4.6 Procedures for Connections

This section provides Tier 2 evaluation procedures that apply to structural connections: anchorage for normal forces, shear transfer, vertical components, interconnection of elements and panel connections.

4.6.1 Anchorage for Normal Forces

Commentary:

Bearing walls that are not positively anchored to the diaphragms may separate from the structure. This may result in a loss of bearing support and partial collapse of the floors and roof.
Non-bearing walls which separate from the structure may represent a significant falling hazard. The hazard increases with the height above the building base as the building response amplifies the ground motion. Amplification of the ground motion used to estimate the wall anchorage forces depends on the type and configuration of both the walls and the diaphragms as well as the type of soil.

4.6.1.1 WALL ANCHORAGE: Exterior concrete or masonry walls shall be anchored for out-of-plane forces at each diaphragm level with steel anchors or straps that are developed into the diaphragm.

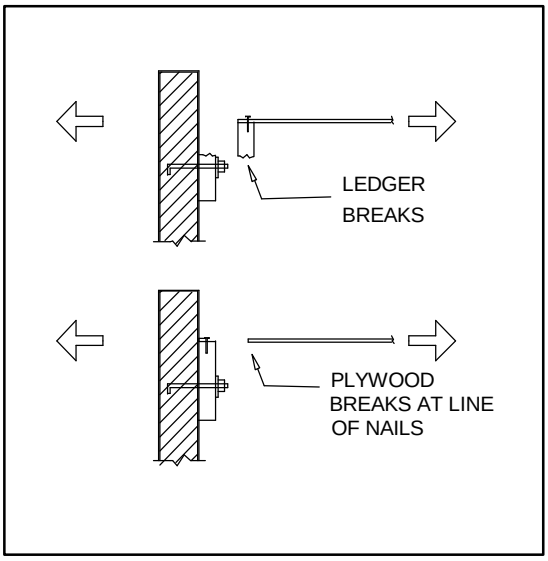
Tier 2 Evaluation Procedure: The adequacy of the walls to span between points of anchorage shall be evaluated. The adequacy of the existing connections for the wall forces in Section 4.2 shall be evaluated.

Commentary:

Bearing walls that are not positively anchored to the diaphragms may separate from the structure causing partial collapse of the floors and roof. Non-bearing walls which separate from the structure may represent a significant falling hazard. The hazard amplifies with the height above the building base. Anchorage forces must be fully developed into the diaphragm to prevent pull out failure of the anchor or local failure of the diaphragm (see Figure 4-38, following page).

If the anchorage is non-existent, mitigation with elements or connections needed to anchor the walls to the diaphragms is necessary to achieve the selected performance level.

Figure 4-37. Wood Ledgers



4.6.1.2 WOOD LEDGERS: The connection between the wall panels and the diaphragm shall not induce cross-grain bending or tension in the wood ledgers.

Tier 2 Evaluation Procedure: No Tier 2 evaluation procedure is available to demonstrate compliance of wood ledgers loaded in cross-grain bending.

Commentary:

Wood members in general have very little resistance to tension applied perpendicular to grain. Connections that rely on cross-grain bending in wood ledgers induce tension perpendicular to grain (see Figure 4-37). Failure of such connections is sudden and non-ductile, and can result in loss of bearing support and partial collapse of the floors and roof.

Mitigation with elements or connections needed to provide wall anchorage without inducing cross-grain bending is necessary to achieve the selected performance level.

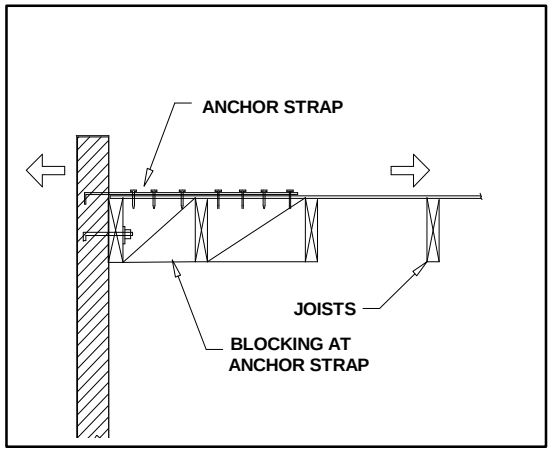


Figure 4-38. Wall Anchorage

4.6.1.3 ANCHOR SPACING: Exterior masonry walls shall be anchored to the floor and roof systems at a spacing of 4 ft. or less for Life Safety and 3 ft. or less for Immediate Occupancy.

Tier 2 Evaluation Procedure: The adequacy of the walls to span between points of anchorage shall be evaluated. The adequacy of the existing connections for the forces in Section 4.2 shall be evaluated.

Commentary:

A sufficient number of anchors should be provided to limit the demand on any one anchor and to adequately prevent the walls from separating from the structure.

4.6.1.4 PRECAST PANEL CONNECTIONS: There shall be at least two anchors from each precast wall panel into the diaphragm elements for Life Safety and the anchors shall be able to develop the strength of the panels for Immediate Occupancy.

Tier 2 Evaluation Procedure: The stability of the wall panels for the out-of-plane forces in Section 4.2 shall be evaluated. The adequacy of the existing connections to deliver all forces into the diaphragm, including moments due to eccentricities between the panel center of mass and points of anchorage, shall be evaluated.

Commentary:

At least two connections between each panel and the diaphragm are required for basic stability of the wall panel for out-of-plane forces. Many connection configurations are possible, including one anchor supporting two adjacent panels.

A single anchor, or line of anchors, near the panel center of mass should be evaluated for an accidental eccentricity of 5% of the critical panel dimension, as a minimum.

4.6.1.5 STIFFNESS OF WALL ANCHORS: Anchors of heavy concrete or masonry walls to wood structural elements shall be installed taut and shall be stiff enough to prevent movement between the wall and diaphragm. If bolts are present, the size of the bolt holes in both the connector and framing shall be a maximum of 1/16" larger than the bolt diameter. This statement shall apply to the Immediate Occupancy performance level only.

Tier 2 Evaluation Procedure: The amount of relative movement possible given the existing connection configuration shall be determined. The impact of this movement shall be evaluated by analyzing the elements of the connection for forces induced by the maximum potential movement.

Commentary:

The concern is that flexibility or slip in wall anchorage connections requires relative movement between the wall and structure before the anchor is engaged. This relative movement can induce forces in elements not intended to be part of the load path for out-of-plane forces. It can be enough to cause a loss of bearing at vertical supports, or can induce cross-grain bending in wood ledger connections.

Compliance can be demonstrated if the movement has no detrimental affect on the connections. Forces generated by any additional eccentricity at bearing supports should be considered.

4.6.2 Shear Transfer

Commentary:

The transfer of diaphragm shears into shear walls and frames is a critical element in the load path for lateral force resistance. If the connection is inadequate, or non-existent, the ability of the walls and frames to receive lateral forces will be limited, and the overall lateral force resistance of the building will be reduced.

4.6.2.1 TRANSFER TO SHEAR WALLS: Diaphragms shall be reinforced and connected for transfer of loads to the shear walls for Life Safety and shall be able to develop the shear strength of the walls for Immediate Occupancy.

Tier 2 Evaluation Procedure: An analysis in accordance with Section 4.2 shall be performed. The diaphragm and wall demands shall be calculated, and the adequacy of the connection to transfer the demands to the shear walls shall be evaluated.

Commentary:

The floor or roof diaphragms must be connected to the shear walls to provide a complete load path for the transfer of diaphragm shear forces to the walls. Where the wall does not extend the full depth of the diaphragm, this connection may include collectors or drag struts. Collectors and drag struts must be continuous across intersecting framing members, and must be adequately connected to the wall to deliver high tension and compression forces at a concentrated location.

In the case of frame buildings with infill walls (building types S5, S5A, C3, C3A) the seismic performance is dependent upon the interaction between the frame and infill, and the behavior is more like that of a shear wall building. The load path between the diaphragms and the infill panels is most likely through the frame elements, which may also act as drag struts and collectors. In this case the evaluation statement is addressing the connection between the diaphragm and the frame elements.

If the connection is non-existent, mitigation with elements or connections needed to transfer diaphragm shear to the shear walls is necessary to achieve the selected performance level.

4.6.2.2 TRANSFER TO STEEL FRAMES: Diaphragms shall be connected for transfer of loads to the steel frames for Life Safety and the connection shall be able to develop the strength of the frames for Immediate Occupancy.

Tier 2 Evaluation Procedure: An analysis in accordance with Section 4.2 shall be performed. The diaphragm and frame demands shall be calculated, and the adequacy of the connection to transfer the demands to the steel frames shall be evaluated.

Commentary:

The floor and roof diaphragms must be adequately connected to the steel frames to provide a complete load path for shear transfer between the

diaphragms and the frames. This connection may consist of shear studs or welds between the metal deck and steel framing. In older construction, steel framing may be encased in concrete. Direct force transfer between concrete and steel members by shear friction concepts should not be used unless the members are completely encased in concrete.

If the connection is non-existent, mitigation with elements or connections needed to transfer diaphragm shear to the steel frames is necessary to achieve the selected performance level.

4.6.2.3 TOPPING SLAB TO WALLS OR FRAMES: Reinforced concrete topping slabs that interconnect the precast concrete diaphragm elements shall be doweled into the shear wall or frame elements for Life Safety and shall be able to develop the shear strength of the walls or frames for Immediate Occupancy.

Tier 2 Evaluation Procedure: An analysis in accordance with Section 4.2 shall be performed. The diaphragm and wall demands shall be calculated, and the adequacy of the connection to transfer the demands to the vertical elements shall be evaluated.

Commentary:

The topping slabs at each floor or roof must be connected to the shear walls or frame elements to provide a complete load path for the transfer of diaphragm shear forces to the vertical elements. Welded inserts between precast floor or roof elements are susceptible to weld fracture and spalling, and are likely not adequate to transfer these forces alone.

If a direct topping slab connection is non-existent, mitigation with elements or connections needed to transfer diaphragm shear to the vertical elements is necessary to achieve the selected performance level.

4.6.3 Vertical Components

Commentary:

The following statements reflect a number of common concerns related to inadequate connections between elements. For example, members may be incapable of transferring forces into the foundation or may be displaced when uplifted, resulting in reduced support for vertical loads. A potential deficiency common to all of the following statements would be a non-existent connection.

4.6.3.1 STEEL COLUMNS: The columns in lateral-force-resisting frames shall be anchored to the building foundation for Life Safety and the anchorage shall be able to develop the tensile capacity of the foundation for Immediate Occupancy.

Tier 2 Evaluation Procedure: An analysis in accordance with Section 4.2 shall be performed. The column demands including axial load due to overturning shall be calculated, and the adequacy of the connections to transfer the demands to the foundation shall be evaluated.

Commentary:

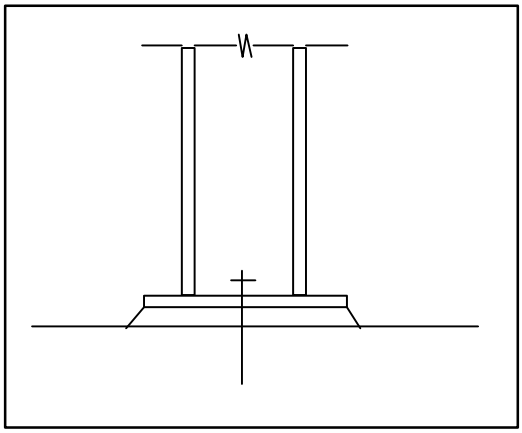
Steel columns that are part of the lateral-force-resisting system must be connected for the transfer of uplift and shear forces at the foundation (see Figure 4-39). The absence of a substantial connection between the columns and the foundation may allow the column to uplift or slide off of bearing supports which may limit the ability of the columns to support vertical loads or resist lateral forces.

As an upper bound limit for the Immediate Occupancy performance level, the connection is checked for the tensile capacity of the foundation, which is the weak link in the load path between the superstructure and the supporting soil. It could be the uplift capacity of the pile, the connection

between the pile and the cap, or the foundation dead load that can be activated by the column.

If the connection is non-existent, mitigation with elements or connections needed to anchor the vertical elements to the foundation is necessary to achieve the selected performance level.

Figure 4-39. Steel Column Connection



4.6.3.2 CONCRETE COLUMNS: All concrete columns shall be doweled into the foundation for Life Safety and the dowels shall be able to develop the tensile capacity of the column for Immediate Occupancy.

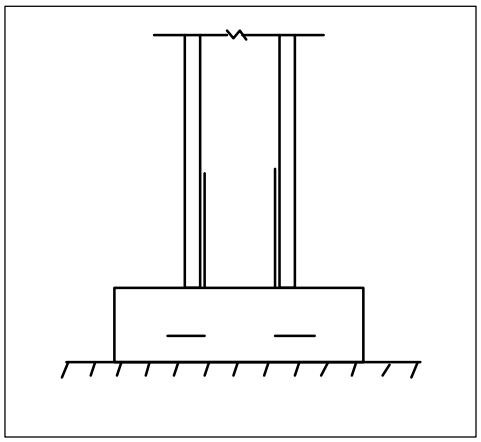
Tier 2 Evaluation Procedure: An analysis in accordance with Section 4.2 shall be performed. The column demands shall be calculated and the adequacy of the connection to transfer the demands to the foundation shall be evaluated.

Commentary:

Concrete column that are part of the lateral-force-resisting system must be connected for the transfer of uplift and shear forces to the foundation (see Figure 4-40). The absence of a substantial connection between the columns and the foundation may allow the column to uplift or slide off of bearing supports which will limit the ability of the columns to support vertical loads or resist lateral forces.

If the connection is non-existent, mitigation with elements or connections needed to anchor the vertical elements to the foundation is necessary to achieve the selected performance level.

Figure 4-40. Column Doweled into Foundation



4.6.3.3 WOOD POSTS: There shall be a positive connection of wood posts to the foundation.

Tier 2 Evaluation Procedure: No Tier 2 evaluation procedure is available for connections in non-compliance.

4.6.3.4 WOOD SILLS: All wood sills shall be bolted to the foundation.

Commentary:

The absence of a substantial connection between the wood posts and the foundation may allow the posts to slide off of bearing supports as the structure drifts in an earthquake.

Mitigation with elements or connections needed to anchor the posts to the foundation is necessary to achieve the selected performance level.

Tier 2 Evaluation Procedure: No Tier 2 evaluation procedure is available for connections in non-compliance.

Commentary:

The absence of a connection between the wood sills and the foundation is a gap in the load path that will limit the ability of the shear walls to resist lateral forces. Structures may potentially slide off foundation supports

Mitigation with elements or connections needed to anchor the sills to the foundation is necessary to achieve the selected performance level.

4.6.3.5 WALL REINFORCING: Walls shall be doweled to the foundation for Life Safety and the dowels shall be able to develop the strength of the walls for Immediate Occupancy.

Tier 2 Evaluation Procedure: An analysis in accordance with Section 4.2 shall be performed. The wall demands shall be calculated and the adequacy of the connection to transfer the demands to the foundation shall be evaluated.

Commentary:

The absence of an adequate connection between the shear walls and the foundation is a gap in the load path that will limit the ability of the shear walls to resist lateral forces.

If the connection is non-existent, mitigation with elements or connections needed to anchor the walls to the foundation is necessary to achieve the selected performance level.

4.6.3.6 SHEAR-WALL-BOUNDARY COLUMNS: The shear wall boundary columns shall be anchored to the building foundation for Life Safety and the anchorage shall be able to develop the tensile capacity of the column for Immediate Occupancy

Tier 2 Evaluation Procedure: An analysis in accordance with Section 4.2 shall be performed. The overturning resistance of the shear wall considering the dead load above the foundation and the portion of the foundation dead load that can be activated by the boundary column anchorage connection shall be evaluated.

Commentary:

Shear wall boundary column anchorage is necessary for overturning resistance of the shear walls. Boundary columns which are not substantially anchored to the foundation may not be able to activate foundation dead loads for overturning resistance.

4.6.3.7 PRECAST WALL PANELS: Precast wall panels shall be doweled to the foundation for Life Safety and the dowels shall be able to develop the strength of the walls for Immediate Occupancy.

Tier 2 Evaluation Procedure: An analysis in accordance with Section 4.2 shall be performed. The wall panel demands shall be calculated and the adequacy of the connection to transfer the demands to the foundation shall be evaluated.

Commentary:

The absence of an adequate connection between the precast wall panels and the foundation is a gap in the load path that will limit the ability of the panels to resist lateral forces.

If the connection is non-existent, mitigation with elements or connections needed to anchor the precast walls to the foundation is necessary to achieve the selected performance level.

4.6.3.8 WALL PANELS: Metal, fiberglass or cementitious wall panels shall be positively attached to the foundation for Life Safety and the attachment shall be able to develop the shear capacity of the panels for Immediate Occupancy.

Tier 2 Evaluation Procedure: An analysis in accordance with Section 4.2 shall be performed. The wall panel demands shall be calculated and the adequacy of the connection to transfer the demands to the foundation shall be evaluated.

Commentary:

The absence of a shear transfer connection between metal, fiberglass or cementitious panel shear walls and the foundation is a gap in the load path that will limit the ability of the walls to resist lateral forces.

In some cases, these panels are not intended to be part of the lateral force resisting system. In this case the evaluation should be limited to the anchorage forces and connections for the panels to prevent falling hazards. Consideration should be given to the ability of the connections to resist the deformations imposed by building movements.

If the connection is non-existent, mitigation with elements or connections needed to anchor the vertical elements to the foundation is necessary to achieve the selected performance level.

4.6.3.9 WOOD SILL BOLTS: Sill bolts shall be spaced at 6 ft. or less for Life Safety and 4 ft. or less for Immediate Occupancy, with proper edge distance provided for wood and concrete.

Tier 2 Evaluation Procedure: The adequacy of the existing bolts for the lateral forces in Section 4.2 shall be evaluated. Reduced capacities shall be used when proper edge distance has not been provided.

Commentary:

The absence of an adequate connection between the wood sills and the foundation is a gap in the load path that will limit the ability of the shear walls to resist lateral forces. Structures may slide off foundation supports.

Sill bolt spacing has been limited in moderate and high seismic zones to limit the demand on individual bolts. Compliance can be demonstrated if the existing bolts are adequate to resist the demands in the building being evaluated.

4.6.3.10 LATERAL LOAD PATH AT PILE CAPS: Pile caps shall have top reinforcement and piles shall be anchored to the pile caps for Life Safety, and the pile cap reinforcement and pile anchorage shall be able to develop the tensile capacity of the piles for Immediate Occupancy.

Tier 2 Evaluation Procedure: An analysis in accordance with Section 4.2 shall be performed. The axial forces due to overturning and shear demands at the pile cap shall be calculated and the adequacy of the pile cap reinforcement and pile connections to transfer uplift forces to the piles shall be evaluated.

Commentary:

Pile foundations may have been designed considering downward gravity loads only. A potential problem is a lack of top reinforcement in the pile cap and a lack of a positive connection between the piles and the pile cap. The piles may be socketed into the cap without any connection to resist tension.

Seismic forces may induce uplift at the foundation which must be delivered into the piles for overturning stability. The absence of top reinforcement means the pile cap cannot distribute the uplift forces to the piles. The absence of pile tension connections means that the forces cannot be transferred to the piles.

4.6.4 Interconnection of Elements

4.6.4.1 GIRDER/COLUMN CONNECTION: There shall be a positive connection between the girder and the column support.

Tier 2 Evaluation Procedure: No Tier 2 evaluation procedure is available for connections in non-compliance.

> **Commentary:**
>
> The absence of a substantial connection between the girders and supporting columns may allow the girders to slide off of bearing supports as the structure drifts in an earthquake.
>
> Mitigation with elements or connections needed to connect the girders and columns is necessary to achieve the selected performance level.

4.6.4.2 GIRDERS: Girders supported by walls or pilasters shall have at least two additional ties to secure the anchor bolts for Life Safety and Immediate Occupancy.

Tier 2 Evaluation Procedure: A determination shall be made as to whether or not the girder connection at the pilaster will be required to resist wall out-of-plane forces. The adequacy of the connection to resist the forces in Section 4.2 without damage shall be evaluated.

> **Commentary:**
>
> Girders supported on wall pilasters may be required to resist wall out-of-plane forces. Without adequate confinement, anchor bolts may pull out of the pilaster (see Figure 4-41). The potential for the pilaster to spall can lead to reduced bearing area or loss of bearing support for the girder.

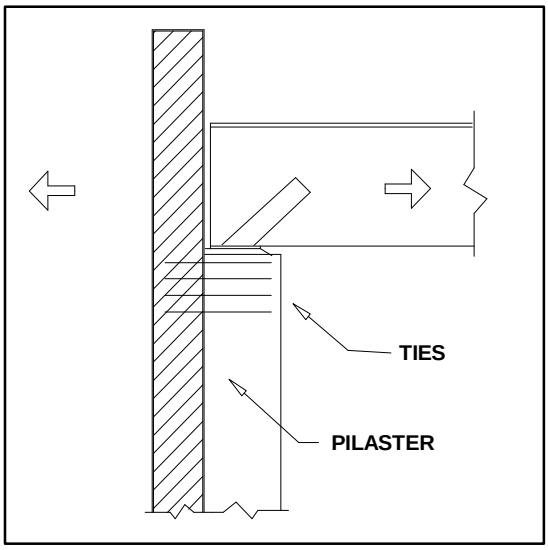


Figure 4-41. Girder Anchorage

4.6.4.3 CORBEL BEARING: If the frame girders bear on column corbels, the length of bearing shall be greater than 3" for Life Safety and for Immediate Occupancy.

Tier 2 Evaluation Procedure: The interstory drift shall be calculated using the procedures in Section 4.2. The bearing length shall be sufficient to provide support for the girders at maximum drift. The adequacy of the bearing support for all loads, including any additional eccentricity at maximum drift, shall be evaluated.

> **Commentary:**
>
> If drifts are sufficiently large, girders can slide off bearing supports without adequate length. At maximum drift, the bearing support may experience additional eccentricity not considered in the design. The support should be evaluated for strength at this extreme condition.

4.6.4.4 CORBEL CONNECTIONS: The frame girders shall not be connected to corbels with welded elements.

Tier 2 Evaluation Procedure: The force in the welded connections induced by interstory drift shall be calculated. The adequacy of the connections to resist these forces shall be evaluated. Calculated overstresses in these connections shall not jeopardize the vertical support of the girders or the lateral-force-resisting system.

Commentary:

Precast elements that are interconnected at the supports may develop unintended frame action and attract seismic forces. The concern is that the welded connections are unable to develop the strength of the members and will be subject to sudden non-ductile failure, possibly leading to partial collapse of the floor or roof.

Connections may be in compliance if failure of the connection will not jeopardize the vertical support of the girder.

4.6.5 Panel Connections

4.6.5.1 ROOF PANELS: Metal, plastic, or cementitious roof panels shall be positively attached to the roof framing to resist seismic forces for Life Safety and the attachment shall be able to develop the strength of the panels for Immediate Occupancy

Tier 2 Evaluation Procedure: An analysis in accordance with Section 4.2 shall be performed. The roof panel demands shall be calculated and the adequacy of the wall panels to transfer the demands to the roof framing shall be evaluated.

Commentary:

The absence of a positive connection between metal, fiberglass or cementitious panels and the roof framing is a gap in the load path that will limit the ability of the panels to act as a diaphragm.

Panels not intended to be a part of the diaphragm represent a potential falling hazard if not positively attached to the framing. In this case the evaluation should be limited to the anchorage forces and connections of the panels. Consideration should be given to the ability of the connections to resist the deformations imposed by building movements.

If the connection is non-existent, mitigation with elements or connections needed to attach the roof panels is necessary to achieve the selected performance level.

4.6.5.2 WALL PANELS: Metal, fiberglass or cementitious wall panels shall be positively attached to the framing to resist seismic forcesfor Life Safety and the attachment shall be able to develop the strength of the panels for Immediate Occupancy

Tier 2 Evaluation Procedure: An analysis in accordance with Section 4.2 shall be performed. The wall panel demands shall be calculated and the adequacy of the wall panels to transfer the demands to the framing shall be evaluated.

Commentary:

The absence of a positive connection between metal, fiberglass or cementitious panels and the framing is a gap in the load path that will limit the ability of the panels to resist seismic forces.

Panels not intended to be a part of the lateral force resisting system represent a potential falling hazard if not positively attached to the framing. In this case the evaluation should be limited to the anchorage forces and connections of the panels. Consideration should be given to the ability of the connections to resist the deformations imposed by building movements.

If the connection is non-existent, mitigation with elements or connections needed to attach the panels is necessary to achieve the selected performance level.

4.6.5.3 ROOF PANEL CONNECTIONS: Roof panel connections shall be spaced at or less than 12" for Life Safety and 8" for Immediate Occupancy

Tier 2 Evaluation Procedure: The adequacy of the existing connections for the lateral forces in Section 4.2 shall be evaluated.

Commentary:

An insufficient number of connections between the panels and the framing will reduce the capacity of the panels to act as a diaphragm.