An analysis of slabs-on-grade as an anchorage system for tilt-up concrete panel temporary braces

by

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Abstract

An analysis of concrete slabs-on-grade as a means of anchorage for temporary bracing of tilt-up concrete panels is presented within this report. A tilt-up concrete panel of 42 feet in height, 26 feet in width, and 9.25 inches in thickness is a constant within the analysis, as is a construction period wind speed of 80 mph. The thickness of the concrete slab-on-grade and the subgrade material directly below the slab-on-grade are varied to achieve comparable results.

ASCE 7-16's procedure for determining wind load outlined in chapter 29 and ASCE 37's provisions for construction period reductions in wind load are used to calculate the wind load on the face of the tilt-up panel. This wind load is then translated into a force taken directly by the temporary braces. This force transmitted through each brace is then divided into a vertical component and a horizontal component upon anchorage to the slab-on-grade for analysis.

Two wind conditions are analyzed in the study, and each condition produces two different potential failure mechanisms that must be studied. The first wind condition is wind blowing on the exterior face of the panel. This wind condition causes the temporary braces to be in compression. With the braces in the compression, the slab-on-grade can fail horizontally as a result of slab sliding and vertically due to punching shear failure. The second wind condition is wind blowing on the interior face of the panel. This wind condition causes the temporary braces to be in tension. When the braces are in tension, pullout of the slab-on-grade anchor can occur, and the slab-on-grade can be lifted up due to the overturning moment of the wind load on the panel face.

The different subgrade materials analyzed in this report are gravel, sand, soil, and a vapor retarder/barrier. The slab-on-grade thicknesses examined are 5-inch, 6-inch, and 8-inch. Each subgrade material has a different coefficient of friction and will affect the slab-on-grade's

resistance to sliding. The thickness of the slab-on-grade will affect the slab's resistance to sliding, punching shear, and overturning moment. This report outlines how each variable is adjusted to determine the slab-on-grade's adequacy as a means of anchorage for the temporary panel bracing. Results of the study show that all thicknesses of the slab-on-grade and subgrade conditions analyzed are adequate based on the assumed surface areas considered effective to resist against slab sliding and overturning. It is recommended that physical testing be conducted to determine exactly how the slab-on-grade acts at saw joint and control joint locations. The study assumes that control joint locations are boundary limits of slab surface area effective to resist against slab sliding, and it is also assumed that saw joint locations will not be subject to slab overturning failure due to the steel reinforcing continuous across the saw joint location. Both of these assumptions need to be studied and verified with physical testing.

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Chapter 1 - Introduction

This report focuses on the analysis of slab-on-grade anchorage for temporary bracing of tilt-up concrete panels. Tilt-up concrete panel construction is a method of wall construction in which concrete panels are formed and poured horizontally and then lifted, or tilted, upright into their final resting position. Most within the construction industry are familiar with cast-in-place (CIP) concrete walls that are formed vertically, and the concrete and reinforcement is placed directly into the vertical forms. After the concrete has attained strength, the forms are removed, and the process is complete. The key difference between CIP concrete walls and tilt-up concrete wall panels is the position of the forms and their location relative to the wall's final resting position. CIP concrete walls are formed vertically in their final resting position while tilt-up concrete wall panels are formed horizontally on a casting surface and must be lifted into their final position. Tilt-up concrete panels are similar to precast concrete wall panels in that they are both not cast-in-place, but precast wall panels are formed off-site whereas tilt-up panels are formed on the job site (Tilt Wall, 2017). When tilt-up concrete panels are lifted into position, they must be temporarily braced until foundation, floor, and roof connections are completed. These temporary braces resist wind forces prior to the foundation and roof connections being made. Due to the size and weight of tilt-up panels, and the potential danger in the event of a collapse, the temporary braces are of upmost importance. As a result, the anchorage of these braces is also of high importance. Three types of brace anchorage systems are common: slab-on-grade anchors, helical ground anchors, and concrete deadmen (Steinbicker, 2018). This report focuses on the slab-on-grade anchorage system and analyze the forces transmitted from the panel, through the brace, and into the slab. The forces transmitted from the brace are divided into horizontal and vertical components. The horizontal component is analyzed to determine if sliding of the slab-on-grade occurs. The vertical component is analyzed to determine if punching shear occurs when applied downward and if anchor pullout or slab overturn occurs when applied upward. Three slab-on-grade thicknesses are examined in this report: 5-inch, 6-inch, and 8-inch. Additionally, four different subgrade conditions are analyzed: gravel, sand, soil, and vapor retarder/barrier. The subgrade conditions affect the slab-on-grade's resistance to sliding from the horizontal component. The different slab-on-grade thicknesses will affect the slab's resistance to both the vertical and horizontal components of the force transmitted through the brace.

1.1 Objective

The objective of this report is to provide an analysis comparison of slab-on-grade anchorage systems for temporary bracing of tilt-up concrete panels. The comparison considers three different slab-on-grade thicknesses and four different subgrade conditions. The tilt-up panel size, brace size, and wind force remain constant.

1.2 Scope of Report

This report contains five chapters. Chapter one provides the introduction, objective, and scope of report. Chapter two offers a literature review of the basics of slab-on-grade design, tilt-up concrete panel construction, temporary bracing requirements, and brace anchorage systems. Chapter three outlines and describes the parametric study. Chapter four presents the discussion & results found from analyzing the three different slab-on-grade thicknesses and four different subgrade conditions. Chapter five describes the findings and conclusions of the study.

Chapter 2 - Literature Review

Tilt-up concrete panel construction is a rapidly growing industry, and, as its advantages become more well known, its share of the construction market is expanding (Tilt-Up Concrete Association, 2011). Although it is a non-traditional building method, it can “deliver quick project completion, low construction costs, and versatile design” (Tilt Wall, 2017). However, compared to cast-in-place concrete, steel, masonry, and timber structural systems, relatively diminutive amount of research on the topic exists; specifically, design information regarding slabs-on-grade as a method of temporary bracing anchorage for tilt-up concrete panels. Slabs-on-grade are a common structural system at the ground level of many buildings, but they rarely are exposed to the magnitude of loads applied from temporary bracing of tilt-up concrete panels. Therefore, careful consideration and analyzation of these forces is needed.

2.1 Basics of Slab-on-Grade Design

Concrete is one of the most common building materials in construction around the world, and one of its most common uses is in the form of a slab-on-grade. A slab-on-grade consists of a concrete element supported by ground, with the main purpose to support the applied loads by bearing on the soil. Slabs-on-grade are versatile structural elements that can be utilized in a variety of situations. As noted in Bernard (2006), “slabs-on-grade are among the most common types of structural members encountered in civil engineering design and construction and account for a large proportion of ready-mixed concrete consumed in most nations.” While common and versatile, the quantity of reinforcement and how slab-on-grades are constructed varies.

Slabs-on-grade can be constructed with or without steel reinforcement (O’Dwyer, 2007). The quantity of steel reinforcement influences the strength of slabs-on-grade to resisting different types of loading conditions. Commonly, a slab-on-grade will resist both tensile and compressive forces depending on the location within the slab. If resisting a load on its top surface, the upper portion of the slab will be in compression while the lower portion will be in tension. Concrete is strong and durable in compression but weak and brittle in tension. Steel reinforcement helps concrete resist these tensile forces (O'Dwyer, 2007). Another function of reinforcing is to limit shrinkage cracking as the slab-on-grade cures from its initial placement (O'Dwyer, 2007).

ACI 302 defines four basic types for construction of slabs-on-ground: (1) unreinforced concrete slab; (2) slabs reinforced to limit crack widths due to shrinkage and temperature restraint and applied loads using mild steel wire or bar reinforcement, or fiber reinforcement, all with closely spaced joints and continuously reinforced slabs; (3) slabs reinforced to prevent cracking due to shrinkage and temperature restraint and applied loads using shrinkage-compensating concrete and post-tensioning; and (4) structural slabs (ACI Committee 302, 2015). While slabs-on-grade for tilt-up buildings may have all of these types without the use of post-tensioning, the focus of the report is slabs reinforced for crack-width control. The thickness is designed to remain uncracked (plain concrete) when loaded and when cracking occurs shrinkage crack widths between joints are controlled by a nominal quantity of distributed reinforcement located in the upper third of the slab. Additionally, ACI 302 defines eight classes (class 1 through class 8) of floors based on intended use. Classes 1, 2, 4, 5, and 6 are single-course monolithic floors involving some variation in joint detailing and final finishing techniques. Class 5 is for industrial use with exposed surface with a hard steel-troweled finish. TCA recommends this type of finish for the casting surface of tilt-up panels. Therefore, monolithic, class 5 floor slabs-on-grade is the focus of this report. Classes 3, 7, and 8 consists of two-course floors, which are outside the scope of this report.

To properly design slabs-on-grade, the following items need to be addressed: slabs-on-grade design criteria; base and subbase materials, preparation, and vapor retarder/barrier; concrete thickness; concrete compressive strength and flexural strength; concrete mixture proportion requirements and ultimate drying shrinkage strain; joint locations and details; reinforcement type, size, and location; surface finish; tolerances; concrete curing; joint filler material and installation; special embedments; and testing requirements (ACI Committee 360, 2010). For this report, the components that are varied are the presence of base and subbase materials, the use of a vapor retarder/barrier, and the concrete thicknesses and corresponding temperature and shrinkage reinforcement size and location. The components of the slabs-on-grade examined that are assumed constant for this report are: preparation and type of the subbase and subgrade; concrete compressive strength and flexural strength; concrete mixture proportion requirements and ultimate drying shrinkage strain; joint details and locations; surface finish; tolerances; concrete curing; joint filler material and installation; special embedments; and testing requirements. Therefore, these items are not discussed in detail within this report. Figure 2-1 indicates a slab-on-grade support system terminology.

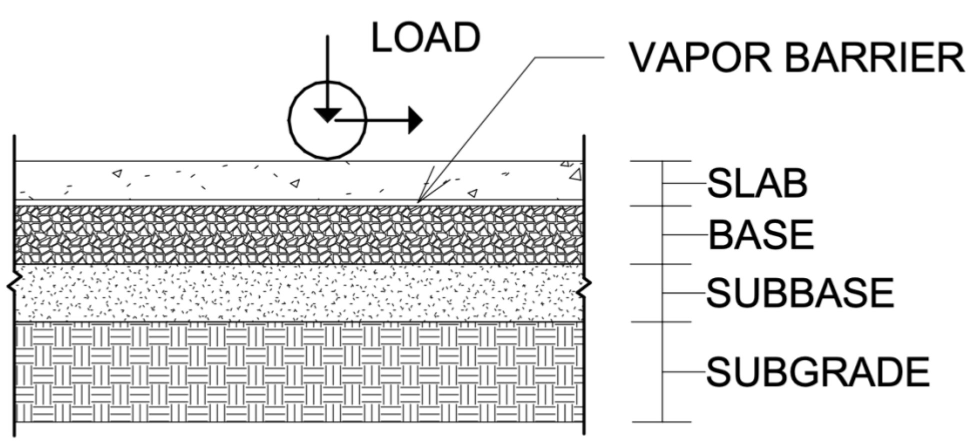


Figure 2-1: Slab Support System Terminology (Modified from ACI Committee 360, 2010)

2.1.1 Loading

Slabs-on-grade are supported by compacted soil and are at ground level of the building and therefore can be exposed to numerous loading conditions at different stages of the construction process. Various types of loads may be imposed on a slab-on-grade: distributed loads, concentrated loads, or moving loads. Distributed loads are a result of piles of materials placed on the floor or pallets of product stacked next to each other. During the construction process, moving loads are often applied to the slab. If a crane is needed for construction of the building, it may be driven across the slab-on-grade, forcing the slab to resist this additional weight. The additional weight of the crane would likely lead to an increase in slab thickness. For the parametric study, no crane will be on the slab-on-grade, so the focus of the study will be on the design of the slab for the brace forces. Moving loads can be seen after completion of the building as well in the case of a vehicle driving across it or a forklift carrying pallets across a warehouse floor. Concentrated loads can come in the form of parked vehicles, heavy objects placed on the slab by a crane or forklift, or permanent storage racks supporting different products and materials (Engelland, 2020a). Another scenario in which a slab-on-grade is subjected to a concentrated load is when it is used as the anchorage system for tilt-up concrete panel temporary bracing. The loads from the temporary brace are applied to the slab-on-grade at the angle of the brace relative to the surface of the slab-on-grade. The vertical component of the load acts just like a concentrated load applied at an angle perpendicular to the surface of the slab-on-grade. This type of load is analyzed in the parametric study and checked against the slab's punching shear capacity.

2.1.2 Design

Stresses in slabs-on-ground result from both applied loads and volume changes of the soil and concrete. The magnitude of these stresses depends on factors, such as degree of continuity, subgrade strength and uniformity, method of construction, quality of construction, and magnitude and position of the loads. Making simplifying assumptions with respect to material properties and soil-structure interaction, the slab-on-grade can be evaluated. When it comes to concrete slab-on-grade design, many methods can be utilized. This report is governed by the American Concrete Institute (ACI) *Building Code Requirements for Structural Concrete* (ACI 318-19). Chapter 14 Plain Concrete is used in the design of the slab-on-grade. The slab-on-grade is designed as plain concrete because it meets the requirements of section 14.1.3(a) that states “members that are continuously supported by soil” may be designed as plain concrete (ACI Committee 318, 2019). Table 14.5.5.1 provides equations to determine the nominal shear strength of the slab-on-grade.

Several methods of design maybe used to determine the required slab-on-grade. Design methods employ the modulus of subgrade reaction as a single property to represent the design support strength. This modulus is a spring constant, k, assuming a linear response between load and deformation form the subgrade (Westergaard, 1926). In actuality, no single subgrade spring constant exists because of the nonlinear relationship between a normal compressive load and the resulting deformation for an area. The load-deformation relationship depends on many factors: the type of soil structure, density, moisture content, prior loading, the width and shape of the loaded area, depth of the subgrade, and position under the slab. ASTM D1196 using plate load field tests or American Association of State Highway Transportation Officials (AASHTO) approach for rigid pavements may be used to estimate the subgrade modulus. Additionally, the

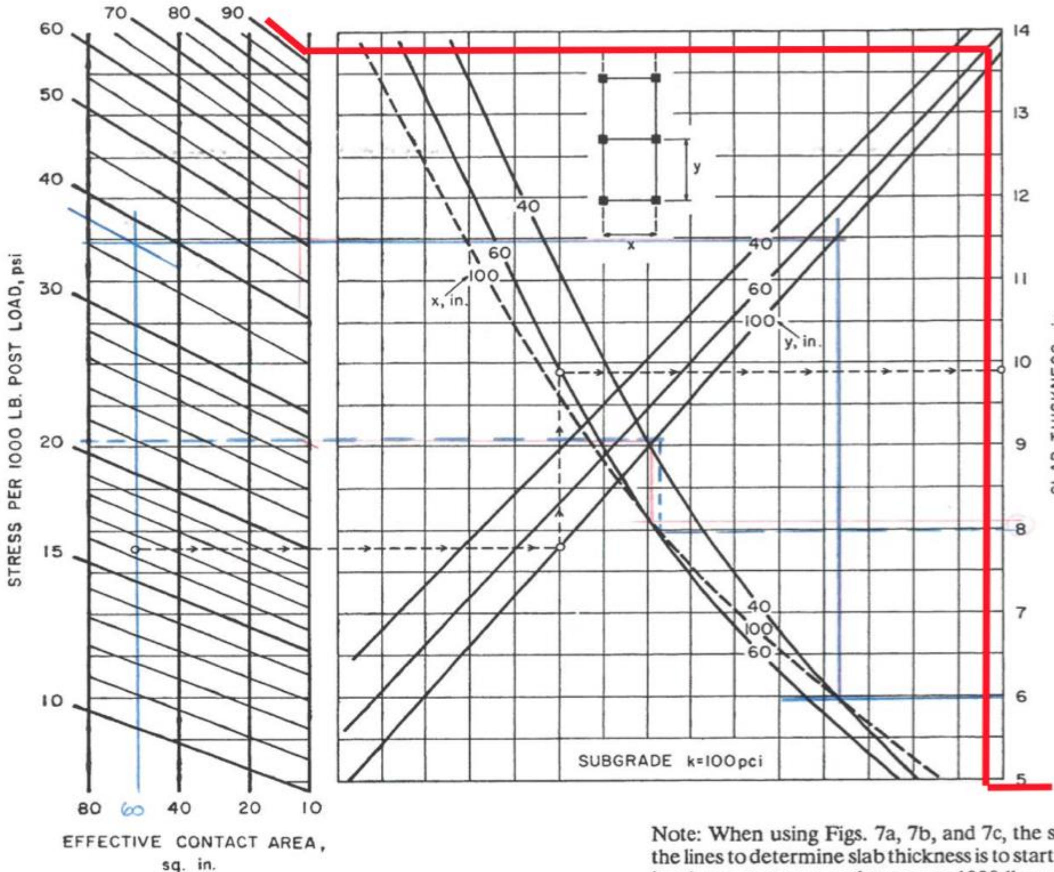
Corps of Engineers (COE) developed empirical relations between soil classification type, California bearing ratio, and subgrade spring constants. All of these test methods and procedures have been developed for pavements, not for slab-on-ground floors for buildings. Nevertheless, correlations are widely used to approximate the subgrade support values for slab-on-ground design and construction (ACI Committee 306, 2010). This subgrade spring constant can be used in a finite element module to determine the slab-on-grade thickness and reinforcement required for the applied loads.

Instead of computer modeling, empirical design aids based on the influence of modulus of subgrade reaction has on the required slab thickness. Design charts of the Portland Cement Association (PCA), Wire Reinforcement Institute (WRI), and COE assume continuous slab contact with the base and a uniform subgrade modulus. Even though a continuous intimate contact is not achievable in practice because of differences in composition, thickness, moisture content, slab curling, and subgrade density, the curling stresses will be sufficiently low that the PCI, WRI, and COE methods provide reasonable solutions (ACI Committee 306, 2010).

One method of concrete slab-on-grade design is that of design tables based on subgrade conditions, concrete slab properties, spacing of concentrated loads, and effective contact area of the concentrated loads. PCA Concrete Information's article *Slab Thickness Design for Industrial Concrete Floors on Grade* by Robert G. Packard is one example that provides these types of design tables. Figure 2-2 shows an example of one of these design tables. This method of slab-on-grade design for concentrated loads was used in Engelland's (2020a) report on comparing slab-on-grade design methods such as this one with more modern and advanced methods that utilize computer analysis programs. Many of these design tables are dependent upon the reinforcing assumed for the condition. The table used in Engelland's (2020a) report, shown in

Figure 2-2, is based on conditions of either unreinforced slabs or slabs with temperature and shrinkage steel only (Packard, 1976). Because unreinforced slabs are only economical when soil conditions are adequate (Packard, 1776), Engelland's (2020a) report proceeded with that assumption and mirrored it when running the computer analysis for comparison. In the report, a warehouse floor slab was analyzed. A post spacing of 95 inches was used (x and y dimensions as shown in the design table), a concentrated (post) load of 2,000 pounds was applied, and a contact area of 16 square inches was assumed. A compressive strength of 4,000 psi, subgrade modulus (k) of 100 pounds per cubic inch, and safety factor of three were also used in the study. A modulus of rupture, calculated by taking nine times the square root of the compressive strength, of 569.21 pounds per square inch was calculated. This modulus of rupture was then divided by the safety factor of three to obtain a working stress of 189.74 pounds per square inch. The working stress was then divided by the concentrated load of 2,000 pounds to determine a slab stress per 1,000 pounds of concentrated load of 94.87 pounds per square inch. This value, along with the contact area of 16 square inches, was used to enter the design table. Upon entering the table, a required slab thickness of 5 inches was determined by sliding over to the 95-inch y-dimension line and sliding down to the 95-inch x-dimension line as shown by the red line in Figure 2-2.

Numerous programs exist that can both analyze and design concrete slabs-on-grade based on variable inputs. Engelland's (2020a) report utilized RISA Foundation. RISA Foundation's program capabilities only allow it to design reinforced concrete slabs. To account for this, Engelland (2020a) set the program's reinforcement settings to its minimum area and maximum spacing to mimic an unreinforced slab to make the comparison between the two methods more accurate. Results of the study concluded that the design tables referenced in Packard's PCA



Note: When using Figs. 7a, 7b, and 7c, the sequence in drawing the lines to determine slab thickness is to start at the point describing the contact area and stress per 1000-lb post load, then proceed horizontally to the "y" curves, vertically, up or down, to the "x" curves, and horizontally to the required slab thickness.

Fig. 7b. Design chart for post loads, subgrade k = 100 pci.

Figure 2-2: Example Design Table for Slab Design (Reproduced from Packard, 1976)

article were more conservative. The design tables yielded a required slab thickness of 5 inches while RISA Foundation's analysis came up with a required slab thickness of 3 inches (Engelland, 2020a).

This comparison of analysis methods showing how concrete slabs-on-grade resist concentrated loads is important to understand when considering how thick slabs-on-grade need to be in order to resist anchorage forces from temporary bracing for tilt-up concrete panels. This study also showed the importance of subgrade conditions when designing a slab-on-grade as the design tables were based off a specific subgrade modulus, *k*. Slabs-on-grade that serve as an anchorage system for temporary tilt-up panel bracing can have a variety of different subgrade conditions, each affecting how the slab performs.

2.2 Temporary Bracing Guidelines

On March 23, 2018, Tilt-Up Concrete Association (TCA) issued an update of *TCA Guideline for Temporary Wind Bracing of Tilt-Up Concrete Panels During Construction* authored by Joseph J. Steinbicker, P.E., S.E., FTCA. TCA originally published *Bracing Guidelines for Tilt-Up Concrete Construction* in September 1994. The original publishing, as well as its updates, were produced in response to the lack of specificity provided by the Occupational Safety and Health Association's (OSHA) standards for tilt-up concrete panels. OSHA's requirements are as follows:

> ***Requirements for Precast Concrete – 1926.704***
>
> *1926.704(a) – Precast concrete wall units, structural framing, and tilt-up wall panels shall be adequately supported to prevent overturning and to prevent collapse until permanent connections are completed.* (Occupational Safety and Health Administration [OSHA], 2003)

OSHA does not specify exactly how to prevent tilt-up panels from collapsing or overturning. According to Steinbicker, this is the primary reason why the TCA developed a temporary bracing guideline to be used by the tilt-up construction industry as a recognized standard. TCA's guideline establishes that life safety is the primary objective of the provisions for temporary wind bracing. This means that the provisions do not account for tornado or hurricane-level winds because construction workers will not be on the site during these extreme events and therefore are not in danger if a panel were to fall. Because the likelihood of either event happening is very low, it is too costly to design for these wind speeds. TCA's guideline does not address seismic loads, and construction period wind loads will most often govern the design of the temporary bracing. The guideline's purpose is to supply a standardized method for designing and installing temporary braces for tilt-up concrete panels to resist against construction period wind load until the panels are tied into the building's structure (Steinbicker, 2018).

Steinbicker (2018) lists a number of factors that must be considered for a temporary bracing system to function safely:

- Construction period wind speed,
- Types, lengths, and capacities of available braces,
- Capacities of the brace anchorages at either end of the brace,
- When to remove the temporary bracing system, and
- Any required documentation for the design and installation.

Planning is an essential part of the tilt-up construction process to ensure that the process goes smoothly and safely. In regard to bracing of the tilt-up panels, many factors must be considered, and coordination must take place to certify that the braces are secure and the job site is safe. Steinbicker (2018) says that a "well-executed tilt-up temporary wind-bracing plan will speed the panel erection process and save money." In order to determine the panel bracing requirements for a project, casting surface location of the panels, crane access, and panel lifting sequence must all be considered (Steinbicker, 2018).

The temporary braces supporting the tilt-up panels must be anchored at both ends of the brace. The panel end of the brace is typically a cast-in anchor at designated locations and is usually specified by the lifting and bracing anchor manufacturer (Steinbicker, 2018). On the other end of the brace, the anchorage system can be the slab-on-grade, a concrete deadman, or a helical ground anchor. If connecting to the slab-on-grade with cast-in anchors, the locations of these anchors based on the geometry of the brace must be determined before the slab-on-grade is placed to ensure proper alignment (Steinbicker, 2018). More often than not, post-installed anchors are used in lieu of cast-in anchors. If using post-installed anchors in the slab-on-grade, they can be determined during the erection process (Steinbicker, 2018). Post-installed anchors are used in the parametric study, and pullout of these anchors is one of the potential failures analyzed. Locations of concrete deadmen and helical ground anchors must also be determined before the erection process begins. Each of these brace anchorage methods is discussed in further detail in section 2.3 Brace Anchorage Systems.

Corner panels can create issues when bracing on the interior face of the panel. If the braces are located at the same height on both adjacent corner panels, they will intersect with each other (Steinbicker, 2018). This issue is not considered in this report as the panel under consideration is not a corner panel in order to simplify the research.

Slab-on-grade leave outs or openings can be a potential issue for anchorage of the temporary braces (Steinbicker, 2018). Braces can be angled slightly, but they must remain within a maximum of five degrees of their centerline (Dayton Superior, 2017). This will not come into play in the parametric study as no leave outs or openings are located near the anchorage locations.

In most cases, tilt-up concrete panels are cast with their inside face up. This allows for the braces to be attached prior to lifting. This is the typical method, and it helps improve erection productivity (Bell, 2014). When the braces are unable to be attached prior to lifting, the panel is to be lifted to a vertical position and held there until crew members attach the braces via ladders or aerial lifts (Bell, 2014). This method is obviously slower and should be avoided when possible, but in certain scenarios it may be required.

2.2.1 Wind Load

Wind is the primary lateral load imposed on tilt-up concrete panels during the construction phase. Based on the surface area of the panel, a large wind force is transferred to the temporary bracing. TCA's guideline does list provisions for panels with large openings, stating that the load transferred to the panel braces can be significantly reduced (Steinbicker, 2018). An open panel is defined as having "openings that equal or exceed 30% of the gross panel area" (Steinbicker, 2018). The guideline assumes a Risk Category I structure, Exposure C, and a basic design wind speed of 100 mph. After applying a reduction factor of 0.8 to account for projects whose duration is six weeks to one year, per section 6.2.1 of the ASCE/SEI 37-14, the resulting strength level design wind speed is 80 mph (Steinbicker, 2018).

The procedure outlined in the guideline for calculating the design wind force assumes the panels are braced freestanding walls. The procedure follows the method prescribed in ASCE/SEI 7-16, Chapter 29, *Wind Loads on Building Appurtenances and Other Structures: Main Wind Force Resisting System (Directional Procedure)*. Only load Case A is considered from this method (Steinbicker, 2018). The ASCE/SEI 37-14 is used as an extension of the ASCE/SEI 7-16 to account for loads and other structural considerations for temporary structures and permanent structures during their construction phases. For solid panels, the velocity pressure, q_h (lb/ft^2), evaluated at panel height h (ft) above the ground, is calculated using the following equation:

$$q_h = 0.00256 K_z K_{zt} K_d K_e V^2 \qquad \text{Eq. 2-1}$$

Where:

K_z = Velocity pressure coefficient at panel height h above ground from ASCE/SEI 7-16 Table 26.10-1

K_{zt} = Topographic factor = 1.0 from ASCE/SEI 7-16 Section 26.8.2 (No hills, ridges, or escarpments are considered to be within 2 miles of the construction site for the parametric study.)

K_d = Wind directionality factor = 0.85 from ASCE/SEI 7-16 Table 26.6-1

K_e = Ground elevation factor = 1.0 from ASCE/SEI 7-16 Table 26.9-1 (Note 1 of Table 26.9-1 states that the conservative approximation K_e = 1.0 is permitted in all cases. Using a value of 1.0 allows the velocity pressure and design wind force to easily be adjusted for different elevations.)

V = Basic construction period wind speed, mi/hr

The design wind force for solid panels is calculated using the following equation:

$$F = q_h G C_f A_s \ (lb) \qquad \text{Eq. 2-2}$$

Where:

q_h = Velocity pressure evaluated at height h (defined in ASCE/SEI 7-16 Fig. 29.3-1), as determined in accordance with ASCE/SEI 7-16 Section 26.10

G = Gust-effect factor = 0.85 for freestanding walls from ASCE/SEI 7-16 Section 26.11.1

C_f = Net force coefficient from ASCE/SEI 7-16, Figure 29.3-1 (Used to determine the net force applied to the surface of the sign or panel based on its aspect ratio and clearance ratio.)

A_s = Gross area of the solid individual panel, ft^2

In the case of solid panels supported at ground level, the design wind force, *F*, acts at a distance of 0.55 times the average height of the panel. This distance of 0.55 times the average height of the panel was the mean vertical center of pressure from results of study conducted by

Letchford and Holmes (1994). This design wind force is then distributed to the temporary braces, with each one receiving a percentage of the force based on their respective tributary areas. Note 2 of Figure 29.3-1 of the ASCE/SEI 7-16 states that panels with openings less than 30% of the total gross area are considered solid. This note also says that the net force coefficient, C_f, can be reduced by a factor of $(1-(1-\varepsilon)^{1.5})$. This reduction is in line with the recommendation presented by Letchford (2001). The variable ε is the panel's ratio of solid area to gross area.

For open panels, the velocity pressure, q_z (lb/ft^2), evaluated at panel height z (ft) of the centroid of area A_f above the ground, is calculated using the following equation:

$$q_z = 0.00256 K_z K_{zt} K_d K_e V^2 \qquad \text{Eq. 2-3}$$

The design wind force for open panels is calculated using the following equation:

$$F = q_z G C_f A_f \ (lb) \qquad \text{Eq. 2-4}$$

Where:

q_z = Velocity pressure evaluated at height z, as defined in ASCE/SEI 7-16 Section 26.10, of the centroid of area A_f

C_f = Net force coefficient from ASCE/SEI 7-16, Figure 29.4-2

A_f = Projected area of the individual panel normal to the wind except where C_f is specified for the actual surface area, ft^2

ASCE/SEI 7-16 requires a minimum strength level design wind force of 16 lb/ft^2 multiplied by the area, A_f, to design the panel braces and their connections.

2.2.2 Braces

Temporary braces support a tilt-up concrete panel during the construction phase of the project until foundation, roof, and floor connections are completed. These braces support the panels from collapsing as a result of wind load. Because tilt-up panels have a large surface area, the design of temporary braces for wind forces is of upmost importance.

The tilt-up bracing industry is dominated by two key figures: Dayton Superior and MeadowBurke. Tilt-Up Concrete Association [TCA] (2011) states that "two types of pipe braces are available, fixed length and telescopic." Both Dayton Superior (2017) and MeadowBurke (2018) offer fixed length and telescopic braces. These two types of braces are shown in Figure 2-3. Dayton Superior braces are used in the parametric study. They are usually constructed using either round or square steel tubing, and both types of braces typically have around 18

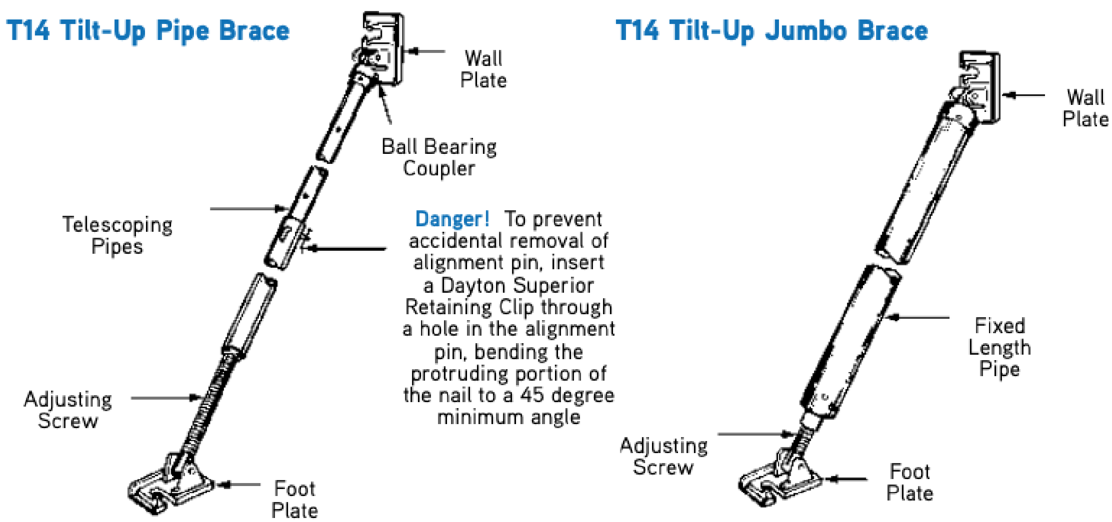


Figure 2-3: Telescoping and Fixed Length Brace (Reproduced from Dayton Superior, 2017)

inches of adjustment capabilities at their bottom end to make installation easier (Dayton Superior, 2017; MeadowBurke, 2018; TCA, 2011). Both types of braces also have extensions that can be added if a greater length is desired. Extensions and other brace components should not be interchanged from one type of brace to another. Each brace has specific components corresponding to it, and the load rating of the brace is based on it having those specific components. A mixture of brace components could lead to a reduction in brace capacity and cause the brace to fail, leading to a collapse of the panel. Each panel requires a minimum of two braces, but three or four braces are often required for large panels or panels located in high wind areas (Tilt-Up Concrete Association, 2011). TCA's current guideline uses limit state loads and strength design principles to determine the size of the braces. This report does not outline the design of these braces. Brace manufacturers have designed the braces and produced nominal load capacity tables for use by engineers. Dayton Superior (2017) lists the nominal capacity of the brace in their load tables (S. McNamara, personal communication, March 18, 2021). This nominal axial strength of the braces is adjusted by a resistance factor of $\phi = 0.9$, based on steel design principles outlined in (American Institute of Steel Construction, 2017) , to determine the strength level capacity of the brace because a limit state wind load force is what the brace must resist. Depending on their length and diameter, some types of braces require additional knee, lateral, and end bracing to complete the bracing system and prevent brace buckling (Tilt-Up Concrete Association, 2011). If this is the case, all components must be properly attached in order to achieve the rated capacity of the bracing system. Knee braces can be 2x lumber or steel pipe. Lateral bracing may consist of #9-gauge wire. Knee, lateral, and end bracing must be continuous (Kramer, 2020). Both Dayton Superior and MeadowBurke offer a variety of bracing options. They can be helpful in deciding whether fixed length or telescopic braces are needed, as well as determining if a sub-support system of knee, lateral, or end braces are required (Concrete Construction Staff, 2005). A sub-support bracing system can be avoided by selecting a larger brace with a greater capacity (Tilt-Up Concrete Association, 2011). The fixed length braces with additional components (knee, lateral, and end bracing) are not part of the scope of this report since this is for smaller panels than examined in the parametric study.

All temporary braces must be anchored at both ends. On the panel end, braces are typically anchored to the panel with ¾" diameter cast-in anchors. The anchor to the panel is outside the scope of this report. On the bottom end, when anchoring to the slab-on-grade or concrete deadmen, ¾" diameter cast-in anchors or post-installed anchors are used (Dayton Superior, 2018). For the parametric study, Dayton Superior's (2018) ¾" diameter x 4.5" long T13 Coil-Anchor is used. It is a post-installed anchor. These anchors must be able to "resist the combined shear and tension loads applied by the braces, including appropriate strength reduction factors for the anchors as determined by the manufacturer" (Steinbicker, 2018). In order for the brace to develop its full capacity, the brace anchor must also have the same strength capabilities. If not, the brace's capacity will have to be reduced. To achieve the brace anchor's ultimate capacity, the manufacturer's recommendations must be followed for slab-on-grade thickness, minimum compressive strength, and edge distance. If these recommendations are not followed, the brace anchor's capacity could be severely reduced, leading to a potential failure of the anchorage system and collapse of the panel.

Tilt-up panels are extremely heavy and should not be detached from the crane until all temporary bracing is installed and all brace connections are complete.

To ensure a safe and secure temporary bracing system during the construction phase of the project, all bracing connections should be inspected after wind speeds of 35 mph or more to see if any connections have loosened (Dayton Superior, 2017; Tilt-Up Concrete Association, 2011). After each use, all braces should be inspected for damage, wear, and proper operation before being used on another project (Dayton Superior, 2018).

2.3 Brace Anchorage Systems

Temporary bracing is one of the most important aspects of a tilt-up concrete panel project. Tilt-up concrete panels can be extremely large and typically weigh 80,000 to 120,000 pounds. Until the panel connections to the final structure are completed, the stability of the panels is imperative. Due to the size and weight of the panels, they are very dangerous if the bracing system fails and an accidental collapse occurs. These temporary braces are attached to the tilt-up panel face on one end. The other end (base) must be anchored to an element that can withstand the forces the brace will encounter by the wind pressure on the tilt-up panels. The three most common methods of anchorage of temporary tilt-up panel bracing are concrete deadmen, helical ground anchors, and slab-on-grade anchors (Baty, 2014). While a slab-on-grade anchorage system is the only system that is considered and analyzed in the parametric study in Chapter 3, all three methods are discussed in this section to gain insight into their similarities, differences, advantages, and disadvantages.

2.3.1 Concrete Deadmen

Concrete deadmen "are perhaps the most basic type of anchorage system known to man (Engelland, 2020b). They utilize the same concept that a boat anchor does: using weight and friction to prevent something from moving. Steinbicker (2018) defines a concrete deadman as "a buried concrete element that is sometimes used to anchor braces on a project that does not have a concrete slab on grade available." Most concrete deadmen are cast in the ground at the job site; they can be cast either as a single pad or a continuous strip of concrete (Steinbicker, 2018). According to Baty (2014), concrete deadmen that are cast and located at specific job sites for certain projects are not meant to be removed and reused after completion of the project. However, precast deadmen are reusable and preferred by some contractors (Baty, 2014). Baty

(2014) states that concrete deadmen are typically buried in the ground, but it is possible to use them above grade; however, this is not a recommended practice as the concrete deadman can easily become unstable and potentially lead to the collapse of a tilt-up panel. Deadmen can become unstable because they rely on the soil, which can become insecure from poor compaction or washout from rainwater, to distribute the force from the brace. Baty (2014) recommends that deadmen be used as a buried element in order to resist the brace forces by way of their "own weight, passive soil pressure, and friction with the ground." Temporary bracing can be attached to either the interior or exterior face of the panel. Concrete deadmen are often used when bracing is to the exterior face of the panel as there is no slab-on-grade present (Tilt-Up, 2011). Concrete deadmen can also be used to anchor braces that are located within the slab leave-out section as shown in the plan view in Figure 2-4.

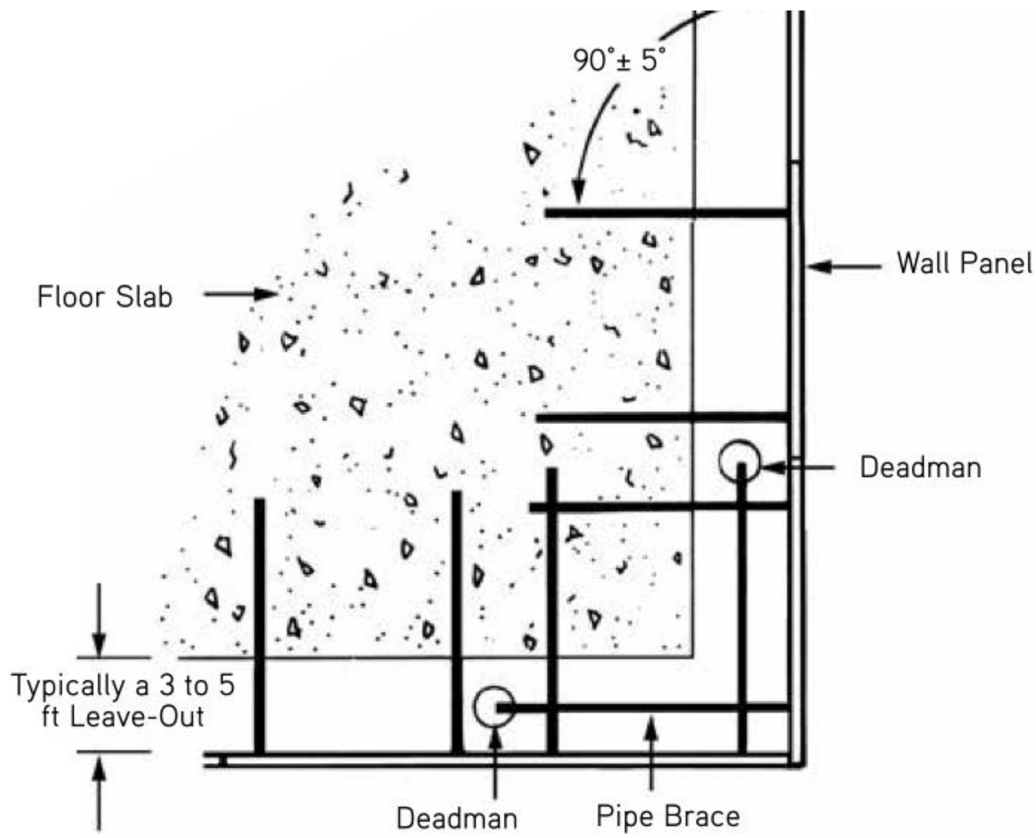


Figure 2-4: Plan View of Concrete Deadmen Anchoring Corner Panel Braces (Reproduced from Dayton Superior, 2017)

As shown in Figure 2-4, when the slab-on-grade is not available to attach to braces, such as a corner of the building, deadmen are used. This plan view shows how concrete deadmen are used:

- Temporary Pipe braces are used to support the wall panels from the interior of the building.
- Concrete deadmen are used to anchor the two braces nearest the corner that are not anchored in the concrete floor slab due to the slab leave out.

Concrete deadmen do have some advantages as a method of anchorage for panel bracing. For one, they can be used for anchorage of exterior braces when a slab-on-grade is not present. Secondly, when in the form of a reusable deadman, they can be a tool for contractors to transport to and from job sites for repeated use. One disadvantage of using concrete deadmen for brace anchorage is cost. Being that they are made out of concrete, extra cost will come as a result of the concrete needed to make the deadmen (MeadowBurke, 2018). Because the deadmen are usually cast-in-place at the site, time is needed to allow the deadmen to cure before they are ready to anchor the braces, and they will potentially be in the way of cranes and other machinery trying to maneuver around the jobsite if they are located outside the building pad.

2.3.2 Helical Ground Anchors

Helical ground anchors are an alternative to both concrete deadmen and slab-on-grade support systems in that they do not rely on concrete to anchor the temporary brace. Developed in the mid-1990s, they are a relatively new method of brace anchorage that has received increased usage in the tilt-up concrete industry as contractors have realized some benefits of bracing to the exterior of the building (Hooker, 2012). Helical ground anchors are manufactured steel foundation elements made up of a solid steel square bar shaft with one or more steel helix plates welded onto the shaft at predetermined spacing (MeadowBurke, 2018). Helical ground anchors look and act like a typical screw. Once driven into the ground by a skid-steer (Figure 2-5), they have the anchor capacity to resist both compressive and tensile forces from the loads on the panel through the temporary brace (Baty, 2014). The holding capacity of the anchor is proportional to the torque at which the anchor is installed (MeadowBurke, 2018). The helical ground anchor

Figure 2-5: Skid-Steer Installing Helical Ground Anchor (Reproduced from Dayton Superior, 2017)

relies on the strength of the surrounding soil to distribute on the load it will endure from the brace. Because of this, geotechnical reports outlining the soil conditions at the proposed locations of helical ground anchors are essential to ensure a secure bracing system (Meadowburke, 2018). In order to confirm adequate bracing of the tilt-up panels, the braces themselves must fall within a range of angles relative to the ground. "Brace angles over 60 degrees from the horizontal results in poor mechanical advantage and excessive vertical kick, while brace angles under 45 degrees decrease brace buckling strength due to greater length and excessive sag" (Dayton Superior, 2018). Helical ground anchors must match that same angle range to ensure that they are parallel and aligned with the brace they are anchoring so that the two act as one unit (Bell, 2014). The task of determining which helical ground anchor and setup is appropriate for the scenario is typically handled by the anchor manufacturer (Bell, 2014). The anchor manufacturer will also inspect the soil conditions and determine the required embedment length of the helical ground anchor based on the existing soil conditions. One aspect of helical ground anchors that makes them a viable option for brace anchorage is their longevity. Once the structure and foundation are complete and the tilt-up panel is secure, "the anchors can be retrieved and all the undamaged bracing system components reused" (Hooker, 2012). Current estimates would suggest that helical ground anchors account for 10% - 15% of the tilt-up brace anchorage market (Hooker, 2012). Helical ground anchors also have the flexibility of anchoring bracing on both the interior and exterior face of the panel. As tilt-up concrete panels are getting taller, Hooker (2012) says that the tilt-up industry is beginning to realize the benefits of bracing to the exterior side of the panel to free up floor space on the interior and reduce the likelihood of an accident. This makes helical ground anchors a viable option for brace anchorage moving forward. When high winds cause forces transmitted through the brace to be very large, it can sometimes be more economical to use a helical ground anchor rather than thickening a portion of the slab-on-grade to resist the brace loads (Hooker, 2012). Figure 2-6 shows a section cut of a tilt-up concrete panel supported by a brace anchored by a helical ground anchor.

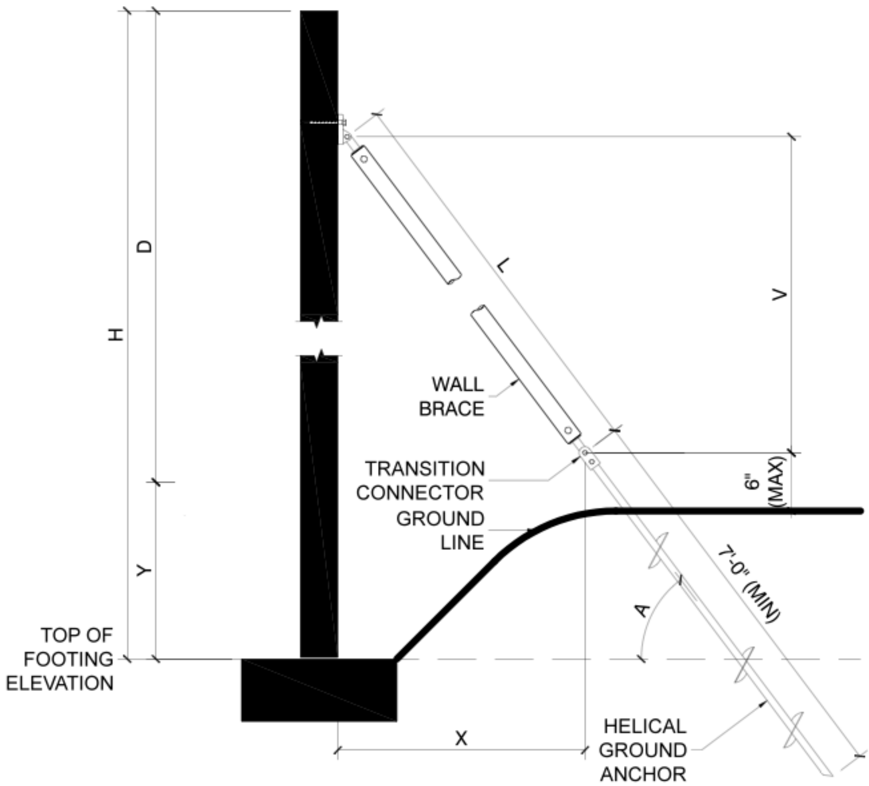


Figure 2-6: Section Cut of Tilt-Up Concrete Panel with Helical Ground Anchor (Reproduced from Steinbicker, 2018)

As shown in Figure 2-6, four basic components on helical ground anchor bracing systems exist:

- The continuous footing for the panel is shown as a large rectangle below the wall panel. It serves as the foundation system for the wall panel, ensuring that the wall panel is secure once construction is complete. It is designed to carry the weight of the wall panel bearing on it.
- The tilt-up concrete wall panel is the tall element bearing on top of the continuous footing. It is poured out of concrete while lying flat on the ground and is then tilted up vertically by a crane. The wall brace acts as a temporary support for the

panel until construction is complete and panel connections to the footing, roof, and floor are made.

- The wall brace is the element supporting the tilt-up concrete wall panel while construction is being finished. In this set up, the brace is anchored by a helical ground anchor.
- The helical ground anchor is the screw-like element that is driven into the ground at the same angle as the wall brace. The wall brace is connected to the helical ground anchor, which anchors the brace as it resists forces from wind load acting on the tilt-up concrete panel.

One advantage of helical ground anchors is their ability to be installed rapidly in any weather condition and be ready for use immediately (Dayton Superior, 2017). Another advantage is that they can easily be removed and relocated if adjustments to the braces are made during installation (Dayton Superior, 2017). Being that they are reusable and require no concrete are a more reasons why helical ground anchors are a good choice for brace anchorage. While they do require a skid-steer to install, this type of equipment is typically on the job site already (Dayton Superior, 2017).

2.3.3 Slab-on-Grade Anchors

Slab-on-grade anchors are the most common form of bracing anchorage for tilt-up concrete panels (Baty, 2014). One reason for this is that slabs-on-grade are part of the finished tilt-up structure and are used as the forming system for the panels prior to erection. Unlike a concrete deadman or helical ground anchor which are temporary anchor elements, slabs-on-grade are a permanent part of the building. This fact calls for careful consideration and coordination on behalf of the construction crew in two areas. The first area that needs consideration is the forces that are being transmitted through the brace to the slab-on-grade. Because slabs-on-grade are a common structural member, they are usually designed adequately for the loads that they will see over the course of their lifetime. However, they are rarely designed for construction loads, such as those that they will see from the temporary braces (Kelly, 2008). In order to account this scenario, "the type and location of slab joints, slab thickness, reinforcing and leave out strips, and the concrete strength all must be considered when determining if the floor slab has the required capacity to resist the applied brace loads" (Steinbicker, 2018). Kelly (2008) writes

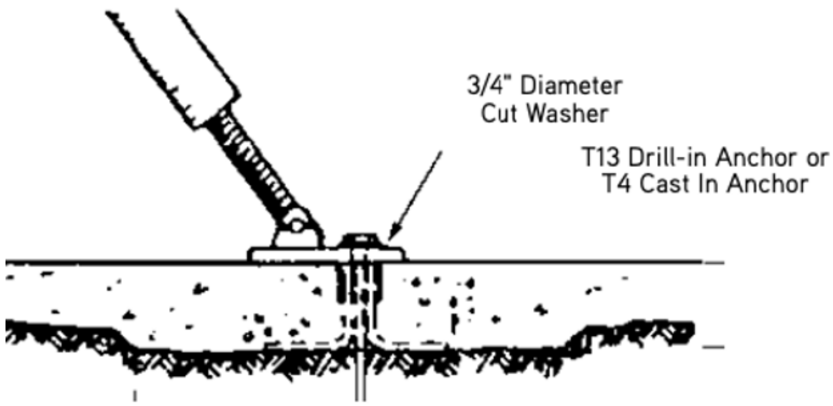


Figure 2-7: Slab-on-Grade Anchor (Reproduced from Dayton Superior, 2017)

that some debate over who is responsible for the design of the slab-on-grade to make sure that it can resist the load from the braces exists. The second area that requires coordination is the placement of the brace anchors. The location of the brace anchors relative to the face of the panel determines the angle that the brace makes with the slab-on-grade. In turn, this angle often determines and regulates the capacity of the braces to withstand the force from the wind load (MeadowBurke, 2018). These anchors can either be cast-in-place or post-installed. Figure 2-7 shows a section cut detail of a slab-on-grade anchor. Cast-in-place anchors require careful planning and coordination as incorrect placement of the anchor could lead to a decrease in the capacity of the brace and potentially an additional cost to relocate the anchor (MeadowBurke, 2018). Post-installed anchors do not require as much planning in advance, but problems can still arise in the field when installing them as the location of steel reinforcement is often unknown when the drilling takes place. Figure 2-8 shows a section of a tilt-up concrete panel supported by a brace anchored in the slab-on-grade.

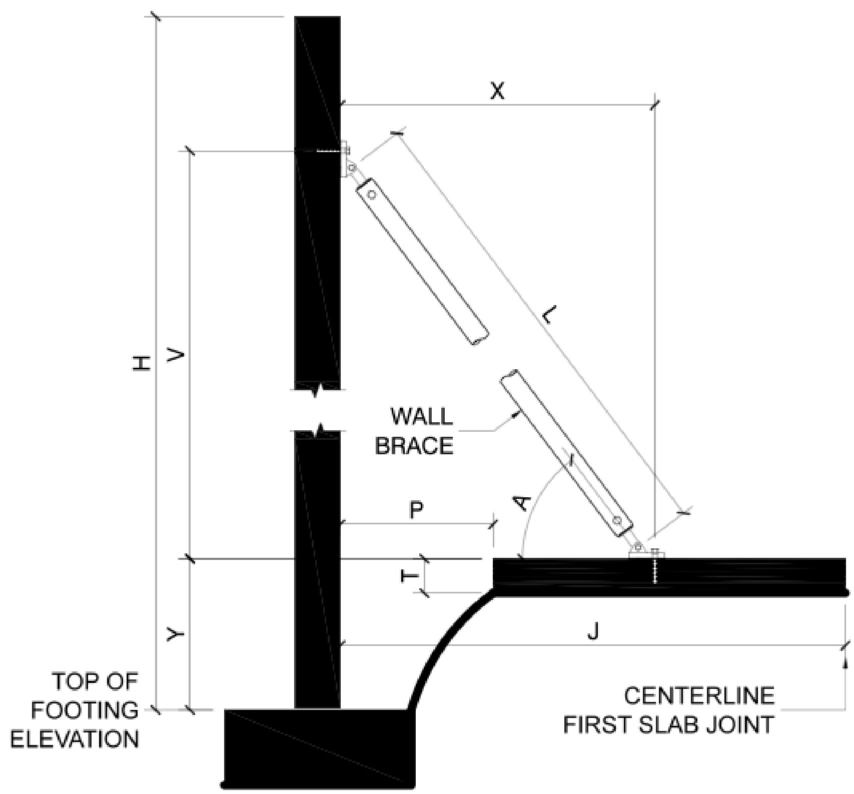


Figure 2-8: Section Cut of Tilt-Up Concrete Panel with Slab on Grade Brace Anchorage (Reproduced from Steinbicker, 2018)

As shown in Figure 2-8, four basic components in this figure are:

- The wall brace is the element supporting the tilt-up concrete wall panel while construction is being finished. In this set up, the brace is anchored in the concrete slab on grade.

- The slab-on-grade is the horizontal section of concrete that the wall brace is bearing on and anchored into. It serves as the anchorage method for the brace as the brace resists forces from wind load acting on the face of the tilt-up panel.

The main advantage for using slabs-on-grade to anchor tilt-up panel braces is that the slab-on-grade is almost always present already. Baty (2014) states that "connecting directly to the building slab is the most efficient and cost-effective form of anchoring the braces." With cost being the driving factor in most construction projects, using a structural member that is already in the budget saves the cost of installing helical ground anchors and the labor of pouring concrete deadmen. A disadvantage to anchoring to the slab-on-grade is the additional consideration and coordination that is needed. The load from the braces must be considered when designing the slab-on-grade, and the location of the cast-in-place anchor inserts must be coordinated unless post-installed, drill-in anchors are used.

Chapter 3 - Parametric Study

As previously indicated, the most common way to secure temporary braces for tilt-up panels during construction is to use the slab-on-grade. To examine the behavior of slab-on-grade with brace loads a parametric study of a typical warehouse building is conducted.

3.1 Panel Variables

The tilt-up panel used in this study is 42 feet tall from its base to its top, 26 feet wide, and 9.25 inches thick. The panel is solid, without openings. It is positioned directly on a continuous footing four feet below finish floor elevation to the top of the footing, making the panel's height above finish floor 38 feet. A five-foot slab leave-out strip is assumed around the perimeter of the building for construction purposes. The building plan dimensions are 300 feet in length as shown in Figure 3-1, by 830 feet. This building layout is based on an actual tilt-up concrete panel construction project located in the Kansas City area.

3.2 Loading Variables

The panel does not have openings and therefore is classified as solid. To calculate the limit state wind loads applied to the braced, the strength level construction period wind speed of 80 mph adopted by the TCA is used. This wind speed assumes an ASCE/SEI Risk Category I structure as defined in Table 1.5-1 of the ASCE/SEI 7-16. The basic wind speed for this category is 100 mph but is adjusted by a factor of 0.8 to account for a construction period of six weeks to one year as outlined in the literature review. To calculate the design wind force acting on the panels while braced, the method outlined in ASCE/SEI 7-16, Chapter 29, *Wind Loads on Building Appurtenances and Other Structures: Main Wind Force Resisting System (Directional Procedure)* is used. This procedure considers the panels as freestanding braced walls, and only load Case A from ASCE/SEI 7-16 Figure 29.3-1 is considered. It begins with determining the panel's total height above the adjacent ground, *h*, the vertical dimension of the panel, *s*, the panel width, *B*, the panel thickness, *t*, and the panel's depth below and height above finish floor. Then, the clearance ratio (*s/h*) and aspect ratio (*B/s*) are determined. For a solid panel supported at ground level, the clearance ratio is 1. If the panel has openings, the opening area is subtracted from the gross panel area to determine the net solid area of the panel. The ratio of net solid area to gross area is calculated, and the panel is classified as solid if this ratio is greater than 70 percent. Once the panel's classification is determined, the design wind force is calculated following the procedure outlined in the 2.2 Temporary Bracing Guidelines section of Chapter 2 - Literature Review. Stress level (ASD) wind force is also calculated by multiplying the design wind force by a factor of 0.6 (ASCE/SEI 7-16). The stress level force will be used to analyze the slab's sliding resistance. After the design wind force acting on the panels has been calculated, the next step is to determine the force transmitted to the temporary bracing. Chapter 29 of the ASCE/SEI 7-16 specifies that the design wind force is to be applied at 55 percent of the panel's height. Although the panel is sitting either a strip footing or a stem wall, the entire design wind force is assumed to be resisted by the temporary bracing. This is because there is no connection made between the panel's base and the foundation. While the weight of the panel on the foundation would create some friction resistance, this procedure does not account for that and instead takes the conservative approach of resisting the design wind force with the braces alone. TCA's guideline states that the brace attachment insert should be located at either 60 percent of the panel's total height or 5 percent above the geometric centroid of the panel, whichever is greater. Once this minimum brace attachment height is determined, the horizontal component of the force transmitted into the brace is found by taking the design wind force multiplied by 55 percent of the panel's height and then dividing by the minimum brace attachment height. This horizontal force component is then divided by the cosine of the brace angle, 53 degrees, to determine the total required axial strength of the braces. The required axial strength is then divided by a resistance factor of 0.9 for strength design. The same procedure is followed using the stress level wind force rather than the design (limit state) wind force. After determining the total required axial strength of the braces, it is then multiplied by a safety factor of 1.67 for allowable stress design.

This reduced total required axial strength is then used to determine the type and number of braces needed for the bracing system. A Dayton Superior B12 Jumbo Brace was selected to be used in this study, and it was found that three braces were required. The total strength level required axial strength of 26,953 lb. is then divided by three to achieve a load of 8,984 lb. for each brace. The brace has a nominal load capacity of 13,500 pounds. Figure 3-2 shows a plan view of the panel braced to the slab-on-grade. It is 32 feet in length, attaches to the panel at a height above finish floor of 25 feet 6 inches, and attaches to the slab-on-grade at a distance of 19 feet 4 inches from the face of the panel. The brace load is converted into its vertical and horizontal components at its connection to the slab-on-grade. The vertical component is obtained by taking the brace load multiplied by the sine of 53 degrees, resulting in a 7.18-kip (1 kip = 1,000 lb.) force. The horizontal component is calculated by taking the brace load multiplied by the cosine of 53 degrees, resulting in a 5.41-kip force. The same process is repeated with the stress level loads. The total stress level required axial strength of 16,172 lb. is then divided by three, resulting in a load of 5,391 lb. for each brace. The stress level vertical component is 4.31 kips, and the stress level horizontal component is 3.24 kips. See Figure 3-3 for a section view of the bracing condition. As previously calculated, three of these braces are used to support the panel. Brace foot plate dimensions are assumed to be 10 inches long and 6 inches wide. A Dayton Superior 4.5" long, ¾" diameter T13 Coil-Anchor is used to attach the brace to the slab-on-grade. It has a nominal load capacity of 11,288 pounds for a 5 inch or thicker slab-on-grade with a compressive strength of 4,000 psi. This nominal capacity is based on a tension applied at a 53-degree angle, the same angle as the brace, so it is to be compared to the strength level brace load, not the vertical component of the brace load, after being reduced by the strength reduction factor. Because this load capacity is less than what the brace can withstand, the nominal load capacity of the brace is reduced to that of the anchor.

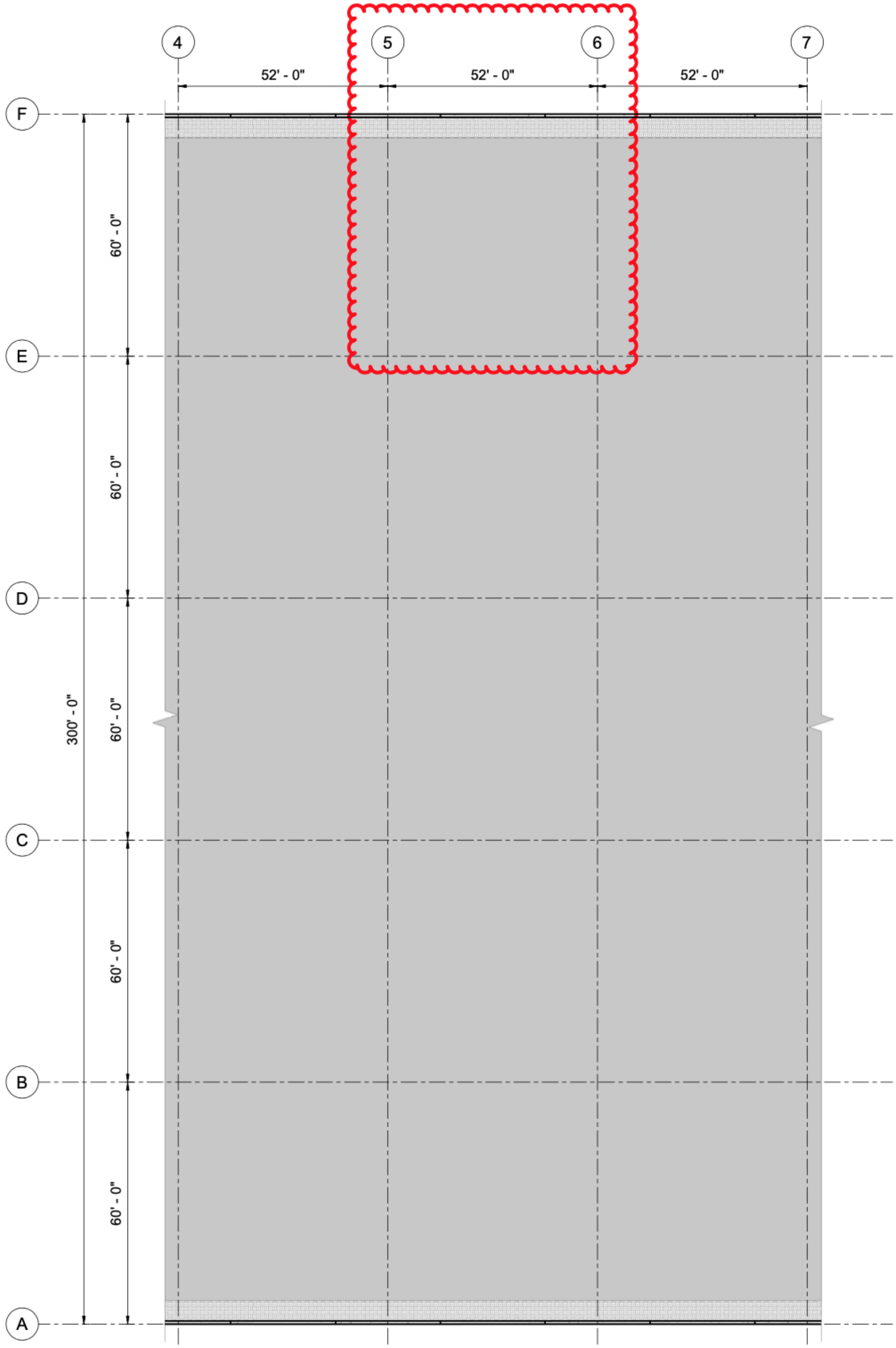


Figure 3-1: Full Plan View of Building

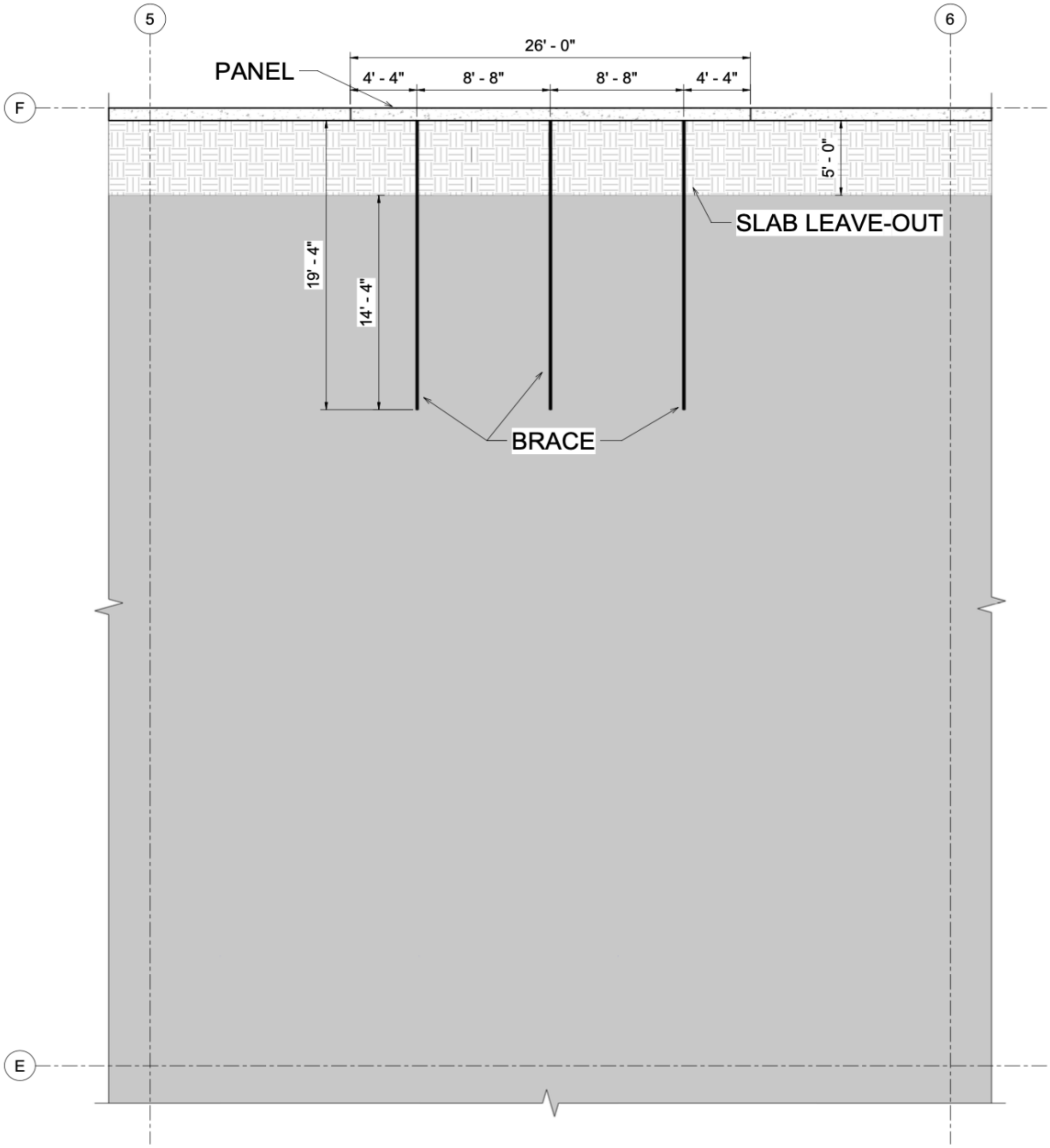


Figure 3-2: Plan View of Bracing Setup

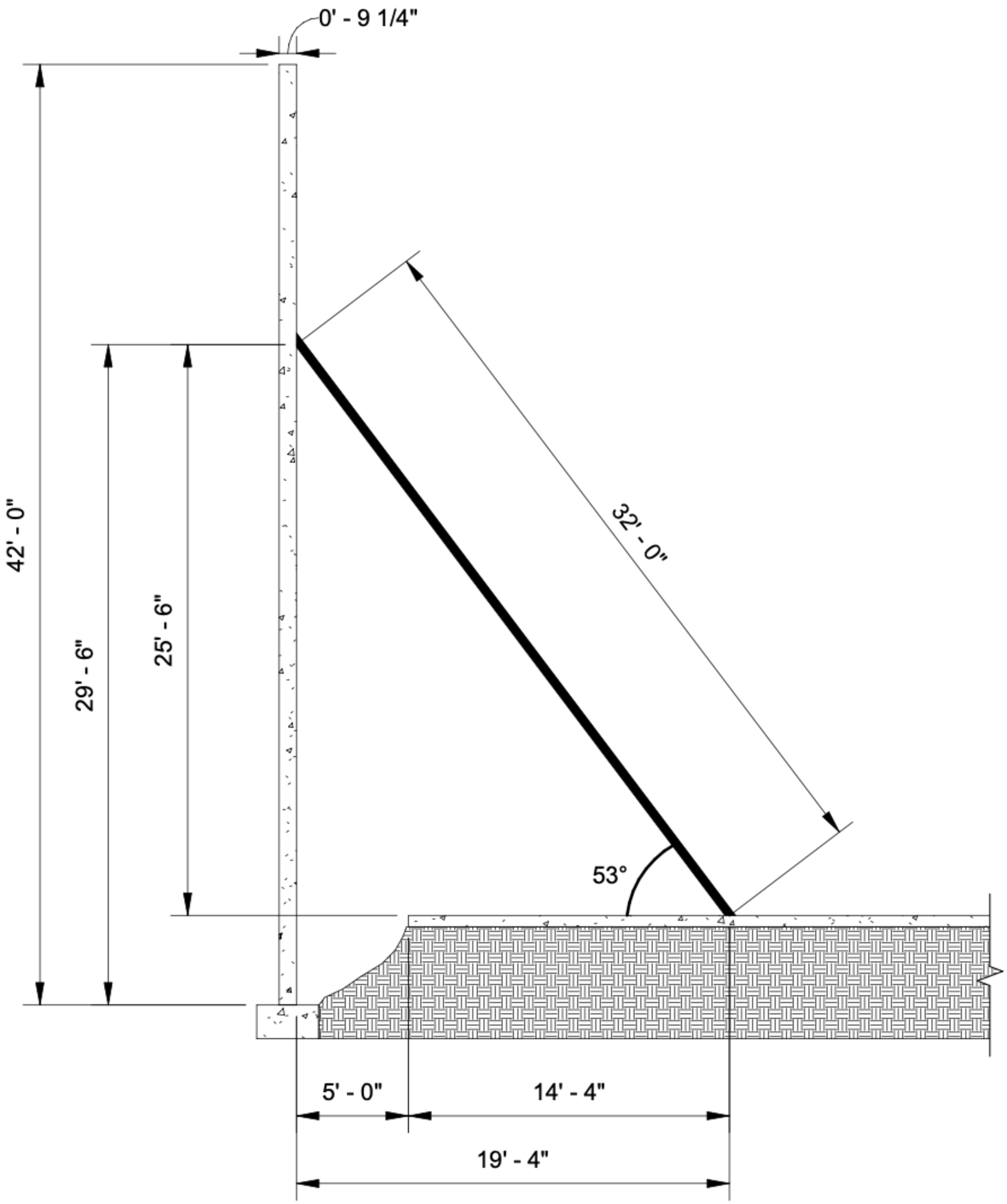


Figure 3-3: Section View of Bracing Setup

3.3 Slab-on-Grade Variables

Slab-on-grade control joints are located at each column gridline. Wind load acts on all the panels at the same time, but for this parametric study one panel, along with its respective slab-on-grade area, is isolated for analysis. Because the slab-on-grade is assumed to not act cohesively across control joints, the only portion of the slab-on-grade analyzed is located within grids E and F vertically and grids 5 and 6 horizontally as shown in the bubbled portion of Figure 3-1. Figure 3-2 is an enlarged view of the bubbled portion in Figure 3-1 and is the focus of this parametric study. Due to the building's length, the brace forces transmitted into the slab-on-grade on the opposite side of the building will have no effect on the portion of the slab-on-grade under consideration for this study. The slab-on-grade is constructed of normal weight concrete (145 pounds per cubic foot) with a compressive strength of 4,000 psi. It has a nominal quantity of distributed reinforcement located in the upper third of the slab as mentioned in the literature review. Three slab-on-grade thickness are analyzed in this study: 5-inch, 6-inch, and 8-inch.

3.4 Soil Variables

Four different subgrade conditions are analyzed. Each condition describes the material that is directly beneath the slab-on-grade. For the purpose of this study, the subgrade below the top material is assumed to have adequate sliding resistance between the layers. The analysis of the sliding plane is between the bottom of the slab-on-grade and the top layer of subgrade material only. The four conditions are gravel (Figure 3-4), sand (Figure 3-5), soil (Figure 3-6), and a vapor retarder (Figure 3-7). Each material has its own coefficient of friction. The coefficients for each material, as based on research, are as follows: 0.6 for gravel, 0.45 for sand, 0.3 for soil, and 0.15 for a vapor retarder (Armstrong, 1992).

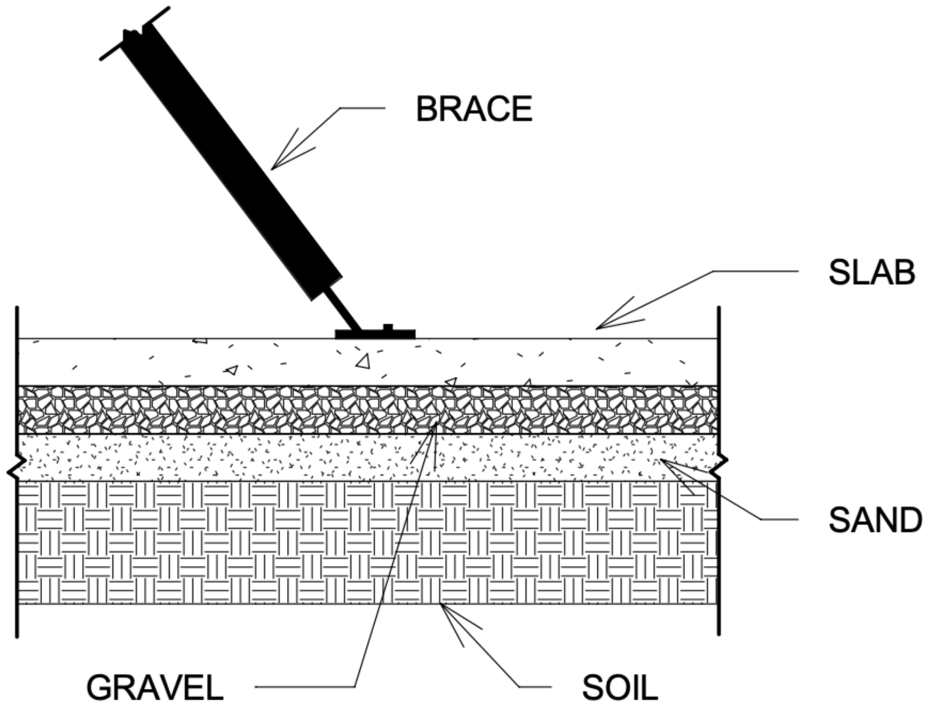


Figure 3-4: Gravel Subgrade Condition

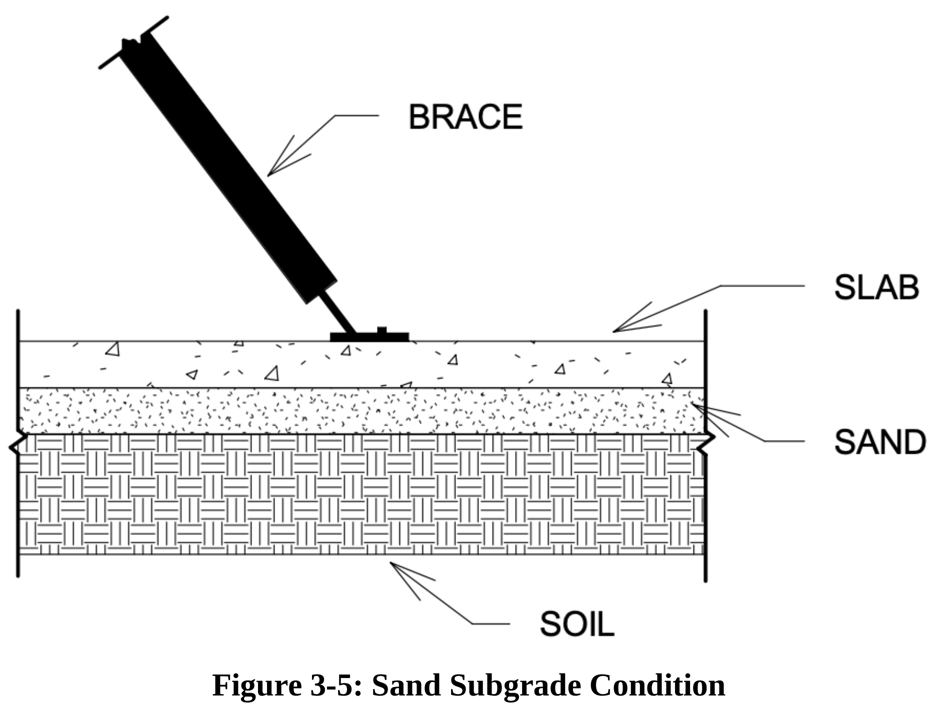


Figure 3-5: Sand Subgrade Condition

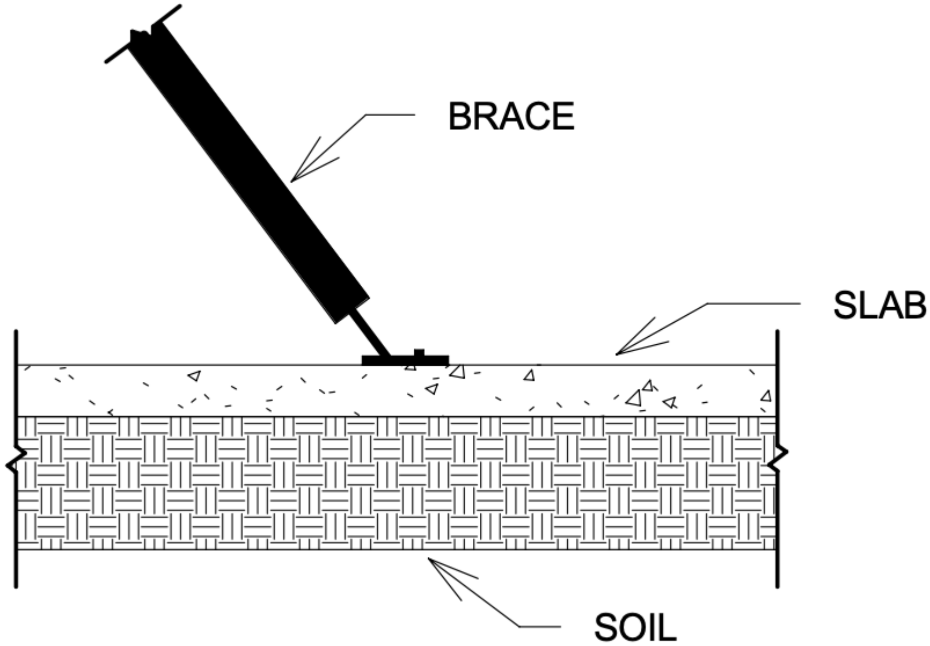


Figure 3-6: Soil Subgrade Condition

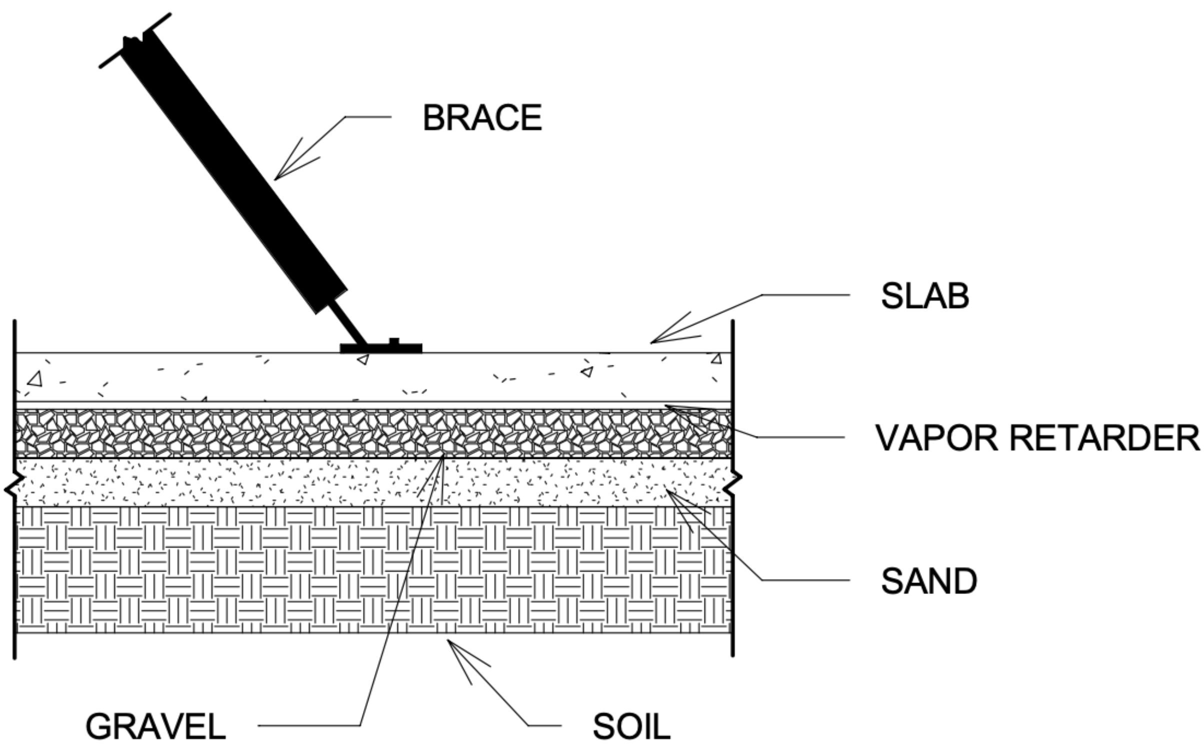


Figure 3-7: Vapor Retarder Subgrade Condition

3.5 Brace Anchor & Slab-on-Grade Interaction

The design wind force is transferred through the temporary braces to the slab-on-grade. The load is then broken up into a vertical component and a horizontal component as previously mentioned. When the wind is from the left as show in Figure 3-8, the two conditions that are checked are slab sliding in the horizontal direction and punching shear in the downward vertical direction. Punching shear capacity is determined following Chapter 14 Plain Concrete of the *ACI 318-19* as outlined in the literature review. The slab-on-grade's friction force, based on its weight and the coefficient of friction of the subgrade, is checked against the stress level (ASD) horizontal force component. The area of slab-on-grade assumed to be effective in resisting slab sliding is based on a tributary width of 8 feet 8 inches for each brace and a length of 55 feet. This length of 55 feet, shown in red in Figure 3-8, is the distance from the face of the panel to the next control joint minus the 5-foot slab leave-out. Control joints, or construction joints, are locations where the concrete pour is stopped and then started again after finishing of the first slab-on-grade section (ACI Committee 302, 2015). The control joints are located along the gridlines as shown in Figure 3-1, and the slab is assumed to be poured in alternating strips with infill strips in between as suggested in *ACI 302.1R-15*. Referring back to Figure 3-1, strips between grids F-E, D-C, and B-A would be poured first, and infill strips between grids E-D and C-B would be poured later, creating control joints at these grid lines. Although the slab-on-grade on the other side of a control joint would provide some resistance to sliding, it is assumed that this cannot be relied upon as there is no adhesion between the two sections of the slab-on-grade. In the downward direction, the strength level vertical component is compared to the slab-on-grade's punching shear resistance. This is based on the thickness of the slab and the footprint of the brace foot plate. Another potential issue with the vertical force component is soil failure. A soil bearing capacity of 4,000 pounds per square foot is assumed for the parametric study. This soil bearing capacity is reasonable to assume with adequate compaction of the subgrade, and it is larger than the maximum stress from the vertical force component distributed over the critical section of the brace foot plate. Therefore, the soil is considered adequate and is not analyzed in the parametric study.

When the wind is from the right as shown in Figure 3-9, the first two conditions considered are anchor pullout and overturning (slab uplift). As previously mentioned, the T13 coil-anchor's capacity is based on the nominal brace load applied at 53 degrees, not the vertical component of the brace force. The overturning moment resistance, however, is checked using the stress level (ASD) vertical component of the brace force. The overturning moment is the ASD wind force applied at a moment arm of 55 percent of the panel's height. A safety factor of 1.5 is used in the resisting moment calculation. The resisting moment is based in the amount of slab-on-grade able to resist the moment and the location of the slab-on-grade anchor's distance from the face of the panel. The assumed area of slab-on-grade to resist against overturning is 390 square feet. This is based on a width of 26 feet, the entire width of the panel, and a length of 15 feet. This length of 15 feet, shown in Figure 3-9, is assuming that 7.5 feet on either side of the slab-on-grade anchor can be considered effective in resisting against overturning. Saw joints, located at distances (in feet) of three times the slab-on-grade thickness (in inches), are assumed to not affect the slab-on-grade's ability to act cohesively as steel reinforcing is present in the center of the slab. Brace anchors are located at least 12 inches from a saw joint (Dayton Superior, 2017). A saw joint is cut with a concrete saw after finishing of the slab is completed and is typically a quarter of the slab thickness deep (ACI Committee 302, 2015). All three slab-on-grade thicknesses and all four subgrade conditions are analyzed to determine the slab's effectiveness to resist both the horizontal and vertical components of the brace load.

When the wind is from the right, slab sliding can also occur. For this study, it is assumed that the sliding force is equal to that of the opposite wind condition from the left. However, the slab's resistance to sliding is not the same as the uplift force reduces the normal force (slab weight) and therefore decreases the slab's friction force. To account for this, a reduction factor can be applied to reduce the effective area of the slab-on-grade, therefore reducing its weight. For this study, it was found that the reduced weight is proportional to the increase in required slab length. For example, reducing the slab weight by 50% due to uplift increases the required slab length by a factor of two. Another option is the use of a thickened slab portion that would protrude below the rest of the slab, like a key, and provide a vertical surface for the soil to bear against and provide resistance to sliding.

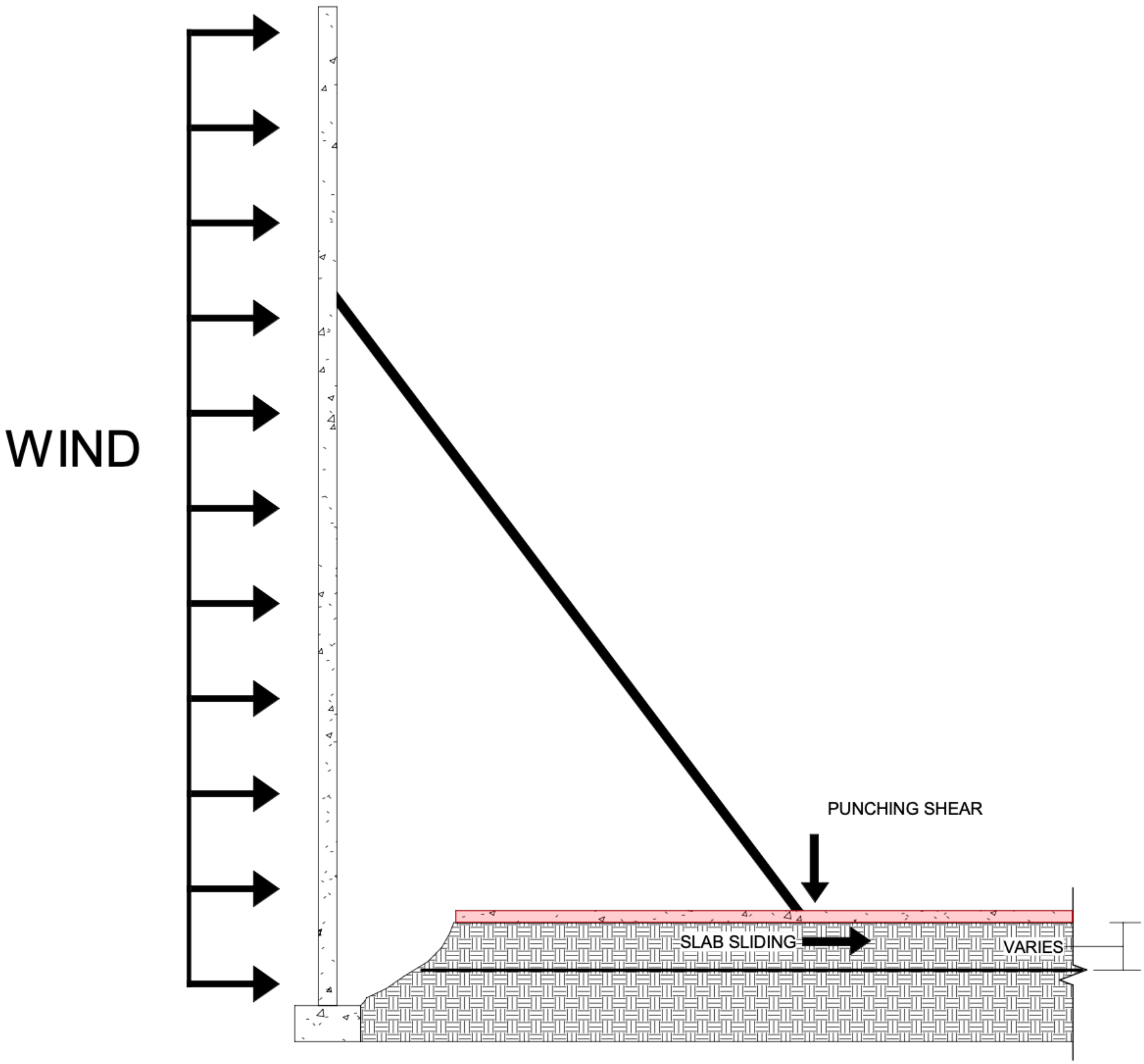


Figure 3-8: Wind from Left

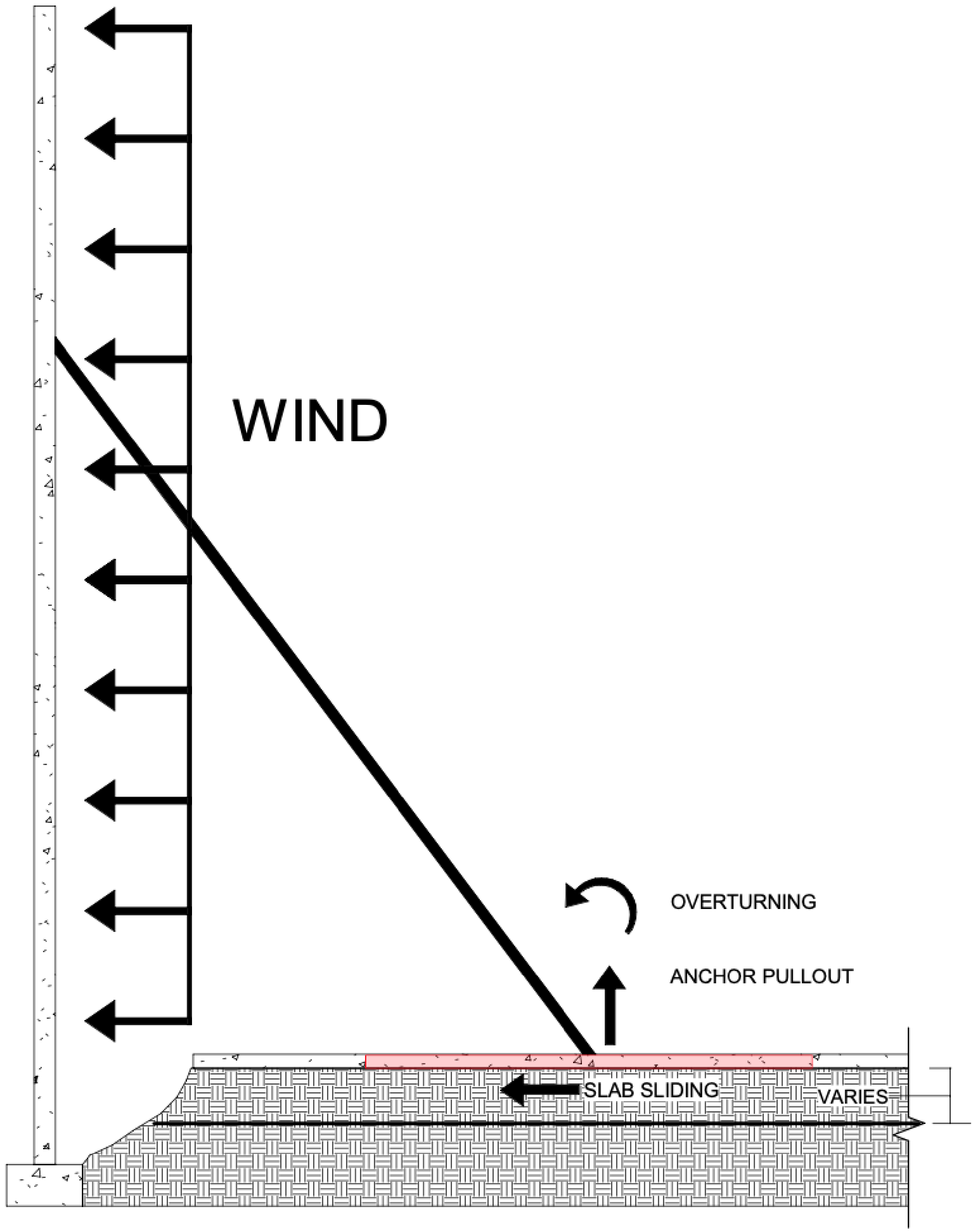


Figure 3-9: Wind from Right

3.6 Sample Calculation

The following is a sample calculation for a 5-inch slab-on-grade with a gravel subgrade. As mentioned previously, the coefficient of friction for gravel is 0.6. Calculations for punching shear, slab sliding, and slab overturning/uplift are shown. Anchor pullout capacity is not shown as the capacity comes directly from the anchor manufacturer. For slab sliding, the slab's friction resistance force is compared to the stress level horizontal component of the brace force. As outlined in chapter 4, the stress level horizontal component is 3.2 kips. The slab's friction resistance force is calculated via the equation below.

$$F = W * \mu \qquad \text{Eq. 3-1}$$

Where:

W = Weight of the concrete slab-on-grade based on its density, effective area, and thickness, kips

μ = Coefficient of friction for the specific subgrade condition

The thickness of the slab-on-grade is set at 5 inches, and the effective width is based on the tributary width of the brace, 8.7 feet for this parametric study. The density of the concrete is 145 pounds per cubic foot. With these three variables set, the required length of slab-on-grade can be found by taking the horizontal component and dividing it by the coefficient of friction (0.6), density (145 pcf), slab thickness (5 inches), and effective width (8.7 feet). This results in a required slab length of 10.3 feet.

The slab's punching shear capacity is calculated using the lesser of equations 14.5.5.1(b) and 14.5.5.1(c) of the *ACI 318-19*. They are listed below.

$$V_n = \left(1 + \frac{2}{\beta}\right)\left(\frac{4}{3}\lambda\sqrt{f'_c}b_o h\right) \qquad \text{Eq. 3-2}$$

$$V_n = 2(\frac{4}{3}\lambda\sqrt{f'_c}b_o h) \quad \text{Eq. 3-3}$$

Where:

f'_c = Concrete compressive strength, psi

b_o = Effective perimeter found by adding half the slab depth to each side of the brace footplate, in.

h = Thickness of the slab minus two inches due to being poured on grade, in.

λ = Lightweight concrete modification factor, 1.0 for normal weight concrete

β = Ratio of long side to short side of effective perimeter dimensions

The compressive strength for this parametric study is 4,000 psi. The effective perimeter is based on the assumed footplate dimensions of 6 inches by 10 inches plus half of the slab depth on each side. For this calculation with a 5-inch slab, the effective dimensions are 11 inches by 15 inches, and *h* is 3 inches. This gives an effective perimeter of 52 inches and a ratio of 1.36. After plugging these values into the two equations above, the lower value is selected. This value comes out to 22.3 kips. It is then reduced by a strength reduction factor of 0.75 for shear, per Table 21.2.1 of the *ACI 318-19*. This gives a punching shear capacity of 16.7 kips, which is greater than the strength level vertical component of the brace force of 7.2 kips.

The required slab length to resist against slab overturning/uplift is found by summing moments about the base of the tilt-up panel. The first moment is the stress level wind force (12.4 kips) multiplied by the distance from the centroid of the wind force to the base of the panel (23.1 feet). This produces an overturning moment of 287.1 k-ft, which is then multiplied by a safety factor of 1.5, resulting in an overturning moment of 431 k-ft. The resisting moment is the weight of the slab multiplied by the distance from the slab anchor to the face of the panel. This distance is 19.3 feet. Dividing the overturning moment by this distance results in a required slab weight of 22.3 kips. Dividing this by the density of 145 pounds per cubic foot produces a required slab volume of 153.7 cubic feet. Finally, after dividing this volume by the slab thickness (5 inches) and the effective width (26 feet), a required slab length to resist overturning of 14.2 feet is found. Complete calculations for all slab-on-grade thicknesses and subgrade conditions can be found in Appendix B.

Chapter 4 - Discussion & Results

Two different wind conditions are analyzed in this report. The first is wind blowing from the left on the exterior face of the tilt-up panel as shown in Figure 3-8. This condition causes the temporary braces to be in compression and creates two potential failure mechanisms. In the downward vertical direction, the slab-on-grade resists punching shear failure caused by the strength level vertical component of the brace force. The second potential failure mechanism is slab sliding in the horizontal direction due to the stress level horizontal component of the brace force. The slab-on-grade's resistance to sliding is based on the weight of the slab portion that is considered effective and the coefficient of friction of the subgrade material immediately beneath the slab-on-grade. The second wind condition is wind blowing from the right on the interior face of the tilt-up panel as shown in Figure 3-9. This condition causes the temporary braces to be in tension and creates two different potential failure mechanisms compared to the first wind condition. In the upward vertical direction, the first potential failure mechanism is pullout of the slab-on-grade anchor. As opposed to slab sliding in the horizontal direction in the first wind condition, the second potential failure mechanism for the second wind condition is slab-on-grade overturning, also known as slab uplift. This happens when the wind attempts to blow the panel over and pull the slab-on-grade up off the ground. The slab-on-grade's overturning-resisting moment is based on the weight of its effective area and the distance of the slab-on-grade anchor to the face of the panel. The assumed effective areas of slab-on-grade for resisting slab sliding and overturning are described in the parametric study. These four potential failure mechanisms are analyzed in this study and are dependent upon two variables.

The first variable is the subgrade material directly beneath the slab-on-grade. The four different subgrade materials are gravel, sand, soil, and vapor retarder. Each material has a different coefficient of friction (listed in the parametric study) and will affect the slab-on-grade's resistance to slab sliding. The second variable is the thickness of the slab-on-grade. The three thicknesses analyzed in this study are 5-inch, 6-inch, and 8-inch. The thickness of the slab-on-grade will affect the punching shear resistance of the slab as well as its overturning and slab sliding resistance as the thickness affects the weight of the slab-on-grade. Calculations for slab sliding and overturning assumed an effective area of slab-on-grade and were checked for adequacy. The calculations also show a required length of slab-on-grade. Both calculations are used to determine the adequacy of the system.

4.1 Five-inch Slab-on-Grade

In the first wind condition, punching shear is analyzed. The 5-inch slab-on-grade has a punching, shear capacity of 16.7 kips. This is much larger than the strength level vertical component of the brace load of 7.2 kips. Therefore, the 5-inch slab-on-grade is adequate to resist against punching shear. In the second wind condition, both anchor pullout and overturning are analyzed. As previously mentioned, the T13 coil-anchor's capacity is based off the tensile brace force applied at 53 degrees. For a 5-inch slab-on-grade with a 28-day compressive strength of 4,000 psi, the anchor pullout design capacity is 10.2 kips (Dayton Superior, 2017). This is larger than the strength level brace force of 9.0 kips; therefore, the T13 coil-anchor drilled into a 5-inch slab-on-grade is adequate. The overturning moment created by the ASD wind force applied at 55 percent of the panel height results in a moment of 287 kip-ft. This is multiplied by a safety factor of 1.5, making the required resisting moment 431 kip-ft. The resisting moment is based off of the effective slab area. The width of this area is assumed to be the entire width of the panel (26 feet). The depth of the slab-on-grade is 5 inches. The required length of the slab is 14.2 feet. It is reasonable to assume that 7.5 feet of slab-on-grade on either side of the anchor can be assumed to be effective; therefore, the 5-inch slab-on-grade is adequate to resist overturning. For the first wind condition, the slab sliding is analyzed for a 5-inch slab-on-grade based on the four different subgrade conditions. Table 4-1 shows results for the 5-inch slab-on-grade.

4.1.1 Gravel

The stress level horizontal component of the brace force is 3.2 kips. The slab-on-grade resists against this via its weight and the coefficient of friction of the subgrade material. The effective width of the slab area is the tributary width of the brace. This value is 8.7 feet (8 feet 8 inches). The slab-on-grade thickness is 5 inches. The coefficient of friction for gravel is 0.6. The required length of the slab area to resist sliding is 10.3 feet. It is reasonable to assume that this length of slab is effective in resisting sliding, so the 5-inch slab-on-grade with gravel directly beneath is adequate.

4.1.2 Sand

The stress level horizontal force component, effective slab width, and slab thickness are the same as the gravel condition. The coefficient of friction for sand is 0.45. The required length of slab area to resist sliding is 13.8 feet. It is reasonable to assume that this length of slab is effective in resisting sliding, so the 5-inch slab-on-grade with sand directly beneath is adequate.

4.1.3 Soil

The stress level horizontal force component, effective slab width, and slab thickness are the same as the gravel and sand condition. The coefficient of friction for soil is 0.3. The required length of slab area to resist sliding is 20.6 feet. It is reasonable to assume that this length of slab is effective in resisting sliding, so the 5-inch slab-on-grade with soil directly beneath is adequate.

4.1.4 Vapor Retarder

The stress level horizontal force component, effective slab width, and slab thickness are the same as the gravel, sand, and soil condition. The coefficient of friction for a vapor retarder is 0.15. The required length of slab area to resist sliding is 41.3 feet. The closest control joint is at 55 feet from the slab leave-out, so no control joints are located within this required length. Saw joints will be located at roughly 18 feet on center for a 5-inch slab, but it is assumed that they will not affect the slab's ability to act cohesively to resist sliding in the horizontal direction. Because of this, it is reasonable to assume that this length of slab is effective in resisting sliding, so the 5-inch slab-on-grade with a vapor retarder directly beneath is adequate.

Table 4-1: Five-inch Slab-on Grade Results

<table>
<tr><th>Failure Type</th><th>Vertical Component / Brace Force / Overturning Moment / Horizontal Component</th><th colspan="2">Capacity (kips) or Required Length (ft)</th></tr>
<tr><td>Punching Shear</td><td>7.2 k</td><td colspan="2">16.7 k</td></tr>
<tr><td>Anchor Pullout</td><td>9.0 k</td><td colspan="2">10.2 k</td></tr>
<tr><td>Overturning</td><td>431 k-ft</td><td colspan="2">14.2 ft</td></tr>
<tr><td rowspan="4">Slab Sliding</td><td rowspan="4">3.2 k</td><td>Gravel</td><td>10.3 ft</td></tr>
<tr><td>Sand</td><td>13.8 ft</td></tr>
<tr><td>Soil</td><td>20.6 ft</td></tr>
<tr><td>Vapor Retarder</td><td>41.3 ft</td></tr>
</table>

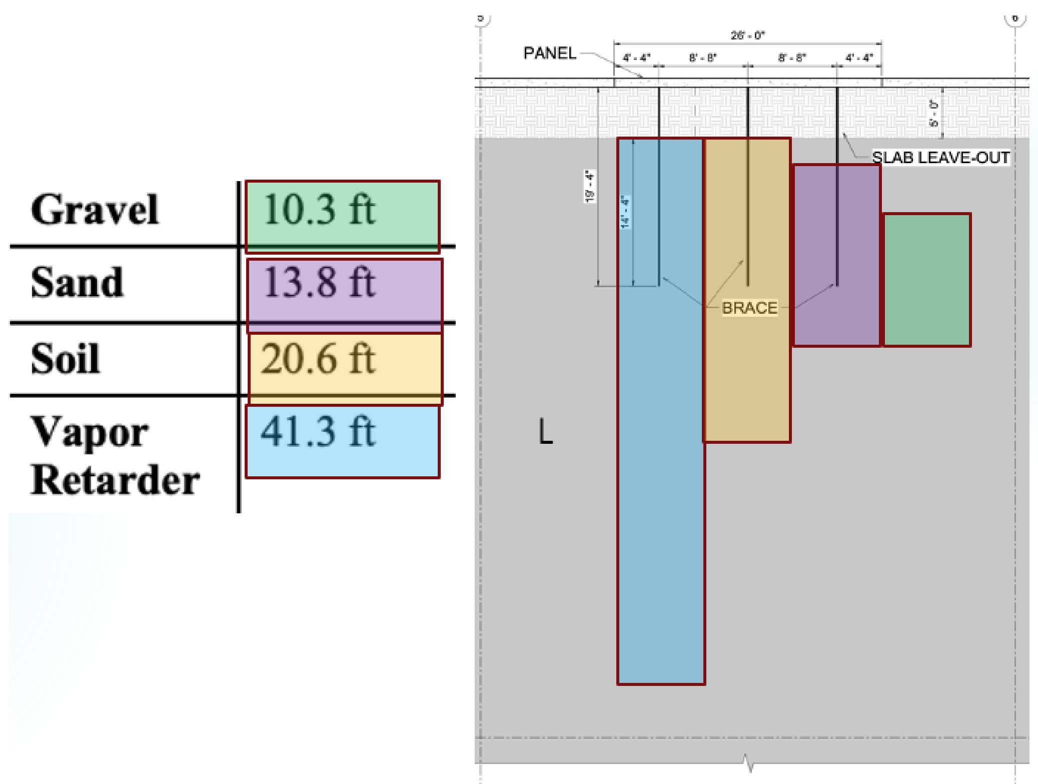


Figure 4-1: Five-inch Slab Sliding Results

4.2 Six-inch Slab-on-Grade

As with the 5-inch slab, punching shear is analyzed in the first wind condition. The 6-inch slab-on-grade has a punching, shear capacity of 24.3 kips. This is much larger than the strength level vertical component of the brace load of 7.2 kips. Therefore, the 6-inch slab-on-grade is adequate to resist against punching shear. Again, in the second wind condition, both anchor pullout and overturning are analyzed. Anchor pullout capacity does not change as it is based on Dayton Superior's (2017) table for a 5-inch or thicker slab. The overturning moment and the 1.5 safety factor-adjusted moment created by the ASD wind force are the same as the 5-inch slab. The width of the effective area is the same as the 5-inch slab (26 feet). The depth of the slab-on-grade is 6 inches. The required length of the slab is 11.8 feet. This decrease in required length is due to the increased slab weight from the larger thickness. It is reasonable to assume that 6 feet of slab-on-grade on either side of the anchor can be assumed to be effective; therefore, the 6-inch slab-on-grade is adequate to resist overturning. For the first wind condition, the slab sliding is analyzed for a 6-inch slab-on-grade based on the four different subgrade conditions. Table 4-2 shows results for the 5-inch slab-on-grade.

4.2.1 Gravel

The following information is the same as the 5-inch slab-on-grade condition: the stress level horizontal component of the brace force is 3.2 kips, and the effective width of the slab area is the tributary width of the brace, 8.7 feet (8 feet 8 inches). The slab-on-grade thickness is 6 inches. The coefficient of friction for gravel is 0.6. The required length of the slab area to resist sliding is 8.6 feet. It is reasonable to assume that this length of slab is effective in resisting sliding, so the 6-inch slab-on-grade with gravel directly beneath is adequate.

4.2.2 Sand

The stress level horizontal force component, effective slab width, and slab thickness are the same as the gravel condition. The coefficient of friction for sand is 0.45. The required length of slab area to resist sliding is 11.5 feet. It is reasonable to assume that this length of slab is effective in resisting sliding, so the 6-inch slab-on-grade with sand directly beneath is adequate.

4.2.3 Soil

The stress level horizontal force component, effective slab width, and slab thickness are the same as the gravel and sand condition. The coefficient of friction for soil is 0.3. The required length of slab area to resist sliding is 17.2 feet. It is reasonable to assume that this length of slab is effective in resisting sliding, so the 6-inch slab-on-grade with soil directly beneath is adequate.

4.2.4 Vapor Retarder

The stress level horizontal force component, effective slab width, and slab thickness are the same as the gravel, sand, and soil condition. The coefficient of friction for a vapor retarder is 0.15. The required length of slab area to resist sliding is 34.4 feet. As mentioned with the 5-inch slab, the closest control joint is at 55 feet from the slab leave-out, so no control joints are located within this required length. Saw joints are not assumed to affect the slab's ability to act cohesively to resist sliding in the horizontal direction. Because of this, it is reasonable to assume that this length of slab is effective in resisting sliding, so the 6-inch slab-on-grade with a vapor retarder directly beneath is adequate.

Table 4-2: Six-inch Slab-on-Grade Results

<table>
<tr><th>Failure Type</th><th>Vertical Component / Brace Force / Overturning Moment / Horizontal Component</th><th colspan="2">Capacity (kips) or Required Length (ft)</th></tr>
<tr><td>Punching Shear</td><td>7.2 k</td><td colspan="2">24.3 k</td></tr>
<tr><td>Anchor Pullout</td><td>9.0 k</td><td colspan="2">10.2 k</td></tr>
<tr><td>Overturning</td><td>431 k-ft</td><td colspan="2">11.8 ft</td></tr>
<tr><td rowspan="4">Slab Sliding</td><td rowspan="4">3.2 k</td><td>Gravel</td><td>8.6 ft</td></tr>
<tr><td>Sand</td><td>11.5 ft</td></tr>
<tr><td>Soil</td><td>17.2 ft</td></tr>
<tr><td>Vapor Retarder</td><td>34.4 ft</td></tr>
</table>

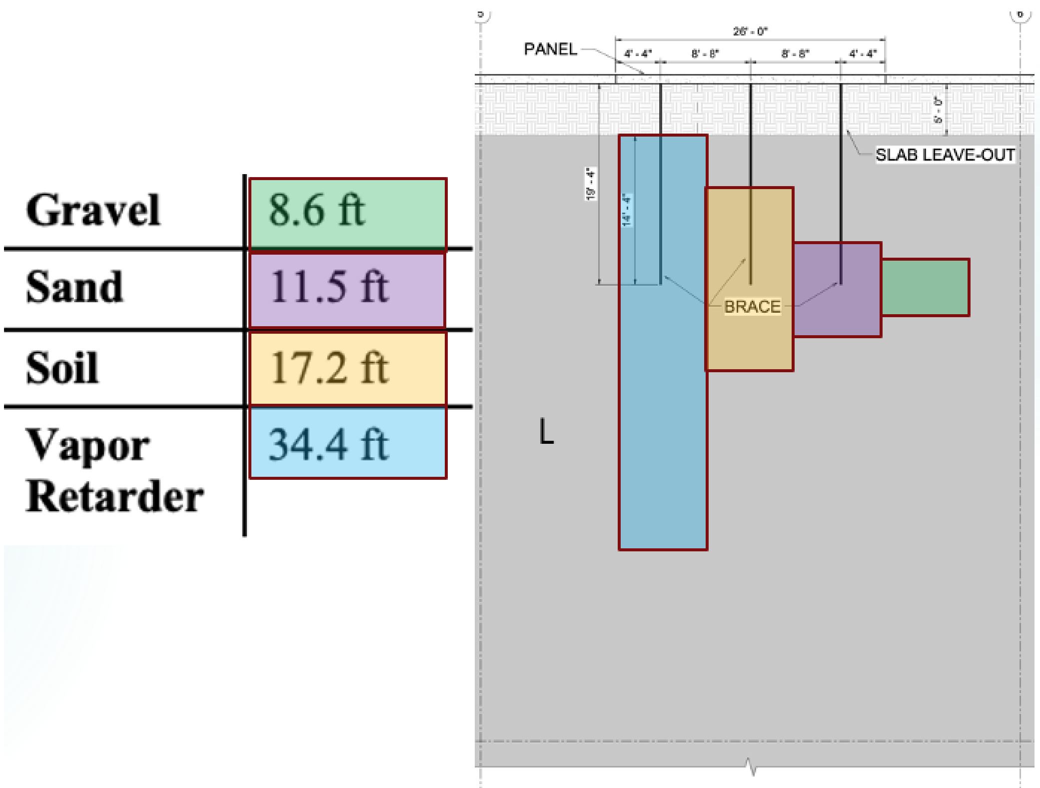


Figure 4-2: Six-inch Slab Sliding Results

4.3 Eight-inch Slab-on-Grade

For the 8-inch slab-on-grade, punching shear capacity increased to 42.5 kips due to a larger depth, which directly affects the capacity in the shear equation. Anchor pullout capacity does not change as it is based on Dayton Superior's (2017) table for a 5-inch or thicker slab. The overturning moment and the 1.5 safety factor-adjusted moment created by the ASD wind force are the same as the 5-inch and 6-inch slab. The width of the effective area is still the entire width of the panel (26 feet). The depth of the slab-on-grade is 8 inches. The required length of the slab is 8.9 feet. This decrease in required length is due to the increased slab weight from the larger thickness. It is reasonable to assume that 7.5 feet of slab-on-grade on either side of the anchor can be assumed to be effective; therefore, the 8-inch slab-on-grade is adequate to resist overturning. For the first wind condition, the slab sliding is analyzed for an 8-inch slab-on-grade based on the four different subgrade conditions. Table 4-3 shows results for the 5-inch slab-on-grade.

4.3.1 Gravel

The following information is the same as the 5-inch and 6-inch slab-on-grade conditions: the stress level horizontal component of the brace force is 3.2 kips, and the effective width of the slab area is the tributary width of the brace, 8.7 feet (8 feet 8 inches). The slab-on-grade thickness is 8 inches. The coefficient of friction for gravel is 0.6. The required length of the slab area to resist sliding is 6.5 feet. It is reasonable to assume that this length of slab is effective in resisting sliding, so the 8-inch slab-on-grade with gravel directly beneath is adequate.

4.3.2 Sand

The stress level horizontal force component, effective slab width, and slab thickness are the same as the gravel condition. The coefficient of friction for sand is 0.45. The required length of slab area to resist sliding is 8.6 feet. It is reasonable to assume that this length of slab is effective in resisting sliding, so the 8-inch slab-on-grade with sand directly beneath is adequate.

4.3.3 Soil

The stress level horizontal force component, effective slab width, and slab thickness are the same as the gravel and sand condition. The coefficient of friction for soil is 0.3. The required length of slab area to resist sliding is 12.9 feet. It is reasonable to assume that this length of slab is effective in resisting sliding, so the 8-inch slab-on-grade with soil directly beneath is adequate.

4.3.4 Vapor Retarder

The stress level horizontal force component, effective slab width, and slab thickness are the same as the gravel, sand, and soil condition. The coefficient of friction for a vapor retarder is 0.15. The required length of slab area to resist sliding is 25.8 feet. It is reasonable to assume that this length of slab is effective in resisting sliding, so the 8-inch slab-on-grade with a vapor retarder directly beneath is adequate.

Table 4-3: Eight-inch Slab-on-Grade Results

Failure Type	Vertical Component / Brace Force / Overturning Moment / Horizontal Component	Capacity (kips) or Required Length (ft)	
Punching Shear	7.2 k	42.5 k	
Anchor Pullout	9.0 k	10.2 k	
Overturning	431 k-ft	8.9 ft	
Slab Sliding	3.2 k	**Gravel**	6.5 ft
		Sand	8.6 ft
		Soil	12.9 ft
		Vapor Retarder	25.8 ft

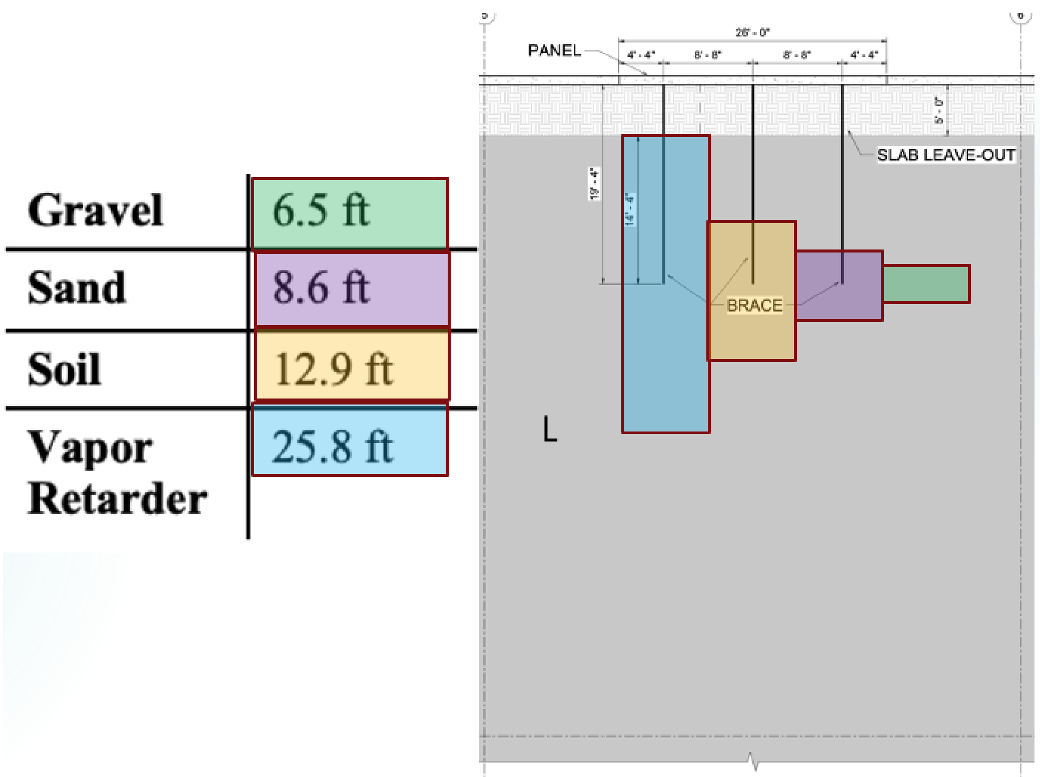


Figure 4-3: Eight-inch Slab Sliding Results

Table 4-4: Results Summary

Slab-on-Grade Results								
Slab Thickness	**Strength Level Vertical Component**	**Punching Shear Capacity**	**Strength Level Brace Force**	**Anchor Pullout Capacity**	**Stress Level Overturning Moment**	**Overturning Required Length**	**Subgrade Condition**	**Sliding Required Length**
5-inch	7.2 k	16.7 k	9.0 k	10.2 k	431 k-ft	14.2 ft	**Gravel**	10.3 ft
							Sand	13.8 ft
							Soil	20.6 ft
							Vapor Retarder	41.3 ft
6-inch	7.2 k	24.3 k	9.0 k	10.2 k	431 k-ft	11.8 ft	**Gravel**	8.6 ft
							Sand	11.5 ft
							Soil	17.2 ft
							Vapor Retarder	34.4 ft
8-inch	7.2 k	42.5 k	9.0 k	10.2 k	431 k-ft	8.9 ft	**Gravel**	6.5 ft
							Sand	8.6 ft
							Soil	12.9 ft
							Vapor Retarder	25.8 ft

Chapter 5 - Conclusion

This report focuses on the analysis of reinforced concrete slabs-on-grade as a means of anchorage for temporary bracing of tilt-up concrete panels. After discussing the existing literature on the subject in order to develop a frame of reference, the parametric study outlines an example tilt-up panel under wind load to determine whether the slab-on-grade is adequate to resist the forces transmitted through the temporary bracing. Two variables are adjusted throughout the analysis of the system. The first is the thickness of the slab-on-grade. Thicknesses of 5-inch, 6-inch, and 8-inch are analyzed. The second variable is the subgrade material directly below the slab-on-grade. The four different subgrade materials analyzed are gravel, sand, soil, and a vapor retarder, with coefficients of friction of 0.6, 0.45, 0.3, and 0.15, respectively. When wind is applied to the exterior face of the panel, causing the braces to be in compression, slab sliding in the horizontal direction and punching shear in the vertical direction are the two potential failure mechanisms. The subgrade material variable affects the slab-on-grade's resistance to sliding as a result of the stress level horizontal component of the brace force. The thickness of the slab-on-grade also has an effect as it determines the weight of the slab-on-grade, which in turn affects its sliding resistance due to friction. The thickness of the slab-on-grade also affects the slab-on-grade's resistance to punching shear in the vertical direction. When wind is applied to the interior face of the panel, causing the braces to be in tension, pullout of the slab-on-grade anchor and overturning of the slab-on-grade are the two potential failure mechanisms. Anchor pullout capacity is consistent regardless of the two changing variables. Resistance to overturning, however, is affected by the thickness of the slab-on-grade.

Based on the results of this study, it is inconclusive exactly how slabs-on-grade resist these horizontal and vertical components of the brace force. While anchor pullout capacity and punching shear capacity for all slab-on-grade thickness are more than adequate, overturning moment resistance and slab sliding resistance are not as clear. Although overturning moment resistance is adequate for the assumed surface area of slab-on-grade and the required length is reasonable, it is unclear exactly how the slab-on-grade acts at saw joint locations where the slab could be cracked completely through and, therefore, is relying on steel reinforcement in order to act cohesively as a unit. For slab sliding, it is assumed that control joint locations are not satisfactory to allow cohesive behavior of the slab to resist the horizontal force component and therefore are a limiting factor in allowable slab-on-grade area considered effective to resist the force. Therefore, a slab-on-grade length of 55 feet is the maximum allowed distance. Although the 5-inch, 6-inch, and 8-inch slabs-on-grade all have required lengths less than 55 feet and therefore are considered adequate to resist against slab sliding, these results are contingent upon engineering judgment of what is considered adequate when looking at required lengths and effective areas. A possible solution to reduce the risk of slab sliding is the use of thickened portions of the slab-on-grade. This thickened portion would provide a vertical surface to bear against the subgrade material and help resist against sliding in the same way that a retaining wall resists against soil pressure. This uncertainty surrounding the slab-on-grade's resistance to overturning and slab sliding is the chief reason for suggesting that it is inconclusive exactly how slabs-on-grade resist these forces in practice.

Further research is needed to better understand exactly how slabs-on-grade resist the combination of forces and prevent slab sliding, overturning, anchor pullout, and punching shear failure. With the tilt-up concrete industry growing rapidly in popularity, and tilt-up panels getting increasingly taller and creating larger brace forces, it is crucial that this subject of brace anchorage via slabs-on-grade is analyzed and understood correctly to ensure safe construction practices. Specifically, physical testing is needed to determine how the slab-on-grade behaves at saw joint locations and control joint locations in response to forces that would cause slab sliding and overturning. Physical testing will allow professionals within the industry to better understand exactly how the slab-on-grade works to safely anchor the temporary bracing of tilt-up concrete panels and ensure that tilt-up concrete construction methods remain both economical and safe.

References

ACI Committee 302. (2015). *Guide to Concrete Floor and Slab Construction (ACI 302.1R-15).* Farmington Hills, Michigan: American Concrete Institute.

ACI Committee 306. (2016). *Guide to Cold Weather Concreting (ACI 306R-16).* Farmington Hills, Michigan: American Concrete Institute.

ACI Committee 318. (2019). *Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary on Building Code Requirements for Structural Concrete (ACI 318R-19).* Farmington Hills, Michigan: American Concrete Institute.

ACI Committee 360. (2010). *Guide to Design of Slabs-on-Ground (ACI 360R-10).* Farmington Hills, Michigan: American Concrete Institute.

Al-Nasra, M. (1994). Parametric Study of Slab-On-Grade Problems Due to Initial Warping and Point Loads. *ACI Structural Journal*, 198-210.

American Association of State Highway and Transportation Officials (AASHTO). (2020). *Mechanistic-Empirical Pavement Design Guide: A Manual of Practice, 3rd Edition.* American Association of State Highway and Transportation Officials (AASHTO).

American Institute of Steel Construction. (2017). *Steel construction manual.*

American Society of Civil Engineers (ASCE). (2016). *Minimum design loads and associated criteria for buildings and other structures: ASCE/SEI 7-16.*

Armstrong, R. C. (1992). *Engineering And Design: Revision Of Thrust Block Criteria In TM 5-813-5/AFM 88-10, Vol 5 Appendix C.* Ft. Belvoir: Defense Technical Information Center.

ASTM. (2016). *Standard Test Method for Nonrepetitive Static Plate Load Test of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements (ASTM D1196).* ASTM.

Baty, J. (2014, August 27). *Bracing and tilt-up concrete*. (Concrete Construction) Retrieved March 23, 2020, from https://www.concreteconstruction.net/how-to/construction/bracing-and-tilt-up-concrete_o

Bell, M. (2014). Developing a Temporary Bracing Plan for Tilt-Up Panels. *Structure Mag*.

Bernard, E. (2006). Influence of Toughness on the Apparent Cracking Load of Fiber-Reinforced Concrete Slabs. *Journal of Structural Engineering*, 1976-1983.

Concrete Construction Staff. (2005, October 12). *Braces for tilt-up construction*. Retrieved from Concrete Construction: https://www.concreteconstruction.net/products/braces-for-tilt-up-construction_o

Dayton Superior. (2017). *Dayton Superior.* Retrieved March 5, 2020, from http://www.daytonsuperior.com/products/accessories?name=t14

Engelland, D. (2020). *A comparison of computer analysis and historical design methods for resisting point loads on slabs on grade.* Kansas State University: Unpublished manuscript.

Engelland, D. (2020). *Methods of bracing anchorage for tilt-up concrete panels.* Kansas State University: Unpublished manuscript.

Hooker, K. A. (2012, September 6). *Helical Anchors Gain Ground in Tilt-Up Concrete Construction*. (Concrete Construction) Retrieved April 8, 2020, from https://www.concreteconstruction.net/how-to/construction/helical-anchors-gain-ground-in-tilt-up-concrete-construction_o

Kelly, D. L. (2008, July 1). *Wall Bracing to Slab-On-Grade Floors*. (Tilt-Up Today) Retrieved April 3, 2020, from https://tilt-up.org/tilt-uptoday/2008/07/01/wall-bracing-to-slab-on-ground-floors/

Kramer, K. (2020). *Tilt-up concrete erection of panels.* [PowerPoint slides]: Retrieved from Kansas State University CNS 629 site.

Krishna. (2020, May 15). *Difference between one way slab and two way slab*. Retrieved from Civil Read: https://civilread.com/differences-one-way-slab-two-way-slab/

Letchford, C. W. (2001). *Wind loads on rectangular signboards and hoardings.* 89, 135-151: J. Wind Eng. Indust. Aerodyn.

Letchford, C. W., & Holmes, J. D. (1994). *Wind loads on free-standing walls in turbulent boundary layers.* 51(1), 1-27: J. Wind Eng. Indust. Aerodyn.

MeadowBurke. (2018). Bracing Tilt-Up Panels. *Tilt-Up Concrete Association, 1*(1), 1-28.

Occupational Safety and Health Administration [OSHA]. (2003). *Tilt-Up Panel Construction Hazard: Safety and Health Information Bulletin.* Occupational Safety and Health Administration [OSHA].

O'Dwyer, D. (2007). Quasi-Plastic Analysis of Slabs on Grade. *Proceedings of the 11th International Conference on Civil, Structural and Environmental Engineering Computing, Civil-Comp 2007.*

Packard, R. G. (1976). Slab Thickness Design for Industrial Concrete Floors on Grade. *PCA Concrete Information*, 1-16.

Sauter, E. (2004). Tall Tilt-Up. *Concrete Engineering International, 8*(4), 28-31.

Steinbicker, J. J. (2018). TCA Guildine for Temporary Wind Bracing of Tilt-Up Concrete Panels During Construction. *Tilt-Up Concrete Association, 18*(1), 1-59.

Tilt Wall. (2017, July 31). *Tilt-Up Construction vs. Precast: What is the Difference?* Retrieved from TiltWall: https://tiltwall.ca/blog/tilt-up-construction-vs-precast-what-is-the-difference/

Tilt-Up Concrete Association [TCA]. (2011). The Construction of Tilt-Up. *Tilt-Up Concrete Association, 1*(1), 1-225.

Westergaard, H. M. (1926). *"Stresses in Concrete Pavements Computed by Theoretical Analysis.* Public Roads, V. 7, No. 2, Apr.

Appendix A - Permission for Use

[External] Permission for Use of Figures

1

MC

McNamara, Shawn C. <ShawnMcNamara@daytonsuperior.com>

Tue 3/16/2021 5:30 PM

To: Dillon Engelland

This email originated from outside of K-State.

Dillon,

You have permission to use these figures/graphics within your report.

Good luck, and let me know if you have any questions.

Thanks,
Shawn

Shawn McNamara , PE
Director of Business Operations, Tilt-Up

Dayton Superior Corporation
7415 Emerald Dunes Drive
Suite 1200
Orlando, FL 32822

Office: 407-859-4541 x18952
Mobile: 321-200-5224
Fax: 407-859-4543
Email: ShawnMcNamara@daytonsuperior.com

Requesting Permission for Use of Figures

Mitch Bloomquist <mbloomquist@tilt-up.org>
Tue 3/16/2021 4:53 PM
To: Dillon Engelland

This email originated from outside of K-State.

Dillon,

You have our permission. Could you please share a copy of your project with us upon completion? Please also let me know if there is any other assistance we can provide.

Mitch Bloomquist
Executive Director, Tilt-Up Concrete Association
(319) 895-6911 | www.tilt-up.org

On Mar 16, 2021, at 4:50 PM, Dillon Engelland <dengelland@ksu.edu> wrote:

Mitch,

Hello, my name is Dillon Engelland. I am in my 5th year at Kansas State University pursuing a master's degree in architectural engineering with a structural emphasis. I am currently working on my master's report titled "An Analysis of Slabs-on-Grade as an Anchorage System for Tilt-Up Concrete Panel Temporary Braces." As I was conducting my research, I found the "TCA Guideline for Temporary Wind Bracing of Tilt-Up Concrete Panels During Construction" (published March 23, 2018) to be very helpful. Specifically, there were a couple figures that I believe would be beneficial to incorporate into my report to assist the reader in understanding the concepts. If possible, I would like to request permission to use and reference Figure 7.1 (page 26) and Figure 7.3 (page 27). I have attached the figures below for reference. Please let me know if this is possible and if you need anything else from me.

Thanks,

Dillon J. Engelland | Kansas State University
Graduate Student | Architectural Engineering
dengelland@ksu.edu | (620) 200-8246
dillon.engelland@gmail.com

Appendix B - Calculations

The following are detailed calculations of determining the strength level and stress level brace component forces as well as calculations for the slab-on-grade's sliding resistance, punching shear resistance, overturning moment resistance, and anchor pullout capacity for all three slab thicknesses and all four subgrade conditions are also shown.

STEP	COMPUTATION				REFERENCE
Panel Information		Panel Depth Below F.F.	4	ft	
		Panel Height Below F.F.	38	ft	
	(above adjacent ground)	Panel Total Height (h)	42	ft	
		Panel Width (B)	26	ft	
		Panel Structural Thickness (t)	9.25	in	
			0.771	ft	
		Vertical Dimension of Panel(s)	42	ft	
		Clearance Ratio (s/h)	1		
		Aspect Ratio (B/s)	0.619		
		Opening Height	0	ft	
		Opening Width	0	ft	
		Gross Area (B x h) (A_s)	1092	sf	
		Opening Area	0	sf	
		Net (Solid) Area	1092	sf	
		Ratio of Solid Area to Gross Area ($\boldsymbol{\varepsilon}$)	1.0		
		$\boldsymbol{\varepsilon}_{solid}$	0.7		
	$(1-(1-\varepsilon)^{1.5})$	reduction factor	1.0		
		PANEL IS SOLID			
Wind Information	(strength level, reduced by 0.8 for construction period)	Basic Wind Speed (V)	80	mph	TCA Guideline
		Risk Category	I		
		Exposure	C		ASCE 7-16
		K_d	0.85		T. 26.6-1
		K_{zt}	1.0		Fig. 26.8-1
	(Manhattan, KS)	Elevation	1124	ft	
		K_e	1.00		T. 26.9-1
	for 42 ft	K_z	1.05	(interpolation)	T. 26.10-1
	$q_h = 0.00256 K_z K_{zt} K_d K_e V^2$	q_h	14.62	psf	26.10-1
	0.00256*(1.05)*(1)*(0.85)*(1)*(80)^2				
Limit State Design Wind Pressure	(14.62)*(0.85)*(1.5262)	Design Wind Pressure	18.97	psf	
		Minimum	16	psf	ASCE 7-16
			PASS		
ASD Wind Pressure	(18.97)*0.6	ASD Wind Pressure	11.38	psf	
		Minimum	10	psf	ASCE 7-16
			PASS		

		A_s	1092	sf	
		G	0.85	(assume)	
	(based on aspect and clearnace ratios listed above)	C_f	1.526	(interpolation)	Fig. 29.3-1
		$C_{f,\ reduced}$	1.526		
					29.3-1
Limit State Design Wind Force	$F = q_h G C_f A_s$ (14.62)*(0.85)*(1.5262)*(1092)	Design Wind Force, F	20714.82	lb	
ASD Wind Force	(11.38)*(1092)	ASD Wind Force	12428.89	lb	
		force applied at 0.55*h	23.1	ft	
Panel Geometric Centroid	Panel has no openings, so G.C. is half of height and half of width				
		h/2	21	ft	
		B/2	13	ft	
		0.6*h	25.2	ft	
		0.05*h + G.C. height	23.1	ft	
		brace attachment inserts should be located at at least	25.2	ft	

	(25.2)-(4)	minimum brace height above F.F.	21.2	ft	
		(commonly used) brace angle	0.925	radians	
		brace angle	53	degrees	
		minimum brace length	26.55	ft	
Find Dayton Superior Brace					
	TRY B12	Use Brace Length of	32	ft	
Limit State (Strength)	check if higher than 25.2 ft	brace height above F.F.	25.50	ft	PASS
	(25.5)+(4)	total brace height	29.50	ft	
		brace length from panel face	19.33	ft	
		nominal load of brace	13500	lb	**USE THIS BRACE**
		horizontal component of brace	16220.76	lb	
		required axial strength of brace	26953.06	lb	
		(LRFD) resistance factor	0.9		
	(26953.06)/(0.9*(13500))	required number of braces	2.218		
		for 3 braces	PASS		

ASD

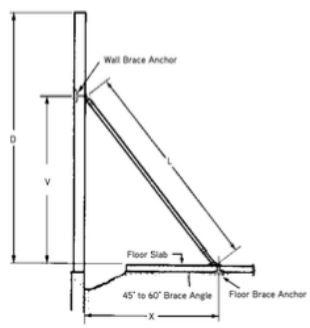
TRY B12	Use Brace Length of	32	ft
	brace height above F.F.	25.50	ft
(25.5)+(4)	total brace height	29.50	ft
	brace length from panel face	19.33	ft
	nominal load of brace	13500	lb
	horizontal component of braces	9732.455	lb
9732.45/(COS(0.93))	required axial strength of braces	16171.84	lb
	(ASD) safety factor	1.67	
(16171.84)/(13500/1.67)	required number of braces	2.001	
	for 3 braces	PASS	

ACI 318-19 21.2.1

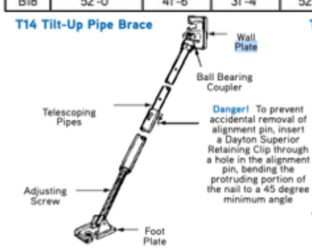
B12 Brace Information

Dayton Superior Tilt-Up Handbook

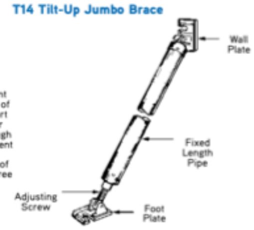
Jumbo Pipe Braces					
Type	D	V	X	L	Ultimate Load
B7	15'-0" to 24'-0"	13'-6"	10'-4"	17'-0"	13,050 lbs
B8	19'-0" to 31'-0"	17'-6"	13'-4"	22'-0"	9,750 lbs
B9	23'-0" to 39'-0"	21'-6"	16'-4"	27'-0"	7,200 lbs
B10	27'-0" to 46'-0"	25'-6"	19'-3"	32'-0"	5,400 lbs
B11	22'-0"	20'-5"	15'-4"	25'-6" Min.	13,500 lbs
B11	58'-0"	32'-0"	24'-0"	40'-0" Max.	13,500 lbs
B12	27'-0" to 46'-0"	25'-6"	19'-4"	32'-0"	13,500 lbs
B13	23'-0" to 39'-0"	21'-6"	16'-4"	27'-0"	18,000 lbs
B14	35'-0" to 60'-0"	33'-6"	25'-4"	42'-0"	7,800 lbs
B15	43'-0" to 60'-0"	41'-6"	31'-4"	52'-0"	5,700 lbs
B16	42'-0"	29'-6"	22'-4"	37'-0"	12,000 lbs
B17A	35'-0" to 60'-0"	33'-6"	25'-3"	42'-0"	19,000 lbs*
B18	52'-0"	41'-6"	31'-4"	52'-0"	19,200 lbs*



T14 Tilt-Up Pipe Brace



T14 Tilt-Up Jumbo Brace



To Order:
Specify: (1) quantity, (2) name, (3) model.

Example:
200, T14 Tilt-Up Wall Braces. Model B8.

T14 Pipe Brace Selection Chart

Type	New Name	Description	Minimum and Maximum Brace Length	Brace Weight (Lbs)
B0	BA0508R	Short Pipe Brace	5'-0" to 8'-0"	60
B1A	BA0814R	Short Pipe Brace	8'-0" to 14'-0"	87
B4	BA1423R	Heavy Duty Regular Pipe Brace	14'-6" to 23'-6"	130
B5***	BA2239R	Heavy Duty Long Pipe Brace	22'-6" to 39'-0"	208
B7	B17R13R	Short Jumbo Brace	17'-0" Fixed Length	107
B8	B22R9R	Jumbo Brace	22'-0" Fixed Length	130
B9	B22+5R7R	Jumbo Brace with 5-0" Extension	27'-0" Fixed Length	172
B10	B22+10R5R	Jumbo Brace with 10'-0" Extension	32'-0" Fixed Length	193
B11	BA2540R	Tru-Itt Brace	25'-6" to 40'-0"	505
B12A	B32R13R	Jumbo 5-1/2"	32'-0" Fixed Length	245
B13**	B27R18R	Jumbo 5-1/2"	27'-0" Fixed Length	237
B14*	B32+10R7R	B12 Jumbo Brace, 10'-0" Extension	42'-0" Fixed Length	382
B15*	B32+20R5R	B12 Jumbo Brace, 20'-0" Extension	52'-0" Fixed Length	410
B16	BA32+5R12R	B12 Jumbo Brace, 5'-0" Extension	37'-0" Fixed Length	360
B17A	B42R19R	Super Brace	42'-0" Fixed Length	613
B17S	B33R25R	Jumbo Brace Fixed	32'-3" to 33'-6"	489
B18	B52R19R	Super Brace	52'-0" Fixed Length	984

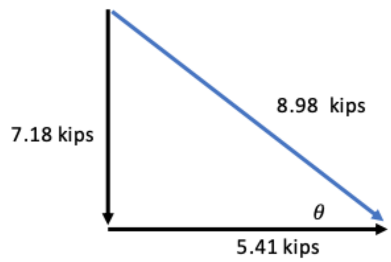
Notes: * Field assembly is required for B14 and B15 braces. Fixed length allows for +/-9" of adjustment except B17A brace has +/-7.5" of adjustment and B18 Brace has 11.75" of adjustment on each end. Pipe Extensions: T15 for the B8 model and T20 for the B12 model
** B13 is Made To Order brace
*** B5 Brace Maximum Length is 39'-0", but a Knee Brace is required over 30'-10"
Ultimate Load based on adequate brace to HGA or slab connection.

Limit State Design (LRFD)

USE 3 **BRACES**

Brace Loading	(26953)/(3)	**EACH BRACE TAKES**	8984	lb
			8.98	kips

Force Component Breakdown



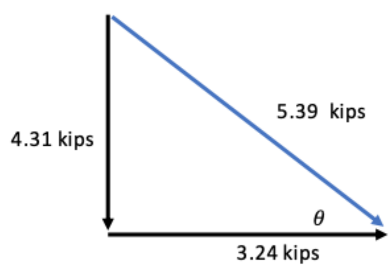
	θ	0.925	radians	
	θ	53	degrees	
(8.98)*cos(53)	Horizontal Component	5.41	kips	for each
(8.98)*sin(53)	Vertical Component	7.18	kips	brace

ASD

USE 3 **BRACES**

Brace Loading	(16172)/(3)	**EACH BRACE TAKES**	5391	lb
			5.39	kips

Force Component Breakdown



	θ	0.925	radians	
	θ	53	degrees	
(5.39)*cos(53)	Horizontal Component	3.24	kips	for each
(5.39)*sin(53)	Vertical Component	4.31	kips	brace

STEP	COMPUTATION				REFERENCE
	Horizontal Forces (5-inch Gravel)				
Slab on Grade Information	Assumed area of concrete slab to resist against sliding	Slab Length	55	ft	
		Slab Effective Width	8.67	ft	
		Slab Depth	5	in	
	55*8.67*(5/12)	Slab Volume	198.69	cf	
		Concrete Density	145	pcf	
	145*198.69	Slab Weight, W	28809.69	lb	
			28.81	kips	
Subgrade Material		Subgrade	Gravel		
		Coefficient of Friction, μ	0.6		Research
Resisting Friction Force	$F_s = W \times \mu$ 28.81*0.6	F_s	17.29	kips	
Horizontal Force	Compare to ASD value	Horizontal Force Component	3.24	kips	Loading
			PASS		
			SLAB DOES NOT SLIDE		
Alternative Method	Find required length of concrete to resist slab sliding				
		Horizontal Force Component	3.24	kips	
	Divide horizontal component by friction coefficient to get required weight of concrete	Coefficient of Friction, μ	0.6		
	3.24 / 0.6		5.41	kips	
			5406.919	lb	
	Divide weight by density to get required volume	Concrete Density	145	pcf	
	5406.92 / 145	Required Slab Volume	37.29	cf	
	Divide volume by slab width and depth to get required slab length	Slab Effective Width	8.67	ft	
		Slab Depth	5	in	
	37.29 / 8.67*(5/12)	Required Slab Length	10.32	ft	

Based on this calculation, when the subgrade material is Gravel, the required slab-on-grade length to resist slab sliding is 10.32 ft.

STEP	COMPUTATION				REFERENCE
	Horizontal Forces (5-inch Sand)				
Slab on Grade Information	Assumed area of concrete slab to resist against sliding	Slab Length	55	ft	
		Slab Effective Width	8.67	ft	
		Slab Depth	5	in	
	55*8.67*(5/12)	Slab Volume	198.69	cf	
		Concrete Density	145	pcf	
	145*198.69	Slab Weight, W	28809.69	lb	
			28.81	kips	
Subgrade Material		Subgrade	Sand		
		Coefficient of Friction, μ	0.45		Research
Resisting Friction Force	$F_s = W \times \mu$ 28.81*0.45	F_s	12.96	kips	
Horizontal Force	Compare to ASD value	Horizontal Force Component	3.24	kips	Loading
			PASS		
			SLAB DOES NOT SLIDE		
Alternative Method	Find required length of concrete to resist slab sliding				
		Horizontal Force Component	3.24	kips	
	Divide horizontal component by friction coefficient to get required weight of concrete	Coefficient of Friction, μ	0.45		
	3.24 / 0.45		7.21	kips	
			7209.226	lb	
	Divide weight by density to get required volume	Concrete Density	145	pcf	
	7209.23 / 145	Required Slab Volume	49.72	cf	
	Divide volume by slab width and depth to get required slab length	Slab Effective Width	8.67	ft	
		Slab Depth	5	in	
	49.72 / 8.67*(5/12)	Required Slab Length	13.76	ft	

Based on this calculation, when the subgrade material is Sand, the required slab-on-grade length to resist slab sliding is 13.76 ft.

STEP	COMPUTATION				REFERENCE
	Horizontal Forces (5-inch Soil)				
Slab on Grade Information	Assumed area of concrete slab to resist against sliding	Slab Length	55	ft	
		Slab Effective Width	8.67	ft	
		Slab Depth	5	in	
	55*8.67*(5/12)	Slab Volume	198.69	cf	
		Concrete Density	145	pcf	
	145*198.69	Slab Weight, W	28809.69	lb	
			28.81	kips	
Subgrade Material		Subgrade	Soil		
		Coefficient of Friction, μ	0.3		Research
Resisting Friction Force	$F_s = W \times \mu$ 28.81*0.3	F_s	8.64	kips	
Horizontal Force	Compare to ASD value	Horizontal Force Component	3.24	kips	Loading
			PASS		
		SLAB DOES NOT SLIDE			
Alternative Method	Find required length of concrete to resist slab sliding				
		Horizontal Force Component	3.24	kips	
	Divide horizontal component by friction coefficient to get required weight of concrete	Coefficient of Friction, μ	0.3		
	3.24 / 0.3		10.81	kips	
			10813.84	lb	
	Divide weight by density to get required volume	Concrete Density	145	pcf	
	10813.84 / 145	Required Slab Volume	74.58	cf	
	Divide volume by slab width and depth to get required slab length	Slab Effective Width	8.67	ft	
		Slab Depth	5	in	
	74.58 / 8.67*(5/12)	Required Slab Length	20.64	ft	
	Based on this calculation, when the subgrade material is Soil, the required slab-on-grade length to resist slab sliding is 20.64 ft.				

STEP	COMPUTATION				REFERENCE
	Horizontal Forces (5-inch V. Barrier)				
Slab on Grade Information	Assumed area of concrete slab to resist against sliding	Slab Length	55	ft	
		Slab Effective Width	8.67	ft	
		Slab Depth	5	in	
	55*8.67*(5/12)	Slab Volume	198.69	cf	
		Concrete Density	145	pcf	
	145*198.69	Slab Weight, W	28809.69	lb	
			28.81	kips	
Subgrade Material		Subgrade	Vapor Barrier		
		Coefficient of Friction, μ	0.15		Research
Resisting Friction Force	$F_s = W \times \mu$ 28.81*0.15	F_s	4.32	kips	
Horizontal Force	Compare to ASD value	Horizontal Force Component	3.24	kips	Loading
			PASS		
			SLAB DOES NOT SLIDE		
Alternative Method	Find required length of concrete to resist slab sliding				
		Horizontal Force Component	3.24	kips	
	Divide horizontal component by friction coefficient to get required weight of concrete	Coefficient of Friction, μ	0.15		
	3.24 / 0.15		21.63	kips	
			21627.68	lb	
	Divide weight by density to get required volume	Concrete Density	145	pcf	
	21627.68 / 145	Required Slab Volume	149.16	cf	
	Divide volume by slab width and depth to get required slab length	Slab Effective Width	8.67	ft	
		Slab Depth	5	in	
	149.16 / 8.67*(5/12)	Required Slab Length	41.29	ft	

Based on this calculation, when the subgrade material is Vapor Barrier, the required slab-on-grade length to resist slab sliding is 41.29 ft.

STEP	COMPUTATION				REFERENCE
	Vertical Forces (5-inch Slab)				
Slab on Grade Information	Assumed portion of slab resisting overturning moment	Slab Length	15	ft	
		Slab Effective Width	26	ft	
		Slab Depth	5	in	
	15*26*(5/12)	Slab Volume	162.50	cf	
		Concrete Density	145	pcf	
	145*162.5	Slab Weight, W	23562.5	lb	
			23.56	kips	
Overturning Moment	Overturning moment is ASD wind force applied at 0.55 times the overall height of the panel.	ASD Wind Force, F	12428.89	lb	Loading
		force applied at 0.55*h	23.1	ft	
		Overturning Moment, OTM	287.11	k-ft	
	$1.5OTM \leq RM$	1.5*OTM	430.66	k-ft	
Resisting Moment	Resisting moment is the weight of the concrete slab on grade applied at the distance from the panel to the location of the brace attached to the slab	Slab Weight, W	23.56	kips	
		distance from brace insert to panel face	19.33	ft	Loading
		Resisting Moment, RM	455.46	k-ft	
Comparison	Check 1.5*OTM ≤ RM		PASS		
Alternative Method	Find required area of concrete to resist overturning moment				
		1.5*OTM	430.66	k-ft	
	Divide by the moment arm of the resisting moment	distance from brace insert to panel face	19.33	ft	Loading
	430.66 / 19.33		22.28	kips	
	Divide by the density of the concrete	Concrete Density	145	pcf	
	22.28*1000 / 145		153.65	cf	

Divide by the thickness of the slab on grade
153.65 / (5/12)

Slab Depth	5	in
Required SF of Concrete	368.76	sf
Width of Effective Area	26	ft
Required Length of Slab	14.18	ft

Based on this calculation, 368.76 square feet of the slab is required to prevent overturning.

Justification

In one direction, the entire width of the panel, 26 feet, can be used as the width of the effective slab area. In the other direction, it is reasonable to assume that 7.5 feet of slab on either side of the anchor location can be considered to help in resisting overturning moment. This gives an effective length of 15 feet, and an effective square footage of 390 sf of slab on grade. This is larger than the required area to resist overturning.

Anchor Pullout

Dayton Superior's Bracing Information section on anchor rating takes into account the tension force from the brace being applied at a 53 degree angle. Because of this, the load rating given is based on the bracing system, and the rating is to be compared to the load that the brace will see.

Factored (strength level) Brace Load	8.98	kips	Loading
Nominal Load Rating of Anchor	11.288	kips	
(LRFD) resistance factor	0.9		
LRFD Load Rating	10.16	kips	

Based on f'c = 4000 psi using the 3/4" diameter x 4.5" long T13 Coil-Anchor

PASS

6. The Ultimate Load per T13 Coil-Anchor is shown below:

Floor Slab Thickness	Average Ultimate Bracing System Load		Minimum Torque Per Anchor
	fc'=2,500 psi	fc'=4,000 psi	
5" or Thicker	8,924 lbs	11,288 lbs	200 ft lbs

Notes: Ultimate load capacity of this system is based on tension applied at 53 degree angle

Warning: When using T13 Coil-Anchor Bolts, always clean and lubricate the bolt with T13L Set-Eez. Failure to do so will result in bolt wear, lower than expected load capacity and possible premature failure.

Dayton Superior Tilt-Up Handbook

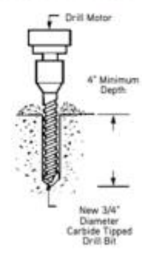
T13 Coil-Anchor Information

Dayton Superior Tilt-Up Handbook

DAYTON SUPERIOR

Bracing Information

T13 Coil-Anchor™ 3/4" Diameter x 4-1/2" Long Application Sequence

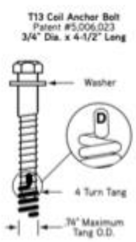


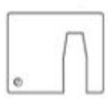
1. Drill a 3/4" diameter hole perpendicular to the floor surface with a new carbide tipped drill. Depth of the hole must be a minimum 4". Holes drilled through slabs that are 5" or greater are acceptable. Do not use core bits for T13 anchor holes. Minimum edge distance for the T13 anchor is 12".

Warning! Do not use T13 (4-1/2")anchors in slabs less than 5" thick. The insufficient embedment depth will not allow required load capacity.

Caution must be used when drilling through slabs so that there is no blowout at the bottom of the hole. Tang may not fully engage, greatly reducing SWL; or tang may not engage at all, making the hole unusable.

2. Thoroughly clean the drilled hole.





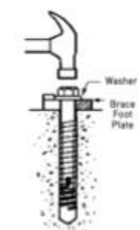
3. Thread the Tang onto the T13 bolt. Finger tight is sufficient, no more than 1-1/2 turn.

Caution! Do not attempt to pre-expand the Tang. For proper load capacity, the Tang must not be installed over 1-1/2 turn on the bolt.

Warning! Do not attempt to use a standard coil bolt with the T13 Coil-Anchor Tang. The Coil-Anchor Bolt is a tapered bolt and is not interchangeable with standard coil bolts.

T13G Thread Gauge

Note: T13G Thread Gauges are recommended, to check T13 bolt thread wear, when reusing T13 Coil-Anchor Bolts.



4. Insert the T13 anchor through the foot plate of the wall brace and into the properly drilled hole. Drive the bolt down until the cut washer rests on the foot plate.

5. Tighten the T13 anchor with a 3/4" impact wrench, then use a torque wrench to insure correct tightness. Refer to the chart for proper torquing values.

Warning! If wind speeds over 35 miles per hour are experienced on the job site, all T13 anchors should be checked with a torque wrench to verify proper torque values are maintained.

6. The Ultimate Load per T13 Coil-Anchor is shown below:

Floor Slab Thickness	Average Ultimate Bracing System Load		Minimum Torque Per Anchor
	f'c=2,500 psi	f'c=4,000 psi	
5" or Thicker	8,924 lbs	11,288 lbs	200 ft lbs

Notes: Ultimate load capacity of this system is based on tension applied at 53 degree angle

Warning: When using T13 Coil-Anchor Bolts, always clean and lubricate the bolt with T13L Set-Eez. Failure to do so will result in bolt wear, lower than expected load capacity and possible premature failure.

T13L Set-Eez™ Dry Film Lubricant

T13L Set-Eez Dry Film Lubricant is designed to facilitate the reuse of the T13 Coil-Anchor bolt. The T13L lubricant is available in 6 oz. jars.

To Order:
Specify: (1) quantity, (2) name.

Example:
4 bottles, T13L Set-Eez Dry Film Lubricant.

Bracing Information

Punching Shear	Punching shear capacity will be determined via chapter 14 of the ACI 318-19 that pertains to plain concrete. The slab is plain concrete because it is continuously supported by soil as stated in section 14.1.3(a).	ACI 318-19 14.1.3
	Brace Foot Plate Dimensions — Length: 10 in; Width: 6 in	
	h for concrete cast against soil is the specified slab thickness minus 2 in. — h: 3 in	14.5.1.7
Critical Section	Critical shear section is foot plate dimensions plus h/2 on each side — Length: 13 in; Width: 9 in	
	Perimeter, b_o: 44 in	ACI 318-19
Concrete Information	f'_c: 4000 psi	
	(normal weight) λ: 1	
	ratio of length to width of floor plate — β: 1.666667	T. 14.5.5.1
Punching Shear Equations (Two-Way)	Punching shear is the least of the following two equations	T. 14.5.5.1
	$V_n = (1+\frac{2}{\beta})(\frac{4}{3}\lambda\sqrt{f'_c}b_o h)$ — V_n: 24.489 kips	14.5.5.1(b)
	$V_n = 2(\frac{4}{3}\lambda\sqrt{f'_c}b_o h)$ — V_n: 22.262 kips	14.5.5.1(c)
	Φ_v: 0.75	ACI 318-19 21.2.1
Punching Shear Capacity	(minimum of the two) V_n: 22.262 kips	
	$\Phi_v V_n$: 16.70 kips	
Compare to Vertical Component of Brace Load	Compare to Limit State value — Vertical Component: 7.18 kips	Loading
	PASS	

STEP	COMPUTATION				REFERENCE
	Horizontal Forces (6-inch Gravel)				
Slab on Grade Information	Assumed area of concrete slab to resist against sliding	Slab Length	55	ft	
		Slab Effective Width	8.67	ft	
		Slab Depth	6	in	
	55*8.67*(6/12)	Slab Volume	238.43	cf	
		Concrete Density	145	pcf	
	145*238.43	Slab Weight, W	34571.63	lb	
			34.57	kips	
Subgrade Material		Subgrade	Gravel		
		Coefficient of Friction, μ	0.6		Research
Resisting Friction Force	$F_s = W \times \mu$ 34.57*0.6	F_s	20.74	kips	
Horizontal Force	Compare to ASD value	Horizontal Force Component	3.24	kips	Loading
			PASS		
			SLAB DOES NOT SLIDE		
Alternative Method	Find required length of concrete to resist slab sliding				
		Horizontal Force Component	3.24	kips	
	Divide horizontal component by friction coefficient to get required weight of concrete	Coefficient of Friction, μ	0.6		
	3.24 / 0.6		5.41	kips	
			5406.919	lb	
	Divide weight by density to get required volume	Concrete Density	145	pcf	
	5406.92 / 145	Required Slab Volume	37.29	cf	
	Divide volume by slab width and depth to get required slab length	Slab Effective Width	8.67	ft	
		Slab Depth	6	in	
	37.29 / 8.67*(6/12)	Required Slab Length	8.60	ft	

Based on this calculation, when the subgrade material is Gravel, the required slab-on-grade length to resist slab sliding is 8.6 ft.

STEP	COMPUTATION			REFERENCE
	Horizontal Forces (6-inch Sand)			
Slab on Grade Information	Assumed area of concrete slab to resist against sliding	Slab Length	55 ft	
		Slab Effective Width	8.67 ft	
		Slab Depth	6 in	
	55*8.67*(6/12)	Slab Volume	238.43 cf	
		Concrete Density	145 pcf	
	145*238.43	Slab Weight, W	34571.63 lb	
			34.57 kips	
Subgrade Material		Subgrade	Sand	
		Coefficient of Friction, μ	0.45	Research
Resisting Friction Force	$F_s = W \times \mu$ 34.57*0.45	F_s	15.56 kips	
Horizontal Force	Compare to ASD value	Horizontal Force Component	3.24 kips	Loading
			PASS	
			SLAB DOES NOT SLIDE	
Alternative Method	Find required length of concrete to resist slab sliding			
		Horizontal Force Component	3.24 kips	
	Divide horizontal component by friction coefficient to get required weight of concrete	Coefficient of Friction, μ	0.45	
	3.24 / 0.45		7.21 kips	
			7209.226 lb	
	Divide weight by density to get required volume	Concrete Density	145 pcf	
	7209.23 / 145	Required Slab Volume	49.72 cf	
	Divide volume by slab width and depth to get required slab length	Slab Effective Width	8.67 ft	
		Slab Depth	6 in	
	49.72 / 8.67*(6/12)	Required Slab Length	11.47 ft	

Based on this calculation, when the subgrade material is Sand, the required slab-on-grade length to resist slab sliding is 11.47 ft.

STEP	COMPUTATION				REFERENCE
	Horizontal Forces (6-inch Soil)				
Slab on Grade Information	Assumed area of concrete slab to resist against sliding	Slab Length	55	ft	
		Slab Effective Width	8.67	ft	
		Slab Depth	6	in	
	55*8.67*(6/12)	Slab Volume	238.43	cf	
		Concrete Density	145	pcf	
	145*238.43	Slab Weight, W	34571.63	lb	
			34.57	kips	
Subgrade Material		Subgrade	Soil		
		Coefficient of Friction, μ	0.3		Research
Resisting Friction Force	$F_s = W \times \mu$ 34.57*0.3	F_s	10.37	kips	
Horizontal Force	Compare to ASD value	Horizontal Force Component	3.24	kips	Loading
			PASS		
			SLAB DOES NOT SLIDE		
Alternative Method	Find required length of concrete to resist slab sliding				
		Horizontal Force Component	3.24	kips	
	Divide horizontal component by friction coefficient to get required weight of concrete	Coefficient of Friction, μ	0.3		
	3.24 / 0.3		10.81	kips	
			10813.84	lb	
	Divide weight by density to get required volume	Concrete Density	145	pcf	
	10813.84 / 145	Required Slab Volume	74.58	cf	
	Divide volume by slab width and depth to get required slab length	Slab Effective Width	8.67	ft	
		Slab Depth	6	in	
	74.58 / 8.67*(6/12)	Required Slab Length	17.20	ft	
	Based on this calculation, when the subgrade material is Soil, the required slab-on-grade length to resist slab sliding is 17.2 ft.				

STEP	COMPUTATION				REFERENCE
	Horizontal Forces (6-inch V. Barrier)				
Slab on Grade Information	Assumed area of concrete slab to resist against sliding	Slab Length	55	ft	
		Slab Effective Width	8.67	ft	
		Slab Depth	6	in	
	55*8.67*(6/12)	Slab Volume	238.43	cf	
		Concrete Density	145	pcf	
	145*238.43	Slab Weight, W	34571.63	lb	
			34.57	kips	
Subgrade Material		Subgrade	Vapor Barrier		
		Coefficient of Friction, μ	0.15		Research
Resisting Friction Force	$F_s = W \times \mu$ 34.57*0.15	F_s	5.19	kips	
Horizontal Force	Compare to ASD value	Horizontal Force Component	3.24	kips	Loading
			PASS		
			SLAB DOES NOT SLIDE		
Alternative Method	Find required length of concrete to resist slab sliding				
		Horizontal Force Component	3.24	kips	
	Divide horizontal component by friction coefficient to get required weight of concrete	Coefficient of Friction, μ	0.15		
	3.24 / 0.15		21.63	kips	
			21627.68	lb	
	Divide weight by density to get required volume	Concrete Density	145	pcf	
	21627.68 / 145	Required Slab Volume	149.16	cf	
	Divide volume by slab width and depth to get required slab length	Slab Effective Width	8.67	ft	
		Slab Depth	6	in	
	149.16 / 8.67*(6/12)	Required Slab Length	34.41	ft	

Based on this calculation, when the subgrade material is Vapor Barrier, the required slab-on-grade length to resist slab sliding is 34.41 ft.

STEP	COMPUTATION				REFERENCE
	Vertical Forces (6-inch Slab)				
Slab on Grade Information	Assumed portion of slab resisting overturning moment	Slab Length	15	ft	
		Slab Effective Width	26	ft	
		Slab Depth	6	in	
	15*26*(6/12)	Slab Volume	195.00	cf	
		Concrete Density	145	pcf	
	145*195	Slab Weight, W	28275	lb	
			28.28	kips	
Overturning Moment	Overturning moment is ASD wind force applied at 0.55 times the overall height of the panel.	ASD Wind Force, F	12428.89	lb	Loading
		force applied at 0.55*h	23.1	ft	
		Overturning Moment, OTM	287.11	k-ft	
	$1.5OTM \leq RM$	1.5*OTM	430.66	k-ft	
Resisting Moment	Resisting moment is the weight of the concrete slab on grade applied at the distance from the panel to the location of the brace attached to the slab	Slab Weight, W	28.28	kips	
		distance from brace insert to panel face	19.33	ft	Loading
		Resisting Moment, RM	546.56	k-ft	
Comparison	Check 1.5*OTM ≤ RM		PASS		
Alternative Method	Find required area of concrete to resist overturning moment				
		1.5*OTM	430.66	k-ft	
	Divide by the moment arm of the resisting moment	distance from brace insert to panel face	19.33	ft	Loading
	430.66 / 19.33		22.28	kips	
	Divide by the density of the concrete	Concrete Density	145	pcf	
	22.28*1000 / 145		153.65	cf	

Divide by the thickness of the slab on grade
153.65 / (6/12)

Slab Depth	6	in
Required SF of Concrete	307.30	sf
Width of Effective Area	26	ft
Required Length of Slab	11.82	ft

Based on this calculation, 307.3 square feet of the slab is required to prevent overturning.

Justification

In one direction, the entire width of the panel, 26 feet, can be used as the width of the effective slab area. In the other direction, it is reasonable to assume that 7.5 feet of slab on either side of the anchor location can be considered to help in resisting overturning moment. This gives an effective length of 15 feet, and an effective square footage of 390 sf of slab on grade. This is larger than the required area to resist overturning.

Anchor Pullout

Dayton Superior's Bracing Information section on anchor rating takes into account the tension force from the brace being applied at a 53 degree angle. Because of this, the load rating given is based on the bracing system, and the rating is to be compared to the load that the brace will see.

Loading

Factored (strength level) Brace Load	8.98	kips
Nominal Load Rating of Anchor	11.288	kips
(LRFD) resistance factor	0.9	
LRFD Load Rating	10.16	kips

Based on f'c = 4000 psi using the 3/4" diameter x 4.5" long T13 Coil-Anchor

PASS

6. The Ultimate Load per T13 Coil-Anchor is shown below:

Floor Slab Thickness	Average Ultimate Bracing System Load		Minimum Torque Per Anchor
	fc'=2,500 psi	fc'=4,000 psi	
5" or Thicker	8,924 lbs	11,288 lbs	200 ft lbs

Notes: Ultimate load capacity of this system is based on tension applied at 53 degree angle

Warning: When using T13 Coil-Anchor Bolts, always clean and lubricate the bolt with T13L Set-Eez. Failure to do so will result in bolt wear, lower than expected load capacity and possible premature failure.

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Punching Shear	Punching shear capacity will be determined via chapter 14 of the ACI 318-19 that pertains to plain concrete. The slab is plain concrete because it is continuously supported by soil as stated in section 14.1.3(a).	ACI 318-19 14.1.3
	Brace Foot Plate Dimensions — Length 10 in; Width 6 in	
	h for concrete cast against soil is the specified slab thickness minus 2 in. — h 4 in	14.5.1.7
Critical Section	Critical shear section is foot plate dimensions plus h/2 on each side — Length 14 in; Width 10 in; Perimeter, b_o 48 in	ACI 318-19
Concrete Information	f'_c 4000 psi; (normal weight) λ 1	
	ratio of length to width of floor plate β 1.666667	T. 14.5.5.1
Punching Shear Equations (Two-Way)	Punching shear is the least of the following two equations	T. 14.5.5.1
	$V_n = (1+\frac{2}{\beta})(\frac{4}{3}\lambda\sqrt{f'_c}b_o h)$ — V_n 35.620 kips	14.5.5.1(b)
	$V_n = 2(\frac{4}{3}\lambda\sqrt{f'_c}b_o h)$ — V_n 32.382 kips	14.5.5.1(c)
	Φ_v 0.75	ACI 318-19 21.2.1
Punching Shear Capacity	(minimum of the two) V_n 32.382 kips; $\Phi_v V_n$ 24.29 kips	
Compare to Vertical Component of Brace Load	Compare to Limit State value — Vertical Component 7.18 kips; PASS	Loading

STEP	COMPUTATION				REFERENCE
	Horizontal Forces (8-inch Gravel)				
Slab on Grade Information	Assumed area of concrete slab to resist against sliding	Slab Length	55	ft	
		Slab Effective Width	8.67	ft	
		Slab Depth	8	in	
	55*8.67*(8/12)	Slab Volume	317.90	cf	
		Concrete Density	145	pcf	
	145*317.9	Slab Weight, W	46095.5	lb	
			46.10	kips	
Subgrade Material		Subgrade	Gravel		
		Coefficient of Friction, μ	0.6		Research
Resisting Friction Force	$F_s = W \times \mu$ 46.1*0.6	F_s	27.66	kips	
Horizontal Force	Compare to ASD value	Horizontal Force Component	3.24	kips	Loading
			PASS		
			SLAB DOES NOT SLIDE		
Alternative Method	Find required length of concrete to resist slab sliding				
		Horizontal Force Component	3.24	kips	
	Divide horizontal component by friction coefficient to get required weight of concrete	Coefficient of Friction, μ	0.6		
	3.24 / 0.6		5.41	kips	
			5406.919	lb	
	Divide weight by density to get required volume	Concrete Density	145	pcf	
	5406.92 / 145	Required Slab Volume	37.29	cf	
	Divide volume by slab width and depth to get required slab length	Slab Effective Width	8.67	ft	
		Slab Depth	8	in	
	37.29 / 8.67*(8/12)	Required Slab Length	6.45	ft	
	Based on this calculation, when the subgrade material is Gravel, the required slab-on-grade length to resist slab sliding is 6.45 ft.				

STEP	COMPUTATION				REFERENCE
	Horizontal Forces (8-inch Sand)				
Slab on Grade Information	Assumed area of concrete slab to resist against sliding	Slab Length	55	ft	
		Slab Effective Width	8.67	ft	
		Slab Depth	8	in	
	55*8.67*(8/12)	Slab Volume	317.90	cf	
		Concrete Density	145	pcf	
	145*317.9	Slab Weight, W	46095.5	lb	
			46.10	kips	
Subgrade Material		Subgrade	Sand		
		Coefficient of Friction, μ	0.45		Research
Resisting Friction Force	$F_s = W \times \mu$ 46.1*0.45	F_s	20.74	kips	
Horizontal Force	Compare to ASD value	Horizontal Force Component	3.24	kips	Loading
			PASS		
			SLAB DOES NOT SLIDE		
Alternative Method	Find required length of concrete to resist slab sliding				
		Horizontal Force Component	3.24	kips	
	Divide horizontal component by friction coefficient to get required weight of concrete	Coefficient of Friction, μ	0.45		
	3.24 / 0.45		7.21	kips	
			7209.226	lb	
	Divide weight by density to get required volume	Concrete Density	145	pcf	
	7209.23 / 145	Required Slab Volume	49.72	cf	
	Divide volume by slab width and depth to get required slab length	Slab Effective Width	8.67	ft	
		Slab Depth	8	in	
	49.72 / 8.67*(8/12)	Required Slab Length	8.60	ft	

Based on this calculation, when the subgrade material is Sand, the required slab-on-grade length to resist slab sliding is 8.6 ft.

STEP	COMPUTATION				REFERENCE
	Horizontal Forces (8-inch Soil)				
Slab on Grade Information	Assumed area of concrete slab to resist against sliding	Slab Length	55	ft	
		Slab Effective Width	8.67	ft	
		Slab Depth	8	in	
	55*8.67*(8/12)	Slab Volume	317.90	cf	
		Concrete Density	145	pcf	
	145*317.9	Slab Weight, W	46095.5	lb	
			46.10	kips	
Subgrade Material		Subgrade	Soil		
		Coefficient of Friction, μ	0.3		Research
Resisting Friction Force	$F_s = W \times \mu$ 46.1*0.3	F_s	13.83	kips	
Horizontal Force	Compare to ASD value	Horizontal Force Component	3.24	kips	Loading
			PASS		
		SLAB DOES NOT SLIDE			
Alternative Method	Find required length of concrete to resist slab sliding				
		Horizontal Force Component	3.24	kips	
	Divide horizontal component by friction coefficient to get required weight of concrete	Coefficient of Friction, μ	0.3		
	3.24 / 0.3		10.81	kips	
			10813.84	lb	
	Divide weight by density to get required volume	Concrete Density	145	pcf	
	10813.84 / 145	Required Slab Volume	74.58	cf	
	Divide volume by slab width and depth to get required slab length	Slab Effective Width	8.67	ft	
		Slab Depth	8	in	
	74.58 / 8.67*(8/12)	Required Slab Length	12.90	ft	

Based on this calculation, when the subgrade material is Soil, the required slab-on-grade length to resist slab sliding is 12.9 ft.

STEP	COMPUTATION				REFERENCE
	Horizontal Forces (8-inch V. Barrier)				
Slab on Grade Information	Assumed area of concrete slab to resist against sliding	Slab Length	55	ft	
		Slab Effective Width	8.67	ft	
		Slab Depth	8	in	
	55*8.67*(8/12)	Slab Volume	317.90	cf	
		Concrete Density	145	pcf	
	145*317.9	Slab Weight, W	46095.5	lb	
			46.10	kips	
Subgrade Material		Subgrade	Vapor Barrier		
		Coefficient of Friction, μ	0.15		Research
Resisting Friction Force	$F_s = W \times \mu$ 46.1*0.15	F_s	6.91	kips	
Horizontal Force	Compare to ASD value	Horizontal Force Component	3.24	kips	Loading
			PASS		
			SLAB DOES NOT SLIDE		
Alternative Method	Find required length of concrete to resist slab sliding				
		Horizontal Force Component	3.24	kips	
	Divide horizontal component by friction coefficient to get required weight of concrete	Coefficient of Friction, μ	0.15		
	3.24 / 0.15		21.63	kips	
			21627.68	lb	
	Divide weight by density to get required volume	Concrete Density	145	pcf	
	21627.68 / 145	Required Slab Volume	149.16	cf	
	Divide volume by slab width and depth to get required slab length	Slab Effective Width	8.67	ft	
		Slab Depth	8	in	
	149.16 / 8.67*(8/12)	Required Slab Length	25.81	ft	

Based on this calculation, when the subgrade material is Vapor Barrier, the required slab-on-grade length to resist slab sliding is 25.81 ft.

STEP	COMPUTATION				REFERENCE
	Vertical Forces (8-inch Slab)				
Slab on Grade Information	Assumed portion of slab resisting overturning moment	Slab Length	15	ft	
		Slab Effective Width	26	ft	
		Slab Depth	8	in	
	15*26*(8/12)	Slab Volume	260.00	cf	
		Concrete Density	145	pcf	
	145*260	Slab Weight, W	37700	lb	
			37.70	kips	
Overturning Moment	Overturning moment is ASD wind force applied at 0.55 times the overall height of the panel.	ASD Wind Force, F	12428.89	lb	Loading
		force applied at 0.55*h	23.1	ft	
		Overturning Moment, OTM	287.11	k-ft	
	$1.5OTM \leq RM$	1.5*OTM	430.66	k-ft	
Resisting Moment	Resisting moment is the weight of the concrete slab on grade applied at the distance from the panel to the location of the brace attached to the slab	Slab Weight, W	37.70	kips	
		distance from brace insert to panel face	19.33	ft	Loading
		Resisting Moment, RM	728.74	k-ft	
Comparison	Check 1.5*OTM ≤ RM		PASS		
Alternative Method	Find required area of concrete to resist overturning moment				
		1.5*OTM	430.66	k-ft	
	Divide by the moment arm of the resisting moment	distance from brace insert to panel face	19.33	ft	Loading
	430.66 / 19.33		22.28	kips	
	Divide by the density of the concrete	Concrete Density	145	pcf	
	22.28*1000 / 145		153.65	cf	

Divide by the thickness of the slab on grade
153.65 / (8/12)

Slab Depth	8	in
Required SF of Concrete	230.48	sf
Width of Effective Area	26	ft
Required Length of Slab	8.86	ft

Based on this calculation, 230.48 square feet of the slab is required to prevent overturning.

Justification

In one direction, the entire width of the panel, 26 feet, can be used as the width of the effective slab area. In the other direction, it is reasonable to assume that 7.5 feet of slab on either side of the anchor location can be considered to help in resisting overturning moment. This gives an effective length of 15 feet, and an effective square footage of 390 sf of slab on grade. This is larger than the required area to resist overturning.

Anchor Pullout

Dayton Superior's Bracing Information section on anchor rating takes into account the tension force from the brace being applied at a 53 degree angle. Because of this, the load rating given is based on the bracing system, and the rating is to be compared to the load that the brace will see.

Loading

Factored (strength level) Brace Load	8.98	kips
Nominal Load Rating of Anchor	11.288	kips
(LRFD) resistance factor	0.9	
LRFD Load Rating	10.16	kips

Based on f'c = 4000 psi using the 3/4" diameter x 4.5" long T13 Coil-Anchor

PASS

Dayton Superior Tilt-Up Handbook

6. The Ultimate Load per T13 Coil-Anchor is shown below:

Floor Slab Thickness	Average Ultimate Bracing System Load		Minimum Torque Per Anchor
	fc'=2,500 psi	fc'=4,000 psi	
5" or Thicker	8,924 lbs	11,288 lbs	200 ft lbs

Notes: Ultimate load capacity of this system is based on tension applied at 53 degree angle

Warning: When using T13 Coil-Anchor Bolts, always clean and lubricate the bolt with T13L Set-Eez. Failure to do so will result in bolt wear, lower than expected load capacity and possible premature failure.

Section	Description	Label	Value	Unit	Reference
Punching Shear	Punching shear capacity will be determined via chapter 14 of the ACI 318-19 that pertains to plain concrete. The slab is plain concrete because it is continuously supported by soil as stated in section 14.1.3(a).				ACI 318-19 14.1.3
	Brace Foot Plate Dimensions	Length	10	in	
		Width	6	in	
	h for concrete cast against soil is the specified slab thickness minus 2 in.	h	6	in	14.5.1.7
Critical Section	Critical shear section is foot plate dimensions plus h/2 on each side	Length	16	in	
		Width	12	in	
		Perimeter, b_o	56	in	ACI 318-19
Concrete Information		f'_c	4000	psi	
	(normal weight)	$\boldsymbol{\lambda}$	1		
	ratio of length to width of floor plate	$\boldsymbol{\beta}$	1.666667		T. 14.5.5.1
Punching Shear Equations (Two-Way)	Punching shear is the least of the following two equations				T. 14.5.5.1
	$V_n = (1 + \frac{2}{\beta})(\frac{4}{3}\lambda\sqrt{f'_c}b_o h)$	V_n	62.335	kips	14.5.5.1(b)
	$V_n = 2(\frac{4}{3}\lambda\sqrt{f'_c}b_o h)$	V_n	56.668	kips	14.5.5.1(c)
		Φ_v	0.75		ACI 318-19 21.2.1
Punching Shear Capacity	(minimum of the two)	V_n	56.668	kips	
		$\Phi_v V_n$	42.50	kips	
Compare to Vertical Component of Brace Load	Compare to Limit State value	Vertical Component	7.18	kips	Loading
			PASS		