Design of Lifting and Bracing for Today's Tilt-Up Structures

By Mark Remmetter, P.E. and James Baty

Panel erection day is an exciting time to be on the project site for a tilt-up building. It is truly an awe-inspiring event to watch the enormous concrete panels as they are lifted and set in to place. However, this production does not occur without careful planning by everyone involved in the construction process. This not only includes the contractors and construction personnel, but also the architect and structural engineer. In fact, proper planning by the architect and engineer can make the panel erection proceed much more efficiently.

Panel Lifting

Many problems with lifting tilt-up wall panels can be eliminated by careful planning by the architect and engineer. The most common lifting problem is wall panels that are too thin and panels that do not have wide enough panel legs adjacent to the openings. It is also best to avoid panels that cannot stand up under their own weight (i.e. center of gravity is too far from vertical support). Inverted L-shaped panels are particularly difficult to lift and require a strongback to hold the panel up after it is erected until the supporting structure is built. While there are numerous ways to overcome these problems, they all add additional cost to the project. Some ways of compensating for lifting problems include increasing concrete strength at time of lift, adding additional reinforcing to the panels, and installing a strongback to lift the panels.

Tilt-up panels are analyzed for lifting by taking into account the location of the lifting inserts and the geometry of the cables used to connect the panels to the crane. This analysis is very intensive and involves special algorithms that are used to calculate the cable geometry as the panel is lifted. As the panel rotates up and off the casting bed, the lifting insert forces will change with the angle the lifting cables make with the insert. The insert forces and bending moments in the panel are calculated for varying angles as the panels are rotated and lifted off the casting slab. The maximum moments for each section of the wall panel are tabulated and compared to the bending capacity of the panel at that section.

One common misconception is that the reinforcing specified on the design drawings takes into account the loads imposed on the panels during the lifting process. The steel reinforcing provided in the panels is designed by the panel structural engineer to resist only the final design loads applied to the panels by the structure they support. For lifting, the wall panels are actually designed as plain concrete bending members to resist the moments generated during lifting. The tensile stress in the panel is typically limited to $6\sqrt{f_c}$ (where fc is the specified concrete compressive stress at the time the panels are lifted). With the bending stress at this level, the panels should not crack as they are erected. Typically, the concrete compressive stress at the time of the lift is specified to be at least 2500 psi. This value is sometimes larger if the lifting moments exceed the allowable tensile stress at this concrete strength. Although theoretically the concrete strength at time of lift could be increased to any value to keep the panels from cracking, it becomes somewhat impractical to require concrete compressive strength much larger than about 4000 psi.

If after increasing the concrete strength the applied bending moments are still too large, additional reinforcing can be added to the panel to increase the moment capacity. This reinforcing is usually in addition to the steel placed in the panel by the panel design engineer. The additional steel should be placed a minimum of one-inch clear to the face of the panel. The lifting engineer should check to verify that the area of steel added is not more than allowed by the ACI code. This can be a problem, since the concrete strength during lifting is usually somewhat less than that used for design of the panel. This additional steel should be clearly called out on the lifting drawings. In addition, it is also good practice to limit the maximum tensile bending stress in the reinforced section to $10\sqrt{fc}$ to limit cracking of the concrete. Limiting the bending stress, and therefore the potential for cracks, may reduce the occurrence of questions that would arise if the panels were designed to crack during lifting. That said, concrete cracks generated during lifting should not affect the structural capacity of the panel and usually close once the panel is set in place.

If inceasing the concrete strength and adding reinforcing still do not provide enough capacity to lift the panel, the remaining option is to add steel strongbacks. Tilt-up hardware suppliers, Meadow Burke and Dayton Superior, can provide strongbacks to aid in lifting the wall panels. These manufacturers also provide details for connecting the strongbacks to the wall panels. When designing strongbacks for panel lifting, it is important to account for the relative stiffness of the existing concrete panel compared to the strongback. If the strongback does not have adequate stiffness, the panel will try to resist the majority of the applied moment until it cracks, transferring most of the bending moment into the strongback. Strongbacks are most often used at the bottom of panels that have relatively small panel legs on either side of large openings, such as those found at a truck dock location. The additional weight of the concrete below the doors tends to increase the bending moments in the panel legs, causing problems when the panels are analyzed for lifting.

Commonly, the architect and panel engineer provide a panel leg that works for in place design loads, but no consideration

is given for lifting. This leads to additional reinforcing in the panel or strongbacks in order to lift the panel. If the architect and engineer consult with a lifting engineer when determining panel thickness, the extra cost for reinforcing and strongbacks might be eliminated. Obviously, it is important to perform an economic evaluation to determine if increasing the panel thickness is a better choice than providing strongbacks. For example, making an extremely tall panel thicker may cost more than the strongback, so it might be better to use a thinner panel with strongbacks. The tilt-up hardware supplier can provide cost estimates that will allow the panel engineer to make an educated economic decision on the correct panel thickness.

Proper lift engineering will take into account more than just the stresses in the wall panels. The panel base reaction as the panel comes off the slab should be at least 10 percent of the panel weight, which helps keep the panel from sliding across the slab leaving gouges in the slab-on-grade and enables the crane operator to control the lifting operation better. Panels with strongbacks can have problems when the center of gravity is shifted due to the weight of strongbacks, so it is important to include this weight when locating the lifting inserts. Unusually thick panels or panels with tapered thickness can be difficult to set in place unless the lifting inserts are located relatively high in the panel. This is because once the panel is lifted free of the casting slab, the center of gravity of the panel will lie directly below the crane hook. The eccentricity between the back face of the panel and the center of gravity will tend to rotate the panel away from vertical unless the lifters are located near the top of the panel.

The lifting insert information is provided to the field personnel in the form of a book or plan sheets that detail each panel by showing the panel geometry as well as the location of the inserts. Other information provided on these sheets includes the panel weight and center of gravity. This information is useful to the panel erection contractor for locating the panels on the casting slab and the crane operator who must know the weight in order to position the crane correctly for the pick. The project's engineer-of-record will typically require the lifting calculations and insert location drawings be signed and sealed by the lifting engineer.

Lifting Inserts

Tilt-up panels are lifted with two to sixteen lifting inserts depending on panel size, weight and layout. Both Meadow Burke and Dayton Superior supply the tilt-up industry with lifting inserts and associated hardware used to lift the tilt-up panels. Lifting inserts from one manufacturer cannot be used with lifting accessories from another. Both companies can supply inserts with capacities up to 22,000 pounds. The inserts are designed to resist both tension and shear loads as the panels are lifted from the casting slab. The concrete must have compressive strength of at least 2500 psi in order to achieve the listed capacities. The available lifting inserts must be installed in the panel in the correct orientation (inserts have an arrow on them that must point to top or bottom of panel) and in the proper position. Depending on the number of inserts, panel width and panel height, the inserts are connected to the crane with any of several cable configurations. The lifting engineer should provide the correct cable configuration and required cable length on the lifting documents. If the cable length does not meet the requirements specified by the lifting engineer, failure of the panel, inserts or both may occur. Lifting cables that are too short will increase the insert forces and can radically change the design moments in the panel during erection.

Bracing Tilt-Up Panels

After a panel has been set but before the crane releases it, temporary erection braces must be installed to hold the panel plumb and in position, and provide resistance from wind. The minimum requirement is two braces per panel, but with the larger panels common today, additional bracing may be required. Three or four braces per panel may be needed to resist the construction period wind loads. Braces are usually made of thin wall steel pipe with approximately 18-inches of screw adjustment at the lower end. The upper end connects to an embedded wall brace insert by means of a bolt. The lower end usually attaches to the concrete slab most often by a post-installed bolt. The design of panel bracing is governed by the recently released *Guideline for Temporary Wind Bracing of Tilt-Up Concrete Panels during Construction (TCA Guideline 1-05)*, published by the Tilt-Up Concrete Association (TCA).

TCA's guideline is based on OSHA requirements and incorporates the provisions of SEI/ASCE 37-02, *Design Loads on Structures during Construction*. The calculated wind loads used to size the panel braces is based on the ASCE 7-95 standard using a basic wind speed of 90 mph. Per SEI/ASCE 37-02, for construction periods up to one year, an adjustment factor of 0.8 is applied the basic 90 mph wind speed. This adjustment results in a 72 mph construction period design wind speed, which is the wind speed recommended for design of the temporary bracing system. Note, however, that panel bracing for tilt-up buildings in hurricane prone areas requires special attention.

The tilt-up hardware supplier using their brace capacities and the specified construction wind load usually chooses the type of brace and designs the brace spacing. A safety factor of 1.5 is typical. In some cases, long braces may need to be supported in two directions to prevent them from buckling since a round pipe can buckle about any axis at mid-length. If you want to avoid lateral and knee-bracing, larger capacity braces may be used. Another important factor is to use hardware that matches the braces selected for the project. Improper matching may lead to fatigue or movement in the panels during this critical stage. The braces and associated hardware are typically rented.

The quantity of braces required for a tilt-up panel is dependent on the capacity of the brace. The location of the brace inserts on a panel is based on the brace length selected

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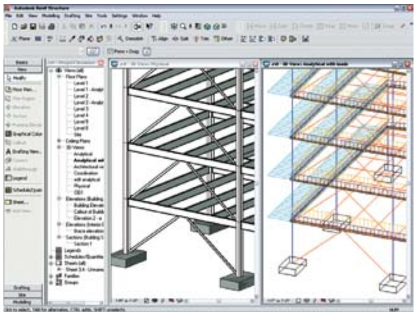

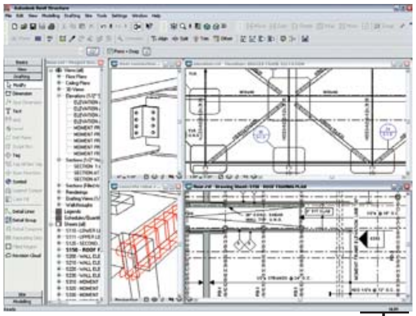

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and several other criteria. The brace inserts in the panel should be located not lower than 60 percent of the panel's height and not less than five percent of the panel's height above the panel's geometric centroid or mass center of gravity, whichever is greater. In addition, brace inserts need to be positioned away from panel edges and openings, typically a minimum of one foot. The braces are spread over the width of a panel such that each brace will resist approximately the same wind load. The first brace insert should be located not more than 25 percent from each edge of the panel, or 10 feet, whichever is less. One often-overlooked item that needs checking when bracing panels is the lateral resistance at the bottom of the panel to resist the wind load. Since the panel is just sitting on shim packs or grout pads, the wind load is resisted entirely by friction unless some other means of resistance is provided.

The panel brace supplier typically does not verify that the floor slab has the capacity to support the brace reaction. Most suppliers will state this on their bracing sheets, along with a note regarding minimum slab thickness of 5 inches for the brace anchors into the slab. The slab capacity to resist bracing loads is affected by concrete strength, reinforcing, control and construction joint location, brace spacing and slab thickness. The horizontal brace component is resisted by friction between the slab and subgrade. The vertical component is resisted by the slab weight tributary to the braces. The strength of the slab must be sufficient to carry its own weight, since it is usually designed to span brace to brace. The slab area used to resist the vertical upward component of the brace reaction cannot also be used to resist the horizontal component; therefore, the slab area required to resist the brace reaction can become quite large.

Multistory tilt-up panels should be checked to verify they have the strength to resist construction wind load while supported by braces, otherwise it may be necessary to provide brace points at several elevations in the panel's height. These types of panels (usually three and four story panels) are designed to be supported at each floor level and may not have sufficient strength if braced at a single elevation above the bottom of the panel. Further, in multistory tilt-up buildings, it is critical to coordinate the brace locations to avoid interference with framing members located at lower floors

During the preparation for lifting, the braces are typically connected to the panel. This reduces the amount of time lost when the panel is raised, because the brace hangs free and can be quickly fastened to the floor slab at its lower end. While one crewmember holds the brace in the desired position, another drills a hole into the floor slab where an insert is placed in the hole to receive a bolt securing the brace. Once the braces are secure and the panel is plumb, the crane slackens the cables and riggers disconnect the lifting hardware from the panels. The crane and crew then move to the next panel.▪

James Baty II, is the Technical Director for the Tilt-Up Concrete Association. With a strong background in technical codes and standards, currently, Mr. Baty is acting secretary for the ACI 332 and 551 committees as well as a voting member on ACI 306, ACI C650 ACI 301 and ACI 314. James can be reached at ***jbaty@tilt-up.org.***

Mark Remmetter, P.E. is a principal and Vice President of Engineering at Steinbicker & Associates, Inc. He has designed hundreds of tilt-up concrete building all over the United States. He can be reached at ***markr@sai-engineers.com.***

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