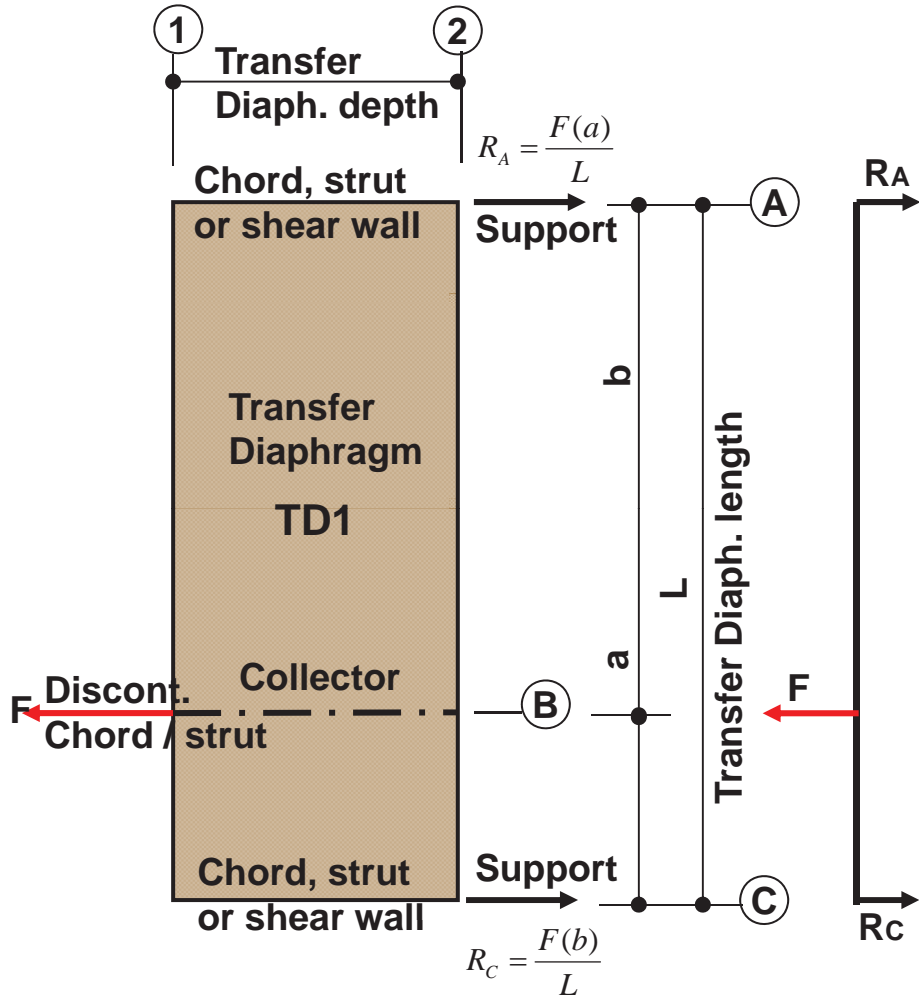
- Place the net diaphragm shear on each side of the collector
- Place the transfer shears on each side of the collector
- Sum shears on collector (based upon direction of shears transferred onto collector).

$$\text{Shear left} = +550 - 225 = +325 \text{ plf}$$

$$\text{Shear right} = +475 - 150 = +325 \text{ plf}$$

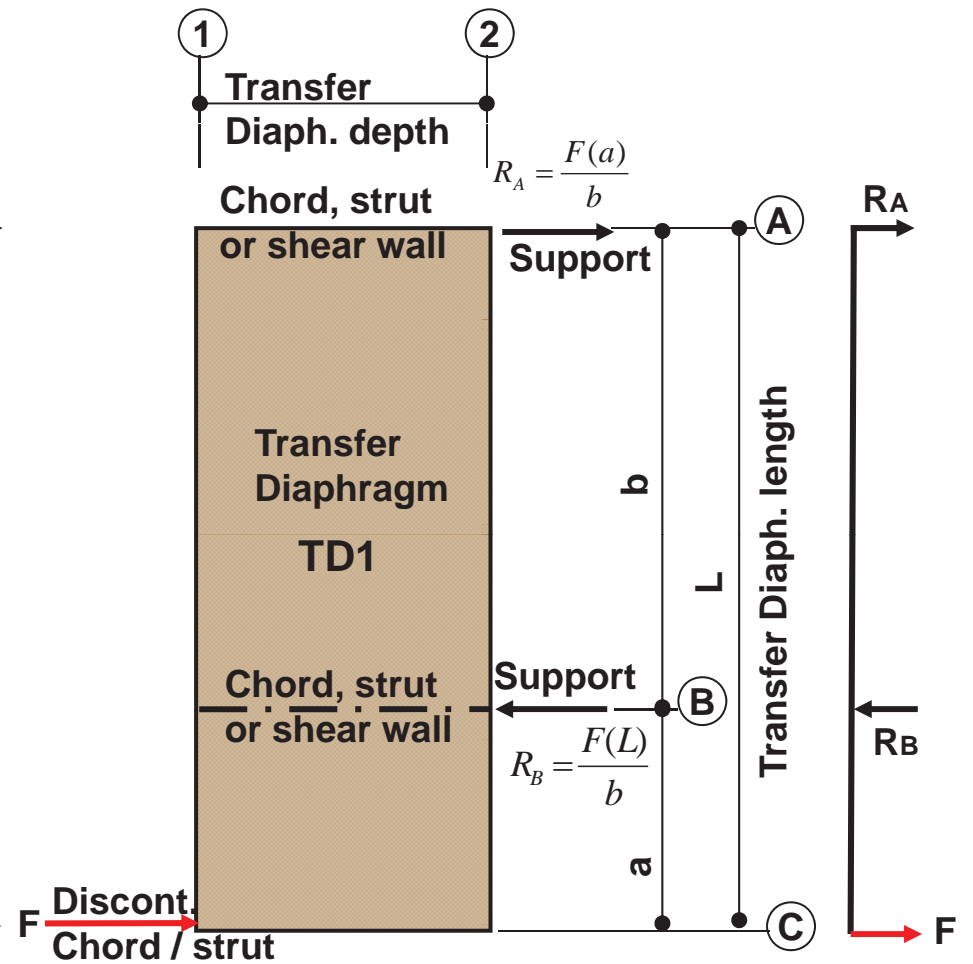
- Collector force = area of shear diagram

$$F_{\text{collector}} = \frac{(325 + 325)(L_{\text{collector}})}{2}$$



Simple Span Transfer Diaphragm

Analogous to a simple span beam with a concentrated load

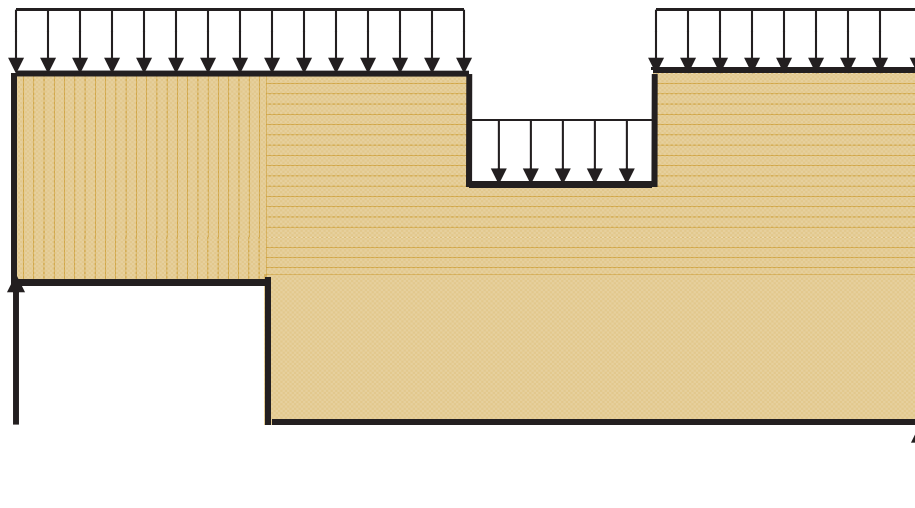


Propped Cantilever Transfer Diaphragm

Analogous to a propped cantilever beam with a concentrated load

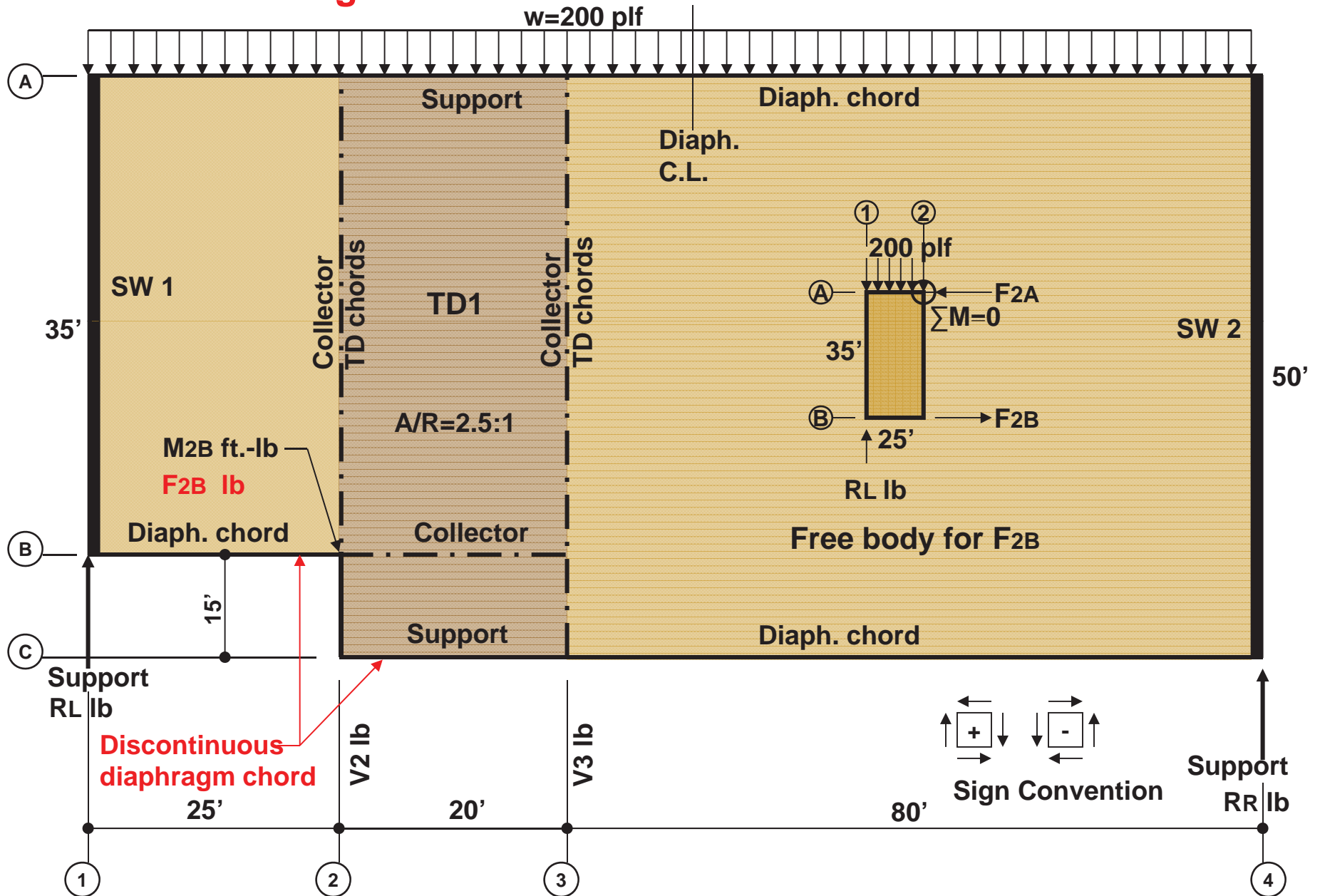
Simple Span and Propped Cantilever Transfer Diaphragms

Diaphragms with Horizontal Offsets

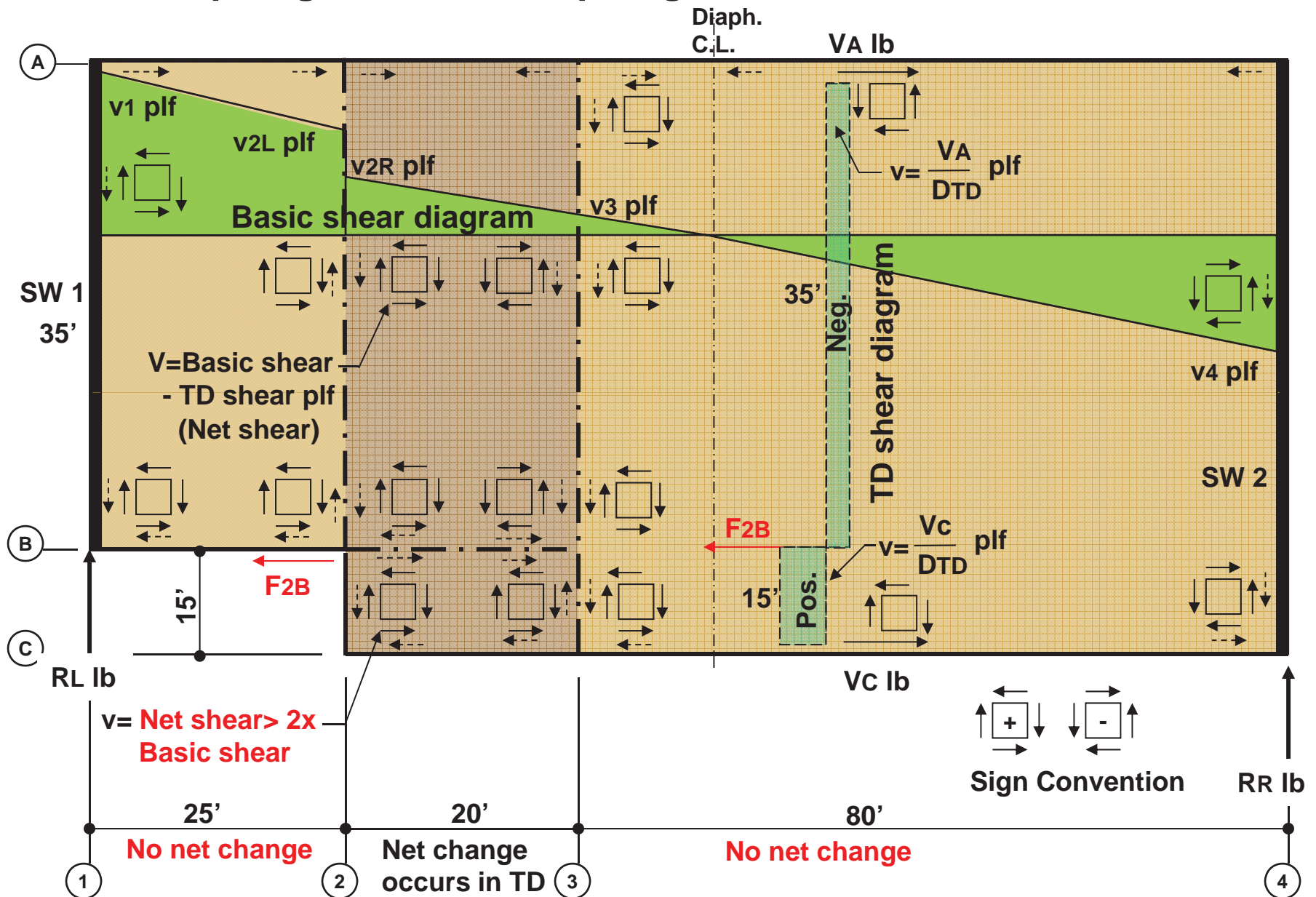


Example 1-Diaphragm with Horizontal End Offset

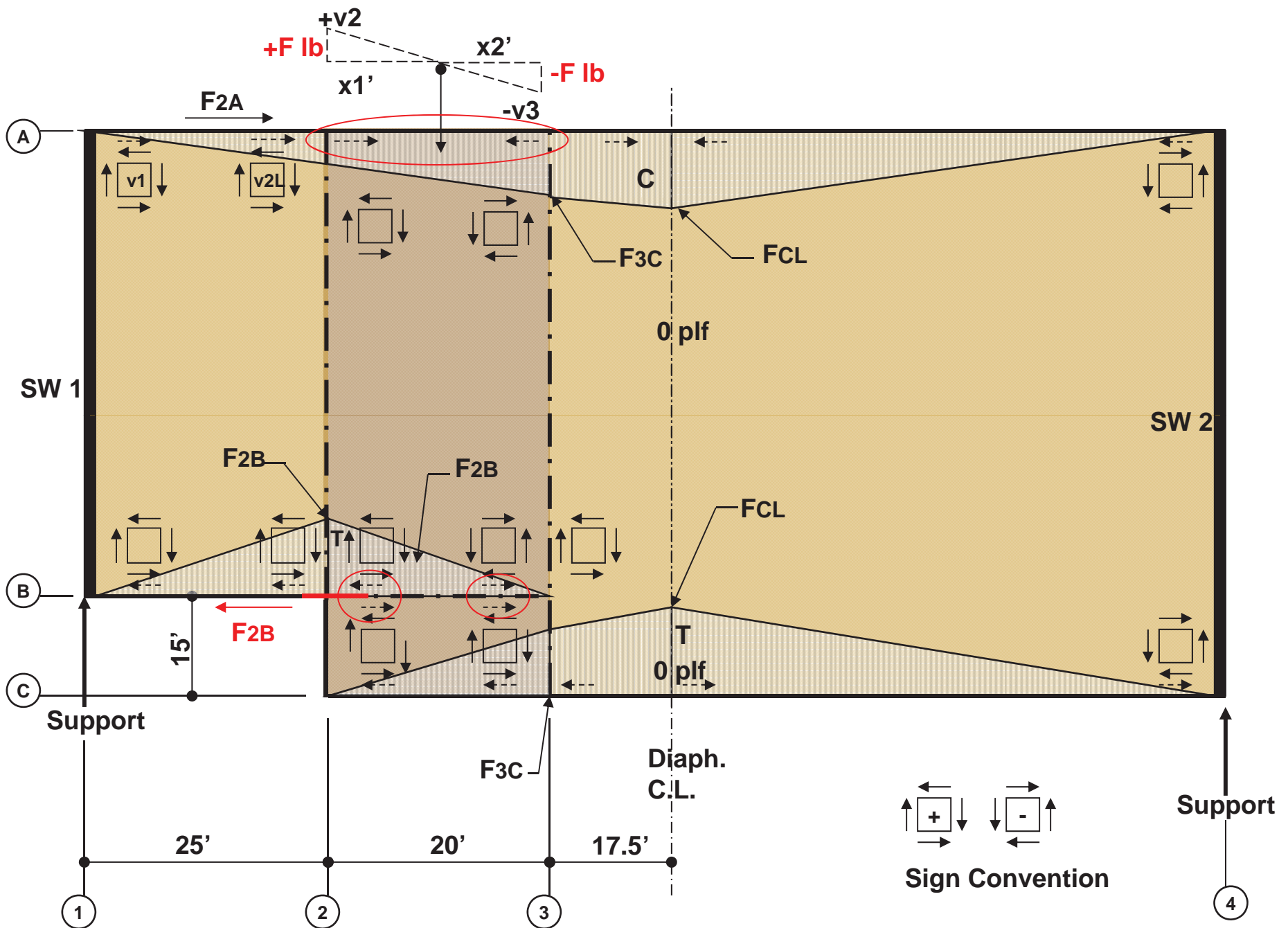
Transverse Loading



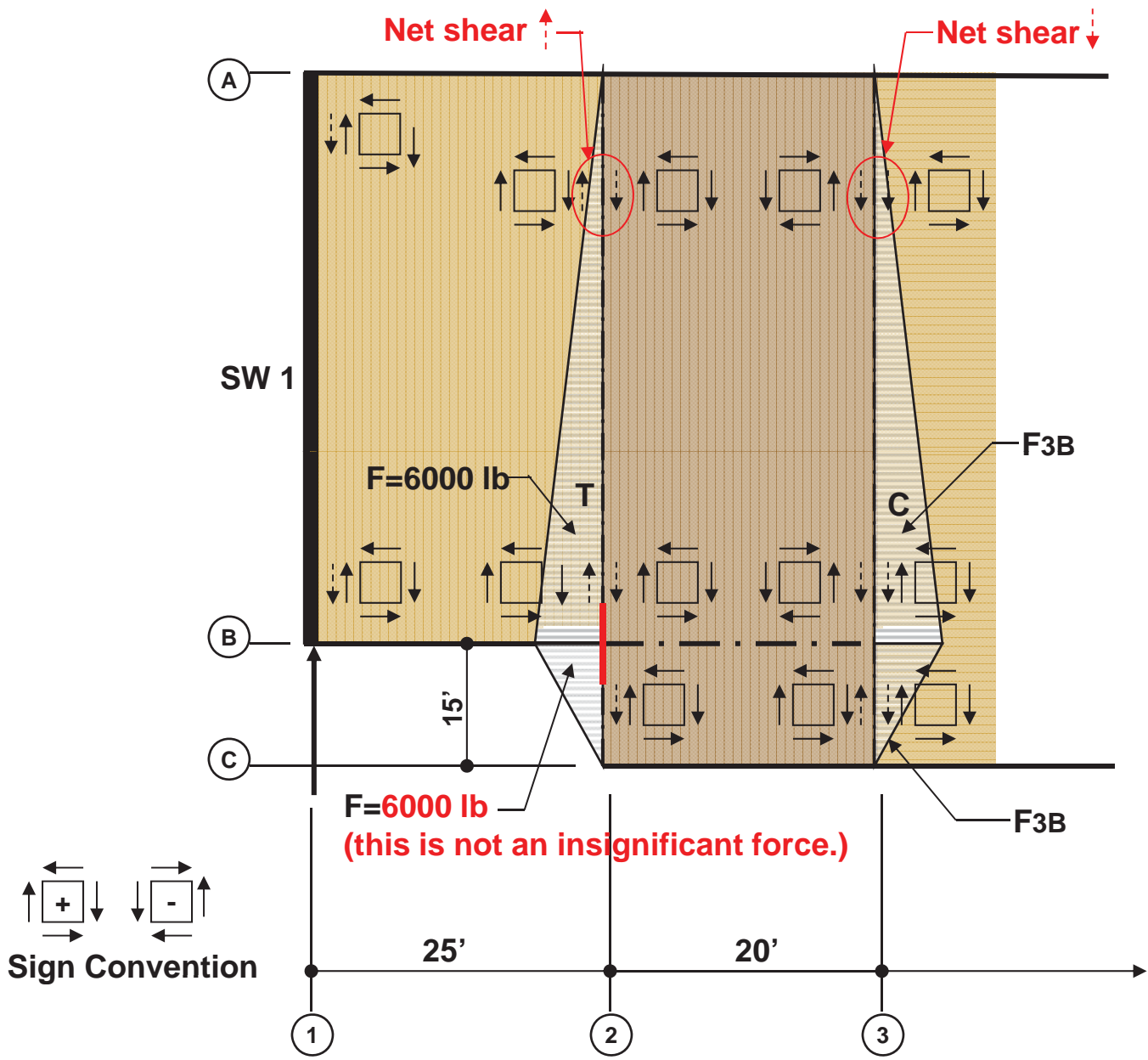
Transfer Diaphragm and Net Diaphragm Shear



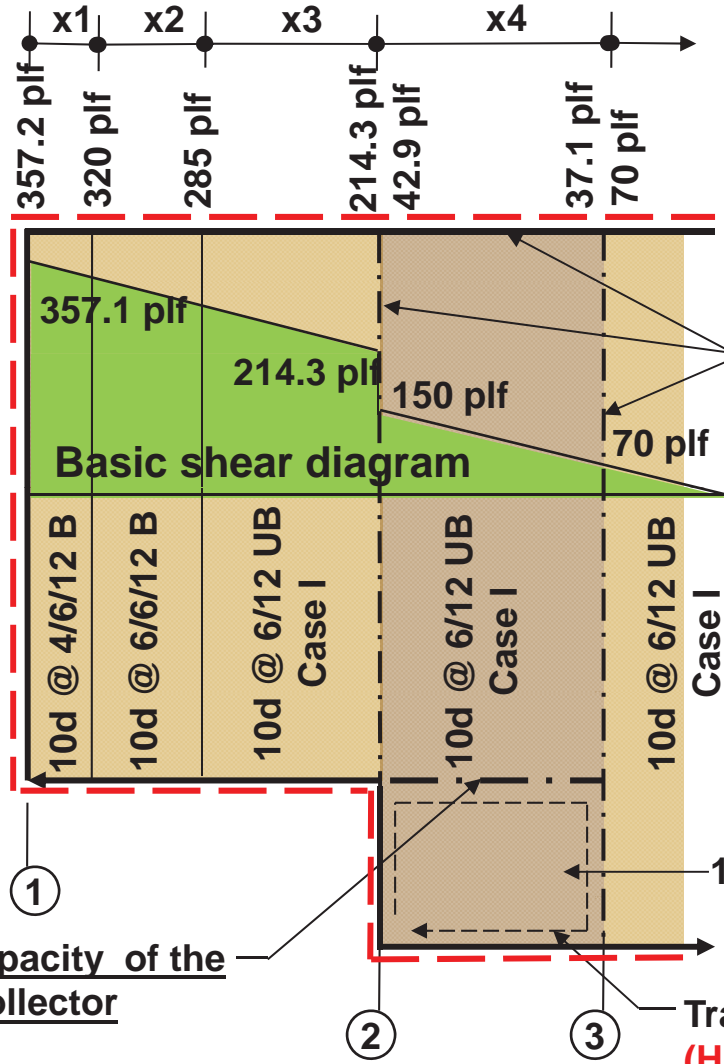
Net TD shears (basic shear +/- transfer diaphragm shears)



Longitudinal Chord Force Diagrams



Transverse Collector Force Diagrams



Special nailing along collectors
 Sum of shears to collector or highest boundary nailing-greater of

Transfer diaphragm Boundary (Typ.)

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

--- Diaphragm boundary

Check the shear capacity of the nailing along the collector

10d @ 4/6/12 B

Transfer area Boundary (High shear area)

Boundary locations

Diaphragm Nailing Callouts

QUESTIONS?

This concludes The American Institute of Architects
Continuing Education Systems Course

Part 1- Offset Diaphragms

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