

Understanding Diaphragms: Practical Design for Engineers of All Fields

An Online Continuing Education Course for Engineers

Course Number: S-3031

Credit: 3 Hours / 3 PDH / 3 CPD

Understanding Diaphragms: Practical Design for Engineers of All Fields

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1. Introduction:

In any building, understanding the interaction between vertical and horizontal systems is critical to ensuring the safety and efficiency of the structure. **Vertical systems** include components such as moment-resisting frames, braced frames, shear walls, cantilever columns, and leaning columns. These elements are designed to support gravity loads, resist lateral forces, or manage both types of loads depending on the design requirements.

The **horizontal systems**, known as **diaphragms**, are equally essential. These elements—such as concrete slabs, untopped steel decks, and wood panels—play a vital role in distributing both gravity and lateral loads to the vertical systems. While diaphragms are often associated with structural engineering, their design and analysis are crucial for professionals across various engineering disciplines, including civil, mechanical, architectural, and construction engineering.

This course provides an accessible, in-depth exploration of diaphragm systems, focusing on how these elements function within the broader context of a structure. We will cover the principles of diaphragm behavior and the critical role they play in ensuring stability and safety. Participants will learn how diaphragms help transfer lateral loads to vertical systems, reduce the buckling length of columns and walls, and enhance local stability for beams within floor systems.

The course delves into diaphragm analysis, starting with an understanding of different types based on rigidity—rigid, flexible, and semi-rigid—and how these influence the design process. Engineers will also gain knowledge of how diaphragms are designed using a variety of materials, including reinforced concrete, steel, and wood, with a focus on practical application across industries.

We will guide participants through topics such as:

- Determining reinforcement requirements for concrete diaphragms
- Designing components like collectors, chords, and their connections
- Understanding the design process for untopped metal decks, including fastener selection and thickness
- Exploring steel collector beams, their connections to vertical elements, and splice design
- Applying diaphragm concepts in wood structural panels (WSP), including nailing patterns and configurations for double-top chords and collectors

Additionally, the course addresses alternative diaphragm solutions for complex structures, including **truss diaphragms** and **moment-resisting frame diaphragms**, which are valuable for engineers involved in projects where traditional diaphragm systems might not be feasible.

By the end of the course, participants from various engineering disciplines will have a solid understanding of diaphragm systems, empowering them to incorporate these crucial design elements into their projects—whether they are involved in building design, construction, or systems integration.

This course covers the following topics:

1. Diaphragm components: chords, collectors, and their connections.
2. Types of Diaphragms: Rigid, Flexible, and Semi-Rigid.
3. Analysis of flexible diaphragms.
4. Analysis of rigid diaphragms.
5. Design of reinforced concrete diaphragms.
6. Design of untopped steel deck diaphragms (Bare Decks).
7. Design of (steel deck and concrete-filled) diaphragms.
8. Design of checkered plate diaphragms.
9. Design of wood diaphragms.
10. Design of truss diaphragms.
11. Design of moment frame diaphragms.

2. Diaphragms and Their Components:

Diaphragms are generally modelled as a beam subjected to uniformly distributed loads; the boundary conditions for this beam are determined based on the type of diaphragm, whether it is rigid, flexible, or semi-rigid. The modelling of diaphragms is discussed in detail in [section 3](#).

Any diaphragm system consists of:

- The diaphragm itself: concrete slab, untopped metal deck, wood structural panels, horizontal bracing, etc. The diaphragm shall be checked for the shear force acting along its depth (the dimension perpendicular to the applied force), and any other forces resulting from the eccentricity between collectors and the vertical force resisting system.
- Collectors: the members parallel to the applied force that transmit the lateral forces from the diaphragm to the vertical force-resisting systems.
- Chords: the members perpendicular to the applied force that are designed for the axial (tension or compression) resulting from the moment exerted on the diaphragm due to lateral loads.

Figure (01) shows the components of a flexible diaphragm, its collectors, and chords.

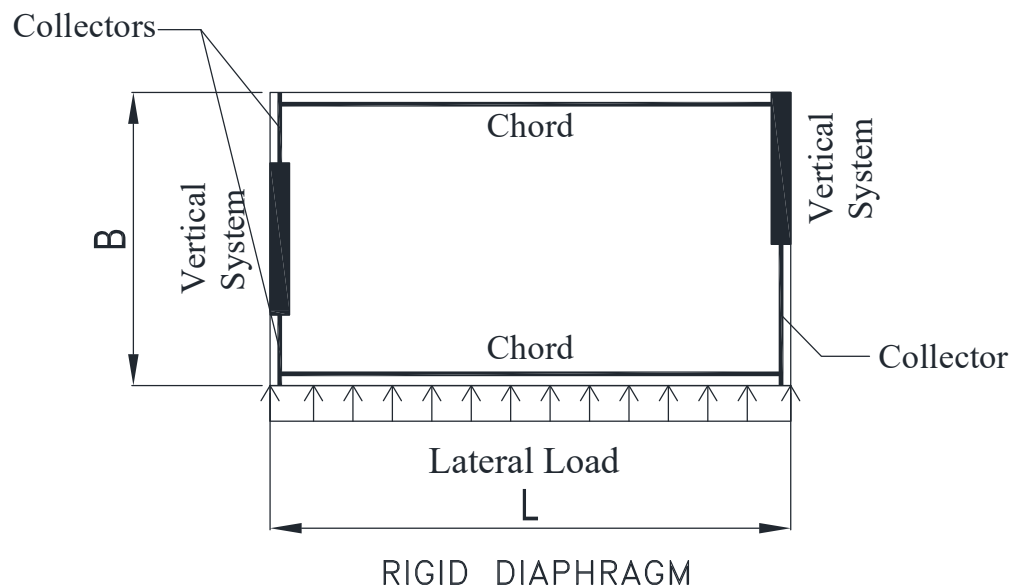


Figure (01). Components of the Diaphragm

3. Types of Diaphragms:

By **ASCE7-22-Section 11.2**, the diaphragm is the horizontal component of the seismic force-resisting system, which includes any membrane or bracing system that is capable of transferring the lateral force (wind or seismic) to the vertical seismic force-resisting system.

The three types of diaphragms discussed in this section are:

- Flexible diaphragms.
- Rigid diaphragms.
- Semi-rigid diaphragms.

The type of diaphragm is used to determine the following:

- Application of inherent torsion.
- Application of accidental torsion.
- Horizontal distribution of story shear to the vertical seismic force resisting systems.
- Deformation of the diaphragm.
- Wall anchorage force.

a) *Flexible Diaphragms:*

Flexible diaphragms are diaphragms that do not severe any in-plane torsional moment due to lateral seismic load.

It is represented by a simply supported beam supporting a uniformly distributed load; the supports represent the vertical seismic force resisting systems, and the uniform load represents the lateral seismic or wind load.

Figure (02) shows the model of the flexible diaphragm.

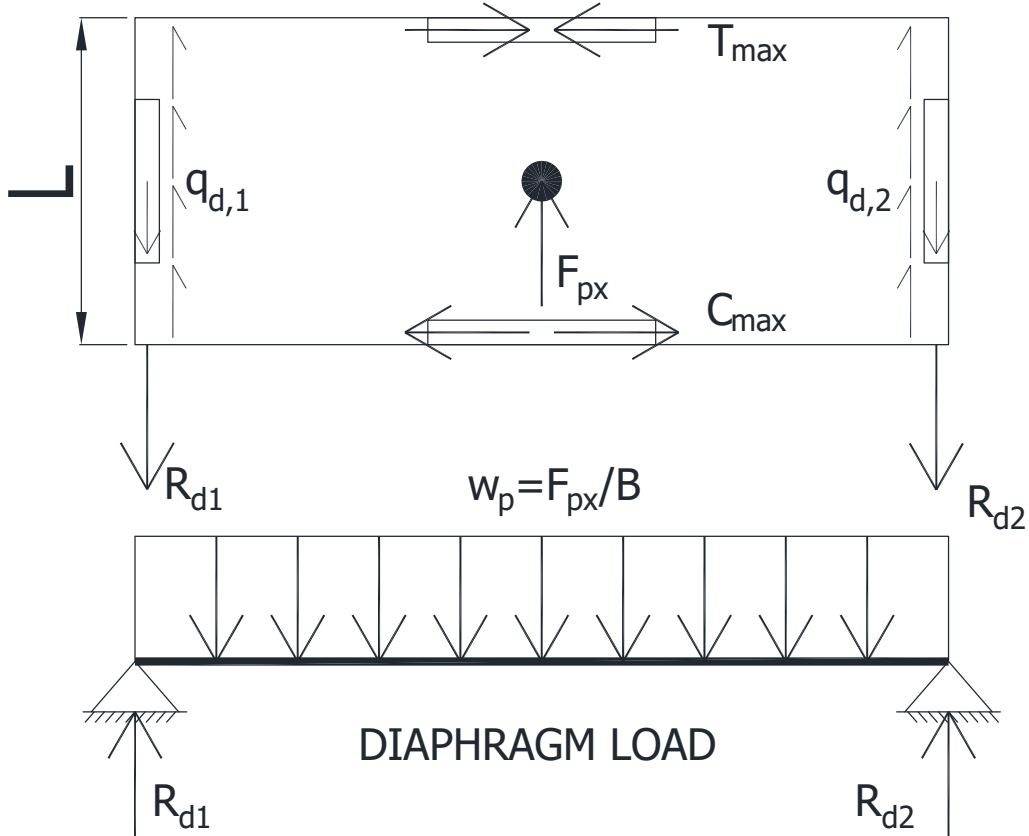


Figure (02). Model of Flexible Diaphragm

For seismic design, diaphragms are considered flexible if one of the following conditions is met:

- Untopped steel decking or wood structural panels, with any of the following conditions:
 1. SFRS is steel-braced frames, steel & concrete composite braced frames, or concrete, masonry, steel, or steel and concrete composite shear walls.
 2. One and two-family dwellings.
 3. Light-frame construction with all of the following conditions:
 - a. Untopped wood structural panels, except for non-structural topping with thickness ≤ 1.5 in.
 - b. Each line of vertical elements of SFRS satisfies the allowable story drift conditions.
- Diaphragms not satisfying the conditions of rigid or flexible diaphragms, if the following equation is satisfied:

$$\frac{\delta_{MDD}}{\Delta_{ADVE}} > 2$$

(12.3-1)

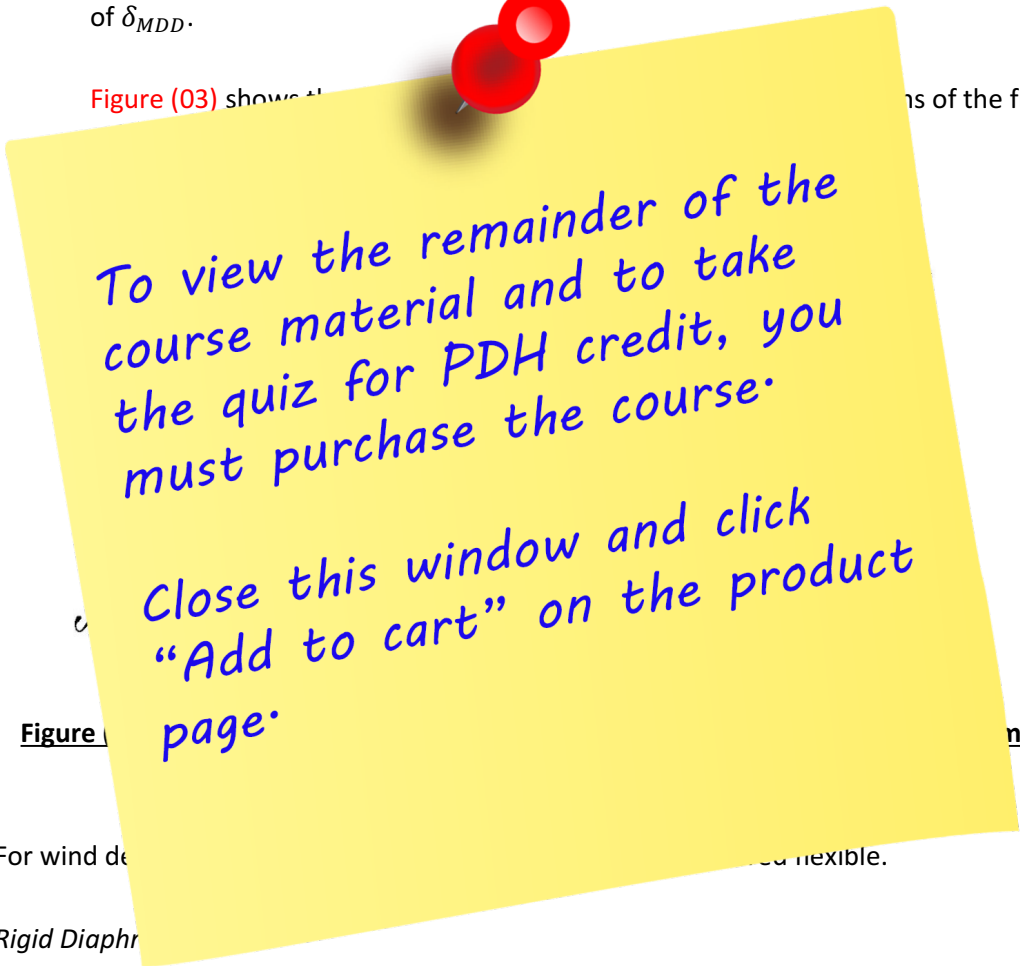
Where;

δ_{MDD} = maximum in-plane deflection of the diaphragm

Δ_{ADVE} = average drift of adjoining vertical elements of the seismic force-resisting system over the story below

The diaphragm under consideration, under tributary lateral load equivalent to that used in the computation of δ_{MDD} .

Figure (03) shows the relationship between the drifts of the flexible



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Figure

For wind design, the diaphragm is considered flexible.

b) Rigid Diaphragm

Rigid diaphragms are diaphragms that have severe in-plane torsional moments due to lateral seismic load.

It is represented by a hinged-hinged beam supporting a trapezoidal distributed load. The hinged supports represent the vertical seismic force resisting systems, and the non-uniform load represents the lateral seismic or wind load, including the effect of torsion.

There are two types of torsional moments: