Tilt-Up Seismic Design

Mark E. Remmetter, P.E., On behalf of the Tilt-Up Concrete Association (TCA)

Early Tilt-Up buildings were constructed typically for industrial and commercial facilities, and were perceived as large gray boxes by many architects and owners. That changed in the past decade, as Tilt-Up buildings crossed the line into a variety of building types. Tilt-Up is now commonly used not only for warehouses, manufacturing and industrial facilities and retail buildings, but also in single and multistory office buildings, religious centers and most recently school construction. Accompanying the expanded use of Tilt-Up is an increase in the complexity of buildings and the resulting additional engineering. Adding to the engineering challenges are the new, more stringent seismic requirements adopted in recent years.

Code Requirements

Requirements for seismic analysis and building design have expanded into many areas not previously required. Buildings now experience stricter code-required seismic lateral loads that may result in changes to the design of the diaphragm, building connections and lateral load resisting system. The International Building Code (IBC) dictates the prescribed design forces and special system requirements. Incorporating these prescribed forces, the structural design of concrete Tilt-Up panels falls primarily under the requirements of the American Concrete Institute's (ACI) 318 code.

Tilt-Up buildings resist seismic lateral forces in much the same way as many other building types. Because most Tilt-Up buildings rely on the wall panels for lateral support, they are typically defined as a "bearing wall system with ordinary reinforced concrete shear walls" for determining the seismic response modification coefficient, R, in the IBC. Areas of the country with higher design seismic loads are required by the IBC to meet the special detailing and design requirements of ACI 318 -- Chapter 21. For seismic design purposes, these buildings are defined as "bearing wall systems with special reinforced concrete shear walls" per the IBC, and can use a higher R-value resulting in a lower calculated design seismic load. ACI 318-02 -- Chapter 21 adds new definitions for intermediate and special precast structural walls for seismic design.

This is a change from previous editions, where the use of precast walls resisting seismic loads was not directly addressed. Intermediate precast structural walls have the same requirements as ordinary structural walls except for the new requirements in section 21.13 of ACI 318 pertaining to yielding of connections between wall panels and at panel base connections. The IBC specifies minimum out of plane forces for the design of the wall panels, as well as load requirements for the anchorage of the panels to the floor and roof systems. The magnitude of these loads varies depending on the Seismic Design Category specified for the building. The structural design of the panel (thickness and reinforcing) is typically not controlled by the design seismic loads, but rather by the wind loads specified in the building code.

Chapter 16 of ACI 318 includes Tilt-Up as a form of precast concrete construction. The design of Tilt-Up wall panels falls under the requirements of ACI Chapter 14 – Walls, Chapter 16 -- Precast Concrete, and Chapter 21 -- Special Provisions for Seismic Design. Contained within the IBC Chapter 19 -- Concrete, are modifications and additions to the text of ACI 318. One of the IBC additions refers directly to the use of precast lateral-force-resisting systems. For precast concrete frames, section 1908.1.6 of the IBC requires that precast lateral-force-resisting systems emulate the behavior of monolithic concrete construction, and further dictates connection requirements and their design forces. For Tilt-Up construction, this requirement would apply only to panels typically found in multistory office buildings or retail stores where the quantity and size of openings in the majority of the panels is relatively large. This results in wall panels with relatively small legs that behave as individual concrete frames instead of shear walls. Buildings constructed with these types of wall panels are considered braced by a concrete moment-resisting frame system when selecting the seismic response modification factor.

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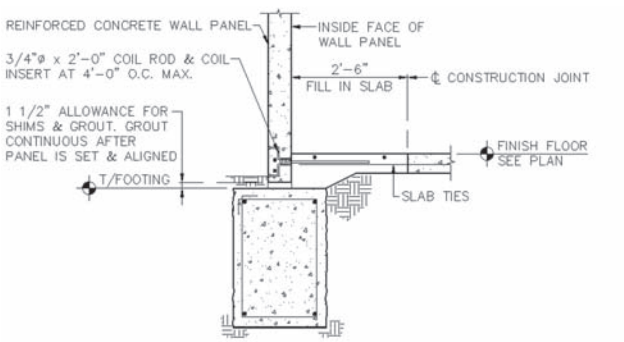
Lateral Loads

Some Tilt-Up buildings are constructed by stacking the wall panels on one another. Although commonly done for multistory buildings, it has also been done on buildings with large interior clear heights. For buildings constructed in this manner, the upper panels need to be analyzed and designed to resist the lateral loads from the supported floors. Tension due to overturning as well as shear will need to be transferred between the upper and lower panels. The lateral load normal to the face of the upper panel may also need to be transferred across the joint. These load requirements should be compared to the structural integrity requirements of ACI section 7.13.3 and 16.5. The connection between panels can be accomplished in many ways, but one convenient way to make this connection is through the use of cast-in-grout sleeves to splice the panel reinforcing across the panel joint.

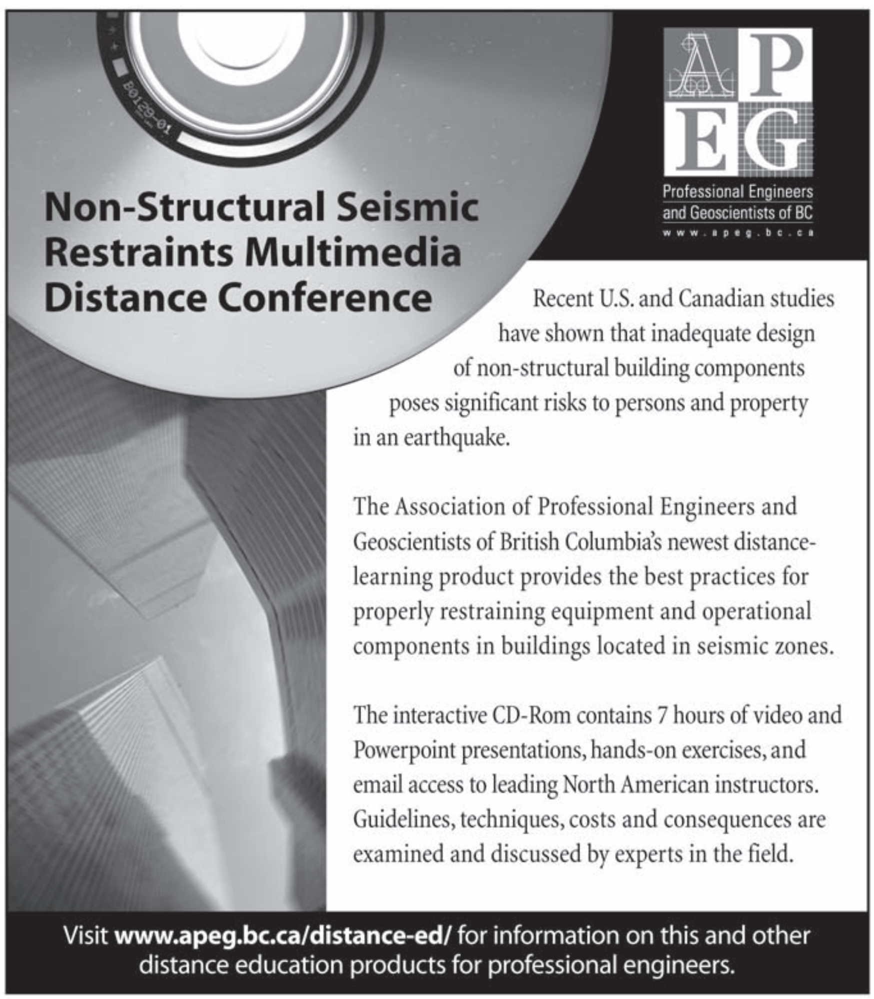
Tilt-Up buildings resist lateral loads through the roof and floor diaphragms that distribute lateral loads to the shear wall panels. Each wall panel is then connected to the slab-on-grade to distribute the lateral loads to the subgrade. Perhaps one of the most commonly misunderstood areas of Tilt-Up buildings is the connection at the bottom of the wall panels. Tilt-Up panels are not required by the building code to be attached to the foundations. The lateral loads in the wall panels are transferred into the slab-on-grade with the use of reinforcing bars, or some structural connection to the slab. If reinforcing bars are used to make the connection, a fill-in strip several feet wide is usually provided adjacent to the wall panels and cast after the panels have been erected and aligned. Section 16.5.1.3 of ACI 318 requires a minimum of two connections at the base of each panel, and also provides the minimum design forces required for these connections. Generally, the connections are spaced a maximum of four feet on center so that the panel does not need to be designed to span horizontally between connections (the four foot dimension is an IBC requirement). The slab-on-grade then acts as a large rigid diaphragm to distribute the lateral forces into the soil. Reinforcing is provided in the slab on grade to insure that the wall panels engage enough of the floor slab to dissipate lateral loads caused by the seismic event.



Typical panel to slab–on–grade connection.

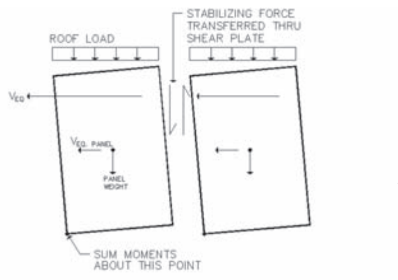

Stapleton Business Center Building EI

Tilt-Up buildings resist lateral loads by treating the wall panels as individual shear walls. There has been much discussion/debate on the "right" way to distribute the lateral loads to the wall panels. Fortunately, there are several valid ways to make this happen. Choosing the model for load distribution is based on several factors. It depends on the relative size of the various panels, solid panel or panels with openings, single



Watch for an article in STRUCTURE's July/August issue on retrofitting Tilt-Up buildings to meet current seismic requirements.

versus multistory panels and relative size of panel legs on panels with openings. Common to all panel stability calculations is the need to add the seismic overturning moment due to the weight of the wall panel. This force is applied through the center of gravity of the panel. The IBC has changed the load combinations used to check overturning stability from previous building codes. Previous codes used two-thirds of the dead load to resist overturning. That has been changed to 0.6 in the IBC. Roof and floor live loads should not be included when calculating overturning resistance, as they are transient loads.



Applied Loads for calculating panel stability

Load Distribution

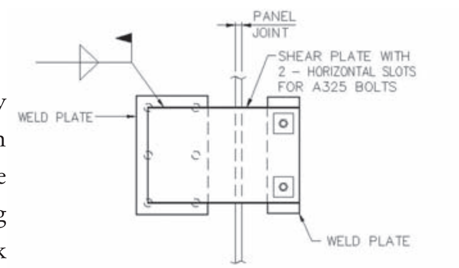
The easiest method for load distribution is to simply distribute the lateral loads uniformly based on panel width (i.e. wider panels receive more load). This works fine for the typical building with various panel widths and opening locations. If this results in narrow panels that do not check and wide panels that are okay, it might be better to distribute the lateral loads another way. The loads can be distributed based on the overturning resistance of the individual panels. Panels with large overturning resistance are used to resist more of the lateral loads. This is achieved using the perimeter angle to collect and distribute loads to those panels with larger overturning resistance. The final method used to distribute lateral loads is typically used on multistory panels, or where most of the panels have many openings. The analysis for this method takes into account bending and shear stiffness of the individual panel legs adjacent to openings for distributing the lateral forces. The panel overturning moment is then calculated based on the resistance of the panel legs for that panel. For the latter two methods, special consideration of the loads in the perimeter angle (collector) and its attachment to the wall panels must be considered in order for this to work.

Combined Systems Solutions

Most Tilt-Up buildings are successfully able to resist lateral seismic loads using the panels as individual shear walls. However, there are buildings that are unable to resist the lateral loads using only the wall panels due to layout or height. For these cases, Tilt-Up panels can successfully be combined with other lateral load resisting systems such as braced frames, moment frames or cast in place shear walls. The design of these combined systems requires careful consideration for the stiffness of each lateral load-resisting element, and a good understanding of dual systems as they are defined in the IBC. Conventional concrete shear walls can be either cast in place or constructed by connecting Tilt-Up panels directly to the foundations. For the latter, a portion of the panel is cast after the panel is lifted into place so that the panel reinforcing bars can be spliced with foundation reinforcing.

Overturning

In most buildings, there will be a few individual wall panels that don't check for overturning. When this is the case, shear plates are often provided across the panel joint. The shear plate transfers a vertical force to the overturning panel from the adjacent panel that effectively increases the overturning resistance. This vertical force passes through the point of rotation on the adjacent panel and has no negative effects on its overturning capacity. It is important in the design of the shear plate connection to allow some horizontal movement to occur, otherwise the restraint forces generated due to shrinkage and panel expansion/contraction could cause the connection to fail. For panels with more extreme overturning problems, several panels can be tied together to increase the moment arm for calculating overturning resistance. The detailing and design of these tied panel to panel connections can be fairly involved, and needs to account for shear flow, bending and panel expansion/contraction.



Example of shear plate connection across panel joint

Tilt-Up buildings are very effective at resisting lateral loads from wind and earthquakes. The design for seismic loads is no more complex than designing for wind loads; there are just additional requirements to consider. As long as a valid load path for the design forces is followed, and proper detailing and design of connections is met, the building should behave as expected.

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For more information about the TCA, visit www.tilt-up.org, or call Ed Sauter at 319-895-6911, or e-mail esauter@tilt-up.org.

The Tilt-Up Concrete Association (TCA) announced the 25 winners of its tenth annual Achievement Awards Program this past January. Eight of the structures received further distinction as Best in Class finalists. *Photos in this article are courtesy of TCA's awards program.*

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An on-line article on the award winners can be found at www.structuremag.org/archives.htm.