THE CONSTRUCTION OF TILT-UP

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Tilt-Up Concrete Association

TILT-UP CONCRETE ASSOCIATION

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Promoting growth and achievement in innovative Tilt-Up design and construction since 1986.

The Tilt-Up Concrete Association was created by a dedicated group of construction professionals interested in improving the quality and acceptance of Tilt-Up construction.

Our mission is to expand and improve the use of Tilt-Up as the preferred construction method by providing education and resources that enhance quality and performance.

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AN INTRODUCTION TO TILT-UP

An extraordinary series of photos chronicling the construction of Express Scripts Building 3 in Saint Louis, Missouri support the text throughout this publication. The images were provided to the TCA courtesy of photographer Matthew McFarland and TCA Sustaining Member Concrete Strategies. More information on these photos can be found in the photo index at the end of this book.

The Tilt-Up Concrete Association (TCA) conducted a survey in 2007 revealing approximately 790 million sq. ft. of Tilt-Up buildings were constructed that year—equating to an estimated 11,000 to 12,000 buildings. These projects ranged in size from 4,000 sq. ft. to several exceeding 1 million sq. ft. And the numbers keep growing as more architects, engineers, contractors, and developers become aware of the many advantages of the Tilt-Up method for constructing walls for low-rise industrial and commercial buildings.

What began more than 65 years ago as a novel way to build concrete walls for warehouses and manufacturing plants grew to a multi-billion dollar market, with an estimated 15% of all low-rise commercial and industrial buildings constructed with Tilt-Up. In some areas, the figure approaches 100% as the use of Tilt-Up for two- to five-story commercial buildings is claiming an increasing share of the construction market. Imaginative design professionals are now applying the Tilt-Up method to office buildings, shopping centers, distribution centers, schools, prisons, auto dealerships, banks, hotels/motels and other building types.

The use of Tilt-Up is growing rapidly, and its share of the construction market is expanding as its advantages become known--the permanence of concrete at low cost and a shortened construction time--and as the expertise to design and build Tilt-Up structures becomes more widely available.

This guide is not all-inclusive, yet presents basic concepts, techniques, and procedures involved in Tilt-Up construction. This guide includes discussions of Tilt-Up concrete's history; planning a Tilt-Up project; foundation and floor slab construction; and wall panel forming, casting, and erection. It briefly describes typical connections used to attach the panels to the rest of the structure, and options for panel finishes are briefly described.

WHAT IS TILT-UP?

The term "Tilt-Up" was coined in the late 1940s to describe a method for constructing concrete walls rapidly and economically without the formwork necessary for poured-in-place walls. It is a two-step process. First, slabs of concrete, which will comprise sections of wall, are cast horizontally on the building floor slab, or separate casting slab. Then, after attaining sufficient strength, they are lifted (tilted) with a crane and set on prepared foundations to form the exterior walls.

Although the method is most often called "Tilt-Up," it is also called "tilt-wall" or, in specifications and technical papers, "site-cast precast concrete walls." However, "Tilt-Up" is the preferred and generally accepted term. The term "Tilt-Up building" refers to any type of building that employs the Tilt-Up technique for constructing the walls.

ACI 551R-92 describes Tilt-Up as "The technique of site-casting wall panels on a horizontal surface and then lifting or tilting them into place..." ACI 318-02 and IBC 2000 define precast concrete as "a structural concrete element cast elsewhere than its final position in the structure." ACI 318 further states that Tilt-Up concrete construction is a form of precast concrete. Based on these definitions and descriptions, Tilt-Up construction is best described as a form of precast concrete.

Several features make the Tilt-Up construction method unique. Tilt-Up panels are generally handled only once. They are lifted or tilted from the casting slab and erected in their final position in one continuous operation. Tilt-Up panels are generally of such large size and weight that they can only be constructed on site and in close proximity to their final location in the structure. Panel gravity loads are supported directly by the foundation instead of being supported by a structural frame. Typically, Tilt-Up panels are erected before the structural frame. Tilt-Up panels are usually load-bearing for gravity loads and lateral loads.

A whole industry has developed around the Tilt-Up construction method. Tilt-Up concrete construction is a unique form of site-cast precast construction and, as such, has its own specialized set of design parameters and construction techniques.

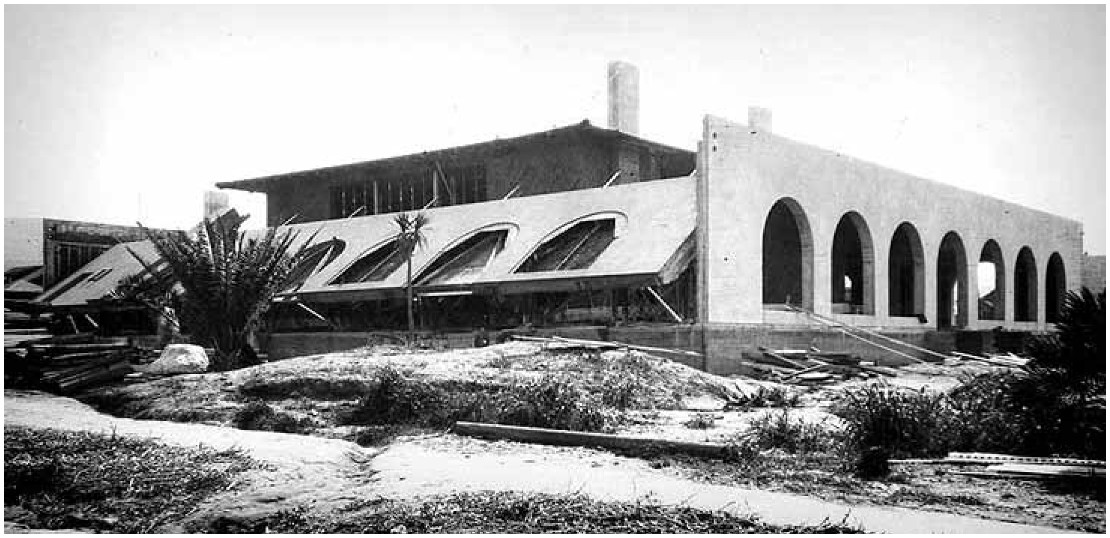
Tilt-Up wall panels typically weigh 60 tons or more, averaging only 6 to 8 in. thick. In Tilt-Up construction, formwork is only required for openings and the perimeter; therefore, very little formwork material is needed. When the wall panels have attained sufficient strength, usually a week to 10 days, a mobile crane is brought to the job site to lift and set them on prepared foundations. The erected panels are temporarily braced and typically connected to one another. The roof structure is then attached to the walls, the braces are removed, joints are caulked, and the wall finishes are applied to complete the building shell.

Techniques continue to improve as research and new innovations evolve, furthering the advantages and economics of Tilt-Up. As information about Tilt-Up is more readily available, Tilt-Up is attracting world-wide attention and activity.

This guide discusses many of the issues related to the planning and construction of what is often described as a form of site-cast precast. Topics include pre-construction, planning, foundations, special considerations for slab-on-ground construction, wall panel forming and casting, panel erection, connections, repair, and painting.

For architectural attractiveness, the design professional has almost unlimited freedom to arrange, assemble, and finish the panel in an effort to achieve what are often award-winning designs.

Photo Credit, U.S. Library of Congress, Prints and Photographs Division, "Built in America" Collection



A BRIEF HISTORY OF TILT-UP

Precasting building elements is not a new idea, states F. Thomas Collins in one of his Tilt-Up publications, *Manual of Tilt-Up Construction*, published in 1955 and 1965. Villagers in Jarmo, Iraq, made walls for their dwellings from “touf,” a pressed mud, as early as 4700 B.C. As cementitious materials became available, the quality and durability of these precast materials improved. The Romans produced pozzolan cement, which they used extensively in their building projects.

An interesting description of an ancient construction technique similar to present day Tilt-Up was referred to in *A Survey of the Turkish Empire*, written in 1799 by architectural historian William Eton. He described a method used in the Middle Ages for constructing an arch when lumber for falsework was scarce:

> *“At Bassora, where they have no timber... they make arches without any frame [work]. The mason, with a nail and a bit of string, marks a semicircle on the ground, lays his bricks, fastened together with a gypsum cement, on the lines thus traced, and having thus formed his arch, it is carefully raised...“*

It was not until the 19th century and the development of Portland cement that construction of concrete structures became an integral part of the construction process. By 1890, Portland cement was widely accepted as the standard cementing material.

Tilt-Up as we know it today evolved from such early innovations, and undoubtedly throughout the evolution of concrete construction it has had many applications. However, its feasibility for constructing large, thin, wall panels had to await the arrival of reinforced concrete, which came into use in the early 1900s.

Some builders in the United States developed an early form of Tilt-Up construction in which a tilting platform was used. Credit for one of the first reinforced concrete site-cast walls that was cast horizontally then tilted up goes, according to the archives of the Portland Cement Association, to an innovative builder, Robert Aiken. In his book, *Monolithic Concrete Wall Building-Methods, Construction and Cost*, Aiken described the innovative method where walls for the building were constructed on a structural platform, then rotated or tilted upward by means of specially designed mechanical jacks, setting the panel in its final position.

The TCA’s Distunguished Architect Award was renamed in 2008 to honor Irving J. Gill. Early in the history of concrete construction, Gill designed and constructed the celebrated La Jolla Woman’s Club, 1912-1914 (pictured above). Without the architectural mindset of Gill, the industry may very well have taken a much slower time to rise to its current dominance.

One of Aiken's buildings was a two-story warehouse at Camp Logan, Illinois; the other buildings were at Camp Perry, Ohio. He also reportedly constructed a Methodist Church in Zion, Illinois, using a "tilt-table" method, incorporating decorative precast elements embedded in the Tilt-Up panels. This tilt-table method was used on the Jewett Lumber Company in Des Moines, Iowa, between 1906 and 1912, and on several Army facilities, factory buildings, and churches.

News of the novel method attracted others, including Thomas Edison, who patented a related technique. In Chicago around 1912, a four-story factory was reportedly constructed using a derrick to raise the concrete walls.

Early structures using Portland cement concrete were usually cast-in-place. By 1914, cast-in-place concrete reinforced with mild steel reinforcing bars was second only to structural steel as a building material.

Collins stated that railroads, during the period before World War I, developed a technique for precasting large sections of bridges from reinforced concrete and setting them in place with their heavy cranes. The cranes, however, were mounted on railroad cars and required additional track to be laid to access the site.

The idea of precasting large structural units using reinforced concrete cast into molds or forms was hastened by World War I. The shortage of steel and labor caused by the war and the subsequent increase in building costs challenged engineers and contractors to develop new methods of building. Most of the improvements in precasting methods were developed in England and Western Europe. Precast elements, however, were small and easily handled without heavy equipment. In Russia, precasting building elements developed along broader lines due to more difficult conditions for fabrication and construction. There, larger sections were constructed using techniques similar to those now used in the United States. Erection was accomplished with stationary cranes.

The popularization of Tilt-Up as we know it had to wait for technological advancements to turn it into a fast, economical production method. The first two of these developments were the heavy-duty truck crane and electric-arc welding. The third development that made site casting of concrete elements a mature industry was transit-mixed concrete. The ready-mixed concrete concept made quality concrete available to anyone in any quantity on short notice. The mobile crane, along with the introduction of ready-mix concrete, became available in the late 1940s at the close of World War II, coinciding with the pent-up demand for new construction, which was dormant during the war years.

As a result of these innovations and the demand for construction, the number of buildings utilizing site-cast elements increased significantly. There were construction projects incorporating new technologies and ideas in local areas of the Midwest, Texas, Pennsylvania, and the New England states. The most progress, however, was in Southern California during 1945 and 1946. The dollar volume of work using this type of construction in Southern California increased from 2 million dollars in 1946 to 180 million dollars in 1952. Other Sun Belt states soon followed.

This post-WWII period was one of the most innovative in building construction history, also giving rise to such innovations as prefabricated metal buildings, glued laminated wood beams, prefabricated trusses, lift slabs, prestressed concrete (invented earlier, but popularized then), lamella roofs, and composite construction.

When the mobility and lifting capacity of truck cranes made Tilt-Up a possible production method, it caught on quickly. Today, Tilt-Up buildings are found in nearly every state and throughout the world.

Tilt-Up was once considered only ideal for constructing warehouses, with their long, windowless walls. As a result, the first Tilt-Up buildings were warehouses, where full-height panels measuring 20 feet wide and weighing 20 tons could be erected at the rate of a dozen or more a day. Today, 60-ton panels are commonplace and erecting 30 panels in a day is typical for an experienced contractor.

Some of the early contributors to the art of Tilt-Up construction were contractors and design professionals in Southern California. In 1958, California consulting engineer F. Thomas Collins, who had designed a number of the early Tilt-Up buildings, published his pioneering book *Building With Tilt-Up*, which subsequently went through six editions before going out of print. In the early 1950s, a Southern California firm attempted to patent the Tilt-Up process, but the patent was declared invalid by the courts in 1954.

All promising technologies improve with time, and Tilt-Up has been no exception. During the past 65-plus years, there have been numerous state-of-the-art advances in forming techniques, rigging, lifting, joinery, and hardware accessories, but the most visible advances were achieved through imaginative architectural designs and applications to multi-story buildings. Engineering research led to better understanding of the structural behavior of Tilt-Up panels, which in turn led to greater safety assurance, more economical designs, and the development of building code design standards.

THE TILT-UP PROCESS

The following is a summary of the steps in the construction of a typical Tilt-Up building:

1. The concrete floor slab, which typically serves as the casting base for the panels, is placed on the prepared subgrade. At the same time, the foundations on which the wall panels will be set are constructed.

2. The wall construction process begins by laying out the panels on the floor slab and constructing the formwork.

3. With forms in place, release agents are then sprayed, chairs and reinforcement are placed, and embedded items attached for items such as structural supports and attachments and lifting and bracing hardware.

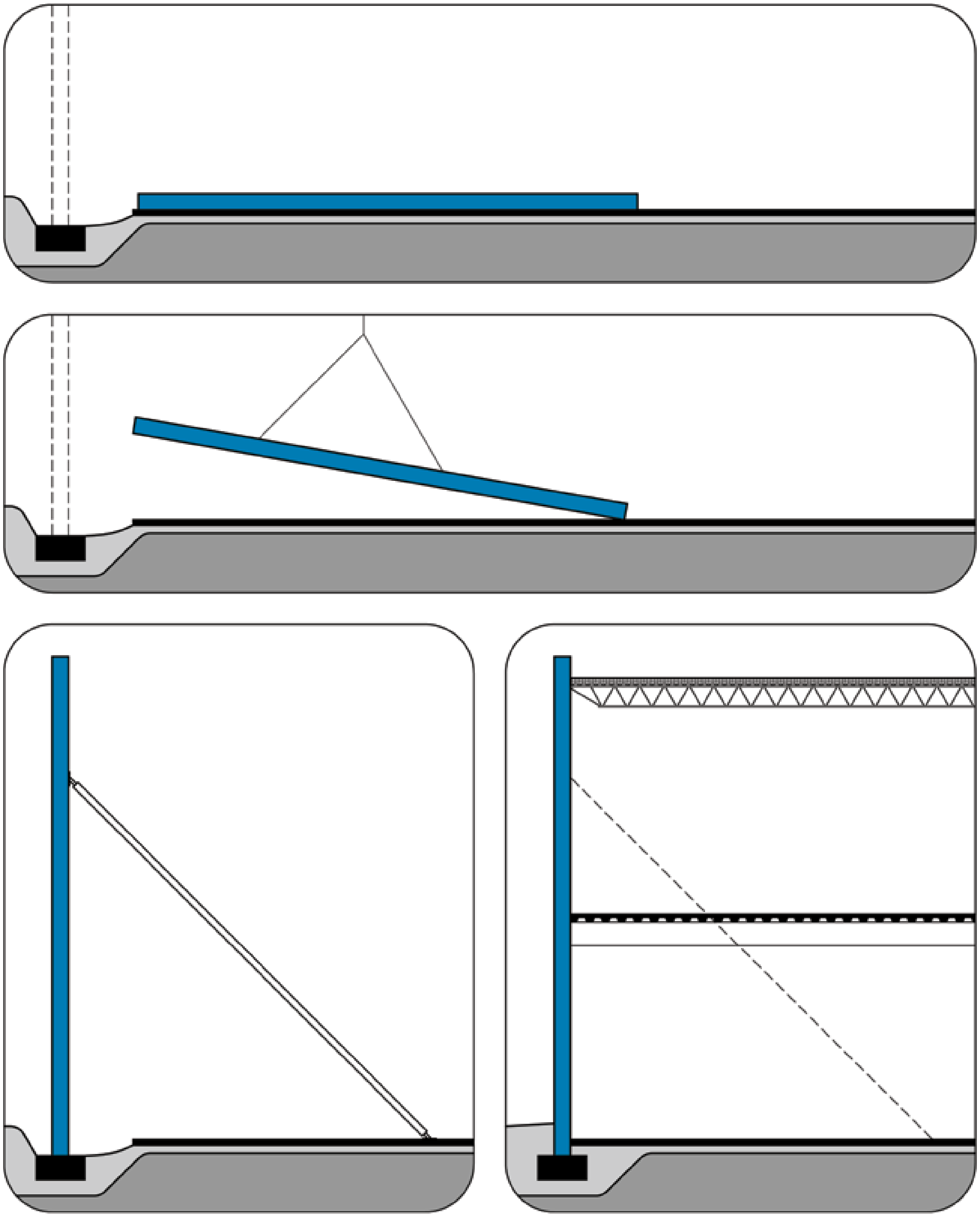
4. Concrete is then placed in the forms, finished, and cured.

5. Next is a waiting period of a week to 10 days while the concrete attains sufficient strength for lifting. Ideally, formwork would be removed at this time but oftentimes formwork is re-used on another portion of the same project.

6. On lifting day, cables are attached to inserts cast into the panels and the crane lifts each panel in the desired sequence and sets it on the prepared foundation; before releasing the panels, temporary braces are installed to support the panel until the roof structure is attached. This process is repeated until all the panels are set into their desired position.

7. Connections between panels are made, concrete is placed to tie the floor slab to walls, joints are caulked, patching is performed if necessary to repair blemishes, and once the roof is permanently connected to the walls, the bracing is removed.

Each of these steps is discussed later in the manual.



William Smithy Jr. Photography

TILT-UP TODAY

Today, Tilt-Up buildings have been constructed in every state of the United States. Canada, New Zealand, and Australia also have strong Tilt-up industries. Mexico, several South American countries, and Europe have recently been added to the list of countries using Tilt-Up.

Tilt-Up concrete is most prevalent in North America, from British Columbia south to the Mexican border, across the southern United States, and up through Nova Scotia. Elsewhere in the United States, pockets of strong Tilt-Up activity are found throughout the Midwest, the Plains, and the Rocky Mountain states.

Tilt-Up construction was first utilized for large, plain, simple structures -- most notably warehouses or distribution centers. This is still the dominant building type in Tilt-Up construction. Familiarity with Tilt-Up by designers and the use of innovative finishes have made Tilt-Up acceptable for use in many other types of buildings, including office buildings and retail structures.

Today's Tilt-Up buildings are hardly recognizable from the squat, gray boxes with the characteristic vertical lines that dotted the industrial landscape of the late 1940s and early 1950s. Today, striking examples of single and multi-story Tilt-Up buildings abound. Design professionals have found in Tilt-Up a medium they can use in a manner limited only by their imaginations. In the newer industrial and commercial areas of Southern California and other Sun Belt states, you will see many attractive buildings constructed using Tilt-Up.

The number of Tilt-Up buildings constructed annually is significantly increasing. One of the factors for this growth is not the continued need for the big box distribution project, but rather the acceptance of Tilt-Up as a more creative design and construction medium and a factor for nearly all market types.

To underscore the importance of Tilt-Up to the ready-mix industry, in 2007, an estimated 7 million cu. yds. of concrete went into Tilt-Up panels in the continental United States.

Through all of the market analysis, it remains that little success is possible in accurately assessing the volume of this market. However, what success can be seen is the achievement recognition of the industry.

Since 1995, the TCA has been keeping records of the most notable Tilt-Up achievements in the form of a series of Top 10 lists. These lists can be visited in their updated and complete state at the TCA website, www.tilt-up.org/topten and include:

1. Largest Building (footprint)
2. Largest Building (total floor area)
3. Largest Wall Area (including windows)
4. Most Panels (single building)
5. Most Panels (entire project)
6. Largest Panel (area)
7. Tallest Panel
8. Heaviest Panel
9. Widest Panel
10. Tallest Cantilever Wall (from top of footing)
11. Largest Spandrel Panel
12. Recycled Concrete Content

It is estimated that the current breakout of building types for Tilt-Up construction yields the following: 60% Industrial/Warehouses/Distribution Centers, 20% Retail/Shopping Centers, 10% Offices,10% Other.

And a geographical breakdown (in the United States): 36% California, 20% Texas and Southwest, 20% Oregon and Washington, 11% Florida.

THE TILT-UP MARKET

Although more than a dozen Tilt-Up buildings, on average, are started every business day, Tilt-Up buildings represent only about 10% of the total U.S. non-residential market. So, there remains a large growth potential, with plenty of opportunity for the enterprising design professional, contractor, and developer. In order to capitalize, the merits of Tilt-Up must be publicized and sold.

Opposite: The look of masonry does not mean hand laid by masons anymore. Liners as well as actual brick and stone transform the downside surface of today's Tilt-Up panel to effective masonry motiffs that are often times highly ornamented.

In some areas of the country, Tilt-Up is accepted as the way to build low-rise industrial and commercial buildings — and in other areas, there is little familiarity with Tilt-Up. It is these areas that offer the greatest opportunities because once a Tilt-Up building is completed and its benefits are demonstrated, others are sure to follow.

Construction methods competing with Tilt-Up for the one-and two-story building market are precast concrete (plant cast), masonry, steel frame, wood frame and -- to a lesser extent -- pre-engineered metal buildings.

SITE CAST VS. PLANT CAST CONCRETE BUILDINGS

Given that precast defines both panels made on a jobsite (Tilt-Up) as well as those manufactured in a plant operation, there are many similarities. However, significant differences exist between the two building methods. Tilt-Up panels are almost always load-bearing and do not require a separate structural frame to resist service loads as architectural plant cast panels do. Full-height structural plant cast panels may not require a separate structural frame, but are usually limited in width due to transportation requirements. The argument for plant cast panels is often that construction is faster, because inclement weather does not delay the casting of panels and they can start even before the site work has begun. However, there are a variety of other factors to consider, such as:

1. How far is the building site from the nearest qualified precaster for transportation costs?

2. What is the widest, tallest, and heaviest panel that can be transported?

3. Will the precaster use architectural precast, which requires a separate structural system to resist service loads or heavier structural precast?

4. Have you considered that the limitations of transporting precast on the roadways result in approximately three times as many precast panels to erect and brace and three times as many joints to fill?

5. Will the narrower precast panels accommodate the anticipated opening widths and architectural pattern?

6. Will the precaster have enough casting beds and/or storage room to meet job requirements?

7. Does the precaster have a long lead time before they can begin casting panels?

TILT-UP VS. MASONRY BUILDINGS

Masonry, when compared with Tilt-Up, is generally more costly and takes longer to build. However, in areas where Tilt-Up expertise is unavailable or where masonry is inexpensive due to a plentiful labor source, you will see many masonry buildings. Enterprising contractors in these areas are introducing Tilt-Up and often winning jobs that were originally designed as masonry buildings. Faced with deciding whether to use Tilt-Up or masonry, the answer you get depends upon whom you ask. Masonry contractors will tell you they can build faster and for less cost, and Tilt-Up contractors will tell you their method is the better choice.

Here are some factors:

1. For a building of less than about 6,000 sq. ft., the choice may be masonry if crane time is found to be uneconomical for the smaller number of panels. Further, the limited floor space may not be enough for casting panels.

2. If the building is in an area of the country where Tilt-Up expertise is not available, or where cranes are scarce, masonry may prevail.

3. For a large building in an area of the country where concrete blocks or bricks and mason labor are inexpensive, Tilt-Up may be the best option, assuming Tilt-Up expertise and cranes are available; if they are not, masonry wins by default. On a large project, an experienced masonry crew can work fast and very efficiently. However, in areas where Tilt-Up is widely used, and all other factors are equal, Tilt-Up is invariably a more economical choice.

4. If a building has a high clear height inside, say more than 24 ft., Tilt-Up is more economical since the thickness of the wall required need only be increased incrementally, whereas masonry jumps in whole block units, such as to 12 in. from 8 in. Additional temporary bracing may also be needed for higher masonry walls.

5. For fire resistance, an 8-in. concrete block wall with all cells grouted is rated four hours, equivalent to a 6½-in. concrete wall. If the block wall is not solid grouted, it is rated two hours, which is equivalent to a 5-in. concrete wall. (These examples assume normal weight, Grade A concrete.)

6. A concrete wall is generally denser and less porous than a masonry wall. With masonry, there is the problem of sealing and painting so water does not enter through the joints, or through the blocks' natural porosity.

A Tilt-Up building is faster to erect than a masonry building, given a relatively large building with repetitive panels. It is not difficult to completely enclose a 60,000-sq- ft. Tilt-Up building in four weeks, from laying out the panels to starting the roof structure.

TILT-UP VS. METAL BUILDINGS

Metal buildings fill a market niche for low-cost enclosures; however, when they are designed to provide a similar level of performance comparable to a finished Tilt-Up building, they can cost as much and still lack the durability, fire resistance, low maintenance, and other desirable features of a Tilt-Up building. Recognizing the advantages of a concrete wall, some metal building contractors are using Tilt-Up panels attached to the steel frame.

The prefabricated, pre-engineered metal building industry has aggressively marketed its product, selling the concept of economy through standardized manufactured components. You can almost pick your building from a catalog.

Metal buildings have their place for low-cost shelter; however, comparing features such as durability, maintenance, fire resistance, insulation, security, and others discussed above, there is little comparison. Additionally, a metal building fitted for office use, with drop ceilings, finished walls, insulation, and other features can cost as much as a Tilt-Up building.

The metal building industry has recognized the advantages of Tilt-Up by offering exterior walls of Tilt-Up concrete as an option rather than metal siding.

TYPES OF BUILDINGS SUITED FOR TILT-UP

The types of buildings which can be economically constructed using Tilt-Up are limited only by the imagination of design professionals, contractors and developers. Correctional facilities, schools, multistory office buildings, low-

Bill Timmerman

temperature storage buildings, industrial and manufacturing projects, recreational facilities, churches, and housing developments also use Tilt-Up construction.

The most recent applications for Tilt-Up structures are small buildings and residential structures. The upscale finishes, discussed in later sections, have helped Tilt-Up gain acceptance.

Building types and panel applications are of as much variety as the location where Tilt-Up is performed. Considering the growth that has occurred since the 1950's it is not uncommon to find Tilt-Up panels in an ever-increasing list of applications including the following:

Warehouses and distribution centers, Factories and manufacturing plants, Shopping centers, Office buildings, Churches, Schools, Correction centers and institutions, Fire stations, Parking structures, Hotels and motels, Mini-storage warehouses and caves, Automotive dealerships, Banks, Theaters, Libraries, Produce storage and timber kilns, Retaining walls, Freestanding walls and fences, Signs, Tanks, Storage bins and bunkers, Sound walls and transportation systems, Seating stanchions, Towers and even Sculptures.

Great examples of housing demonstrate the emerging market potential for Tilt-Up from single-family and townhomes to condominiums and apartments structures. Thus far, however, the reported activity is low in the United States. Mindsets remain that wood frame construction dominates due to lower costs. However, this is beginning to change as more contractors gain confidence with the smaller scale of the traditional home and build valuable experience for their subcontract trades. Still, when durability and low maintenance are important factors, Tilt-Up is certainly a viable alternative.

North America and other countries have experienced the successful construction of multi-story housing projects using Tilt-Up panels. Also, in Australia and New Zealand, Tilt-Up has been successfully used for housing for many years. (See *Cement and Concrete Association of Australia's* publication *Residential Tilt-Up Construction*.)

THE ADVANTAGES OF TILT-UP

The construction market is highly competitive, and Tilt-Up is chosen only when its advantages, given the locale and circumstances of a project, clearly favor it. These advantages include:

1. **Economy**. In areas where Tilt-Up design and construction expertise is available—par-


Charles Davis Smith

ticularly a trained crane and rigging crew—Tilt-Up proves to be more economical than competing construction methods for similar types of buildings. For example, in the highly competitive Southern California construction market, it is rare to see a large masonry industrial building, as Tilt-Up dominates in that geographical marketplace.

2. **Speed of Construction**. From the time the floor slab is placed, the typical elapsed time from starting to form the panels until the building shell is completed is four to five weeks.

3. **Durability**. Tilt-Up buildings constructed in the late 1940s show little sign of age (except architectural styling!) and some are being handsomely remodeled.

4. **Fire Resistance**. Concrete is an obvious first choice for fire resistance. A 6½-in.-thick wall, for example, has a four-hour fire rating.
5. **Low Maintenance Costs**. Typically, the only maintenance required is a new coat of paint every six to eight years.

6. **Lower Insurance Rates**. The fire resistance and durability of Tilt-Up concrete walls results in lower premiums.

7. **Architectural Attractiveness**. A look through the Portfolio of Tilt-Up Buildings section will attest to this feature of Tilt-Up.

8. **Low Heating/Cooling Costs**. Tilt-Up walls can be economically insulated to give higher insulation values. Insulation is integrated with Tilt-Up concrete walls to provide an insulative value that often exceeds anything found in masonry and wood frame construction.

9. **Expandability**. By planning for the possibility of expansion, panel connections can be designed so the panels can be detached and relocated.

10. **Security**. Unlike metal buildings, forced entry through walls can only be made through door and window openings.

11. **Value Appreciation**. All of the above features of Tilt-Up help ensure the desirability of an investment in a Tilt-Up building.

THE CONSTRUCTION TEAM

Although many general contractors do their own concrete work, many subcontract all of the concrete work to a concrete subcontractor. This typically includes the foundations, floor slab, and Tilt-Up panels. This concrete subcontractor (or the general contractor) then usually subcontracts with:

1. A reinforcing steel subcontractor who supplies and places the reinforcing.

2. A structural steel subcontractor who provides the various embedded items that go into the panels for joining them or making other attachments.

3. A crane and rigging subcontractor who provides the crane and rigging crew to lift the panels into place. This subcontractor is generally on the job one to four days, depending upon the number of panels to be erected.

4. A lifting accessories supplier who provides all the hardware required for lifting and bracing the panels. This supplier checks the panels

for erection stresses, designs the location of lift inserts, selects the proper hardware, selects the bracing, and delivers all these items to the job site. The lifting accessory supplier is a key player in the Tilt-Up process.

5. A welding subcontractor who welds all diaphragm connections.

6. A sealant subcontractor who applies the joint sealant between the panels.

7. A specialty engineer.

These are the primary members of the construction team involved with Tilt-Up work. There may be others, too, such as the testing laboratory to take test cylinders and check the slump of the concrete. Inspection agencies also may be required by the building department or local codes for quality control.

Strengthened by strongback, this panel is being lifted with proper technique. Fewest number of crew members as possible and a single panel foreman communicating with the crane operator.

TILT-UP CERTIFICATION

ACI Certified Tilt-Up Supervisor

Enjoying phenomenal growth and expansion into new areas and building types, the Tilt-Up Concrete Association (TCA) recognized the necessity of a pool of qualified supervisors available to serve the needs of the industry. As such, the Tilt-Up Certification program was developed so that owners, designers, and general contractors could have some degree of assurance that an individual representing themselves as a Tilt-Up professional has at least a basic level of knowledge about the Tilt-Up building system.

The TCA-American Concrete Institute (ACI) Field Superintendent certification program began in 2001. There are two levels of certification, Technician and Supervisor. To be listed as a Tilt-Up Technician, an applicant is required to pass the then-current exam. The higher level, Tilt-Up Supervisor, qualifies by submitting work experience requirements for evaluation. The candidate must have a total of five years of construction experience, three of which must be in a supervisory or assistant supervisory role. The experience must also be spread over the areas of knowledge (see above) in which a supervisor is expected to have experience. The form must be authenticated by the candidate's superior.

The designation is valid for a period of five years. To renew certification, the individual need only pass the then-current examination. Work experience requirements do not need to be resubmitted. An individual classified as a Technician who obtains the requisite experience only needs to submit the work experience qualifications. If approved, the Technician will be elevated to a Certified Superintendent status for the balance of the five-year validity of the certification.

The Certification Study Guide for the exam consists of Chapters 2-8 of the Tilt-Up Construction Manual, the ACI 551 Guide to Tilt-Up Construction, and the TCA Bracing Guidelines. The study guide and other resources may be obtained from the TCA and ACI Web sites. These materials should be purchased well in advance of sitting for the exam. The knowledge required of the Tilt-Up Supervisor covers several key areas including planning, site preparation, foundations, slabs, layout, forming, placement and finishing, erection and bracing, structural systems, safety, scheduling, concrete properties, and finishes. The number of questions in the exam dealing with each area varies depending on the established "importance matrix." Safety, scheduling, and planning are the most important followed by layout, forming, and erection.

TCA Certified Tilt-Up Company

The goal of the TCA Company Certification Program is to provide a marketable and universally accepted verification program for assuring the experience, quality, and performance of Tilt-Up concrete producers.

This certification program is designed to certify the companies that manage the overall Tilt-Up construction process. It is acknowledged that many companies and different trades are involved in one way or another in the process, and this program does not attempt to certify each individual company or trade that may be used on a project; rather it is meant to be used to certify the construction company that is ultimately responsible for the overall production and quality of the finished Tilt-Up concrete elements.

The program puts the burden on the TCA Certified Company to hire responsible individuals and sub-contractors to insure that the finished product is produced safely and in accordance with project specifications and the minimum standards of this program. The program does include requirements for the certification of some of those individuals and trades as a means of quality assurance.

For more information visit www.tilt-up.org/certification.

CERTIFIED TCA COMPANY

SECTION 2
PLANNING THE TILT-UP BUILDING

Opposite: Tall structures with narrow floor plans, like this dormitory for Florida Atlantic University necessitate perimeter casting slabs. Their reuse and proximity to the in-place condition maintain the efficiency of Tilt-Up construction.

As in most construction projects, success is measured by the overall budget, completed schedule, and profitability of the team members. Planning, therefore, is critical to the overall success of the following factors:

Budget. Was the project completed under a set target by the owner?

Schedule. Was the project completed in a time-frame acceptable to the owner?

Profit. If the budget was correct and the proper construction time provided, then the contractors and design team members should expect a profit.

However, with poor planning at any stage, the overall budget may be exceeded, the projected schedule extended, and projected profits eroded accordingly. Therefore, elements such as planning are critical to the success of any project. This statement is consistent with Tilt-Up construction, as much of the project is based upon a shortened schedule of a series of precise events, known as constructing Tilt-Up Panels.

It is possible that the most traditional method of building delivery is one of Design, Contractor Selection, Construction. Therefore, one might suggest that Tilt-Up has evolved as a way of embracing that process while being equally as effective in offering a value-engineered approach to building delivery. Regardless of the project development model, planning to involve Tilt-Up requires the specific consideration of many variables. The key components of planning Tilt-Up occurs in the typical project phases of Design and Pre-Construction.

DESIGN

Planning should begin as soon as an owner has the requirement for a new or extended facility. The first step in planning is considering the design.

The following design considerations must be resolved in order to facilitate a completed set of working drawings:

1. Building/panel height. The heights of the panels are a result of the vertical access required by the owner, with the allowances for the mechanical and electrical systems, and interior structural shell components.

2. Interior structural framing. This will affect the building height, construction cost, and schedule. The design team must acknowledge this aspect when selecting such component.

3. Underground piping. Depending on the location of the under-slab plumbing drainage or electrical distribution, this will affect the project schedule. The days required to bury pipes and conduits are days panels are not cast! This relationship affects the project schedule, which in turn affects the budget.

4. Size of panels. The design team should discuss with a local Tilt-Up contractor the preferred panel size so maximum panel sizes and minimal panel joints are utilized.

5. Exterior finishes. Lead time allowance, pre-tendering of exterior components to ensure the products are available for the successful contractor. The construction phase is not the time-frame for architectural research and development. Mock-ups and sample panels, constructed by the Tilt-Up contractor, become the benchmark for the owner and architect's review of the contractor's understanding and commitment to the pending project.

THE ARCHITECTURAL CHALLENGE OF TILT-UP

Architects who embrace the flexibility of Tilt-Up will quickly discover it doesn't restrain their architectural talent and actually challenges that very creativity. It is a medium of almost unlimited opportunity for architectural expression. Although the principle components are flat concrete panels, a plethora of sizes, shapes, finishes, and textures are available to explore.

Whether arranging and assembling panels in an infinite number of ways to the use of innovative joinery—the connections between the panels and to abutting materials, architects will find a much broader palette of opportunities available. Just remember to keep it simple. Many architects feel the design of a Tilt-Up building is among their more interesting challenges, and they frequently produce award-winning designs.

Developers often have input for the design process. Desiring their product to be competitive and appealing in the marketplace, developers often tell architects how they think it should look, what colors they think are popular, and how the building should be sited. Developers may suggest that their architects drive by several buildings to observe features they want incorporated into the building. Developers also listen to real estate agents telling them what is selling and what designs best meet the market.

Architects should embrace opportunities to work with developers and contractors, thereby creating excellent learning experiences for all involved in the process. Many architects who work almost exclusively for developers acquire the lingo and sensitivity to the developers' needs so that the shoe is soon on the other foot. Developers look to them for fresh ideas and in turn become trend setters for other developers—and their architects—to copy. Remember that each good idea a developer sees is another architect's creation. Having your ideas copied, while perhaps not financially rewarding, is at least gratifying. Owners and developers interested in doing Tilt-Up work want to work with architects and engineers who have expertise and creative talent. They seek you out as word gets around that your office can design an attractive, functional, and economical Tilt-Up building.

DISPELLING THE MYTHS OF TILT-UP

The Tilt-Up industry has experienced numerous advancements and innovations in recent years. Yet while the building method can now accommodate nearly any architectural vision, numerous misconceptions still exist about Tilt-Up construction. For example, size is not a limiting factor for Tilt-Up buildings. In fact, today's professional Tilt-Up contractors find opportunities for using the Tilt-Up process in increasing numbers. Adaptations now make, stairs, elevators, fire walls, blast walls around pad mounted transformers, signs sculptures, and dumpster or screen walls more all viable options. What's more, Tilt-Up structures are no longer limited to box-shaped designs. Tilt-Up is now defined as an industry where form can inspire function. Below is a list that debunks the misconceptions of Tilt-Up.

Building Size

Myth: Only certain-sized buildings can be Tilt-Up, or you must have at least 20,000 square feet to make Tilt-Up economical.

Form doesn't always follow function and Tilt-Up excells in these conditions. Leaning and bi-axially curved, this design feature could only have been constructed using the site cast Tilt-Up method.

Fact: Buildings with footprints less than 600 square feet and exceeding 2,000,000 square feet have been built with Tilt-Up.

Corners

Myth: There is no versatility with the corners of Tilt-Up panels.

Fact: There are at least five types of corners being used on a routine basis.

Alternate Casting Methods

Myth: I can't cast Tilt-Up panels because I have a drain in my floor.

Fact: Although the floor slab is an ideal place to cast panels, it is not the only option.

Curves/Arches

Myth: Tilt-Up wall panels are all flat and rectangular.

Fact: Concrete is a flowable (liquid) medium when delivered to the formwork, anything you can form, you can pour.

Building Site

Myth: I have a very small site with buildings next door, so I won't be able to use a Tilt-Up process.

Fact: As long as you have 35 to 40 ft. around the perimeter of a building OR the option to lift from the interior OR the availability of a longer boom on your crane to reach out, panels can be lifted on a site with limited space.

Building Panel Height

Myth: Tilt-Up wall panels are limited to a maximum of 30 ft. high.

Fact: Four- to five-story office buildings are consistently completed with Tilt-Up construction, and panels in excess of 90 ft. have been done on several projects.

Building Configurations

Myth: My building is not simple configured and I have odd shapes in my elevations. Tilt-Up is for rectangular panels.

Fact: Tilt-Up panels can be any shape and/or size. In fact, Tilt-Up is often selected for extremely complex panels.

Openings

Myth: Tilt-Up panels can not have large openings.

Fact: Tilt-Up panels with openings on more than 80 percent of the panel have been lifted successfully and safely.

Multi-story, winter construction with considerable openings; this project demonstrates the versatility of Tilt-Up to dispell many common myths.

Building Use

Myth: Tilt-Up is only for warehouses and distribution centers.

Fact: Tilt-Up construction is used in many types of buildings, including offices, schools, religious facilities, and more.

Building Schedule

Myth: I have a very tight schedule and don't have time for Tilt-Up.

Fact: Tilt-Up construction is the fastest form of construction from conception to completion.

Budget Benefits

Myth: My building needs to pay for itself.

Fact: Tilt-Up buildings have a typical life of 100 to 150 years and generate significant savings in operating and maintenance expense. This offers a multitude of cost benefits.

Sustainability

Myth: I want a building that is not a drain on the economy.

Fact: Tilt-Up construction is a smart and sustainable delivery method.

Concrete Perception

Myth: Concrete buildings are bland and unappealing with little aesthetic variety.

Fact: Tilt-Up concrete buildings have some of the most diverse and inviting forms and finishes available in construction today.

Tilt-Up in Winter Months

Myth: I see all the Tilt-Up in the Southeast and Southwest where conditions are perfect for Tilt-Up year-round. We can't do that in colder climates.

Fact: Concrete can be poured any day the temperature reaches 32 degrees Farenheit. Furthermore, protection systems with varying economic impact can be employed when schedule plays a significant role in the driving force for a project.

Opposite: A “monumental” task is often overcome with the flexibility of Tilt-Up panels. Craftsman can deliver polished, exposed aggregate faces, complex edges and dramatic detailing with exacting tolerances.

Safety

Myth: My crews are afraid of Tilt-Up construction.

Fact: Tilt-Up construction is one of the safest forms of construction being utilized today. The floor is the working surface.

Enhanced Moisture Control

Myth: We have had problems with mold and mildew in the past and I don’t see how you stop moisture that condenses in the wall.

Fact: Tilt-Up panels provide enhanced moisture control because the wall itself is a highly-impermeable layer.

Finishes

Myth: My community mandates a brick façade for my building and I can’t afford Tilt-Up with a full masonry wythe.

Fact: Why stop at just brick as a requirement? Tilt-Up buildings are built regularly with thin brick, thin block, exposed aggregate and even more costly and difficult finishes such as tabby (oyster shells).

Tilt-Up Sculptures

Myth: I have a large concrete sculpture to build. Can I use Tilt-Up?

Fact: Yes, Tilt-Up construction has already been used and would be an ideal construction methodology for sculptures of all kinds.

Stairs/Elevators/Towers & More

Myth: I have run into construction delays waiting for the expensive elevator and stair shaft; can Tilt-Up help?

Fact: Yes, Tilt-Up construction for use in elevator shafts, towers, and stairs is ideal and eliminates waiting and often delays caused by other construction trades.

Firewalls

Myth: I need firewalls in my building.

Fact: The building code recognizes that 7.2-in. concrete wall provides a 4-hour fire rating.

Dror Baldinger

THE MINIMUM SIZE TILT-UP BUILDING

Talking with contractors, you most often hear 5,000 sq. ft. as the smallest practical size for a Tilt-Up building. But many contractors report doing even 3,000-sq.-ft. buildings successfully and economically.

Actually, a Tilt-Up building can be just about any size from 400 sq. ft.—one 20-ft. wall panel on each side—on up, but as the size gets larger, unit costs go down, assuming equivalent complexity.

Determining the minimum size building that is both practical and economical for using Tilt-Up involves asking two primary questions. First, is there enough space on the floor to cast the panels and still have working space for concrete trucks and crane access? Second, what is the minimum size that is efficient for the available crane in the area? Neither of these is essential for the success of Tilt-Up; however, they do affect the economics of the construction.

For example, assume wall panels are 26 feet high, and the building has a rectangular plan with a ratio of 1.5 to 1; and the panels do not occupy more than 70% of the floor area. A 23,000- sq.-ft. building is the minimum size to accommodate these assumptions. The closer the building is to a square, the larger the required floor area. Conversely, the longer and narrower the floor plan, the smaller the required floor area. Panel height also affects the required floor area and the building ratio.

Depending upon the shape of the building's footprint and the height of the wall panels, the minimum size for maximum economy calculates to between 20,000 and 30,000 sq. ft. However, many industrial parks have clusters of Tilt-Up buildings in the 4,000- to 6,000- sq.-ft. range.

The second factor for minimum building size is efficient crane usage to erect the panels. Since an experienced rigging crew erects 20 to 30 panels in a day, and the cost of the crane and crew is as much as $6,000 per day, economy suffers if the crane and crew lift only 10 or 12 panels. In our hypothetical example above, the 23,000-sq.-ft. building consists of approximately 26 panels -- an efficient day's work.

MULTI-STORY TILT-UP BUILDINGS

A growing number of Tilt-Up buildings are two-, three-, and four-stories. Some are even higher. Most of these are office buildings. Since it takes only a little additional time to erect a two- or three-story-high panel, as compared to a one-story panel, the wall cost for a multi-story building can be very economical.

Structurally, multi-story buildings are easily designed. The only significant difference from a one-story building is the greater weight of the individual panels and the additional temporary wind bracing required. Panels are not typically thicker than for a one-story building, since each floor provides lateral support for the panel, and thereby reduces the structural requirements.

Multi-story construction with Tilt-Up offers design flexibility for the panel configurations. Panels can be designed to span the entire height of the project, or can be designed with heights equal to one or more stories.

The application of Tilt-Up for housing appears only to be competitive (over conventional wood frame) where wood is expensive or unavailable, or where the low maintenance and near indestructibility of concrete offers an advantage. Panels for multi-story housing can be designed traditionally, can be designed with panels stacked with joints at each floor level.

OTHER SITE USES OF TILT-UP

Construction of the Tilt-Up building is not the only application for panels cast on site. Contractors have also discovered the advantages of using Tilt-Up panels to serve as screen walls, entrance features, structural columns, and site signage. Tilt-Up has also been used for stairway walls, trash enclosures, and loading dock ramps as well as many other unique applications.

ACHIEVING A CONTINUOUS GLASS LINE

For most office buildings, many windows are desirable. To avoid the patch-work appearance of many individual rows, a continuous glazing line is achieved by recessing solid sections of the panels to allow glazing to pass in front of the thickened structural elements. The recess need only be a few inches, varying with the manufacture of the glazing.

PANEL SIZES AND SHAPE

Although Tilt-Up is a highly flexible construction method, here are some guidelines to keep in mind when establishing panel sizes and shapes that can help maximize the economy for a given project:

1. Limit the heaviest panel to about 40 tons, which is 80,000 lbs. As a rule of thumb, the crane capacity is about twice the weight of the heaviest panel;

80-ton capacity truck cranes are commonly used for Tilt-Up work. This is not a hard-and-fast rule, since rigging contractors select the cranes they use based on other factors, such as how far out the boom must extend to set a panel (lifting capacity reduces the further out the boom extends). Occasionally, heavier panels are used for architectural effect or structural requirements. Remember that heavy panels often increase costs; however, they may resolve issues that offset the cost increase. For very heavy panels, two cranes are often used lifting in tandem. Another option is to bring in a large capacity crawler-type crane to lift panels of 60 tons or more.

2. An easy way to determine the weight of a panel is to multiply its area in square feet by its thickness in inches and then multiply by 12 to get the weight in pounds (or divide by 167 to get the weight in tons). Forty tons is equivalent to 800 sq. ft of 8-in.-thick panel, 920 sq. ft. of 7¼-in. panel, or 1,100 sq. ft. of 6-in. panel. Remember to deduct for door and window openings.

3. Rectangular panels are the most economical.

4. Where door openings occur, don't have an open bottom; have at least 8-in. depth of panel across the bottom to tie the two sides together.

5. Don't have door or window openings closer than about 24 in. from an edge of a panel.

6. One large panel takes no longer to lift and set than two smaller panels, provided weight limitations are heeded.

7. Lintel panels are frequently used to span recessed entries and to achieve other architectural effects. Limit their span to about 40 ft. and a depth not less than about 5 ft. (More on lintel panels later.)

8. Avoid L-shaped panels where possible since they usually require strongbacks (more information will be presented about this topic later in this document) to lift, and they take longer to set.

WILL THERE BE ENOUGH CASTING SPACE?

Before panel layout and casting, the contractor should determine if there is sufficient slab area to cast the panels and maneuver equipment during construction. This subject is covered more thoroughly in Section 4: Panel Layout And Forming, since this is primarily the contractor's concern. However, the architect should at least be aware, in the interest of economical construction, that if there is not enough floor slab on which to cast all the panels at one time, the cost increases.

Generally, at least 20% of the floor area is needed for the concrete trucks and for crane maneuvering during lifting, although this requirement is reduced if advanced placement equipment is used. As a general rule, no more than 70% to 80% of the floor area is covered by the panels.

To estimate the total area of the panels, multiply the average panel height by the building perimeter. Then divide by the floor area. In actuality, a 3-ft.-wide strip around the building perimeter is unavailable due to the closure strip, the strip of slab placed after the panels are erected to close the gap between the panels and the floor slab.

For buildings with large plan areas, it is common to cast only the perimeter bay of floor slab, enough to form and cast panels. This has the advantage of casting the majority of the slab after the panels and roof have been erected and in a relatively controlled environment. This can eliminate placing large construction loads on the slab as well. Proper planning is required to designate traffic access into and out of the building and which areas of the slab are to be cast.

However, it isn't essential to have floor space to cast all the panels. Panels are often formed one above the other in a method known as stack casting. Stack casting can be used where space is limited. This method should only be used when the top panel is equal in size or smaller than the panel below, where openings can be easily aligned, and the number of panels to be stacked is relatively few. Formwork should be properly braced if stack casting is required.

Other casting methods include casting on a disposable casting slab outside the building and a method whereby panels are cast and erected first, and then the remaining panels cast and erected.

WHAT ABOUT SLOPED FLOORS?

Occasionally, the floor of a long Tilt-Up building is sloped, typically to facilitate site drainage. The slope should not exceed one-half percent, which is about 1/16 in./ft. In 20 ft., this is 1¼ in., and difficult to notice visually. When the floor slopes, the entire building is constructed parallel to the slope. In other words, all doors and joints between the panels are slightly out of plumb. This means interior doors are also slightly out of plumb, but experience shows that this does not noticeably affect operation. The wall panels at the end of the building should, however, be plumb, which means the end panels of the long walls will be slightly trapezoidal.

The form for a Tilt-Up panel is a custom canvas readied to receive ornamentation of any configuration. Reveals are one of the best ways designers emphasize portions of the facade and contractors accomplish the result with efficiency.

PAINT REVEALS

To separate colors on a painted wall surface, continuous recesses, called reveals or rustication strips, are frequently used to achieve visually pleasing lines. Or, a reveal is used solely for a shadow line to break up the surface. They are usually ¾ in. deep and 3½ in., 5½ in., or wider, and are typically formed with fiberboard or from 1-in. nominal boards.

As popular as reveals are with architects, they are as unpopular with structural engineers since they reduce the structural thickness at their location. This requires added wall thickness or more reinforcing to compensate.

Reveals are carefully detailed in their precise location. Dimensioning them is critical. If the panel is lifted and they're in the wrong place or don't line up with abutting panels, it's a costly problem to correct.

WHAT ABOUT CURVED PANELS?

Curved Tilt-Up panels are not only possible, they are becoming increasingly popular. They are more costly to construct due to the forming required; however, a few well-placed curved panels create very effective focal points.

Curved panels are formed using a variety of methods. Traditionally, they are formed using plywood sheets bent and nailed to curved ribs. To maintain the ability to control concrete placement and finishing, the radius of the curve using this method is limited to approximately 4 ft. Today, curved panels are also constructed using excavated earth forms or modified steel forms in addition to the more traditional methods. This shows the creativity of today's Tilt-Up contractor.

Also gaining in popularity are building façade curves created from panels arrayed in segments around the radius.

WHAT ABOUT PROTRUSIONS FROM THE PANEL SURFACE?

Normally, Tilt-Up panels are cast, using the floor slab as the casting surface, with the exterior face down. Depending on the contractor's experience level, protrusions may be incorporated into this down-side surface of the panel using shallow forms on the floor surface (called “platforming”). This results in recessed areas in the panel.

Projections from the top-side surface of the panel can also be incorporated using vertical forms attached to the perimeter forms of the panel area. These projections (typically seen as return legs) are then monolithically cast with the concrete placed in the general panel area.

STRUCTURAL CONSIDERATIONS

Structural considerations are addressed in-depth in the Engineering for Tilt-Up Manual. However, a basic understanding of how panels work structurally and how they form a structural system can help the construction process progress smoothly. Below is a basic discussion of structural considerations for Tilt-Up panels.

Forces. A Tilt-Up panel is subjected to forces from three directions:

1. Vertical (downward) forces from loads imposed by roof or floor framing, and from the weight of the panel itself, tend to cause the panel to buckle like a column, or be over-stressed in compression. The thinner the panel, the more likely the tendency to buckle.

2. Lateral (sidewise) forces, from wind or seismic, tend to bend the panel. To resist this bending, the panel spans like a flat slab between points of support, which are usually provided by the floor and roof diaphragm. Alternatively, the panel is designed to span horizontally between pilasters, but this is rarely done.

3. The third force acts in the plane of the panel—parallel to it—and tends to cause the panel to shear, or slide on its foundation. In this case the panel acts as a shear wall.

Resistance to all three forces is provided by the thickness of the panel and its reinforcing. The forces that nearly always control the design and determine the panel thickness and reinforcing are the lateral forces—wind and seismic.

The wind load prescribed by the code is a function of the wind velocity and varies with the geographical area. Design wind load can vary from 15 psf to over 40 psf.

The seismic load is calculated as a percentage of the weight of the panel and depends upon the seismicity of the geographical area. The building codes divide the country into four seismic zones, Zone 4 being the most severe. In Zone 4 (primarily California), one must use 30% of the panel weight as a horizontal force or higher in some circumstances. This translates into 20 psf for a 5½-in. panel and 30 psf for an 8-in. panel. In high seismic areas, wind is usually less critical than seismic, but not always.

In high seismic areas, the connections between the wall panels and roof diaphragm are extremely important. Numerous roof collapses have occurred during earthquakes due to the failure of these connections.

Reinforcing is placed in the middle of the panel since it then offers equal bending resistance from forces acting either inwardly or outwardly. Where stress concentrations occur, such as at beam connections or at jambs alongside openings, reinforcing is usually placed on each face to provide greater rigidity and strength. For an unusually heavy concentrated load, a pilaster or thickening of the panel below the beam connection may be necessary.

P-Delta Effect. Structural engineers talk about the "P-delta" effect. It sounds mysterious, but is quite simple. The "P" stands for a vertical force acting on the panel, and "delta" is a term used by engineers for deflection, in this case, the out-of-plane deflection of the panel resulting from wind or seismic forces. When the panel is deflected sidewise, the vertical load increases.

H/T Ratio. Engineers also use the term h/t ratio. This is the ratio of the unsupported height of the panel to its thickness. "Unsupported height" is the span of the panel between supports, which is usually the distance between the floor slab and the roof diaphragm, also referred to as the "clear height." This is an important ratio since the required thickness of the panel is a function of its bending, which in turn is a function of its span (unsupported height).

The height of the wall panel from floor slab to roof (or between floors for multi-story buildings) determines the thickness of panel required. It is not uncommon for warehouses and distribution centers to have inside clear heights of 30 ft. to 40 ft. constructed with Tilt-Up panels. For very high panels, one option is to thicken the panel edges for greater stiffness. For example, a panel that is 60-ft. high by 20 ft. wide can be 6 in. thick, with edges thickened to 24 in. A quick way to estimate panel thickness is the h/t ratio. After engineers make their calculations, a typical ratio is between 44 and 52 or an average of 48. Then for each 48 inches of unsupported height, the panel needs to be approximately 1-in. thick. Or put another way, one quarter of the unsupported height in feet is the required panel thickness in inches. For a 24-ft. unsupported height (floor to roof), a 6-in. panel is required using this assumption.

Table 2.1 - Panel Net Area For 40-Ton Weight					
Panel Thick	5 1/2	6	6 1/2	7 1/4	8
WT./SQ. FT.	69	75	81	91	100
Max Area	1160	1070	990	880	800

"PANELIZING" THE BUILDING

Panelizing the building is one of the most important steps in the design of a Tilt-Up building. "Panelizing" means determining how the walls are divided into panels, what their shapes are and where the joints between them occur.

This is best accomplished by working with the structural engineer to resolve any structural considerations. Unfortunately, the architect sometimes establishes the panel divisions only to learn later that they must be changed to alleviate structural or erection problems.

To "panelize" the building, take each building elevation at a time. Sketch in the panel joints for a first try, making sure each one does not exceed weight limits. Remember to make them as close to the available crane capacity as possible. A 600-sq.-ft. panel is lifted and placed in nearly the same amount of time as one only 200 sq. ft. Keep in mind these guidelines when sketching in the joints separating panels:

1. Each panel should not exceed the area shown in Table. 2.1. (To use this table, the panel thickness must be obtained from the structural engineer or estimated using the rule of thumb in the preceding section.)

2. Avoid lintel panels longer than 40 feet. Also decide how the ends of lintel panels are to be connected and supported. A bearing-type support is preferred, as previously mentioned, but sometimes lintel panels frame into another panel perpendicularly. In this case a pocket is made to accommodate it. (But if this is done, remember that it shows on the other side.)

3. Consider where roof or floor beams frame into panels. The joint should be centered on the beam so the reaction is spread between two panels, or the connection point should be several feet away so there is not a concentrated load near the edge of a panel. The use of pilasters under beams is not recommended. Instead, add reinforcing within the panel thickness. If a pilaster is required, it is usually best positioned at the edge of a panel.

4. Don't locate door or window openings at the end of a panel. Construction tolerances between adjacent panels might not accommodate the door frame. It is much easier to cast a door frame inside a panel than at the edge.

5. Leave at least 18-in. – preferably 2 ft.—of solid panel between openings or between an opening and the edge of a panel. This provides sufficient space for reinforcing for both erection stresses and structural integrity of the panel for lateral loads. For solid piers between openings, limit the height-to-width ratio to less than four.

6. Bottoms of panels usually extend 12-in. below the floor, unless the outside grade requires it to be deeper. The bottom of the panel should be at

Above: Exposed concrete achieved with recessed forming and chemical retarders. (below) Large stones set into a sand bed prior to concrete placement achieve soften the building facade.

least 8 in. below grade on the outside to minimize any water intrusion. (CAUTION: Make sure the panels extend below grade on the outside—errors resulting in the bottom of a panel above grade require an expensive and unsightly correction.) Door openings should extend about 4 in. below floor level, so that when the closure strip is placed it will go over the bottom of the door opening to give a smooth, finished effect.

7. Select either a mitered or overlapped corner detail. Although overlapped corners are more common and less expensive, make sure to define which one overlaps. This is important when dimensioning the panels.

8. If there are protrusions to the interior side of the wall, such as short wing walls, these can be poured monolithically; that is, cast as part of the panel rather than as a separate panel. This holds true if the projecting wing wall is less than approximately 3 ft. Since it is more difficult to form and pour, it is advisable to make longer protrusions separate panels.

9. Look for other walls that can be erected, such as those around trash enclosures, and retaining walls at depressed truck docks. Divide these into panels also.

The feasibility of using certain panel sizes, shapes, and locations should be discussed between the contractor, engineer, and designer.

SURFACE FINISHES

The first Tilt-Up buildings had very inexpensive finishes—nothing at all except for gray concrete. Then came paint, followed by exposed aggregate, form liners, sandblasting, and other ways to produce a textured finish on the exposed surfaces.

The development of new finishes, coatings, and construction techniques, along with improvements in methods for traditional finishes, has given designers and contractors many expressions for Tilt-Up panels.

Aesthetic enhancements can be achieved using form liners, applied elements, offset panels, panel shape variations, and blockouts. Thin brick inlays also can be cast with the panel.

Finishes may be obtained in many different ways. Color can be varied with cements, colored admixtures, aggregates, mixture proportions, and coatings. Surface texture and appearance can be developed through various mechanical methods, by special forming techniques, or through application of surface-retarding coatings.

Textured surfaces can be obtained with the use of form liners, sand blasting, or exposing aggregates. Form liners should be strong enough to minimize displacement or distortion during concrete placement. An exposed aggregate finish can be obtained with the use of chemical retarders, sand or water blasting, and mechanical abrasion (bush hammering).

Here are the finishes that are most often used, in order of increasing cost:

1. Painting. This is the least expensive and most commonly used.

2. Reveal Patterns. A wall surface can be broken up into square or rectangular patterns by using strips of masonite or fiberboard nailed to the casting surface.

3. Dimple Finish. A dimple surface finish can be used as an accent or to “soften” the appearance of an entire panel.

4. Trompe L’Oeil (pronounced "tromp-loy") is a French phrase meaning to "fool the eye." Tilt-Up uses this technique to create a three-dimensional effect on a flat surface.

5. Sandblasting. The effect is accomplished by blasting the surface with a high-pressure stream of air (or water, called “waterblasting”) mixed with sand particles to erode away the fine aggregate surrounding the larger aggregate, leaving a pebbled surface. It results in an attractive textured surface.

6. Form Liners. These are elastomeric or plastic (polysytrene) sheets which are laid onto the casting surface, with the patterned side up. They impart a variety of textures to the surface that is cast against them.

7. Exposed Aggregate. The exposed aggregates referred to here are rocks or stones, usually specially selected for their appearance, which are laid onto the casting surface over a thin layer of sand. The aggregate must be carefully laid and spread, since it will be forever exposed. Concrete is placed over the aggregate, and the loose sand is water-jetted off after the panel is erected, resulting in the exposed aggregate finish.

8. Embedded Brick & Stone. Brick finishes made with “thin brick” can be constructed as a finish for Tilt-Up panels. The brick finish allows Tilt-Up to be used in areas where brick is traditional.

These are the surface treatments most often used. Some contractors have experimented with other methods to create a textured surface, with varying degrees of success. Some have cast the panels directly on the ground, resulting in a rough, wavy look. And some have laid wood boards, sprayed with form release to prevent bonding, and placed the concrete over them. This has produced some dramatic results, but also some disastrous problems when the boards stick to the concrete and must be chiseled off. For more information on surface finishes, refer to the *TCA Engineering Manual* and *The Architecture Of Tilt-Up*.

Table 2.2 - Fire Ratings Of Tilt-Up Walls						
Fire Resistive Period In Hours		4 HR	3 HR	2 HR	1½ HR	1 HR
Wall Thick Required	Siliceous Aggr.	7.0	6.2	5.0	4.3	3.5
	Carbonate Aggr.	6.6	5.7	4.6	4.0	3.2

HOW PANELS ARE JOINED

Panels are joined end to end with only a narrow joint between them, which is caulked for water-tightness. Joint width is generally ½-in. for panels up to about 20 ft. high, and ¾-in. for higher panels. The precision to which panels are set is such that there is rarely more than 1/8 in. variation in thickness along the length of the joint. When a wall must be fire resistive, there are joint fillers available that give two-, three-, and four-hour fire wall ratings. Choice of the joint filler is important since it must remain relatively flexible to accommodate the expansion and contraction of the wall and adhere properly to the concrete to ensure its watertightness.

Structural connections between panels are usually made by welded chord bar splices, or splicing the steel ledger, at the roof line (and floor levels, if applicable). This type of connection produces a continuous tie along the length of a wall for resistance to lateral forces imposed by the roof and floor diaphragms. In areas of low seismic risk, the structural ties between panels are sometimes omitted.
In the earlier days of Tilt-Up, the panels were joined by poured-in-place concrete pilasters or “stitch joints.” In this method, which is rarely used now since it is more costly and often results in cracking, a 1-foot gap is left between panels and the horizontal wall reinforcing projects into this gap. Concrete is then placed to make the closure. Shotcrete was sometimes used, which required a form on only one side.

FIRE RATINGS OF TILT-UP WALLS

The design of many buildings may require specific fire ratings for a panel envelope or separation wall. Tilt-Up panels are construction assemblies and therefore do not have a U.L. fire-rating. Instead, the International Building Code (IBC) provides reference to the endurance that is to be expected from a panel thickness. In the 2009 IBC, Table 721.2.1.1 gives fire ratings for concrete walls of varying thickness and aggregate type, as shown in Table 2.2

1. As defined in the IBC, “Siliceous aggregate” is concrete made with normal weight aggregates consisting mainly of silica or compounds other than calcium or magnesium carbonate, whereas “Carbonate aggregate” is concrete made with aggregates consisting mainly of calcium or magnesium carbonate, such as limestone or dolomite. For classification, check with your concrete supplier.

2. As mentioned above, joint fillers are available to match the fire rating of the wall.

The TCA has a flyer in the Reference Topic series providing additional information and background on this subject.

THERMAL PERFORMANCE OF WALL PANELS

Tilt-Up concrete wall panels provide economy, speed of construction, durability, fire resistance, and reduced air infiltration levels over other types of wall systems. A Tilt-Up concrete wall panel also has the capacity to absorb and store large quantities of heat energy (high mass value). Concrete's high mass value allows it to react slowly to changes in external temperatures, thus reducing and shifting peak energy demands accredited to energy passing through building materials.

The design of a building assumes a minimum level of insulating value for the exterior wall envelope. This information may be requested of the contractor by a designer or owner so it is important to understand the key pieces of information. Two terms are often used for this requested information "U-value" or conductivity and "R-value" or thermal resistance. They are related and are simply the inverse of each other. R-value is the most understand, because the numbers are larger and deliver the concept that you are keeping energy from traveling through the wall.

The R-value of standard ready mix concrete used throughout the Tilt-Up industry is 0.08 per inch of thickness. For an 8-inch thick wall panel, the R-value then is 0.64. All wall assemblies have an additional rating applied for the air film coefficient (internal and external) of 0.85 or a total R-value for the 8-inch wall panel of 1.49.

In today's world of sustainability and a desire for higher performing buildings, it is easy to see why this R-value is not high enough. Insulation systems provide a dramatic increase in the R-value for Tilt-Up wall panels. These systems increase the R-value of the panel by the thickness of the insulation and R-value per inch of the insulation product. For example, an extruded polystyrene insulation of 2 inches in thickness provides an estimated R-value of 10 to the wall system R-value. The most common method for insulating Tilt-Up wall panels during the panel construction sequence is to create an insulated sandwich wall panel. This consists of a two concrete wythes or layers separated by the layer(s) of insulation. One layer is the exterior facade of the building and receives the same architectural treatments of any standard, uninsulated Tilt-Up panel. The other layer is the interior surface for the building and is most commonly troweled smooth, again like any standard, uninsulated Tilt-Up panel. The concrete layers are connected by structural connectors or ties through the insulation layer. Older systems used various steel connections or areas of solid concrete to hold the two layers of concrete together with the insulation between. This has proved to significantly reduce the thermal value of the assembly so today's systems offer connections that maintain high strength without reducing the R-value but what is known as "thermal bridging". Fiber composites are the most common connector material.

Sandwich panels are designed as load-bearing or non-load bearing and therefore serve both a structural and thermal function. From a structural point of view, sandwich wall panels can be categorized as composite, partially composite, and non-composite. More information on the structural performance of these configurations can be obtained from various industry resources including the *Tilt-Up Construction* and *Engineering Manual*.

PRE-CONSTRUCTION

As with all construction projects, pre-construction planning is essential for the smooth progression of events in the construction of a Tilt-Up building. Efficient on-site production operation is important to the economy of Tilt-Up construction. Successful production requires organization and planning.

Many projects are developed with a contractor as a member of the design team. This facilitates coordination of the design with the construction process. If possible, planning of a Tilt-Up project should begin during the design phase. A meeting including the architect, engineer, and an experienced contractor can address limitations and concerns such as slab thickness, panel size (height, weight, width, thickness, and configuration), temporary bracing requirements, finishes and reveals, and many other elements. This is of particular importance if one of the team members is not familiar with Tilt-Up.

All general contractors prepare projects in a manner suitable to their organization. At a minimum, the following planning procedures guide a contractor through this critical stage:

1. Determine the completion requirements. Planning typically begins with the part of the building requiring the most man-hours. As such, a contractor begins in this area and continues in a methodical process for the balance of the project.

2. Order materials, award contracts. Securing sub-contracts and ordering related Tilt-Up components in the early stages reduces the cost of extending schedules and/or transportation costs of critical components.

3. Verify concrete supply, design, placement equipment, and all related chemicals are compatible and acceptable to all. Take caution in specifying certain products, due to the risk of mixing components and the inherent problems. Use performance specifications to ensure the concept and minimal expectations of the architect are realized; however, the burden for responsibility is clearly placed upon the contractor, who ultimately must erect that Tilt-Up panel.

4. Familiarize yourself with the building site. The existing and potential site conditions must

be respected when working on Tilt-Up projects. Overhead lines may require relocation prior to any panel erection. Movement of materials on and off the site is essential, as the typical Tilt-Up project is shorter than conventional construction. Movement logistics are paramount to suppliers, who may alter their prices based on historical conditions. These savings are then realized by the owner, who is typically rewarded with the contractor's preferred costs.

During initial planning of the project, it is important for the contractor to become familiar with the building site. Building location on the site can greatly affect many aspects of construction. Locating the building adjacent to a property line will affect foundation design and construction, panel layout and erection, and panel repairing and painting.

Crane access in and around the site is critical to a smooth panel erection process. Many owners do not want the crane on the floor slab due to potential slab cracking. As a result, many specifications restrict the crane to the building exterior or to an uncast strip of floor. If panel erection is to proceed from outside the building perimeter, the area should be graded smooth and compacted so no soft spots or ruts impede the crane's progress. Utility trenches into or around the building may restrict crane access.

Lateral clearance around the building should also be sufficient to allow the crane to maneuver. This is especially critical in urban areas. The contractor should account for any lateral or overhead obstacles. Overhead power lines within roughly 25 ft. (8 m) of the building footprint may have to be temporarily removed for panel erection or, at a minimum, have the power shut off.

Early planning for this situation is critical to be the least disruptive to surrounding property owners.

If crane access around the building is limited, some or all panels may have to be erected from within the building perimeter. The panel erection crane is typically much heavier than the framing erection crane. Consequently, if the panel erection crane is to drive on the slab, the slab edge may need to be thickened where the crane enters and exits the building. Slab recesses or other obstructions may also restrict crane access.

5. Job staging. Job-site staging can begin when most of the submittals have been approved. Location of the site office, equipment and tool trailers, and sub-contractor trailers result in time savings for both suppliers and field staff. Respect distances, and make temporary electrical panels and toilets available with minimal travel. Movement of workers and materials should be reviewed and potentially staged to reflect the progressive changes in a Tilt-Up project. A thorough plan broken down into stages reduces any last-minute changes or unexpected movements of mass materials due to unforeseen circum-

stances. No subcontractor wants to relocate materials as the general contractor continues to make last-minute decisions. The time required to relocate is time lost constructing.

Staging also includes selection of locations for support structures and materials storage, fabrication areas, and paths for movement of materials and heavy equipment, such as ready-mixed concrete trucks, cranes, and concrete conveyance equipment.

All planning should be done with safety as an underlying goal. Essential items should be placed in areas that will not be affected by rain or other adverse weather. In winter conditions, provisions for removal or depositing of snow may be advisable.

6. Checklist. Like a pilot departing with a plane, a general contractor should commence a project with a thorough checklist. Checklists are a minimal guidance tool of the critical components believed to be paramount to the task at hand. Usually, in a general contractor's world, these checklists are a mere history of prior mistakes they are committed not to repeat. However simple or complex, relevant or time-consuming, a checklist aids any project should one error be eliminated. No architect wants to resolve construction errors or accept an inferior product when the proper solutions were researched and properly conveyed in the construction documents. General contractors should provide the architect and owner with some means of quality assurance. This is a standard commitment by all successful corporations.

7. Consider the crane. Planning should consider which panel or panels are to be used to allow the crane to exit the building. If the framing erection crane is used to place the closure panel(s) into its final position, it must have the capacity to do so.

Panel size, weight, and lift distance will dictate the required crane size. The crane's operation manual provides guidance on maximum reach. A general rule of thumb is that the crane's rated capacity should be three times the maximum panel weight.

8. Tool requirements. Job-site tools should be kept in good working order. If a tool is critical to the workflow, a backup should be available. Sufficient power should be available at key locations to operate all tools that may be needed at a given time. Water should be available on the job site at all times.

PRODUCTION SCHEDULE

As with all construction projects, the contractor often utilizes a flow chart, bar graph, or other visual form of planning depicting all stages and steps in the process, including the sequence in which they must proceed; the items that are dependent on other phases before they can proceed; lead time; the time period for completion; and the manpower, resources, and materials required for each task. The task of putting this schedule together can highlight problem or critical areas and provide visual depiction of the entire process. The production schedule should be coordinated with the overall building occupancy schedule.

Planning should also include scheduling of subcontractor start times. On large warehouse buildings, panel forming, casting, and erection may progress simultaneously with roof framing. Failure to account for these activities can produce inefficiency or even a safety hazard.

SUBMITTALS

Panel shop drawing submittals should include at least the following: openings and reveal locations, reinforcing steel, lift and brace insert locations and product information, embedments, panel thickness, all dimensions.

Material submittals should include at least the following: concrete mixture proportion (typically around 4000 psi [28 MPa] per design requirements), bond breakers and curing compounds (check compatibility), form liners and reveal details, grouting and repairing materials, aggregate samples (if exposed aggregate is used), any other materials integrated into the panel, reinforcing chairs, finishes and coatings.

Submittals should be approved before commencement of any aspect of the work that will be influenced by the respective material or work item.

CHOOSING A STRUCTURAL CONSULTANT

Structural Engineers play a critical role in successful projects. Their design decisions can greatly affect the cost of the project—and architects' reputations. Therefore, it is important to use careful consideration when choosing structural consultants. They, too, must understand the Tilt-Up construction process—perhaps more so than architects—and know its pitfalls. They must be familiar with state-of-the-art structural design procedures for Tilt-Up and know how to prepare readable, definitive plans.

Structural consultants, in a sense, are in a precarious position. They certainly do not want to under-design, yet they cannot be overly conservative and remain a contender for Tilt-Up work. Their approach is then to design carefully, in accord with established procedures and code requirements, and err on the conservative side for connections. Connections are designed not only for structural adequacy, but also they are easily constructed. Contractors are not shy about telling engineers their details are impractical or won't work, and word gets around. To avoid this, engineers should plan details carefully and visualize their installations. For example, engineers may need to ask themselves whether or not an embedded connection interferes with other reinforcing in the same location.

Here are some questions to consider when choosing a structural consultant:

1. Has the structural engineer successfully completed several Tilt-Up buildings?

2. Talk to contractors who have built from the structural engineer's plans. Were the details well thought out? Were there dimensional errors? Were the plans consistent and easy to read?

3. Is the structural engineer's reputation generally good? Does the structural engineer belong to professional associations? Does the structural engineer carry liability and errors and omissions insurance? How long has the structural consultant been in business? How experienced is the structural engineer's staff? No office is better than the person in the back room doing the work.

4. Is the structural engineer innovative? Is the structural engineer challenged by coming up with clever details (that work!) and creative solutions to architectural requirements?

5. Does the structural engineer have good relationships with contractors?

6. Does the structural engineer visit the jobsite regularly?

These are a few suggestions for selecting or evaluating a structural consultant. However, it is also important that an amicable relationship is possible. The ability to work well together is an important factor leading to success.

Don't choose a structural consultant on the basis of fee alone. If the consultant's budget is pinched, it could cost the owner in undue construction expenses and affect the positive outcome of the project.

Make the selection of the structural consultant early enough for involvement at the beginning of the project. Many times the structural engineer is brought into a project too late to offer suggestions that could have affected considerable cost savings.

SELECTING THE TILT-UP SUB

Just as it is important to involve the structural engineer early in the job, it can also be helpful to call in an experienced Tilt-Up contractor to review designs and proposed connection details. A contractor's input can be cost-effective, and the early involvement lays the foundation for a more cooperative relationship during the construction phase. This is particularly important if you have limited Tilt-Up experience.

ADDITIONAL PLANNING STAGES

Construction:

Probably the simplest phase to plan is the construction phase. Having an entire project plan broken down into stages, the general contractor can deal with the unexpected and inevitable project challenges. However, further decisions are guided with the knowledge and comfort of the overall plan.

Post Construction:

After any project, the various team members should review the performance of the project. This commitment draws from the experience of all team members and charts a path for future projects.

Proper planning demonstrates leadership, commitment, and an appreciation for the overall design, as the time required to perform the tasks were allotted and accounted for in the overall project schedule.

MARKET YOUR SERVICES

By acquiring Tilt-Up expertise, you can offer it to your clients and thereby generate additional fees. But you need to let your potential clients know you have this service to offer.

The market for Tilt-Up continues to grow rapidly, and as Tilt-Up competition increases and advantages are more widely accepted, your services will be increasingly in demand.

If you are in an area where Tilt-Up is relatively new, here are a few marketing suggestions that can be effective:

1. When you complete a Tilt-Up building, contact your local newspaper as well as trade publications. If you can add an interesting twist to your story, it will very likely be published and result in inquiries. Don't forget to notify the TCA of innovative projects, as the Association is always expanding its database of Tilt-Up projects across the globe.

2. Be an innovator. Come up with new, economical uses for Tilt-Up, such as for signs, retaining walls, and dramatic features for your buildings. However, make certain your ideas will work by first checking with the contractor and structural engineer.

3. Invite prospective clients to watch the panels being lifted.

4. Put up a job sign with your firm’s name: “A NEW TILT-UP BUILDING FOR...”.

5. Send sales letters to developers who may be interested in your services. Remember that they are always looking for talented firms with

expertise in the types of buildings they build. Include a list of projects you have completed. If this list is limited to only a few, emphasize how successful they were. This is done with letters from the owner, contractor, or both. Ask for the letter before you start the job, and then collect it upon finishing.

6. Contractors often have the first contact with an owner who is thinking of building. They can put you in touch with the prospective clients and should be included in your marketing efforts.

7. If clients need convincing that Tilt-Up is a viable construction method, convince them to visit an area where they can see a variety of Tilt-Up buildings. This nearly always sells them.

8. The best marketing effort is to do the best job. Design an outstanding building, deluge your client with service, and wait for the recognition to come and the word to spread...it will.

WHERE TO GET HELP

Today, the expectation for someone seeking information, whether out of curiosity or urgent need, is to be able to find it quickly at the click of a mouse or the typing of a quick phrase in a search engine. The world of information has been compressed to instantaneous sound bites and text blocks that may seemingly give direction but more often confuse the issue further. The TCA continues to evolve to bridge the gap between this instantaneous and often ineffective information and the need for true direction and partnership in developing a foundation for success.

Consider TCA membership. Among the great benefits of joining the TCA, actively participating in a network of the most experienced professionals in the global Tilt-Up industry ranks at the top for business decisions. This level of participation occurs at the TCA Annual Convention through committees, teleconferences and webinars and through convenient email communications, task forces and focus groups. There is no substitute for the experience gained through such physical meetings by sharing stories, tips, and tricks.

TCA's website at http://www.tilt-up.org has evolved to be the strongest collection of information, resources, and evidence of modern Tilt-Up construction. The site features historical content; information about the Association and the network; technical solutions; resources, like this manual, for purchase; updated event information; and a collection of project information to evidence the breadth of the global Tilt-Up industry. More than 1,500 projects can be searched by project type, location, and more. Tilt-up.org is also the place to find information on common brands. The Tilt-Up Concrete Association and Sustaining Member, CON/STEEL Tilt-Up Systems®, have forged a relationship to bring forth the most complete reference site for accessing today's products manufactured and supplied specifically for the Tilt-Up industry. Common brands are your ticket to learning about and resourcing these important, revolutionary and effective products and services that are the keys for the sustained growth and evolution of this world-wide method of construction.

This manual focuses on the aspects of constructing Tilt-Up buildings and structures. Among the large collection of printed Tilt-Up resources is *The Architecture of Tilt-Up*. This companion reference manual demonstrates the diversity of architectural style, form and application of modern Tilt-Up construction. Together, these manuals establish the cornerstones of building tomorrow with Tilt-Up and will soon be joined by *Engineering Tilt-Up*, the newest TCA resource and final volume of the Tilt-Up Trilogy.

Finally, if assistance is needed in locating or accessing the information you are looking for or you would like to speak with someone about a specific question, the staff of the TCA is always available to assist and can be reached at (319) 895-6911.

SECTION 3
THE FLOOR SLAB AND FOUNDATIONS

Essentially, a concrete floor is a concrete floor. What makes it such an integral part of the construction process for Tilt-Up, is that panels are braced off of it, panels are formed and poured on it, and the slab has to accommodate motorized vehicle access during the process. In essence, the floor slab is everything to a Tilt-Up project.

Slab Terminology

The following are definitions of terms relating to floor slabs:

1. Slab-On-Grade is the term for a concrete slab cast on the ground surface.

2. Sand Bed is a casting surface intended to set larger aggregate or large stones in a random pattern, resulting in uneven surfaces that would not otherwise be effective on a solid concrete slab.

3. Grade refers to a surface.

4. Subgrade is the surface below a slab or below a base. It means a surface upon which a slab is placed or upon which a base material is placed.

5. Base is a granular material placed directly below the slab. It breaks capillary moisture that could rise from a damp subbase and distributes concentrated loads from the slab over a wider area of the subbase.

6. Subbase is the surface beneath the base, often used interchangeably with base.

7. Reinforced slab is a concrete slab containing either welded-wire fabric (also called "mesh"), reinforcing bars, or fibers.

8. Unreinforced slab is a concrete slab without reinforcing.

The following are additional terms related to floor slabs that are more technical in nature:

1. Subgrade Modulus. Often referred to as "k-value," "foundation modulus," "soil modulus," or "Westergaard's modulus of subgrade reaction," it is a measure of the resiliency, or compressibility, of the soil and is an important characteristic for determining the soil's supporting value. The subgrade modulus cannot be reliably correlated to the soil bearing value as used in the design of foundations. It is a separate value determined by the soils engineer after performing a test at the site. The test measures the load required to compress a 30-in.-diameter steel plate 0.05-in. into the soil. The resulting modulus of subgrade reaction, ("k-value"), is that load expressed in pounds per cubic inch. Its value ranges from a low compressibility of 50-100 psi for clays to 300-400 psi for well-graded sandy soils. The higher the k-value, the better the support it provides.

2. Modulus of Rupture is a measure of the bending or tensile strength of unreinforced concrete. Its value varies with the square root of the compressive strength of the concrete and ranges from approximately 400 psi for 2,000 psi concrete to nearly 600 psi for 4,000 psi concrete, not accounting for a factor of safety. The safety factors are determined by the design engineer. Many engineers calculate the design modulus of rupture as 7.5 times the square root of the compressive strength of the concrete, but this is subject to judgment and code interpretation by the design engineer.

Modulus of Rupture and Subgrade Modulus combined determine the required slab thicknesses.

FLOOR SLABS FOR TILT-UP

The floor slab of a Tilt-Up building is especially important since it not only functions as the floor surface for the life of the building, but also as a casting base for the panels and a platform supporting construction equipment. As such, the floor slab must accommodate service loads as well as construction loads.

Service loads during the life of a manufacturing or warehouse building rarely exceed 500 lbs./sq. ft. and usually do not exceed 100 lbs./sq.ft., particularly in office buildings. Forklift trucks and posts under steel storage racks rarely impose a point load greater than 10,000 lbs.

In contrast to service loads, construction loads are the heaviest loads applied to a Tilt-Up building's floor. These loads include the weight of concrete trucks and the crane when lifting panels from the floor slab. Construction loads can exceed 40,000 lbs. from the rear axles of a ready-mix truck. However, this is dwarfed by the weight a crane can hold when lifting wall panels where the load measured at the rear axle when carrying a heavy panel can be 200,000 lbs., or 25,000 lbs. on each of eight tires.

It is important to consider the area over which these point loads are applied. For example, a 5,000 lb. single wheel load from a forklift truck, using hard rubber tires, may be supported on an area only 8 in. wide by 2 in. long. In this case, the bearing area is only 16 square inches and the pressure under the hard rubber tire is over 300 psi, which explains why hard rubber tire forklifts are so hard on joints in a floor. In contrast, the unit pressure applied by a ready mix concrete truck, or a pneumatic tire forklift, will not exceed the tire inflation pressure, which may average 75 psi. The pressure under crane tires can be as much as 150 psi.

The slab should be investigated wherever construction loads are to be placed, including loading applied from temporary wind bracing. It is difficult to guarantee that the crane will not cause floor slab cracking because outrigger loads can be very large and subgrade conditions may not be adequately known. Adding to the uncertainty is placement of outriggers near control and construction joints. Timber cribbing is often placed under outriggers to distribute the loads. Pile-supported slabs may be inadequate for supporting the crane or other construction loads.

Because the floor slab is used as a casting bed for the panels and poured before the building’s roof system is erected, proper precautions should be taken to protect against the adverse effects of weather such as wind, temperature extremes and relative humidity, as recommended in ACI 302.1R, ACI 360R, ACI 305R, and ACI 306R.

The slab should resist uplift forces imposed by temporary wind braces. In thinner slabs of office buildings or shopping centers, a portion of the slab at the temporary wind brace anchorage location may be thickened, reinforced, or both, to resist these forces, as determined by an engineer.

The following sections discuss several components for foundations and floor slabs. With a well-designed foundation and floor, and adherence to the following guidelines, a quality durable structure is produced that will retain its quality over time.

STEPS IN DESIGNING A FLOOR SLAB

Proper floor slab design involves the critical steps outlined below and explained in greater detail following.

1. Determine what loads will be on the floor during its life, or at least the foreseeable future. This may include steel storage racks, forklift trucks, palletized storage, stacked goods, or other types of loads, but not crane loads (addressed later).

2. Determine the required thickness of the floor slab.

3. Specify the concrete, including aggregate size, cement content, water-cement ratio, 28-day compressive strength, slump, and any admixtures.

4. Decide whether to include a granular base, and if a vapor barrier or retarder is required.

5. Decide whether or not to reinforce the slab either with welded-wire fabric (also referred to as “mesh”) or reinforcing bars.

6. Select joint spacing.

7. Select type of joints to be used, as well as dowel sizes and spacings.

8. Specify testing (quality control) requirements.

HOW THICK SHOULD THE FLOOR SLAB BE?

Although there are formulas, charts, and tables to determine the required thickness of a slab for various load conditions, experience shows that a 5-in. slab on a well-compacted subgrade is satisfactory for light industrial use and for construction loads for the typical Tilt-Up building. Many contractors recommend a 6-in. slab, since there is less curling (see Curling later in this section) and there is a substantial increase in resistance to cracking under crane loads. Four-in. slabs have been used on dense, hard subgrades effectively supporting a crane without distress; however, this is not recommended! Conversely, 6-in. reinforced slabs on poorly compacted bases can crack badly. Since the trend in panel design is larger and heavier with correspondingly heavier crane loads, a 6-in. slab is recommended. Some contractors thicken the slab only in areas where the crane travels, and a thicker slab may be required where braces are attached to resist uplifting and sliding at the base.

Even if construction loads are light and the panels are lifted from outside of the building, a 5-in. minimum slab is still recommended.

Since the floor slab’s strength is a function of the square of thickness, an additional inch of floor slab can give substantial strength gain. For example: if a 4-in. slab is increased to 5 in., the extra material costs 25% more, but the load carrying capacity increases by 56% (5 squared divided by 4 squared). Similarly, the material in a 6-in. slab is 20% more than a 5-in. slab, yet its load capacity increases by 44%. Or reversing the comparison, a 5-in. slab has 69% of the load capacity of a 6-in. slab, and a 4-in. slab has only 44% of the load capacity of a 6-in. slab.

The charts most commonly used for determining slab thickness for various forklift and rack-post loads were developed by the Portland Cement Association (PCA). They are found in PCA's free publication, *Concrete Floors on Ground*. For a given wheel load, spacing between wheels, tire pressure and contact area, concrete strength, and foundation modulus ("k-value"), the charts determine the required thickness. These charts are more conservative than calculating the loads and resulting requirements.

On the other hand, many engineers use formulas that consider the slab to be a beam on an elastic foundation, such as those developed by Miklos Hetenyi in his classic textbook *Beams On Elastic Foundations*, (University of Michigan Press, 1946). These formulas are condensed in an essential reference on most engineers' bookshelves titled Formulas for Stress & Strain by Roark (McGraw Hill). These formulas, which require knowing the soil modulus of subgrade reaction (k-value) and the modulus of rupture of the concrete, are used for more load conditions than are covered in PCA charts, but are more mathematically challenging.

TEMPORARY CONSTRUCTION LOADS

Tilt-Up panels are typically cast directly on the building floor slab. Therefore, it is necessary to minimize the possibility of temporary construction loads damaging the slab. Loads imposed on the slab by temporary panel braces or stored construction materials, such as reinforcement, form materials, aggregate, bond breaker containers, and embedment steel, are generally not a problem for slabs designed for industrial use. These activities may result in damage to thinner slabs that may be specified for shopping center, or office applications. Loads imposed by a crane or a ready-mixed concrete truck are much heavier than most other construction loads and may exceed the slab capacity. If loads are to be placed on the slab shortly after casting, the four to seven day concrete strength will be less than the specified 28-day strength.

If panel erection requires the crane to be placed on the floor slab, it may be necessary to improve the subgrade or increase the slab thickness and reinforcement. Often, crane outrigger loads substantially exceed the floor slab capacity, and there is a risk of slab cracking. A strip of floor slab is often omitted where the crane will travel during panel erection. This strip of slab is cast after panel erection is completed.

Planning is only part of the success. Project management and maintenance is imperative. The base for a floor slab may be affected by erosion and shoring necessary to maintain the support during construction.

As discussed in Section 2: Planning the Tilt-Up Building, pre-construction meetings should address crane placement on the slab for panel erection. If the crane is allowed to drive on the slab for panel erection, the engineer should verify that the slab and subgrade load capacity are adequate to support construction loads.

A WELL COMPACTED SUBGRADE IS ESSENTIAL

To illustrate the importance of a well-compacted subgrade, imagine a sheet of plate glass laid on a mattress. You would not want to walk on it. But if the sheet of glass is laid on the floor, you would walk on it without much concern. This analogy illustrates the danger of a poor subgrade under a relatively brittle floor slab.

The subgrade should be granular, non-expansive soil (without clay), which is compacted to at least 90% modified proctor at optimum moisture and verified by on-site testing. (Note: 90% compaction means the subgrade is compacted to 90% of its theoretical maximum for optimal moisture content). For an even more unyielding subgrade, specify 95% compaction. The actual compaction requirements for the project should be determined by the soils engineer and the engineer of record.

IS A BASE NECESSARY?

A granular base under the slab serves two functions. It acts as a cushion to spread out loads when the underlying soil is uneven or not consistently dense, and it acts as a capillary break to prevent moisture from rising and damaging a floor covering.

If a moisture-sensitive floor covering is used, it is customary to specify a 4-in. crushed rock, gravel, or sand base. Under moisture-sensitive office areas, it may be overlain by a plastic vapor retarder as specified. To avoid piercing the plastic during construction, and to serve as a blotter to reduce plastic shrinkage cracking, a 1-in. layer of sand over the membrane has been used in the past. However, some contractors object to this method since the sand layer is compressible and can contribute to slab cracking under construction loads. Instead of Visqueen and sand, some prefer an integral waterproofing admixture, such as IPANEX (IPA Systems, Philadelphia; 800/523-3834).

As these slabs are placed prior to the building going up, there are problems with the sand blotter getting filled with water from any precipitation. ACI 302.2R (Guide for Concrete Slabs to Receive Moisture-Sensitive Flooring Material), states on page 29 that “when a granular fill layer is used, it is best to place the slab after the building is enclosed and the roof is watertight.” Even with just the poly as a vapor barrier, without the sand blotter being used, there is the potential for water to get under the poly, especially if its integrity is compromised with holes/slits in the membrane. Refer to the ACI 302.2 Guide with respect to the base if any moisture-sensitive flooring is to be used.

The decision of whether or not to use a base is usually determined by the soils engineer based on the assessment of soil conditions at the site.

SPECIFYING THE CONCRETE

Designing a concrete mix is usually done for the contractor by a testing laboratory or ready-mix supplier.

The parameters to which the laboratory designs the mix are determined by the engineer and are specified on the plans. The mix design varies with locale, weather, and other job conditions.

The following are guidelines for mix designs applicable to floor slabs:

1. Maximum aggregate size should not exceed one-third the slab thickness. The maximum and typical size is 1½-in. The larger the aggregate size, the less cement is required to fill all the interstices, hence the more economical the mix. Given the maximum size aggregate, the laboratory designs the gradation of crushed stone, gravel, and sand to minimize the amount of cement required. Pea gravel mixes are not recommended for slabs since they are both uneconomical and cause abnormally high shrinkage (pea gravel mixes require about 50% more water). The larger the aggregate size, the less the shrinkage.

2. The water-cement ratio (W/C ratio, or the amount of water per sack of cement) is the most important measure of concrete strength. The less water for a given amount of cement, the higher the strength. However, too stiff a mix is impractical to place, so there must be a trade-off between enough water for placing, but not so much as to impair the strength.

3. The 28-day concrete strength specified should not be less than 3,500 psi to result in a hard, durable surface (although ACI recommends 4,500 psi concrete for such a result). The hardness of the surface is also a function of the removal of surface water during finishing. Many engineers call for a 2,500 psi strength because the Uniform Building Code requires a deputy inspector to be present when a strength of over 2,500 psi is specified, and they want to save the cost of the inspector; however, this is avoided by specifying a higher strength and noting that the design is based on only 2,500 psi.

4. The cement content is dictated by the gradation and types of the aggregates, as well as the strength requirement, and varies from about 470 lbs. (5 sacks) per cubic yard for a 2,500 psi, 1-in. aggregate mix, to 610 lbs. (6.5 sacks) per cubic yard for a 4,000 psi mix using the same aggregates. Note that one additional sack of

cement is roughly equivalent to an additional 1,000 psi in strength.

5. Slump, which is a measure of the workability of the mix, should be specified to be 4 in. or 5 in. at the most. If it is a pumped mix, a 4-in. slump is achievable. A 6-in. slump is not acceptable unless used for mass foundations or structurally unimportant work.

ADMIXTURES AND WHEN TO USE THEM

An admixture is used to modify the properties of either the fresh concrete or the hardened product to make it more suitable for the intended purposes. Admixtures improve certain properties but produce less desirable effects on others. The cost of an admixture should also be considered since it may be more economical to change the proportions of a mixture or to modify some of the basic ingredients.

The admixtures that are generally used for Tilt-Up concrete buildings, including both floors and walls, are placed in to six categories. These include: (1) accelerating admixtures, (2) water-reducing and set-controlling admixtures, (3) air-entraining admixtures, (4) mineral admixtures, (5) admixtures to reduce alkali-aggregate expansion, and (6) coloring admixtures.

1. Accelerating admixtures are generally used in cold weather to speed up setting time and strength gain. These are principally a form of calcium chloride, although non-chloride products are available. Under certain conditions calcium chloride may act as a catalyst to corrode embedded steel, so non-chloride products are preferred. As a general guide, most accelerators permit earlier finishing operations in cold weather, and the 28-day strength is achieved in approximately 7 days. A limit of 2 pounds of calcium chloride per bag of cement is suggested as a maximum, and smaller amounts yield proportionate effects. Due to its potential for corroding the reinforcing steel, calcium chloride is not recommended for Tilt-Up panels.

2. Water-reducing and set-controlling admixtures are among the most widely used. These permit a reduction in the total water per volume to produce a given slump, which results in a reduction in the water/cement ratio for a given quantity of cement. In many cases this ultimately results in a reduction of the amount of cement needed per volume to achieve a specified strength. Such a reduction is made with caution to prevent possible detrimental effects upon other desirable properties such as durability. A relatively new group of admixtures falls into this same category and are called “Superplasticizers” or “High-Range Water-Reducers.” These admixtures produce a drastic change of several inches in the slump when added to the concrete mixture (generally at the jobsite). For example, this type of admixture can produce a change from a stiff 2-in. slump to a very fluid 8-in. slump. This change

in slump lasts for about 45 minutes, depending on site conditions, which permits workmen to place the concrete with considerable ease before it reverts to its original stiffness. This admixture permits much drier mixes, which reduces long-term shrinkage and resultant cracking.

3. Air-entraining admixtures are used to incorporate minute air bubbles into a concrete mixture. The primary reason for the addition of these air bubbles is to improve the resistance of the concrete to surface scaling during cycles of freezing and thawing. Although there is a slight loss in strength in the less dense concrete, there are secondary advantages such as less segregation, reduced bleeding, and more uniform distribution of aggregate. The latter feature is of particular importance in architectural concrete finishes involving exposed aggregates.

4. Mineral admixture is the generic name for a number of finely powdered mineral materials. Natural pozzolans as well as fly ash products fall into this category. Both of these materials have the capacity to unite with some of the free lime in the cement to produce additional cementing properties. In many cases they are used as a replacement for part of the Portland cement to achieve some economy in the mixture, but the rate of strength gain may not be as rapid as desired for most Tilt-Up jobs. Experience with mineral admixtures has proven beneficial in reducing pressures needed to pump concrete. In some cases their use requires less mix water, which can be beneficial.

5. Admixtures that reduce alkali-aggregate expansion are becoming increasingly popular in many areas of the country where non-reactive aggregates are not economically available. Essentially, these admixtures are the same as the mineral admixtures previously described. An optimum amount of these mineral products (generally 15 to 25%) inhibits the formation of the sodium-silicate gel, which causes the objectionable expansion. Of course, the use of "Low-Alkali" cement is recommended when reactive aggregates are encountered. The disruptive effect of sulfate soils in contact with concrete can also be inhibited with certain fly ash products. However, not all soils contain detrimental amounts of sulfate, nor do all fly ash products produce the same chemical reaction.

6. Coloring admixtures, as their name implies, are added to a concrete mix to give color to the hardened concrete. These products are generally a powdered mineral metallic oxide and are available in various colors. The red and brown colors appear more permanent and result in less fading. The amount of these pigments per volume varies depending on the desired color. Trial batches are suggested. A limit of 10 lbs. of pigment per sack of cement is suggested to prevent excessive mixing water. However, follow the recommendations of the coloring ad-

Left: Confirming the proper slump is a requirement prior to concrete placement.

Right: Without the proper slab design or crack control, shrinkage stresses in the slab will find relief uncontrollably and become imperfections that affect the panels cast on top of them.

mixture manufacturer. Coloring admixtures are sometimes used with special aggregates also selected for their color, especially for exposed aggregate or sandblasted finishes.

HOW MUCH CONCRETE DO YOU NEED?

Here's a simple formula to determine how many cubic yards of concrete you need for a given slab area and thickness.

Most contractors don't allow anything for waste, but monitor the amount of concrete used as the work progresses, and then call the ready-mix supplier if adjustments are needed. The volume occupied by stakes, dowels, re-bar, or other items usually cancels spillage.

C.Y. = tA/324
C.Y. = Cubic yards of concrete required
t = Slab thickness in inches
A = Slab area in SF

MORE ABOUT SLUMP

Once the mix is designed, the most important jobsite control is the slump. If too much water is added en route or at the job (to improve workability), it shows up as greater slump, which reduces strength and increases shrinkage. Remember, one additional gallon of water added per cubic yard will increase the slump by about 1 inch.

On a large project it is a good idea to reject a truck or two when the slump is too high, in order to convey the message to the ready-mix supplier that the concrete must arrive as requested. If the foreman or any of the finishing crew requests water to be added at the job site, show the amount on the delivery ticket. The person who signs the ticket then becomes responsible.

WHY CONCRETE CRACKS

It is clear that concrete does crack, and this occurs because it shrinks. Concrete shrinks because the excess water needed to make concrete workable evaporates. This is an oversimplification of the cause since other factors, such as type and gradation of aggregate and amount of cement, also affect shrinkage. But, basically, water is the root cause of shrinkage, which leads to cracking.

Only a small amount of water, approximately 2½ gallons per sack, is necessary for the chemical reaction with the cement that causes the hardening (this process is called "hydration"). If, for example, 36 gallons of water per cubic yard constitute a workable mix, only about one-third of this is theoretically required. The rest evaporates, resulting in a contraction of the volume, or shrinkage.

Shrinkage begins as soon as the concrete mass begins to set and continues almost indefinitely.

Early entry saw systems are the most popular method to control shrinkage stress and maintain floor slab quality.

Innumerable tests were made to plot shrinkage versus time, with widely scattered results depending upon many variables such as mix design, type of aggregate, method of curing and temperature. As a general rule, about 20% of the ultimate shrinkage takes place in the first three days. Rough estimates of the shrinkage process are as follows: 65% at the end of 30 days; 80% at the end of three months; and 90% after one year.

An average value of normal drying shrinkage that is expected in one year is about 1/8th of an inch in 20 ft. Or about 0.0005 in./in. of length.

ACI offers a helpful report on the subject titled *Causes, Evaluation, and Repair of Cracks in Concrete Structures*.

CONTROLLING SHRINKAGE

Aside from controlling shrinkage by limiting the amount of water in the mix and the rate at which it evaporates, cracking resulting from shrinkage is managed by providing artificially weakened places for the concrete to crack, called crack control joints.

In order to minimize the amount of shrinkage:

1. Control the slump. Keep it 4-in. or less. Send back trucks when this slump is exceeded.

2. Don't place concrete in hot weather. If it is more than 85-degrees-Fahrenheit, don't pour, or if you must, use sun shades. Or, use a fog spray to provide a surface film of water that replaces the rapid evaporation. But if you must place in hot weather, place at 2 to 4 a.m. under lights, so the concrete is placed and finished before the weather becomes too hot.

3. Avoid placing concrete in windy weather. If the wind speed exceeds 15 miles per hour, evaporation and shrinkage increase dramatically. If wind comes up during placement, one choice is to use PVC sheeting after bull floating.

4. Slow down the evaporation by curing with two coats of curing compound, not just one. Apply each coat at right angles to the other, and apply according to manufacturer's recommendations. Some contractors are now switching to wet curing—placing burlap or similar proprietary products over the slab.

Using these precautions minimizes the amount of shrinkage. Cracks should occur at control joints, not between them.

Refer to ACI 305 (hot weather concreting), ACI 302 (concrete floor and slab construction) and ACI 308 (curing concrete) regarding the use of evaporation reduction and other procedures.

Table 3.1 - Spacing Of Control Joints For Un-Reinforced Slabs			
Slab Thickness	Aggregate Size		Slump
	< ¾ in.	> ¾ in.	< 4 in.
5 in.	10 ft.	13 ft.	15 ft.
6 in.	12 ft.	15 ft.	18 ft.

CRACK CONTROL JOINTS

Joints have purposes other than to control shrinkage cracking (such as forming a plane between sections of concrete placed at different times) but this section is focused on their use for controlling cracks.
Since we can't eliminate shrinkage (except by using expensive "shrinkage compensating" cement, which expands when it sets to offset the effect of drying shrinkage), we can try to anticipate where cracks form, and provide control joints at those locations. In order to do so, an understanding of how floor slabs are placed must come first.

Many contractors pour strips using vibratory screeds 48 ft. wide (or to match column spacings), and then sawcut at 16 ft. on center and every 16 ft. transversely. However, slabs can be placed in strips the length of the building, and usually about 20 to 25 ft. wide.

The joints between the strips are referred to as "cold joints," or "construction joints," since some time elapses before the abutting strip is placed. These joints also function as crack control joints. To form crack control joints transversely in the length of a strip, either make saw cuts partially through the slab, or place plastic strips to form weakened planes.

SPACING OF CONTROL JOINTS

Assume for a minute that a long strip of concrete slab is placed without any joints. Then, if the concrete shrinks as it should, every so often a crack develops. The theoretical distance between cracks is determined by the *Subgrade Drag Theory*. This theory simply states that

as a concrete slab shrinks, even very slightly, it must drag itself across the subgrade as it shortens. But the longer the length of concrete that it has to drag, the more tensile stress the slab must possess to drag itself. At a certain length the concrete can no longer resist the tension and cracks.
Table 3.1 above shows the spacing between crack control joints as recommended by the Portland Cement Association.

From this chart, you see that for a 5-in. slab with a 4-in. maximum slump, the recommended maximum spacing is 15 ft. Another rule of thumb often quoted is a spacing in feet of three times the slab thickness in inches. This, too, gives 15 ft. for a 5-in. slab and 18 ft. for a 6-in. slab.

If saw cuts are used to form the weakened plane, the cut is made as soon as the slab will support the saw and the saw will not ravel the cut. This is usually four to 12 hours after finishing. The slab begins to shrink as soon as it begins to set. If too much time passes before sawing begins, a minute crack will form at a spacing the slab thickness determines, becoming the weakened plane and a permanent crack.

JOINT LAYOUT

With the spacing of joints determined, the next step is to lay out the locations of joints. This requires the architect or engineer to know how the contractor plans to place the concrete. If the architect or engineer is not familiar with the contractor's preferred sequence of placing, it is a good idea to review the sequence to avoid changes and accommodate the contractor's operation. The spacing limitations are determined by the architect or engineer and not by the contractor's desire for fewer and more widely spaced joints to reduce their costs. The increasing use of laser screeds permits large slab areas between construction joints but still requires sawed control joints as discussed.

Control joints should always occur at re-entrant corners or at other abrupt changes in dimensions since these are stress concentration points, which almost always cause cracks. Joints should intersect column centerlines and where columns occur in a diamond pattern. Never dead end a 90° joint.

Sections between control joints should be approximately square, but not more than 1.5:1, since concrete shrinks equally in all directions. Sections that are twice as long as they are wide are apt to crack transversely to the long direction.

TYPES OF JOINTS

There are essentially three kinds of joints used for concrete slabs on grade:

1. Construction Joints. Also called "cold joints," they separate concrete placed at different

times. A typical construction joint would be the joint at each side of a strip of floor slab between each day's placement. There are several types of construction joints:

Keyed joints. Also called tongue-and-groove joints, they provide resistance to shearing by the keyway. As a moving load goes across the joint, it must shear off the key in order to fail. Recommended dimensions for a wood-formed key are shown.

There are also formed metal key joints available, which have holes for dowels for additional shear resistance. Metal joint forms require careful placing to avoid subsequent spalling.

Keyed joints can result in a small displacement between sides of the joint, which causes the edges of the joint to ravel from forklift traffic. This displacement is caused by one side of the joint slipping down over the tapered key when the concrete shrinks. Keyed joints do not hold up well under forklift traffic.

Another entry into the keyed joint market is precast concrete joints. Resembling a rail in cross-section, this joint seems to have an added advantage of providing a very rigid joint that is less likely to ravel from forklift traffic.

Plastic keyway forms are also available.

Wood forms create keyed joints when a beveled wood strip is nailed on the inside face to form a keyway. It is recommended that a longitudinal saw kerf is made on the back side of the strip so it can swell, which avoids cracking and makes it easier to remove.

Keyed joints are declining in use in favor of the more effective, doweled joints. It is possible to dowel keyed joints, however this largely negates the effect of the key.

2. Butt Joints. These joints between strips of slab are perhaps the most commonly used joint, since they require only a single wood form (typically a 2x6). This type of joint requires dowels to transfer the shearing loads across the joint.

Isolation Joints. These are most often used around machinery foundations or where a slab abuts a wall. They are not able to transfer shear since they are intended to “isolate” one side with respect to the other. The joint is filled with a sealant.

3. Crack Control Joints. These are the joints used to control cracking. As discussed earlier, spacing is critical. Since current practice is to place concrete floors in long strips, it is essential to use easily-installed control joints so that a high production speed is maintained. The two most popular types of these joints are:

Sawed Joints. As we mentioned earlier, this joint should be made as soon as possible after placement or it is ineffective.

By using the increasingly popular early-entry dry cut sawing, a cut is made 1/8 in. wide by 3/4 in. deep—or at least as deep as the largest aggregate size—immediately after hard troweling.

Load transfer across a sawed joint depends on "aggregate interlock," or the rough, jagged crack below the saw cut that provides the necessary resistance to slippage. (The aggregate interlock effect decreases rapidly for cracks wider than about 1/16 in.)

Preformed plastic or hardboard strips. These strips (now rarely used) are embedded into the top one-fourth of the slab thickness, as soon as possible after concrete placement. They act similarly to sawed joints. Care should be taken to prevent tipping of the plastic inserts, which leads to later spalling. These are difficult to install straight and plumb, and finishing causes small raveling and spalling along the surface.

SLAB JOINT TREATMENTS

Construction joints and contraction joints are integral parts of any floor slab-on-ground design and construction, and they cannot be completely eliminated. Because every imperfection on the floor surface will be reflected on the panel, it is important to minimize joint lines transferred to the panel. There are many ways to reduce the effects of the mirror image of joints on panels. Joints may be filled with caulking, sand, drywall compound, or a polystyrene rod. Filling with sand is probably the least effective because it could be washed or blown

Careful selection of the joint treatment before panels are cast is important as it impacts the finish quality of the panel face. A contractor carefully applies drywall joint compound to this joint.

Table 3.2 - Spacing Between Joints For Reinforced Slabs		
Slab Thickness	Reinforcing	
	6 X 6 - W2.9 X W2.9	#3 @ 18 In. O.C.
5 In.	39 Ft.	35 Ft.
6 In.	32 Ft.	29 Ft.

Based On Subgrade Drag Theory: Fs=30,000 For Wwf; 24,000 For Bars; Cf=1.5

out of the joint before panels are cast. Use of tape to cover the joints is not recommended because it will leave a mark on the panel that will be very difficult to remove or hide behind paint. If slab joints are not filled, fins will be created on the panel, which can often be successfully removed by light grinding. Paint or coatings alone will not always eliminate the visual effects of untreated joint impressions on panels.

Reinforcing does not significantly contribute to the bending resistance of slabs, unless it is heavily reinforced. For example, a 6-in. slab would need #5 bars at 10 in. on center to be truly “reinforced.” Reinforcing does, however, hold the cracks together so they are smaller and more closely spaced.

REINFORCING IN SLABS

Using greater amounts of reinforcing tends to develop a greater number of cracks, but each is reduced in width. If the area of reinforcement is 0.5% (= 0.005) or more of the concrete cross-section area, and it is positioned at or just above the mid-depth of the slab, the crack widths are just barely visible. The amount of steel for a 5-in. slab based on this assumption is #5 bars spaced 12 in. on center.

A commonly used formula for determining the amount of reinforcing needed for a given joint spacing for a slab is:

SUBGRADE DRAG THEORY FORMULA

A = LCfwt/24fs or L = 24fs/Cfwt

A = Area of reinf. per lin. ft.
L = Distance between joints in ft.
Cf = Coef. of subgrade
resistance to slab movement
(1.5 in most cases, but 1.0 if on plastic sheet)
w = Weight of concrete in pcf
t = Slab thickness in inches
fs = Allowable reinf. stress

Example:
For L = 40 ft., fs = 30,000 psi, w = 145 pcf, Cf = 1.5, t = 6 in.
Then A = 0.0725, Use #3 bars @ 16 in. o.c.

Using a subgrade friction coefficient of 1.5, and fs (steel tension value) of 30,000 psi, results in the following table for various slab thicknesses and reinforcing: (Table 3.2)

If the joint spacing exceeds those shown in this table, intermediate cracks are expected, even though reinforcing is used. The reinforcing simply keeps the crack widths smaller.

Reinforcing is most effective for crack control, if used, when it is positioned near the top of the slab, perhaps 1½ in. down. However, if reinforcing is used to increase bending resistance of a cracked slab, locate it at mid-depth or lower.

Slabs are reinforced with traditional reinforcing bars or welded-wire fabric.

When reinforcing bars are used, the diameter is usually 3/8 in. or 1/2 in.

Welded-wire fabric is usually a 6-in. square grid and either 6-gauge (which comes in mats) or 10-gauge (which comes in rolls). The fabric specified in the past as 6-in.x6-in.x6/6 fabric is today referred to as 6x6-W2.9xW2.9 WWF. W2.9 means the cross sectional area is 2.9 hundredths of a square inch, which is the same as 6-gauge wire.

Light gauge welded-wire fabric (meaning W1.4 or smaller, which is 10-gauge wire) does not significantly contribute to crack resistance. Despite the contractor's intentions to lift it up during placement, it provides little resistance to surface cracks. If mesh is considered, an extra inch of concrete thickness is a better investment than light gauge welded-wire fabric.

Steel and plastic fibers are used to increase tensile strength and reduce width of cracks in some slabs. The fibers are either added at the mixing plant or into the concrete truck at the job site. Fiber suppliers can provide additional technical information. Both mat and bar reinforcing should be supported on chairs. But often the contractor assigns a workman to pull up the fabric as concrete placement progresses, which is an operation that is not always successful and is not recommended.

Even with the best placing and finishing techniques, however, some fibers may protrude above the surface of the slab. Generally these are easily broken or burned off. Casting of Tilt-Up panels on slabs with poly fiber reinforcement has not been a problem, either for lifting or finishing, when projecting fibers are removed. Fewer problems are associated with steel fibers projecting above the slab surface.

Reinforcing is effective in reducing the width of cracks and extending the spacing between joints. However, it does not contribute significantly to supporting the capacity of the slab when subjected to wheel or rack column loads. For the latter cases, it is more effective to use an additional inch or two of concrete and delete the equivalent cost of the reinforcing.

DOWELS ACROSS JOINTS

The purpose of dowels across a joint is to transfer the shearing load due to a forklift truck, or other moving load, crossing the joint. In a sense, they act like bolts connecting two members. In fact, their shear resisting value can be computed as if they were bolts of the same diameter as the bar.

These dowels should be smooth (non-deformed) #5 or #6 bars, 16 in. long and spaced from 12 in. on center at construction joints to 24 in. on center for sawed joints.

Dowels extending from the slab are essential to tie in the “closure” strip after panels are erected and connected to the foundation.

The spacing depends on the shearing force they must resist. For heavy forklift traffic, #6 dowels at 12 in. on center are often used. This is also recommended for joints in crane travel areas. Since the dowel only acts as a pin between the abutting slabs, it does not need to be embedded more than 8 in. into each side.

Dowels are not intended to tie abutting slabs together to transfer forces perpendicular to the joint. In fact, they must offer little or no restraint in this direction, allowing for shrinkage of the slab perpendicular to the joint. The crack is designed to occur at the joint, not at the end of the dowels resulting from the dowels restraining this movement. In order to allow the dowels to move, one side is coated with grease, covered with a paper or sleeved to prevent bonding. It is also very important that the dowels are straight; if a dowel is embedded at an angle, it grips and restrains movement. To check this condition, one crew member walks along the length of a doweled construction joint to confirm the alignment of each one just before placing concrete.

The problem with using dowels along the length of a construction joint is that when a strip of concrete shrinks, control joints are designed to initiate cracks. But dowels near the corners of sections act to restrain shrinkage, and the result is cracking. One solution is to wrap or sleeve each dowel with a cushioning material that absorbs the slight movement resulting from this transverse shrinkage.

Another dowel system is a plate-type system that allows for a plate to transfer shear across the point.

PLACING AND FINISHING THE SLAB

Placing and finishing of the slab should be in accordance with the recommendations of ACI 302. The floor slab should have a smooth steel trowel finish because the panel face cast against the slab will mirror all imperfections. It is not unusual for an experienced concrete subcontractor with a good crew to place 150 cubic yards of concrete floor slab per hour. High volume contractors place 35,000 to 50,000 sq. ft. or more in approximately six hours.

To allow time for finishing and application of curing, placing usually starts early so that it is completed around 11 a.m. In warm weather, placing starts around 5 a.m., or earlier, and finishes by 9 a.m.

Additional tips for successful placing and finishing of the slab are as follows:

1. Specify a low-slump mix (4-in. max), and control it. Use a 4,000 psi mix design.

2. Dampen the subgrade before placing the concrete so it won't soak up the water too quickly.

3. Pull a garden hose across the finished surface to remove excess bleed water.

4. Use a fog spray to keep the surface damp during hot weather, before applying a curing compound.

Start curing as soon as the finishers are done.

5. Saw the control joints immediately following hard troweling. Use an evaporation reducer.

LASER SCREED PLACEMENT

There is an increasing use of laser screeds to achieve a flatter floor. Using a self-propelled laser guided screed, it is possible to place up to 50,000 sq.ft. of floor in a six-hour period. Since placement is monolithic between perimeter forms, there are no interior construction joints. Instead, all crack control joints are sawed as soon as the slab can support the weight of the saw. Several varieties of laser-guided screeds are available, including the truss type. For more information, contact the manufacturers listed in the Products and Services section.

MORE ABOUT BLEEDING

Bleeding, or free surface water, occurs as aggregates settle in the placed concrete, displacing water to the surface. If allowed to remain on the surface, it dilutes the cement content, significantly reducing the strength near the surface. When the water evaporates, surface crazing and dusting results.

To remove bleed water, drag the surface with a garden hose. Do not apply dry cement since this causes dusting. If bleeding is excessive, reduce mix water on subsequent loads.

CURING

Curing is perhaps the most neglected operation in concrete construction today. When deficient, it is the cause of most plastic cracking.

Curing begins immediately after final troweling. The purpose of curing is to keep the surface from drying too rapidly, and to produce an even loss of moisture in the depth of the slab, from top to bottom.

The predominant curing method for large slab areas is to spray the surface with a liquid curing compound. This places a thin membrane over the surface. A number of excellent products are available. See the Products and Services section of this manual.

To ensure a tightly sealed surface, the material is applied in two coats, each at right angles to the other, in accordance with the manufacturer’s instructions.

Wet curing is increasingly used by experienced contractors to reduce surface cracks. Although burlap is sometime used, there are also effective proprietary products on the market. The following example is a procedure for wet curing:

1. Position covering material in close proximity to the floor area being placed.

2. Saw cut immediately after finishing, as soon as the concrete will support the saw.

3. Keep slab moist until covered.

4. Place covering. Use heavy objects at the site (i.e. sand bags, concrete blocks, or lumber) to keep covering from blowing off. Be sure to place these off of the fresh concrete.

5. Wet top of covering and leave in place for 7-10 days.

Refer to ACI 308 for all methods of curing and ASTM standards associated with the methods recommended.

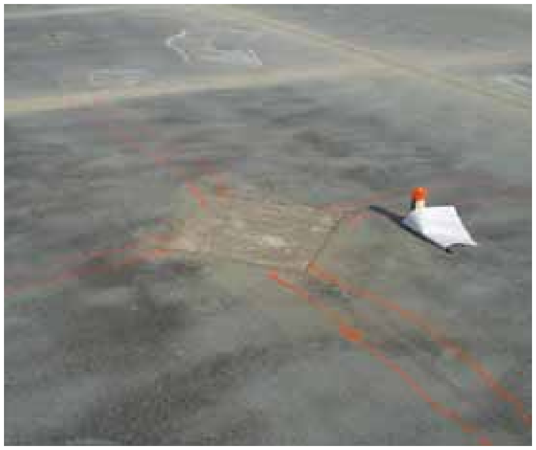
SURFACE CRACKS: CAUSES AND PREVENTIVES

Following are types, causes, and preventive measures of the most common surface cracks:

1. Plastic Cracking. This cracking occurs soon after the concrete is placed and while it is still plastic. It is caused by too rapid drying of the surface, usually due to hot weather, wind, low humidity, or a delay in applying the curing membrane. To prevent, do not place concrete in hot or windy weather, or when the humidity is very low, and use a fog spray to replenish surface moisture. Dampening the subgrade before pouring also helps. For an exaggerated illustration of plastic cracking, see how clay cracks. Also, the use of an evaporation reducer is recommended by ACI 302 and 308.

2. Random Cracking. The most common type of cracking occurs where it isn't supposed to, not at control joints. Remedies include low slump concrete (generally 4 in. maximum), closely spaced control joints, and proper curing as described above. (Random cracks are also caused by structural distress, but these cracks are usually easy to identify.)

3. Map Cracking, Pattern Cracking, and Crazing. These are terms for closely spaced short cracks running in all directions in a roughly hexagonal pattern, resembling a road map. They are caused by too much water at the surface



A raveling crack pattern is identified coming from the corners of this column blockout where slab joints were not provided.

(bleed water), which both weakens the surface layer and causes it to shrink excessively. It is prevented by removing bleed water as soon as it forms and by not delaying curing.

SIZES OF CRACKS

Cracks continue to open as the slab ages up to approximately one year, and reach 50% of their final size in approximately 30 days. Some cracks are so small they are barely noticeable and are of little concern. Others are so large they are visibly objectionable and may pose raveling problems if subjected to forklift traffic or other wear, such as water intrusion. The following is a suggested guideline, or "objection scale," for cracks of various widths:

0.01 in. wide. Too small for concern; subject to autogenous healing. (About the width of a business card.)

0.02 in. wide. Visible but not overly objectionable; about the smallest size that can be injected with epoxy (if structurally required).

0.03 in. wide. Objectionable if in a traffic area, and are either filled, or if large in number, the slab is removed and replaced.

0.04 in. wide. Definitely objectionable and could begin to ravel with forklift traffic if not filled or the slab area replaced.

0.06 in. wide. Too much shrinkage occurred, perhaps due to high slump concrete or poor curing. Cracks are filled or slab is replaced.

0.12 in. wide. This is nearly 1/8-in. wide. Determine the cause of this large crack and fill or replace slab.

The extent of cracks in a slab and the degree of their undesirability should take into account the use of the slab and whether the slab is to be covered with a flooring material. Many cracks in a warehouse floor are both visibly objectionable and pose a maintenance problem, whereas a few such cracks in a large area might be acceptable. Remember that no slab is crack-free. Even control joints are cracks along a predetermined straight line.

HOW TO MEASURE THE WIDTH OF A CRACK

There is a helpful device for measuring crack widths called a Crack Comparator, which is available from the Construction Technology Laboratories, a subsidiary of the Portland Cement Association (Skokie, Illinois). It is a clear plastic template that is placed over a crack and the width of the crack compared to varying line widths on the template. The device gives the width in both millimeters and inches.

Household products can also be used to gauge the size of cracks: a business card is about 0.01 in. thick and a credit card is about 0.03 in.

CURLING

Curling is a phenomenon that unfortunately occurs frequently in industrial floor slabs. It is evidenced by a warping up, or curling, of the corners of a square or rectangular section of slab. It is caused by the more rapid drying of the upper half of the slab, causing this upper region to shrink more than the lower region, thereby causing the corners to lift.

From this formula we can see that the amount of curling depends on the difference in shrinkage (hence rate of drying) between the top and bottom, the thickness of the slab, and the square of the distance between joints.

To minimize curling, use a thicker slab if possible, control the curing so the moisture gradient is more uniform, and keep the joints closer together. However, keeping the joints closer is not always practical. The best insurance against curling is low slump concrete and good curing. If reinforcing is used, it should be placed in the top third of the slab to most effectively restrain curling. Wet curing is also effective in reducing curling.

If curling occurs, there are two remedies. One is to inject grout under the void at the corners so a rigid support is provided. The other is to saw cut on a diagonal several feet back from the corner and allow it to crack and settle to the ground. Quite often a forklift going over the corner will do this for you, as the load of the forklift will break the corner.

SLAB SURFACE TOLERANCES

The generally accepted standard for slab surface tolerances is 1/4-in. in 10 ft. To specify 1/8 -in. is hard to achieve, and the extra flatness is hardly discernable. Greater than 1/4 in. is readily visible and impairs operations, particularly when steel storage racks are used. However, this method of measuring “flatness” is difficult to apply and of arguable value, and has been replaced by the F-Number system, described below.

THE F-NUMBER SYSTEM

With the increasing use of high material storage and handling operations, there is an increasing demand for a very level floor, thus measuring the flatness is critical. The F-Number system, developed by the Face Companies, is a measuring system that is now the industry standard.

This method for classifying flatness and levelness of slabs uses an instrument to statistically determine its classification based upon a number of readings. It is described in ASTM E1155,

Slope in a floor or casting slab does not prevent Tilt-Up from being successful. Constant slope within a panel region is, however, imperative for flat panels. Seen here is a casting surface in a parking lot with 2-ft of slope from one end to the other.

STANDARD TEST METHOD FOR DETERMINING FLOOR

Flatness and Levelness using the F-Number System.

Using the F-Number system, two values are used, FF (for flatness — the bumpiness of the floor) and FL (for levelness — the tilt or pitch of the floor). As an illustration, the older standard of 1/4-in. in 10 feet is roughly equivalent to the F-Number designation: FF=25, whereas 1/8-in. in 10 ft. is about FF=50. A typical specification for a high quality floor might be FF=40/FL=30. A super-flat floor is often defined as FF=100/FL=50.

SLOPED FLOORS AND UTILITY PENETRATIONS

Panels are usually cast on flat floors or on floors with constant slope. Areas where slope changes occur should be avoided for casting panels.

Electrical and plumbing penetrations should be capped below the floor level. Utility penetrations above the floor slab interfere with the screeding operation and become an obstacle for crane movement. These projections can also become a source of cracks in the slab. It is imperative to coordinate utility penetrations with the slab casting procedures, panel forming, and panel erection sequencing.

OTHER SLAB PROBLEMS

Below is a list of additional problems that occur in floor slabs:

1. Dusting is a wearing of the surface to a powder. It is caused by accumulated water at the surface causing a very high water-cement ratio with a corresponding loss of hardness. It is also caused by finishing while bleed water is still present, or by lack of adequate curing.

2. Scaling of the surface appears later and is a separation of thin layers of the surface. This, too, is caused by finishing before bleed water is removed. Water is trapped just below the surface and makes it susceptible to scaling off during freezing and thawing cycles.

3. Raveled joint is the tearing and grinding that can occur at a joint subjected to forklift traffic. It is caused by relative movement across the joint due to a void under the slab. Good keying and proper support can minimize this occurrence. When it occurs, it can be progressive, but can be repaired by routing out the joint and filling it with an epoxy joint filler. In severe cases, a strip of the slab may have to be sawed out and replaced.

Occasionally slabs crack parallel to free edges when the edge is thickened. When the slab shrinks, the thickened edge tends to grip the soil and prevent moving inward to accommo-

date the shrinkage. Therefore, excessively thickened and squared edges can be undesirable.

4. Scouring may occur as panels are dragged across the slab. When a proper bond breaker is used, there should be very little damage to the slab in areas where panels are cast. During initial panel lifting, the base of the panel may drag along the slab surface before it is lifted clear. On occasion, dragging may cause some damage to the slab in the form of scour. An easy way to reduce or eliminate this scour is to cast a 1 x 2 strip of lumber along the bottom outside edge of the panel. As the panel is lifted, it will rotate about this sacrificial piece of lumber, resulting in very little direct contact between the concrete panel and the slab.
5. Holes in the slab caused by temporary wind brace anchors and form anchors should be repaired. Various repairing materials are available, which should meet the same strength requirements specified for the slab.

OTHER SLAB FEATURES

When space is limited, it may be necessary to cast panels over openings or recesses in the floor slab that are required by other trades. These may be isolated equipment pads, trenches, pits, recessed computer floors, recessed tile areas, or column blockouts. Slab blockouts may be filled with sand to within 2 to 3 in. (50 to 75 mm) from the surface and then topped with a thin concrete layer. After panel erection, the concrete layer is saw-cut around the perimeter, chipped out, and discarded. An alternative method for deep depressions is to use plywood on formwork, level with the slab. The plywood should be sprayed with a bond breaker similar to that used on the slab. Support for the plywood should be adequate to prevent sag during construction activity. The plywood surface may also be depressed 2 or 3 in. (50 to 75 mm) to allow a layer of concrete to be placed on top.

THE PERFECT FLOOR SLAB

The flawless floor slab is probably unachievable; however, a near-perfect slab can be achieved if additional precautions are taken and the owner is willing to pay for them. Since several of these things can be very expensive, most owners are willing to live with some of the cracks and thus save significant costs.

CASTING BEDS

Before starting panel layout and forming, it is necessary to verify that the slab area is large enough to cast all the panels and allow room for construction equipment to maneuver. A general rule of thumb is that a panel area should not exceed more than about 70 to 85 % of the floor slab area for casting panels. Otherwise, stack casting or additional casting beds may be required. If temporary casting beds are employed, they may be located outside the main floor slab. Casting beds are typically 3 in. (75 mm) thick and constructed of concrete with 3,000 psi (21 MPa) compressive strength. These should be cast on a compacted subgrade, finished, and cured by similar procedures used for the floor slab. Casting beds generally are not designed to support loads from the crane. After panel erection, casting beds are usually broken up and hauled away. Control joints in casting beds are optional. Random cracking can be dealt with by filling with latex caulk, depending on crack width and location.

SAND BEDS

The sand bed method involves hand placing aggregates on a sand layer within the forms. Concrete is then placed over the aggregates. This method has been successfully used with maximum sizes of coarse aggregate up to 6 in. (150 mm). These larger aggregates must be hand placed in the sand. Large, thin slices of facing stone have also been used successfully in sand bed casting.

The best results are obtained with dry masonry sand as the sand bed. The color of the sand should be consistent with the aggregates used in the concrete to avoid a mottled appearance. Sand is usually spread to a depth of 20 to 30% of the stone diameter but depth is dependent on the amount of exposure desired. All aggregate to be exposed should be of uniform size and gradation for best results.

Special care should be taken to ensure that adequate aggregate density is obtained around edges, corners, and openings. This may require special tamping tools in these areas. After aggregate distribution has been obtained, the aggregate is pushed or hand tamped into the sand bed. The aggregate can be rolled into the sand bed using a tennis court roller. Once final adjustment in sand thickness has been made, a fine spray of water is then used to settle the sand around the aggregates. Excessive use of water from a normal nozzle may disturb the aggregate bedding and promote cement migration into the sand bed.

Reinforcement should be placed in its proper position within the thickness of the concrete portion of the panel. The reinforcement may be supported by chairs with sand pads on top of the aggregate. If aggregate thickness varies significantly, proper reinforcement location may be difficult to maintain. If so, the engineer should be notified in case more reinforcement is necessary to account for variations in placement.

With smaller aggregates, or if a specific color of mortar is desired, a thin cement and sand slurry can be placed over the aggregate and allowed to harden to ensure that the aggregate is not dislodged when the normal back-up concrete is placed. Provisions should be made to cure the slurry or grout. A curing compound should not be used because it may prevent a bond with the concrete. The grout surface should be raked to promote bonding with the concrete.

After the Tilt-Up panels have been erected, the sand is hand brushed or removed with water under low pressure, 1,000 psi (7 MPa) or less. Whichever method is used to obtain an exposed-aggregate finish, or if plain concrete is the desired look, panels should be cleaned and sealed with a good-quality, non-gloss, penetrating concrete sealer. This sealer should be clear and remain clear for the life of the sealer.

THE FOUNDATION SYSTEM

The foundation system for a Tilt-Up building requires a few extra considerations not encountered in a masonry, steel frame, or wood frame building.

The foundation system for a typical Tilt-Up building consists of interior footing pads to support columns, interior continuous footings to support bearing walls, and perimeter footings or pads to support the wall panels. Foundations transfer loads from the structure to the soil or rock supporting the structure. Foundation systems can be categorized as shallow or deep. Shallow foundations bear on a soil layer at or near the surface. These include continuous footings, spread footings, combined footings, and mats.

Deep foundations, such as piles and drilled piers, transmit the loads by friction or bearing at some depth below the surface. The permissible soil bearing capacity or pile-load capacity is typically specified in the geotechnical report prepared for the project. The foundation engineer should determine the size and reinforcement of any foundation element.

Wall panels are supported on spread or continuous footings.

Spread footings are placed under joints between panels, so that each footing pad supports one-half of each adjacent panel and the panel spans between footing pads. They were the original standard; however, continuous footings are customarily used now. Excavation for continuous footings are done economically with a trencher, and little reinforcing is required.

Whether a pad or continuous footing is used, the top is held down about 1½ in. below the bottom of the panels and this space is filled with grout after the panels are up to provide full bearing onto the footing.

In order to set the panels at the correct elevation, high density plastic shims or grout bearing pads are constructed on top of the footings under the end of each panel. Customarily, just one pad is used under the joint between two abutting panels. These pads are about 1 1/2 in. high, set precisely at the correct elevation (bottom of the panel), and are of a length sufficient to safely support the weight of the panel until the grout is placed under the remainder of the panel.

Depending on site and building conditions, subgrade preparation may be necessary. This can include excavation and removal of poor soils, compaction of existing soils, or importing engineered fill. Subgrade integrity should be maintained throughout construction.

THE CONSTRUCTION SEQUENCE

Following is the sequence most often used for constructing the foundations and floor slab:

1. Prepare the subgrade for placing the floor slab. This includes possible importing of fill material, compaction, installation of underground electrical and plumbing, and excavation of the interior footing pads and interior bearing wall footings.

2. Place concrete for the interior footings. This includes setting the anchor bolts using a steel plate template furnished by the structural steel fabricator.

3. Place, finish, and cure the floor slab.

4. Excavate and place exterior foundations. Sometimes this is done before the slab is poured, or at the same time.

5. Construct the leveling pads on the perimeter footings in preparation for setting the wall panels. (At this point the wall panels are formed and cast.) Steps 4 and 5 can also be done after placement of panel concrete, so concrete trucks can back close to the head of the panel.

6. Place grout under the wall panels once they are up and braced for continuous bearing onto the footings.

7. Place the closure strip between the exterior walls and the floor slab. This should be done after the roof is in place but before the wall braces are removed.

8. Grout the base plates for the interior columns once they are up, and then place concrete in the blockouts.

9. Check for excessively wide cracks or joints. Route, fill, and patch as required (customarily if cracks are over 0.03 in. wide or are in heavy traffic areas).

INTERIOR FOOTING PADS

Base plates for interior steel columns can be bolted directly to the top of the floor slab. This is inexpensive and allows the foundations to be placed at the same time as the floor slab. However, it is not the most aesthetic solution and it often creates maintenance problems.

The preferred, customary practice is to hold the top of the footing pads down about 8 in. below the finish floor so the base plate and anchor bolts are encased in concrete. This may need to be lowered if interior roof drains are used.

To accomplish this and to achieve a smooth, level floor for casting the panels, the anchor bolts are covered with sand or gravel to within a few inches of the finish floor elevation. Next, a diamond-shaped form is set at a 45-degree angle to the slab joints, with its points aligning with the four crack control joints meeting at the column. Finally, the floor slab is placed. After the panels are erected, the diamond forms and sand within are removed and concrete is placed to fill the recess. Caution: Keep water out of recess until it is filled!

FOUNDATIONS SUPPORTING WALL PANELS

The size of the foundation is determined by the engineer based on the loads supported and the allowable soil bearing values. Pad footings are usually between 4- and 6-feet square, and continuous footings are usually from 14 to 30 in. wide. Pad footings are reinforced with bars each way located near the bottom, and for continuous footings, the engineer normally specifies a continuous bar at the top and bottom. The latter are to resist upward soil pressure at panel openings, and to bridge over weak spots in the subgrade.

Continuous Footings

Where soil conditions are adequate for the use of shallow foundations, continuous strip footings are typically used to provide support to interior and exterior Tilt-Up wall panels. Continuous footings are typically designed for the weight from the panel to bear on the center line of the footing. The foundation engineer usually determines the continuous footing size and reinforcement. How the panel is set on the footing during erection should always be considered during footing design and construction.

Continuous reinforcement in footings helps to distribute panel loads over weak spots in the subgrade. Heavier reinforcement may be required if the footing must span trenches, drain lines, or other site features. Footing width is inversely proportional to soil capacity, so wider footings are necessary for softer soil conditions. Panels are usually centered on continuous footings, unless property lines or other restrictions exist. At a minimum, the bottom of the footing should extend below frost depth in accordance with local building codes.

Continuous footings for dock high panels may be located 4 to 6 ft (1.2 to 1.8 m) below floor slab elevation. The floor slab is typically held back 5 to 10 ft (1.5 to 3 m) to allow the panel to be erected onto the footing. The crew should avoid lateral displacement of the panel due to soil pressures during backfill compaction. The panel may require temporary bracing or welding of the reinforcement dowels.

Isolated Footings

Where soil conditions permit, individual spread footings at panel joints are often used to provide support for Tilt-Up wall panels. Spread

Left: Shim packs are assembled and set ahead of the erection sequence.

Both: Guide rods in the foundation increase the quality control and ease of placement for the panels while the crane is lowering them to the foundation.

footings are typically reinforced with one layer of reinforcement in each direction located 3 in. (75 mm) clear from the bottom of the footing.

Foundation Walls

Site conditions or architectural considerations may necessitate the use of foundation walls. A foundation wall is a cast-in-place concrete wall constructed on top of the footing to approximately 1 to 2 in. (25 to 50 mm) below the panel bottom to accommodate setting pads (Section 3.2.1). The footing is constructed as a continuous element with reinforcement dowels projecting vertically. Typically, reinforcement is placed horizontally and vertically in the center of the foundation walls for at-grade conditions.

Using a foundation wall at a dock condition requires the wall to be designed as a cantilevered retaining wall resisting the backfill pressure and may require reinforcement on both faces. Dowels projecting horizontally from the top of the foundation wall may be required for connection to the floor slab. Usually, the panels are connected to the slab or foundation wall.

Deep Foundations (Piles and Drilled Piers)

Where soil conditions dictate the use of deep foundations, continuous grade beams on piles or pile caps on groups of piles may be used to provide support to Tilt-Up wall panels. Grade beams or pile caps are constructed similar to continuous strip footings and are located 1 to 2 in. (25 to 50 mm) below the panel bottom to accommodate grout setting or bearing pads (Section 3.2.1). Panels are centered on the continuous grade beam or pile cap, unless property lines or similar restrictions exist. Floor slabs supported on piles may not be adequate to support construction loads from the panel erection crane. Panel erection for pile-supported buildings will often take place with the crane located outside the building perimeter.

Foundation systems for drilled piers are similar to those on piles when grade beams or caps are used. If the drilled pier is of sufficient diameter (approximately 2 ft [0.6 m] minimum), however, panels may bear directly on the drilled pier without the need for a grade beam or cap. If so, the top surface of the drilled pier should be finished smooth and level and be located 1 to 2 in. (25 to 50 mm) below the panel bottom.

Eccentrically Loaded Footings

Property line footings are an example where an eccentrically-loaded footing may be unavoidable. A deeper footing is one method the engineer uses to provide for this condition. Other solutions include adding dowels to the floor slab or using other means to keep the footing from rotating from this eccentric load. Still other engineers solve the eccentricity problem by designing a dog-leg on the bottom of the panel so the panel weight is centered on the footing.

Grade Beams

Continuous footings are sometimes designed as "grade beams," reinforced to span over underground drain lines or to serve other purposes. When grade beams are used, the engineer specifies heavier reinforcing at the top and bottom and ties to enclose the bars.

Where panel widths can be established before foundation construction, the panels can be designed and constructed to span from pile to pile with the piles centered on the panel joints. The purpose of the grade beam then would be to prevent frost heave. Nominal reinforcement of the grade beam may be specified by the foundation engineer. If panel widths cannot be established before foundation construction, or if pile capacity does not permit placement only at panel joints, the grade beam should be designed and constructed to span from pile to pile and provide continuous support to the panels. Continuous horizontal reinforcement and reinforcement ties should be provided (as specified) to permit the grade beam to span from pile to pile. Pile embedment into the grade beam should be specified by the engineer.

Individual Pile Caps

Individual pile caps used to support the panels are usually located under the joint of adjacent panels. Panel widths should be known before foundation construction. The pile cap size and reinforcement as well as pile embedment into the cap should be specified by the foundation engineer. Pile caps can usually accommodate small tolerances (usually less than 3 in. [75 mm]) in pile location. As with individual spread footings, the bottom of the cap should extend below frost depth as required by local building codes. Provisions should also be made to address frost heave under the unsupported edge of the panel if it does not extend below frost depth.

SPECIFYING CONCRETE FOR FOUNDATIONS

Usually, the minimum strength specified for foundation concrete mixes is 2,000 psi with an economical aggregate size of 1½ in. It is also permissible for the slump to be higher, usually 5 to 6 in.

PLACING THE FOUNDATIONS

Placing the foundations for a Tilt-Up building is little different from any other building. Since restriction of the work area is usually not a problem, concrete is usually placed from the chute of a ready-mix truck or placed with a pump.

The top of footing is located approximately 1 to 2 in. (25 to 50 mm) below the panel bottom to accommodate grout setting pads as outlined in Section 3.2.1. Panels are centered on the footing, unless property lines or similar restrictions exist and have been accounted for in the design. As a minimum, the bottom of the footing should extend below frost depth as required by local building codes. Provisions should be made to address frost heave under the unsupported panel edge if it does not extend below frost depth.

A code requirement to keep in mind when placing reinforcing in foundations is that there must be at least 3 inches of concrete coverage over the reinforcing where concrete is placed against earth.

GROUT SETTING PADS

It is critical that grout setting pads are set at exactly the correct elevation. Otherwise the panel will not be level and will require shims, requiring expensive rigging crew time. These pads are a few inches wider than the panel thickness and of a length sufficient to support the panel temporarily until the space under its full length is grouted. The length of these pads is generally about 24 in.

A common method is to form grout setting pads and mark them for panel alignment. Final elevation checks may indicate slight adjustments by shim layers.

One way of constructing these pads to the precise elevation is to drive a concrete nail into the top of the foundation until the head of the nail is at the exact elevation as determined by a level. Then a shallow wood form is constructed and a stiff grout mix is placed in the form level with the top of the nail. The top is finished exactly level so that the panel has full bearing on the pad. After the grout has set, spray paint or snap a line indicating the outside edge of the panel to facilitate setting. Another helpful practice is spraying the panel's number on top of the setting pad as a final check for proper placement.

Shrinkage of the panels between these bearing pads after the panels are set can cause diagonal shrinkage cracks in the lower corners of the panels. To avoid shrinkage and to reduce bending in the footing prior to grouting underneath, the setting pads can be placed about one-quarter panel width in from each edge. Construction loading of panels placed on two sets of shims could be more critical than the in-place loading continuously supported by grout. Some contractors install additional plastic shims at intermediate points immediately after panels are set and prior to grouting. Some contractors use shims exclusively as setting supports.

The top of continuous footings for wall panels is often located approximately 1 to 2 in. (25 to 50 mm) below the bottom of the panels to accommodate grout setting or bearing pads. Pads are positioned on top of the footing to temporarily support the wall panel. A single pad is commonly used under the joint of abutting panels, but this may cause large restraint forces and can result in diagonal cracks at panel corners. If this is a concern, two separate pads can be placed 1 to 3 ft (0.3 to 0.9 m) on each side of the panel joint. Additional setting pads may be required for wider panels or for panels with openings to better distribute panel weight more evenly to the footing. These pads can be placed during or immediately after panel erection. Panel weight alone may account for 75% or more of the total load to the footing, so proper distribution of this load is essential.

Alternatively, neoprene pads can be placed on top of the setting pads. Then, as the panel shrinks, the neoprene deforms slightly to accommodate the shrinkage. The pad should be at least 1/2-in. thick to work effectively. It is important to grout the space under the panels soon after they are set.

Once the panels are set and aligned, the space between the footing and panel is packed with grout to provide continuous panel support onto the footing. The construction crew should install grout from both sides of the panel to provide full bearing. Use of flowable grout from one side is another alternative. Grout does not have to be a non-shrink type but should maintain continuous bearing.

STEPPED FOOTINGS

Occasionally, it is necessary to step a continuous footing, providing for changes in grade, or providing for a recessed loading dock. These steps should not be too abrupt. A step should be made to occur at panel joints and should change in even inch dimensions.

FOOTINGS UNDER FREESTANDING WALLS

Freestanding yard walls, or walls at the sides of depressed loading docks, are constructed by setting the panel on temporary pads at each end, and then placing concrete under and around the bottom of the panel to secure it in place. Reinforcing projects from the bottom of the panel structurally ties the panel to the footing.

SECTION 4
PANEL LAYOUT AND FORMING

Opposite: A big enough crane may be the only solution in a tight setting to erect all panels from one point such as the San Diego Children's Museum shown here.

One critical task a Tilt-Up contractor performs during the planning stage is panel layout and sequencing.

To determine a workable and efficient layout, the designer must determine the fixed and variable factors that affect this process. Assuming the panel sizes have been set (refer to Section 2 – Panelizing), size and weight are fixed factors. The size of useable floor area (for casting), floor slab design (for lifting) and site access are also fixed factors.

Variable factors affecting the layout process include the following:

1. Crane types and capacities available (including their costs)

2. The decision to lift from inside, outside or both

3. The ability to stack cast and where to use stacking as an advantage

4. If and how many temporary casting beds are required

As the number of variable factors increases, so does the complexity of developing the best solution to safety, cost and speed of erection.

CRANE TYPES AND CAPACITIES AVAILABLE

The Tilt-Up contractor needs a general working knowledge of the different types and capacities of cranes available for a particular project. There are three types of cranes used to erect Tilt-Up wall panels: truck-mounted lattice boom, truck-mounted hydraulic boom and track-mounted lattice boom. These are commonly referred to as: conventional, hydraulic and crawlers.

Ultimately, the decision is a compromise based on optimizing several variables. For example, a crane selected with a very large capacity moves around the site less, with greater reach, but costs significantly more to bring to the site. Conversely, a crane with just enough capacity to lift the heaviest panel may have a lower mobilization cost and hourly rate, but has to reset for each panel, influencing the erection efficiency. Another important factor the contractor must consider is whether the crane has the ability to "walk" a panel when making the final selection.

The goal is to use the lowest cost crane to do the job safely. This statement can be evaluated using the following formula:

$$C = m + ht \qquad \text{(Formula 4-1)}$$

Where: C=cost, m=mobilization fee, h=hourly rate, t=erection time.

See Section 7: About Cranes for crane size recommendations.

THE DECISION TO LIFT FROM INSIDE OR OUTSIDE

Whether the crane is to lift primarily from the inside or the outside is closely related to the type and capacity of the crane. Inherently, larger cranes do more slab damage and crawlers (cranes with tracks rather than tires) are almost always kept outside of the building. Other considerations include accessibility of the slab from the perimeter site, the space more valuable for casting purposes, and potential damage to the slab.

When slab damage does occur, the question of responsibility arises. Whether it is the general contractor, the crane supplier, or any other subcontractor, the fact remains that the owner has a cracked floor.

THE ABILITY TO STACK CAST AND WHERE TO USE STACKING AS AN ADVANTAGE

At first thought, stacking may not seem to offer any advantages to the Tilt-Up process. However, similar panels are easily stacked without significant costs and offer cost-effective casting surfaces required for additional wall areas. Strategically, the Tilt-Up contractor may want to stack some panels to allow for either crane access or to relax the requirements of the floor slab. Relaxing includes excessive plumbing pipe

Murray Legge, AIA

The thin, unreinforced casting slab does not require finished edges like the building slab; only an exacting surface finish that matches.

overpours or suspended slabs that may not be designed for the dead loads of concrete panels.

THE DECISION TO USE TEMPORARY CASTING BEDS AND HOW MANY

Temporary casting beds are closely related to stack casting. Often, temporary casting beds are required because the floor is not acceptable as a casting surface due to floor slopes, physical size or strength. Once determined that temporary casting beds are indeed required, the question of how much casting area is weighed against stack casting.

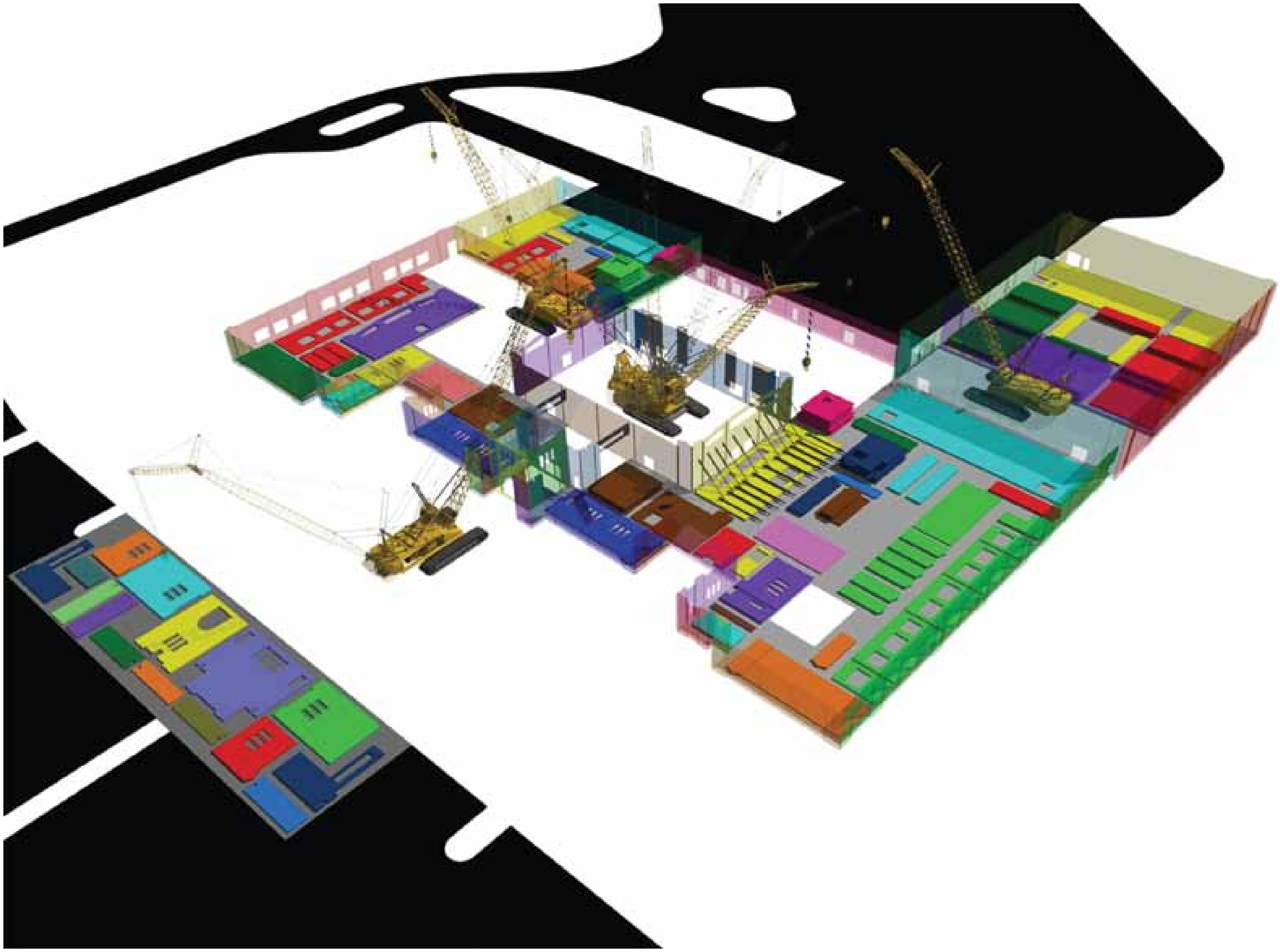
THE LAYOUT AND SEQUENCING PROCESS

One of the most important items to discuss during pre-construction planning is the panel casting and erection sequence. This planning session may include the Tilt-Up project manager, superintendent, concrete subcontractor, panel crane operator, rigging foreman and framing erector (if they are to set the closure panel). The plan shows where panels are to be formed and cast as well as their final erected positions. Crane access into and out of the building and the panel erection sequence are also shown. Crane size, access in and around the building (including whether or not the crane is permitted on the slab), and site layout greatly affect the panel casting layout.

A proper layout plan should provide enough space between the panel being erected and panels yet to be erected to attach temporary wind braces to the slab. A qualified engineer should verify slab capacity.

The most costly item in the process is the crane. Therefore, all panels are normally scheduled to be erected with a single crane mobilization. Phasing of panel erection may cost more because of a second crane mobilization fee but can accelerate the schedule by allowing the first phase of panels to be erected before all panels are cast and cured.

To optimize the construction schedule, panels should be cast in nearly the same order as they are to be erected and as close as possible to their final position. Time could be lost if the first panel to be erected is the last panel to be cast or if the panel is cast too far from where it is to be erected. Panels should be arranged so that they are erected consecutively. It is difficult to break a panel free when it is cast between two other panels. If panels are cast in the wrong location, they may have to be lifted, walked, or temporarily braced while other panels are moved out of the way. In addition to the increased cost and time involved, safety concerns increase each time panels are handled. Lifting insert manufacturers may require increased safety factors if panels are handled too often. Lack of planning of panel sizes and casting locations may require a larger crane than anticipated or scheduled.



Thorough planning will involve the concrete supplier, who should be aware of approved mixture proportions (including flexural and compressive strengths) and quantities of concrete that will be needed for each series of panel castings, and whether a concrete pump will be used for concrete placement. (Limited site access for ready-mix trucks may necessitate the use of a concrete pump). Panels are often erected within seven days of being cast. Specified strength tests (flexural and compressive) should be conducted in accordance with ASTM C78 and C39 requirements before erection to verify concrete strengths meet erection requirements. These tests involve breaking beam and cylinder specimens that are cast from the same concrete used in the panels and stored on-site in conditions similar to those experienced by the panels. The testing agency should be notified when panels are to be cast so they can fabricate test specimens and perform other on-site tests such as slump and air content of the fresh concrete.

Other items to be addressed during pre-construction planning include whether the panels are to be cast inside face up (more common) or outside face up. When panels are cast outside face up, it may be necessary to provide temporary deadman blocks or slabs outside the building to anchor the braces. (This will not be possible if the building is located adjacent to a property line.) Alternatively, the panel can be lifted and braced in a temporary location with braces initially attached to the outside face of the panel. Additional braces should then be attached to inserts on the inside face. The panel can then be moved to its final position and braced in the normal manner to the floor slab. This will double or triple the time required to erect the panels. Refer to Section 6 for panel bracing.

Given these fixed and variable factors, the Tilt-Up contractor then develops a panel casting layout that most effectively suits the project at hand. Armed with a chart of panel sizes and weights, a scale drawing of the site with building footprint, and the appropriate crane lifting chart, the Tilt-Up contractor then plans the placement and lifting sequencing. Prior to the advent of computer aided drafting (CAD), it was common practice to place scaled "cutouts" on a scaled floor plan as a model to the actual lift day procedures.

It is essential to consider sequencing in this process. The aforementioned factors seem inconsequential if a panel is picked cleanly from the slab but has another panel cast in the way of the brace attachment to the floor slab. This prevents the final set of the panel and increases the handling costs on the project.

Layout is an important process unique to each Tilt-Up project. It is complex and may take several iterations to arrive at the most efficient plan. These layouts can range from quite simple.

Lastly, the site supervisor and foremen must understand that deviations from the plan can lead to costly consequences on site.

The panel casting and erection sequence plan shows where panels are to be formed, their final position in the structure, and their casting and erection sequences. One technique to assist in the layout of panels is to use scaled paper cutouts of the panels and arrange them on a scaled floor plan. This allows the superintendent, concrete subcontractor, and panel erection subcontractor to plan the sequence of panel construction and erection. Another common method of planning is the use of scaled CAD (computer generated) drawings.

Panels should be arranged so that they will be erected consecutively.

FORMING MATERIALS AND METHODS

Once the layout is determined, attention shifts to forming the panels on site to prepare them for receiving steel and concrete. Additionally, this is when any architectural treatments that impact the panel face are added.

While rectangular panels are still the norm, panels with previously unconceivable bends, curves, and shapes are being constructed on a regular basis. Curved and unusual shaped panels cost more to construct than rectangular panels, but they are still much less expensive to build than using vertical formed or other types of concrete construction. Many, in fact, would be impossible to build with other methods of construction. Tilt-Up eliminates expensive formwork and scaffolding. Proper panel formation is critical to project success and demands appropriate attention.

FORMING MATERIALS

Dimension lumber (such as 2 x 6 and 2 x 8) is the most common form material. Engineered wood forms made of plywood or pressed wood are also used. Basic lumber dimensions can be modified to suit the project needs by ripping to the desired dimension. Sandwich panels are typically cast with wider dimension lumber to accommodate the insulation thickness and the additional face layer of concrete. Only straight and true lumber should be used. Using poor quality lumber will cost you in the long term. Lumber should be ordered in lengths that will minimize the number of splices needed. Knots are typically not a problem, since the sides of the panels are usually hidden in the joints. The side forms should not be oiled, because the form oil is not compatible with bond breakers. Standard dimension lumber can be used one to three times while engineered lumber and metal products can be used indefinitely.

Steel edge forms, such as channels or angles, can also be used but are less common and offer less dimensional flexibility.

Edge Forms. The height of an edge form is built up with the wood members (thinner panels required them to be ripped down) to suit the specifics of the designed panels. For panels thicker than 10 inches (usually insulated sandwich panels), it is more efficient to use a sheeted form rather than dimensional lumber. Because the edges of most panels are not exposed, regular plywood can be used, rather than the more expensive form ply.

The structural thickness of the panel determines the size of the lumber. If a panel is to be 5.5 inches thick, then the simplest edge form is a 2x6, or if the panel is to be 7.25 inches thick, then a 2x8 is the correct choice. The contractor and engineer should work together to produce the most efficient design. A thinner panel will often need more steel reinforcement, so the cost of extra concrete (and a heavier panel) versus extra steel should be evaluated.

Occasionally, the required structural panel thickness will be slightly thicker than the depth of standard dimension lumber. The first option in this scenario is to still use a 2x6 or 2x8 and build up the top by nailing on a strip of plywood or a 1x2 (if an additional ¾ inches is required). For example, if the panel is to be 8 inches thick, use a 2x8 plus strips of plywood or ripped lumber. The second option is to use a wider piece of dimension lumber and rip it lengthwise to the designed height. For example, rip down a 2x10 to get an 8.5 inch form height. One caution with this method is that it wastes more material. It is impractical to use taller sides and hold the concrete below the top, as this makes screeding and finishing much more difficult.

Sister Forms. Similar to edge forms, sister forms differ only when the contractor decides to cast panels side by side, separated with only a common form. Several manufacturers produce extruded pieces for this purpose. The extrusions are fastened or adhered to the slab and have a chamfer on either side. They accept a strip of 3/4 inch plywood to divide the panels. These extrusions are reusable and are generally made of aluminum or PVC. See *Appendix D: Products and Services* for more information.

Common forms may be of either 1x or 2x construction. The advantages of a common form are that fewer form boards are required, and any inconsistency in straightness of the form is in, and matches, the adjacent panel (assuming the adjacent panel shares the common form). The main disadvantages are the difficulty of securing the common form and the additional restraint generated during the erection of the panel because the common form cannot be stripped until one panel is erected. In addition, there is no place to wedge the panel free from the casting bed if the need arises due to suction or bond breaker problems.

Chamfers. When exposed, concrete should not terminate at a sharp corner. As a result, there is extensive use of chamfer strips around the perimeter of the panel and the perimeter of panel openings. These chamfers can take various shapes, but the most common has a 3/4 inch face with equal sides. The 3/4 inch chamfer strips are attached directly to the side form. One common use of a chamfer strip with legs of unequal size is for the forming of a window ledge.

Above: Panel ready for concrete placement with all steel, inserts and embeds tied and secured.

Below: Chamfer strips (like the polystyrene shown) and reveals are installed to create durable corners and edges of the panel while integrating with the facade graphics.

Panel edges are usually chamfered, resulting in fewer spalls and a cleaner appearance. Chamfers are normally formed at 45-degree angles and are made from wood or specially fabricated, extruded polystyrene. Any damage to the polystyrene strip, in particular the edge, will result in deformations or ragged edges, so the crew should exercise care. Chamfers should be caulked if the joints are not tight.

Panels at building corners can be formed with either butt joints or mitered corners. The butt joint is the simplest and least expensive to form. The mitered corner should be accurately formed because the miter magnifies any inconsistency. It can be formed from an assembly of dimension lumber or by using specially fabricated materials such as extruded polystyrene shapes. Mitered corners need not terminate in a point, which is very difficult to execute. The materials used for chamfers can range widely. Materials can include: solid wood, plywood, fiber board, PVC, extruded polystyrene, aluminum or rubber. All wood chamfers should be sealed on all three sides with two coats of a polyurethane sealer to minimize swell and sugar migration-related concrete panel surface retardation.

Reveals and Recesses. Reveals (often referred to as rustications or rustication strips) create the most basic of architectural influence on the panel surface by producing recesses and shadow lines in the face of the Tilt-Up panels. Large panel areas can be enhanced by dividing the surface with reveal strips. Painted coating and reveal strips can also be applied in a trompe l'oeil technique whereby a two-dimensional surface is made to appear three dimensional. Such reveals are often continuous and are fastened to the floor.

Reveal strips are the simplest method to divide the visual expanse of a large Tilt-Up panel and hide casting slab irregularities reflected in the panel. Reveals may run vertical or horizontal; there may be one or several bands on a building. Reveals are typically 1/2 to 3/4 inch (13 to 19 mm) deep and 2 to 4 inches (50 to 100 mm) wide with 22.5 or 45 degree beveled sides for ease of stripping.

It is important to remember that the reveal strips reduce the effective structural depth of un-insulated panels. The location and depth of reveals must be accounted for in the design of the structural engineer. Reveals should be fastened with concrete nails or by a pneumatic stapling gun. When the panel is lifted, you want the strips to stay on the slab so they can be removed more easily. It is necessary to ensure that the reveals are in the right place, particularly if they are to match with adjoining panels. Square edge reveals are not recommended due to stripping problems, which result in poor-quality edges. Chamfers and reveal strips should have a consistent depth and angle. If

A hanging form creates the 45 degree miter for an effective and balanced corner detail.

a deeper reveal is required, its location and subsequent effect on the panel's structural performance should be considered because the reveal, regardless of how shallow, reduces the structural thickness of the panel.

Reveals are generally fabricated from solid wood, plywood, wafer wood, fiberboard, PVC or extruded polystyrene. All wood reveals should be sealed on all four sides with two coats of a polyurethane sealer to minimize swell and sugar migration-related concrete panel surface retardation. When using extruded polystyrene, care should be taken to avoid damage from foot traffic and from the use of solvent-based bond breakers.

Accurate placement of reveals is important, particularly if the reveal continues from one panel to the next. It is important to mark the location of both the top and bottom of the reveals on the slab with chalk lines and should be either screwed, nailed, or adhered to the slab. The edges of the reveal strip should be caulked with a silicon or latex caulk to produce a clean, crisp edge. The reveal strips should be thoroughly coated with bond breaker after caulking.

It is important to note, while many materials may seem like good choices to effect surface change, the Tilt-Up contractor needs to confirm the compatibility of the product with water and Portland cement so there are no unexpected chemical reactions.

FORMING PANEL FEATURES

Mitered Corners. Beveled or mitered side forms are often required for mitered joints as previously discussed in Section 2. The construction of these mitered corners requires more attention to securing the "hanging" form that creates the interior of the mitered joint.

Doors and Windows. Windows, personnel doors and overhead doors are formed within the panel similar to side forms except the anchoring cleats are located inside the opening. Fewer cleats and the use of spreaders between the opening forms are more effective at keeping them apart. Cleats are crucial, however, as failing to secure the opening side forms can result in bowed opening edges that will not conform to the design dimensions.

Sandwich Panels. Thicker than standard Tilt-Up panels, the insulated sandwich panel adds both an insulation layer and a non-structural exterior concrete wythe to the standard structural concrete layer. This means you may be forming an additional five inches or more of panel thickness than the structural layer.

Windows have recesses and sloping sills built into the forms as required for glazing details. Personnel door frames are placed on the slab and make their own forms. They become integral to the panel when the concrete is placed, filling in the hollow metal regions. They are checked for squareness and affixed securely to the floor slab. The bottoms of door frames terminate at the finished floor line, although the bottom of the actual opening is approximately 5 inches lower, so the floor slab extends over the rough sill and out to the exterior face of the wall. A rigid polystyrene product is used to efficiently create these blockouts. Blockouts for the hardware attachment screws in the door frames are also made with a rigid polystyrene. This protects the metal drill while drilling through the frame. Use duct tape to cover hinge and strike boxes to prevent concrete leakage from filling them in.

One of the advantages with openings in Tilt-Up construction is that if the location needs to be changed at the last minute, it can be accomplished very simply. After a quick check with the engineer to make sure reinforcement is adequate, an opening can be moved in a matter of minutes.

Pilasters. When loads dictate, it is necessary to create reinforced concrete columns in the panel that are thicker than the general panel thickness. These columns are referred to as pilasters. Even when these are located at the panel edge, one side of the form is suspended allowing concrete to flow throughout the face of the panel under the forms. One method is to tie the form horizontally to other solid form members and provide a temporary "stake" to support the suspended form until the concrete is placed. Once the concrete is placed, the stake is removed and no evidence of its presence remains.

Stacked Forms. Occasionally, the amount of floor area that is available for casting panels is not sufficient for the entire project. One option contractors have is stack-casting panels on top of each other. This is accomplished by setting another level of forms on top of the previous set and bracing them to the subgrade or panel below securely. If stack-casting is used on a project, specific attention to the order of casting is given to reduce the forming labor by repeating as much of the panel area from the lower panel into those on top.

FORM LINERS

Form liners are an effective tool to provide a texture or pattern to the panel surface. These are available from many manufacturers and in a wide variety of materials, patterns and textures. They can be used as an accent or for the entire panel.

Some important considerations when using form liners include:

1. Make sure the form liner is properly sealed to the slab or form edge to prevent concrete leakage during the pour.

2. Make sure the form liner is compatible with the bond breaker.

3. Make absolutely certain the structural engineer is informed of the form liner profile.

4. Start and end form liners with a reveal. Liners designed for a single use, manufactured from polystyrene or vacuum-formed plastic, are most common on Tilt-Up projects. Corrugated siding, metal decking, and other commonly available materials have been successfully used as form liners.

Trompe l'oeil, the French term for "fool the eye," can produce dramatic effects for architectural finishes. Trompe l'oeil finishes are usually executed one of two ways. The traditional method is to paint a scene or some other finish directly on a flat surface after the panel is erected. An artist is typically used for this technique. A variety of effects have been achieved, from painted windows to a medieval castle. The method more commonly seen on Tilt-Up projects uses a combination of multiple reveal strips and painting to give the illusion of a third dimension. This method is particularly effective when used to articulate windows, doors, columns, or fascias.

Drawings showing the finished impression and the layout of the reveal strips should be produced. Panels should be laid out to avoid floor joints, column blockouts, and other obstructions, where possible.

Reveal strips are typically 1x3s or 1x4s. The multiple reveals are placed on two sides of the opening. The sides with multiple reveals are often painted a darker color than the balance of the building to enhance the illusion of shadow and depth. The resulting appearance gives the illusion that the feature is three-dimensional.

FORMING OBSTACLES

Any defects or depressions in the floor show on the final panel surface. Saw-cut crack control joints are common on most Tilt-Up casting/floor slabs. Failure to properly fill or mask these joints will result in the formation of fins or ridges on the wall panel surfaces. Several options are available to fill the saw cut joints, ranging from specially designed premolded or extruded joint fillers to the use of silicone or latex caulking materials, cementitious fillers, gypsum, wax, foam or tape.

Other common floor overpours include column baseplates. If panels are cast over the top of column locations these need to be prepared.

Generally, to aid in the removal of this over-pour after panel erection, the concrete over-pour is only 1 inch to 1 1/2 inches thick over a sand or gravel filler.

In the case of larger floor openings, generally the opening is kept down 1 to 1½ inches from the top surface, covered with plywood and then a skim of concrete as part of the slab pour. This also applies when stack casting panels over panels with dissimilar shapes or openings.

FORMING POCKETS

Pockets are often cast into one face or the other of concrete panels. These are either made of a solid or hollow material. Two popular choices are polystyrene foam and plywood boxes. These are firmly secured in place preventing them from "floating" when concrete is placed. The most common reasons for pockets include structural connections and recesses for plumbing or electrical fixtures.

FORMING METHODS

Now that we have discussed some of the different materials used to create panel forms, consideration is also given for the method of securing them in place long enough for the concrete to gain sufficient strength and not require further support.

There are many ways to fasten forms to the slab after drilling holes. These methods include: driving wood dowels, self-tapping screws, two nails in a single hole, one nail and a piece of wire in the hole, and one nail and a piece of nylon wire. To prevent damage to the slab from drilling and spalling, several effective adhesive methods are available for attaching forms.

Of the methods that penetrate the slab, there are continuous wood cleats or even steel angles. Attaching form supports to the slab with adhesives requires the brackets to be of a plastic material.

The most common method, however, is securing the forms using wood cleats. The wood cleats should be spaced between 36 and 48 inches apart on center and located at each corner. Attach the cleats to the slab by drilling a 3/16-inch hole and driving in three 16d double-headed nails, which just fit and are easy to pull out when the forms are stripped. Pins should not be shot into the slab with a stud gun to anchor the cleats, because they are hard to remove and can splinter the slab.

When using metal form brackets to secure the forms, use a roto-hammer to drill a 1/4-inch hole through the bracket hole into the slab. Next, drive in a 1/4-inch wood skewer, also known as a miniature dowel, and break it off flush with the bracket. Finally, install one 16d double-headed nail into the skewer to secure. This method is easy to strip and does not spall the slab.

The newest forming methods involve the use of adhesive-based form attachments. This eliminates the need for holes in the slab to anchor the form supports – an important consideration for many owners. Special tape or adhesives secure the bracket to the slab, which must be clean and free of dust. Portions of this system are reusable.

FORMING PREPARATIONS AND LAYOUT

Remember, accurate layout of forms is critical because panel joints are typically only 1/2 to 3/4 in. (13 to 19 mm) wide. Holes in the floor from attachment anchors should be repaired after erection of the panels. Minor bows in the forming lumber can be corrected with the form supports.

The slab should be clean and free of dirt or other materials. All control joints and blockouts for columns should be filled before placement of edge forms. Slab curing chemicals should be thoroughly dry before panel forms are placed. If the slab is cured with a chemical different from the bond breaker, they should be compatible.

Panel edges and openings should be marked before setting any forms. Chalk lines are the common method for marking location of panel forms. Methods of chalking vary among contractors (such as, outside of forms and outside of panels). Some contractors prefer to mark both sides of the form to eliminate any confusion as to what side of the line the form belongs. It is important to be consistent in the method used. Chalk lines can be sprayed with bond breaker to prevent them from washing away during a rain and to reduce fading from foot traffic. Forming tolerances are provided in ACI 117.

Column and utility blockouts may be either formed flush with the surface of the slab or filled with sand to within 2 to 3 inches (50 to 75 mm) of the top of the slab, topped with concrete, finished flush with the slab surface, and saw cut after panels are erected.

FORMING CURVED PANELS

Curved panels are either convex or concave. They are cast on a formed surface rather than on the slab on grade. As a result of the capabilities of computer aided drawing (CAD), there can be amazingly exact curves constructed into forming surfaces. To achieve the smoothest surface on the concrete face, it is best to use either a form-ply or masonite.

Other methods exist, however, for forming curved panels; showing the creativity of the Tilt-Up contractor and the versatility of the construction medium. One such method involves more of a vertical precast technology to build forms on site for specific radius sections. Yet another method eliminates the need for above-grade forming platforms and instead

Above: a plywood platform is prepared for the broad curve of these panels.

Below: A curved concrete slab excavated into the grade has been selected for this set of dynamic entrance panels.

involves excavated areas from the earth to create "natural" form surfaces. This reduces construction time and costly forming processes.

FORMING IRREGULAR PANEL SHAPES

To this point, the discussion of forming has focused on rectilinear panel areas. Today's Tilt-Up market is growing in every direction, including the popularity of irregular panel shapes. Panel designs with radius tops both concave and convex are quite common, as are sloped tops to match higher-pitched roof lines. Circular panels and complex angles are other shapes gaining popularity with designers as they discover the abilities of the contractor and the method.

Forming complex or irregular shapes often requires the forming technique known as "sistering" or using a common divider form to separate one panel from the next. This is advantageous for rectilinear forms as well as irregular forms because it assures that the joint created between the two panels is a mirror rather than tapering or bowing in one direction or the other.

Curved, tapered, irregular and frequent openings, and ribbed, the forming process can often be the most tedious portion of the Tilt-Up process. It may be the only way to deliver the intended architectural design.

SEALING THE FORMS

The joint between the form bottom and slab should be sealed either with a chamfer strip, caulk, or both. If concrete paste seeps under the edge form, it will leave a ragged edge that will require grinding or repair after panel erection.

SANDWICH CONSTRUCTION PROCESS

The casting of a sandwich wall panel typically spans two pours. The exterior wythe pour and insulation/connector placement occur simultaneously. The second step involves the installation of the interior concrete reinforcing, lifting and bracing hardware, and any inserts isolated to the interior wythe of concrete.

During construction of sandwich wall panels, the exterior wythe of concrete is cast first, usually in forms that contain architectural treatments. The minimum exterior wythe thickness is two inches plus the depth of any reveal or rustication. Therefore, if incorporating a 3/4-inch architectural reveal, the minimum exterior concrete thickness is 2¾ in.

After casting the exterior wythe, the insulation and wythe connectors are immediately placed in the fresh concrete.

Sandwich panel wythe connectors interlock in cured concrete through mechanical means. Therefore, proper performance of the connector is dependent on having consistent, workable, and properly consolidated concrete around the anchorage point of the connector. Unique to a sandwich wall panel is the mix design and anchorage capacity of the connector. Since the exterior concrete layer of a sandwich wall panel is typically nonstructural and the connectors are installed in a plastic mix, pursuant to ACI 551R, the concrete is typically reinforced with a 6x6xW2.9xW2.9 mesh positioned on plastic bolster strips or chairs, and a slump of 5 to 7 is recommended to ensure proper consolidation of the connector. Additionally, minimum size aggregate is 1/2 in. and a 4,000-psi minimum concrete is typical.

Key points to remember include:

1. Exterior wythe concrete shall be at least 3,000 psi so that sufficient strength is obtained.

2. Cold joints shall not be permitted.

3. Concrete shall have a minimum compressive strength at 28 days as indicated on the project drawings and as required for panel erection, or specified, and tested according to ASTM C39.

4. The exterior wythe concrete slump should be specified in the range of 4 to 7 in., out of the tail-gate or the pump. It is necessary that the concrete slump specified be maintained during installation of the insulation system. This slump may be achieved by adding a mid-range water




reducer to the 1 to 2 in. slump mix design produced at the ready-mix supplier's batch plant.

5. Maximum size aggregate should be 1/2in. for the exterior wythe concrete. This size constitutes an economical mix and coincides with pumping requirements. Larger size aggregate impedes wythe connector placement. Please contact the wythe tie manufacturer for installation guidelines.

6. If a vapor retarder is required, it is placed on the warm side of the insulation. A vapor retarder is a sheet material with sufficiently low vapor permeance to minimize the rate of water vapor diffusion. A vapor retarder is typically specified to be of thicknesses from six to 10 mils.

7. In order to achieve a high R-value and consistent thermal and moisture protection, the insulation must be placed edge-to-edge, completely separating the two layers of concrete. If the insulation is not continuous, thermal bridges will occur, resulting in a loss of R-Value as well as increasing the likelihood for moisture migration Another recommended detail is to fill all gaps between the insulation sheets greater than ¼ in. with a foaming insulation to avoid thermal bridges.

8. A pull-out test on the connector should occur once the exterior concrete achieves 25% of its 28-day strength. Depending on outside ambient air temperature, this could be 12 to 36 hours. Additionally, in some cold climate locations, this could require a cylinder test. Below is a reference chart:

Ambient Temperature Range (°F)	Minimum Time from Casting to Anchorage Test (hrs)
70 and higher	12
60 to 70	24
40 to 60	36
Below 40	Field-Cured Cylinder Test Required

Once the anchorages of the connectors are confirmed and the interior concrete components are in-place, concrete placement proceeds and is placed and finished, erected and braced, in a manner consistent with uninsulated Tilt-Up wall panels.

BOND BREAKER

Bond breaker is one of the most critical materials used on a Tilt-Up project. As the name suggests, the bond breaker will facilitate separation between the wall panel and the casting slab.

Categories. Bond breakers generally fall into one of two major categories: chemically active or non-chemically active. They can be either water-based or solvent-based. Solvent-based bond breakers do not meet U.S. Federal EPA Clean Air Standards and, therefore, require the end user to pay an exceedance fee.

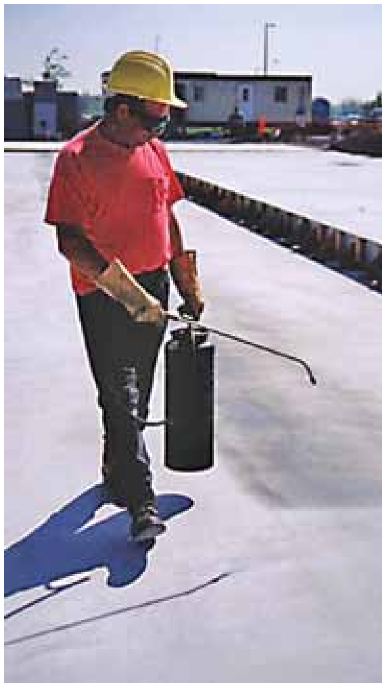
Chemically active bond breakers contain carboxylic acids which chemically react with calcium hydroxide (lime water) in fresh concrete to form metallic soaps which prevent wall panel sticking. Non-chemically active bond breakers contain organic resins or wax which form a barrier on the casting/floor slab surface to prevent wall panel sticking.

Chemically active bond breakers have the advantage of being easily removed from floor and wall panel surfaces once the wall panels have been raised, allowing for the application of exterior patching materials, exterior coatings and flooring products. Non-chemically active bond breakers are generally more difficult to remove, and often interfere with adhesion of exterior patching materials, exterior coatings and flooring products.

Application. When the forming is complete and the casting beds are ready for the insertion of reinforcing steel and inserts, it's time to apply the bond breaker. Before placing anything on the slab, the bond breaking compound must be sprayed on the slab surface. The compatibility of the slab curing compound and the bond breaker, if separate items, must be verified before beginning construction. The use of a single bond breaker from the same manufacturer should be used, and dissimilar products should not be used.

A quality, hard steel-troweled slab finish is a prerequisite for any applied treatments and good panel surface. Slabs that are poorly finished, poorly cured or have low strength will exhibit higher permeability, thus increasing absorption of the bond breaker and reducing its effectiveness. All casting slabs should be cured according to ACI 302.1R, ACI 308 and ACI 360R.

Apply the bond breaker in strict accordance with the manufacturer's recommendations. Bond breaker application rates, application procedures and user instructions vary widely among manufacturers. Although the chemical makeup of bond breakers varies among manufacturers, most bond breakers are reliable and perform properly if used correctly. Make sure the product is within its shelf life, has not frozen and is thoroughly mixed (applies primarily to water-based bond breakers) prior to use. Be sure the surface is clean and free of any sawdust, dirt or other substance that would impede the action of the bond breaker or stain the panel. Most manufacturers recommend that the bond breaker be applied in a mini-



mum of two coats after all wood reveal strips, chamfer strips and blockouts are installed, but before installation of reinforcement and embedments. These coats are sprayed at right angles to each other to ensure complete coverage of the casting slab. Apply the bond breaker inside the forms to the outside face and the perimeter of the formwork. It is well worth the effort to apply additional bond breaker around the outside of the formwork nearby. This ensures easy cleanup of any concrete that was spilled during the placing process.

Although bond breaker manufacturer recommendations vary, in general, the casting/floor slab should have a uniform film of bond breaker and should exhibit a slightly darkened uniform appearance prior to insertion of reinforcing steel and panel inserts. Avoid puddling the material, as this will cause discoloration and retardation of the panel surface. When in doubt as to the presence of an adequate bond breaker, consult the manufacturer.

Floor Hardeners and Coverings. After the panel has been lifted and set in position, the bond breaker's compatibility with floor hardeners and floor coverings should be verified. When a penetrating liquid floor hardener is specified for the floor slab, it is generally recommended to apply the liquid floor hardener after panels have been raised at the end of the project. All residual bond breaker must be removed from the floor slab prior to application of the liquid floor hardener. Consult with the bond breaker and liquid floor hardener manufacturer to ensure compatibility. Always check the compatibility of the bond breaker with the finish coating to be used.

Troubleshooting. Good construction practices require the bond breaker to be uniformly apparent with a slightly darkened surface appearance. The surface should not appear blotchy or bright white.

Most cases of panels sticking to the casting or floor slab are the result of improper use or application of the bond breaker. When properly applied, most chemically active bond breakers do not leave sufficient residue to interfere with the adhesion of wall panel finish coatings. If over applied, the residue must be removed. Follow the bond breaker manufacturer's recommendation for removal of residual bond breaker prior to paint or coating applications. To minimize problems, it is best to consult in advance with the exterior painting contractor and the flowing contractor to ensure bond breaker compatibility with all subsequently applied wall or flooring products.

In general, the preferred method to remove chemical bond breaker residue, as well as calcium carbonate (chalk), from wall panel surfaces is with a power washer. Wall panel surfaces should be pretreated with a mixture of 2 lbs. of trisodium phosphate detergent (TSP) dissolved in 5 gallons of water. After 15 to 20 minutes, the wall panel surfaces should be pressure washed with a minimum 2,500-psi pressure washer.

The removal of non-chemically active bond breakers is often more difficult. Those bond breakers containing wax are nearly impossible to remove from wall panel surfaces and often require sand blasting to obtain sufficient adhesion of finish coatings.

If light spots appear, relative to the rest of the casting slab, reapply bond breaker on the casting or floor slab surface.

If reapplication is required, reinforcement and embedded items should be lifted clear of the slab so the bond breaker can be properly applied without coating the reinforcement and embedded items with the bond breaker. If a very small area can be reapplied without coating the reinforcement, the reinforcing steel would not need to be removed.

Current building codes do not allow coatings on the reinforcement. The real problem is not the effect of coating the reinforcing steel, but rather the rebars affecting the proper application of the bond breaker. With reinforcing steel in place, it is very difficult to apply an even coat of bond breaker. Furthermore, excessive bond breaker caught on the reinforcing steel drips into concentrated regions on the slab mirroring the reinforcement pattern. These concentrated areas of bond breaker will affect the finished appearance and quality of the concrete and, perhaps, even the performance of the bond breaker.

Bond Breakers Used for Curing. Many bond breakers are also frequently used as a cure. Although some bond breakers meet the curing requirements of ATM C 309, most do not. If the project requires the application of a liquid-applied cure meeting ASTM C 309 but the intended bond breaker does not meet the requirements, it will be necessary to consult with the bond breaker manufacturer to select a curing compound compatible with the bond breaker.

SECTION 5
REINFORCEMENT, INSERTS AND EMBEDMENTS

Crew assembles a vertical column of steel at the edge of a multi-story panel with large windows. It will be lowered into the form when complete.

In addition to the quality of concrete, Tilt-Up panels have a wide variety of steel components that provide the structural integrity for load resistance as well as the structural connections. Steel reinforcement, then, is the primary embedment in any panel. In addition to the reinforcement, a number of other items are embedded for construction purposes or in-place structural connection. These include inserts, such as lifting or bracing inserts (anchors), as well as structural embeds, such as floor and/or beam connections, weld plates and roof diaphragm connections for girders, trusses or decks. In many panels, door and window frames are also items that may be specified as embedded or cast-in-place for the panels.

PANEL REINFORCEMENT

American Concrete Institute's (ACI) Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary governs the design of reinforcement with regard to cover, lap lengths and other particulars. Reinforcing steel is critical to the performance of the panel, and all instructions and information relating to it should be precisely followed.

The project's engineer of record typically designs the panel reinforcement, for in-service loads

only, indicating the size, number, shape and spacing of the required reinforcement. The horizontal reinforcement is primarily used to control cracking of the concrete due to shrinkage and temperature changes. The engineer will determine the lap lengths required for splices in the bars; however, laps are normally not used in Tilt-Up panels.

Placing the reinforcement begins after all formwork, including openings, is completed and after all reveals and other architectural features have been secured to the casting surface. The time required to place the reinforcement depends on the size and complexity of the panel. A rule of thumb is that a two-person crew can place all the reinforcement in a typical solid panel in approximately 30 minutes. A more complicated panel with several openings and an integral beam may take an hour or more.

Proper reinforcement location within the panel thickness is most important in placing and tying the reinforcement. Placing the reinforcement begins with marking the desired location of the bars on the forms or slab, together with the bar size. The mats of reinforcing steel must be properly supported and tied sufficiently to allow workers to walk on the mats, as this is unavoidable during concrete placement.

It is important to use the proper height of bar supports to ensure that the bars are in their specified location. Some engineers specify the bar support heights. Bar supports are available in ¼-inch height increments. Bar supports should be placed at a maximum of 4 ft. on center each way.

Typical requirements for placing the reinforcing steel include:

1. Spacing of bars does not exceed three times the panel thickness or 18 in., whichever is less.

2. Panels thicker than 10 in. will normally have the horizontal and vertical reinforcement placed in two layers, one layer at each face.

3. The minimum clear distance between parallel bars must not be less than the bar diameter or 1 in., whichever is greater, or 1.33 times the largest size aggregate.

4. Tolerance for bar placement in the thickness of the panel is ± 3/8 in. and also applies to the coverage.

5. Normally, the engineer will require at least two #5 bars that extend 24 in. beyond the opening. The engineer may specify more, particularly in jambs alongside large openings.

An engineer should also determine the stresses inducing into the panel during the lifting process. In most cases the insert supplier performs this analysis. Many times the lifting stresses will require additional reinforcement beyond that required for the in-service loads. The engineer providing the panel lift designs will indicate the size, number and spacing of this reinforcement on the panel erection drawings. Close coordination is required between the reinforcement required for lifting and the reinforcement required for in-place service loads to ensure that all the required reinforcement is placed.

All reinforcement specified must be positioned as called for on the drawings, or the strength of the panel will be significantly reduced. Using the wrong chair height, using a chair for the wrong size bar or tying bars in the wrong layers results in a reinforcement location that does not match the engineer's design and a panel with reduced structural capacity. The bar supports connect to the casting surface (outside face of the panel) and remain in the panel, therefore exercise caution when using them. Make certain the bar support will allow a sufficient amount of concrete to encase the tip of the support to prevent holes or weakened areas that can break away during thermal cycles. The use of plain carbon steel, plastic coated or tipped carbon steel bar supports can result in unsightly rust stains appearing on the face of the panel. It is recommended that composite plastic bar supports be used to support the panel reinforcement.

This is especially important when panels are to be painted or coated with a textured coating. Bar support must be of sufficient strength to support the weight of the reinforcing steel mat and the workers during concrete placement. The strength of the bar supports should not be affected by high temperatures, as they typically lie on the casting surface in direct sun.

The last process completing the placement of the reinforcement is tying. This process is inherently important to properly maintaining the locations of the bars. A minimum of 50 percent of bar intersections should be tied.

Careful attention to the casting surface is required once all of the reinforcing is installed and tied. All loose pieces of tie wire and clippings should be removed from inside the forms to eliminate the possibility of exposing steel on the exterior face of the panel, which can produce rust stains on the finished panel surface.

If rain or other action has occurred that causes you to question the effectiveness of the bond breaker, the reinforcement needs to be removed before reapplication of the bond breaker. Bond breaker is not allowed to come in contact with the reinforcement in most building codes.

An excellent resource for any questions regarding the placement of reinforcement is the publication *Placing Reinforcing Bars* by the Concrete Reinforcing Steel Institute (CRSI). This publication covers nearly every aspect of reinforcing placement and conforms to the ACI 318 Building Code.

TYPES OF REINFORCEMENT

The structural integrity of the Tilt-Up panel during its service life, as well as resisting stresses during lifting and bracing, is heavily dependent upon steel reinforcement or proper quantity and location.

Most panels contain steel reinforcement consisting of #4, #5 or #6 bars placed as close to the center of the panel thickness as possible. The vertical bars are centered by positioning chairs, and then the horizontal bars are placed on top of the vertical rebars. By placing the vertical reinforcement at the center of the panel, bending resistance is equal in either direction. When a greater strength is required, such as alongside openings or at points of concentrated loads (such as beam pockets), additional steel reinforcement is added by the panel engineer and called out for placement near each face. These additional bars are usually specified as #5 or #6. Steel reinforcement larger than #7 or #8 is not common in Tilt-Up panels.

The standard specification for steel reinforcement is based on the requirements of ASTM A615 Grade 60 having a minimum yield strength of 60,000 psi. ASTM A615 requires reinforcement meeting this specification be marked with the letter S.

Weldability of the steel reinforcement is

extremely important. In general, welding of reinforcement conforming to ASTM A615 should be avoided. If a detail calls for welding of this reinforcement type, the process should be approached with caution, as there are no specific provisions included in this specification to enhance its weldability. Welding of ASTM A615 Grade 60 reinforcement requires chemical analysis of the steel, a written welding procedure and controlled preheating.

A more appropriate selection when weldability is desired would be ASTM A706 Grade 60 reinforcement. This specification provides for restrictive mechanical properties along with a chemical composition to enhance its weldability. The ASTM A706 specification requires that the reinforcement bars be marked with the letter W. Steel reinforcement meeting the A706 specification, however, has limited availability in some areas and may only be available in larger quantities.

Welded-wire fabric and welded reinforcement, in the form of prefabricated mats, are also used as reinforcement, which is discussed later.

In general, the use of fiber reinforcement in Tilt-Up panels has not been significant enough to warrant discussion.

REINFORCING STEEL SHOP DRAWINGS

It is customary for the reinforcing steel subcontractor to prepare shop drawings showing sizes of bars, lengths and bends corresponding to the appropriate panel. These drawings are sent to the architect or engineer for approval prior to fabrication.

The reinforcement is delivered to the project site, cut and bent to the specified lengths. Each bundle is tagged to indicate the bar size, length, grade of steel and the panel where it is to be used.

WELDED REINFORCEMENT MATS

Some contractors are using mats of welded-wire fabric to supplement or replace reinforcement bars.

When welded-wire fabric is used, engineers select a wire size to meet the minimum required steel. They then add conventional bars for additional structural reinforcement where required.

Reinforcement mats, which consist of mild steel bars welded into a custom grid, generally cost more per pound but provide higher yield strengths (and less area of steel) and lower placement costs, possibly offsetting the added material cost. The structural engineer who designed the panels prescribes the actual size, configuration, type and location

Slab bolster chair supports the welded wire matt reinforcement for the face of a sandwich panel.

of reinforcement. However, the area of steel cannot be reduced in all panels due to the higher yield strength of the steel. Many times the lateral deflection of the panel at mid-height is the controlling condition which requires a certain minimum area of steel independent of the yield strength.

EMBEDDED ITEMS

As previously stated, there are numerous items embedded into the Tilt-Up panels to facilitate a structural connection to the panel either during construction or for in-service conditions. These embedded items are classified as either inserts items that are used one time for construction service loads, or embeds, items that are designed for the in-service conditions for the duration of the building. It is essential that the guidance provided by this manual (and, ultimately, by the manufacturer or engineer) for the items to be embedded are followed in order to ensure the full designed capacity.

LIFTING AND BRACING INSERTS

Inserts are required for lifting and setting the panels from their cast position to their final in-place position. They are also required for the connection of temporary braces that secure the panels in place until the roof and floor connections are made. The size, height and weight of the panel, as well as the crane mobility and size, are factors that influence which lifting configuration and system is best for the project.

A variety of lifting systems are available to the contractor, including coil bolt systems and ground release systems. The inserts are designed for a single use, and the lifting and bracing systems they connect with are specifically designed for compatibility. Any attempt to lower the cost of construction by mixing and matching devices to inserts should never be considered. As there are no industry standards for coil threads, coil bolts and inserts should be compatible in diameter and from the same manufacturer. Differences from one manufacturer to another may be subtle, but they do exist. Deviation in threads' shape, length or strength could cause the insert or the bolt to fail when subjected to loading. If products from different manufacturers are used, the safety of workers could be endangered, and the warranty from either manufacturer will be voided.

Each panel is individually designed for the lifting process, including the selection of the lifting and bracing inserts. The engineer will analyze each panel to determine the number, location of inserts and any additional reinforcing steel that may be required. These requirements are a function of a bending moment analysis in the longitudinal and transverse direction and flexural capacity of the panel. The supplier will provide inserts that are properly sized for the anticipated loading, panel thickness and other characteristics. In addition, drawings detailing the exact location for the inserts and any additional reinforcement requirements will be provided for each different panel.

Both lifting and brace inserts should be rigidly wired to the reinforcement to ensure they stay in position. All supporting feet of the inserts must remain in contact with the slab when the crew walks on the reinforcement during concrete placement. Inserts are sized to the proper height to guarantee they are about 3/8 of an inch below the top surface of the panel.

Lifting inserts should be installed to a tolerance of ±1 in., unless otherwise specified on the erection details.

Inserts are supplied with a plastic void form designed to prevent concrete from filling the insert during concrete placement. These void forms have “antenna” that project above the surface during the troweling or finishing operation. As the concrete surface is finished, the antenna marks the surface in a manner that looks like “chicken tracks,” which allows the inserts to be easily located.

Most of the lifting inserts used today can be connected to the crane rigging with ground-release hardware. This allows the inserts to be released from the panel at the appropriate time without the need to climb ladders.

Concrete compressive and flexural strength must have reached the design strength required in the lifting analysis, prior to the panel being lifted. Higher-strength or high early-strength concrete can be used if early panel erection is desired.

Braces are normally attached to panel inserts before lifting. Braces are then attached to the floor slab or a temporary in-ground anchoring device in the form of either a deadman (large block of concrete set in the ground) or a helical anchor after the panel has been erected. Wall attachment of the braces should be with cast-in-place inserts only. Floor attachment may be with cast-in-place or post-drilled anchor bolts.

Panel bracing is subjected to cyclic wind loads, and only those bracing inserts specially designed for cyclic loading should be used as brace anchors. Anchors designed for only static loads should not be used as brace inserts. The TCA Guidelines for Wind Bracing should be consulted for additional information on the design, installation, and inspection of these systems.

Manufacturer's instructions should be explicitly followed regarding bracing system capacity based on slab thickness, edge distance and other parameters.

Placement of bar supports close to each lifting and bracing insert reduces the likelihood of dislodgement during concrete placement that results in an improper depth. Inserts that do not remain close to the surface are very difficult to locate after the concrete is placed and set. The result may be severe enough that secondary lifting inserts will have to be bolted on to the panels to allow for erection. Make certain all clasps, anchors and other components fit in their slots and are working properly prior to bringing in the crane—or at least several panels in advance. It is very costly to have a crane and crews waiting while corrections are made.

STRUCTURAL EMBEDS

The other category of embedded items consists of beam pockets, support angles, plates for attachment of structural components and other items that are an integral part of the panels after they are erected.

Steel embedment (weld) plates are used to attach the panel to other building components, such as roof or floor framing members, or for panel-to-panel connections. They are fabricated from plate steel with lugs, headed studs or weldable deformed bar anchors welded to the back. The embedment plate should be exposed to facilitate ease of attachment. The plates may be either flush with the surface or recessed.
In structures where appearance is a factor or where a highly corrosive environment is anticipated, a recessed embedment is preferred because it can be concealed with grout. Galvanized embedment plates should be used in corrosive environments if they are to be exposed. Steel embedment plates may be either galvanized, or the exposed surface may be painted to minimize rusting. The embedded portion should not be painted. Welded areas should be touched up with paint or galvanizing paint.

Welding is the most frequent form of connection to an embedment plate. It gives maximum flexibility and allows greater latitude to adjust for inconsistencies in height or dimension. Bolting can also be used but is often weaker and requires the use of slotted attachment members to account for dimensional variations.

Embedments are designed by the panel engineer. All recommendations regarding accuracy of placement for reinforcement and inserts apply to embedments. Embedments should be firmly fixed and supported in their designed position and should not be wet set or "floated" into place. Wet setting embedments can result in less consolidation around the anchors, which weakens the embedment's load capacity. If they are on the edges of the panels, they can be secured to the side forms.

All embedments should be on the jobsite prior to casting the panels.

An excellent resource for any questions regarding the placement of reinforcement is the publication *Placing Reinforcing Bars* by the Concrete Reinforcing Steel Institute (CRSI). This publication covers nearly every aspect of reinforcing placement and conforms to the ACI Building Code.

CHORD BARS

Sometimes in areas of the country where wood roof framing and plywood roof diaphragms are used, chord bars cast into the panel are designed to carry the diaphragm chord forces. When welding the chord bars at the panel joints, subsequent shrinkage cracks can occur at these locations. Placing the bars in plastic sleeves (tubing) in from the panel ends prevents this from occurring.

CONTAMINANTS

Steel reinforcement used in tilt-up panels is normally recognized as "deformed bar." By this description, the reinforcement bars have deformations consistent through their length to anchor the bars in the concrete. Similarly, the welded-wire mats and welded bar mats are secured in the concrete section with the welded crossing pattern resisting slip. Steel embeds and inserts are to be physically tied to the steel reinforcement, and each has a profile specifically intended to prevent pulling out of the concrete section before the concrete shears. Therefore, the presence of foreign substances or natural surface conditions does not affect the performance of the steel items in the concrete. Normal amounts of light rust on steel reinforcement are not detrimental to its use. In fact, laboratory testing indicates that surface rust will increase the roughness along the surface of steel reinforcement, which can increase the bond with the concrete. Similarly, the presence of chemicals such as fuel oil, release agents, paint, soil or grease will not prevent the steel from being fully developed in the concrete section. However, current building codes do not allow coatings on the reinforcement.

Bond breakers or release agents do pose a particular problem for Tilt-Up panels when the steel reinforcement is in place. The TCA strongly recommends the removal of the steel before any reapplication of the bond breaker when it is determined that the coating is ineffective. If a very small area can be reapplied without coating the reinforcement, then the reinforcement would not need to be removed. Despite the discussion above related to the lack of influence on concrete bond, the real problem is not the effect of coating the steel reinforcement, but rather the pattern of that reinforcement affecting the proper application of the bond breaker. With the reinforcement in place, it is very difficult to apply an even coat of bond breaker. Furthermore, excessive bond breaker caught on the reinforcement drips into concentrated regions on the slab mirroring the reinforcement pattern. These concentrated areas of bond breaker will affect the finished appearance and quality of the concrete and, perhaps, even the performance of the bond breaker.

SECTION 6
PLACING AND FINISHING THE PANELS

Pouring panels can be a high production process, as it is for the floor slab, provided a number of panels are ready for a same-day pour. It is not uncommon for a six man crew to place up to 20 panels in a day. With a good crew, one panel should not take longer than 30 minutes until it is left for the finishers.

It usually requires at least one, and often, two ready-mix trucks, at about 10 cubic yards each, to place concrete in one average size panel. Therefore concrete trucks must be scheduled 15-20 minutes apart to keep up with a production crew. Plan to provide paths for the entering and departing trucks, and accessibility for the discharge chutes to reach each panel. Placing with other machinery is an option too, discussed later.

THE PLACING OPERATION

A high-production placing crew consists of five or six laborers to rake and vibrate, and as many as four to six concrete finishers to screed, float and run edges.

Before placement of the concrete begins, the crew should make a final check of all inserts and embeds to confirm their location and assure their fixed position. Additionally, final checks of the forms for dimensions and squareness is suggested.

During periods of higher temperatures, over-heated floor slabs can create problems for concrete flow and accelerate the initial set. Therefore, it may be advisable to mist the floor slab with water to provide cooling. This would not be advised when using architectural treatments such as retarders where the water would alter the effectiveness of the chemical.

Concrete placement in today's Tilt-Up market remains quite varied based on the region, equipment availability, access to the panel perimeters and the preference of the contractor. The use of direct chute, conveyor or concrete pump can alter the way concrete is initially placed and continuously flowed into the forms. The key to successful placement is controlling the initial pressure of the concrete on the casting slab. This prevents abrasion of the bond breaker occurring when concrete is placed directly on the casting slab from the pump hose or concrete chute. Flow modifiers or diversion shields should be considered for high-volume placement equipment to lower the force at which the concrete reaches the bare slab.

Once concrete placement has commenced, it is important to maintain the placement flow into the fresh concrete already in the form. Concrete should not be dumped in separate piles and then leveled and worked together; nor should the concrete be deposited in large piles and moved horizontally into final position. The higher the working slump of the concrete, the easier it will flow throughout the forms, filling in all the voids and around all the embedded items. This is one of the main advantages to such concrete mix designs as self-consolidating concrete.

As the concrete placement fills the forms, part of the crew responsible for this operation should begin vibrating the fresh concrete in and around all embedded items. This consolidation or vibrating process compacts fresh concrete to mold it within the forms and around embedded items and reinforcement and eliminates stone pockets, honeycomb and entrapped air. Vibration, either internal or external, is the most widely used method for consolidating concrete. When concrete is vibrated, the internal friction between the aggregate particles is temporarily destroyed

Adequate crew size is important during the placing operation. This pour sequence for the faces of sandwich panels shows a placement crew, finishing crew and insulation crew within two or three panels.

and the concrete behaves like a liquid; it settles in the forms under the action of gravity and the large entrapped air voids rise more easily to the surface. Internal friction is reestablished as soon as vibration stops.

PLACEMENT SEQUENCE

Regardless of the concrete placement method used, it should proceed from one edge of the panel to the opposite side, not from the perimeter to the center, or vice versa. The concrete should not abrade the curing compound or retarders from the slab during placement. A shovel, piece of plywood or other surface can be used to slow the concrete during the initial drop. Freshly placed concrete can then be used to break the impact from the chute or nozzle. Concrete should be placed as close as is practical to its final location. It is acceptable to rake concrete short distances. The vibrator should not be used to move concrete.

If a common form is used between panels, concrete should be evenly distributed on both sides of the form to reduce the chances of movement.

To ensure concrete gets under and around reinforcing and embedded items, vibrating is recommended. The low slump concrete, which is desirable for panels due to the resulting higher strength and less shrinkage, may not readily flow into corners and around inserts without the aid of a vibrator. When a vibrator is used, prod it up and down in the concrete, but do not allow it to touch the floor since this could cause a separation of the bond breaker from the floor slab. Excessive vibrating can cause the coarse aggregate to settle to the bottom. Vibrators are effective to within about a 6 in. radius of the head.

In general, sandwich wall panels are comprised of two layers, or wythes of concrete, separated by a layer of rigid insulation, and are tied together with a series of connectors or fasteners. The performance of the Tilt-Up sandwich panel, both structurally and thermally, depends greatly on the capacity of the connector and the detailing of the insulation.

A sandwich wall panel is formed up to the total wall thickness, which will include the exterior layer of concrete, the integral insulation, and the interior layer of concrete. The panels themselves are prepared in a fashion similar to that of an un-insulated tilt-up wall panel.

Architectural features, such as reveals and rustications, are laid out and a bond breaker is applied.

CONSOLIDATION

Vibration is critical to ensure consolidation around reinforcement, inserts and embedments, and to get a proper finish on the panel. A pencil vibrator or "stinger" is one method commonly used. The tubular end of the vibrator should be held horizontal to, but should not touch, the slab. An attachment to hold the end of the vibrator can be fabricated if one is not available. The vibrator should be drawn through each successive deposit of fresh concrete into the previous placement to ensure adequate blending. The vibrator can also be placed in contact with the forms to ensure flow at the edges. Secondary vibration will promote the flow of concrete between reinforcement if two layers are used. The use of vibrating screeds is another widespread consolidation method currently in use with supplementary pencil vibrator at embedments. See ACI 309R for further information.

FINISHING AND CURING

Just before the concrete takes its initial set, a tamper (jitterbug) may be used to lightly push the coarse aggregate below the surface to facilitate finishing. (ACI, however, frowns on any use of tampers). Take care not to push the aggregate down too far or excess water forms on the surface, causing excessive surface shrinkage and consequent cracking.

Interior finish of the panels is often an owner's preference. If the panels are to be left exposed, a hard trowel finish may be desired. (Hard trowel finish is required if panels are to be stack cast). Many times a bull-float finish is all that is required. For concrete to develop the desired properties for strength and durability, it should be properly cured. ACI 308 discusses proper curing procedures.

When the placing crew begins the next panel, the finishing crew (usually two finishers) start their work. A wood bull-float is recommended. If excessive bleed water forms, drag a garden hose across the surface to remove it. On a hot day or if the humidity is low, keep the surface moist by fog-spraying or using a chemical evaporation retardant. The final step is to steel trowel the surface, or use a machine-powered rotary finishing machine. Steel trowel along the sides and use a finishing tool to get a rounded edge. Don't steel trowel above the ledger line, since it won't show and a rough surface makes a better bond for the roofing which is applied against the face of the parapet.

As soon as the finishers leave, spray the surface with a curing compound as per the manufacturer's instructions. An extremely important operation, its proper application should not be neglected.

Another option is the use of wet curing as described in *Section 3: Floor Slab and Foundations.*

THE MIX DESIGN

Concrete for panels should have a minimum compressive strength of 3,000 psi to obtain sufficient strength and allow lifting to take place in a relatively short time. The minimum recommended strength at lifting is usually 2,500 psi, which is typically attainable in five to seven days.

As mentioned for the floor slab, the mix design will depend upon many factors, such as strength, slump, desired setting time and weather conditions.

The contractor is most interested in the performance of the mix during placement to ensure a high quality finish. The design of the mix may not be satisfactory to achieve the highest quality finish. Therefore, the use of high range water reducers and other chemical admixtures are desired to produce a mix design with better workability, without affecting the engineering properties of the mix. Water added at the job site is not an ideal method for improving the workability and it should be carefully monitored and documented. Remember that each gallon of water added per cubic yard increases the slump about 1 in. Concrete test cylinders and test beam molds are taken at this time and cured in actual field conditions. These test methods are used to confirm that the concrete reaches the minimum strength requirements prior to the lifting process.

Maximum size aggregate is most commonly ¾ in. or 1 in. These sizes constitute an economical mix and can be pumped if desired. Larger size aggregate impedes placing and finishing. Admixtures are frequently used to modify various characteristics of the design mix, such as to

obtain faster setting time, slower setting time, cement reduction and other purposes. For a description of types of admixtures and when to use them, see "When and How to Use Admixtures," in *Section 3: Floor Slab and Foundations.*

If panels are left uncoated, color variations should be expected due to variations in cement color, colored admixtures, forming surfaces, release agents, water-cementitious materials ratio (w/cm), consolidation procedures, fly ash, aggregate and the amount of cement used. To limit color variations, close control of the above factors is critical.

PLACING EQUIPMENT

Placing concrete by means of a pump or conveyor is increasingly used for Tilt-Up panels. The ability to reach greater distances reduces congestion, often resulting from multiple concrete trucks entering and exiting the pour area, and gives better control of the arrival of concrete. Pumps and conveyors are found in sizes available to reach the most remote panels of most jobs. Low slump concrete (4 in.) and larger size aggregate (1 in.) mixes are readily delivered, although pumping requires a closer control on the mix design than the use of conveyors.

Placing concrete with these pieces of equipment adds up to $2,000 per day. However, the resulting significant savings in time and greater utilization of the floor slab space often offsets this additional cost. Placing methods are discussed in greater detail below:

Pumping/Conveying. Pumping or conveying has several advantages, including easier and quicker placement, especially on difficult sites.

Pumped concrete requires special considerations to minimize shrinkage and resulting cracks. A concrete mixture proportion formulated for pumping with appropriate aggregate size, w/cm, additives, maximum allowable slump and minimum hose size (preferably at least 4 in. or 100 mm diameter) should be selected.

When pumping, the height of drop should be kept to a minimum, and the fresh concrete should always be directed over an area of previously placed concrete. This method absorbs the impact of pumping and minimizes abrasion of the bond breaker (or retarder for an exposed-aggregate panel) and aggregate segregation. Concrete placement then progresses across the panel beginning at one corner.

Bucket. A crane with a bucket is still used on some projects. The bucket has few moving parts and no pumps. Placement with a bucket also has the advantages of placing concrete where it is needed and works well on difficult or tight sites. No special mixtures are required. It can be unwieldy and is slower than pumping, and requires a crane and operator to transport the bucket. Placement should follow the same procedures previously outlined above under pumping.

Direct Chute Placement. This method of placement may be the most economical and dependable, if the site conditions and building layout are favorable. Access to at least two sides of the panel is required. If access from the interior of the building is desirable, a decision should be made as to whether concrete truck traffic on the slab is permissible or if sections of the slab should be omitted until the panels are cast.

HOT WEATHER PRECAUTIONS

Special precautions should be taken when working in hot weather. If temperatures reach 85 degrees Fahrenheit or higher, use a fog spray to keep the slab from drying too fast during finishing, use a retarder to slow down setting time, and apply the curing compound as quickly as possible after the finishers leave. Keep the surface moist until nighttime on the day of the pour. Wet curing by means of burlap or Burlene are the best methods; however, they are more expensive.

Some contractors start concrete placement before daylight on very hot days and finish before noon.

To reduce the occurrence of waffle cracking over the reinforcing bars, cool them down by spraying with water just prior to pouring.

These steps will help prevent problems caused by hot weather, such as excessive shrinkage cracking.

The American Concrete Institute (ACI) has an excellent guide: *Hot Weather Concreting*.

COLD WEATHER PRECAUTIONS

The American Concrete Institute defines cold weather when the mean air temperature for three consecutive days is below 40 degrees Fahrenheit, or the concrete temperature is below 50 degrees Fahrenheit.

Adverse weather, although obviously more difficult and requiring special precautions, need not be a deterrent under extremely cold conditions. Many contractors in cold climates place air-supported tents over the construction area to form, pour and finish panels. Some build a temporary wood frame enclosure covered with Visqueen. Here are some suggestions from the cold weather pros, including one contractor in Nova Scotia who does a large volume of Tilt-Up work, including many projects in mid-winter:

1. Plan your procedures well in advance to make sure all operations go as planned.

2. Provide adequate equipment for heating concrete materials and protecting concrete during freezing or near-freezing weather.

3. Use a richer mix (more cement) to speed up strength attainment.

4. Use an accelerator (other than calcium chloride, since it can cause corrosion problems later).

5. Use a protective insulation blanket during curing if exposure to freezing at night is anticipated.

6. Curing at low temperatures is especially important since a low humidity associated with low temperatures causes more rapid moisture loss which increases shrinkage.

7. Prevent the ponding of water on newly-finished surfaces when casting concrete slabs in the open. Freezing of this water causes the concrete surface to flake off or spall.

8. Air entrain all concrete left exposed to freezing temperatures. Air entrainment is the addition of an air-entraining admixture which forms minute bubbles, generally smaller than 1 mm. This air-entrainment provides expansion areas for water during freezing. The admixture is added during the mixing of the concrete.

9. Make sure your test cylinders are cured under the same conditions as the work they represent.

10. When using construction heaters in enclosed spaces, make sure they are vented to the outside. If this is not done, there is carbon monoxide build-up, which combined with the calcium hydroxide

of the surface of the fresh concrete, forms a weak layer of calcium carbonate that interferes with cement hydration. The result is a soft, chalky surface that dusts under traffic. This condition also occurs when ready-mix concrete trucks or cutting equipment are operated inside an enclosure and the fresh concrete surface is not protected. Direct fired heaters which produce carbon dioxide should not be permitted to heat the air after casting operations for at least 24 hours.

11. Do not use straw or hay to protect architectural concrete surfaces. Even after the concrete attains its initial strength, the sap from the hay and straw permanently stains the concrete surface.

12. Protect concrete with blanket insulation until the concrete reaches the compressive strength of approximately 1,000 psi. This represents a point which the degree of saturation of water is such that no freezing occurs. This strength is usually achieved within 24 hours; however, conditions may require a longer period.

13. When stacking concrete Tilt-Up panels, the heat generated from the initial panels cast in the stack greatly assists in curing panels above, provided the time between pouring successive slabs is not more than approximately three days.

14. It is good practice to leave any forms in place for as long as possible, as the form acts as insulation to help distribute the heat more evenly over the concrete surface.

15. Do not place concrete when the exterior temperature is below 22 degrees Fahrenheit. The concrete will freeze in a ready-mix truck or in the concrete pump when the exterior temperature drops this low.

16. Do not cast concrete on frozen ground, since the ground settles afterward, causing voids under the slab. Also, the frozen ground seriously affects the temperature of the concrete, freezing the bottom one or two inches of the concrete slab.

17. Place concrete at night during the lower temperatures for slabs in the open when the temperatures are at or near-freezing. The sunlight and heat of hydration the next day permits successful finishing of the slab.

Remember that these precautions take time and cost money, and you must convince your clients and workmen that they are viable.

Many contractors routinely do Tilt-Up work year round in cold climates, and each develops their own unique methods to deal with the conditions successfully.

ACI recommendations for these conditions are contained in their publication titled *Cold Weather Concreting*.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SECTION 7
LIFTING, SETTING, AND BRACING THE PANELS

THE BIG DAY...

Lift day is an exciting day in the construction of a Tilt-Up building. The building's owner is often on site with a camera to record the birth of the building and to watch what some call high-tech barn raising.

The crane and erection crew arrive early at the job site, and -- if all goes according to plan -- by noon the building begins to take shape, with a dozen or more wall panels in place. By the end of the day, all the panels may be standing, or for a very large building, just a day or two more is all that is required. It is not uncommon for an experienced crane and erection crew to erect 30 or more panels in a day, enough to enclose a 30,000-sq.-ft. building.

This kind of production doesn't just happen. It is the result of careful planning, training, and experience. This section describes how it is done by the pros and will offer guidelines to help ensure that you will have a productive and mistake-free operation.

...AND THE DAY OF TRUTH

The day of lifting is also the day of truth.

Any errors in dimensions show up -- glaringly. If there is a dimensional “goof,” a panel may end up being too short or too long, leaving either a gap between panels, or requiring a panel to be lowered, sawed off and set again. Panels cast in the wrong location, crane inaccessibility to the site or portions of the site, panels stack cast in the wrong order, an inexperienced crane operator or crew, or inadequate crane size will severely hinder the erection process.

Errors do occur, and they can be fixed, but they are both embarrassing and costly. An expensive crane and erection crew can sit idle while a welder burns off an interfering angle iron ledger. This is a dimensional error that was easily avoidable.

Careful checking of dimensions by the architect and structural engineer can prevent errors. The contractor’s superintendent should always check dimensions. All good superintendents do, even going so far as to prepare sketches of each panel, showing all embedments, dimensions and any special features, such as scupper openings or form liners. All too often a draftsman, perhaps preoccupied or in a hurry, puts down a wrong dimension, and the panel is built accordingly with no one checking the draftsman’s work. Just a 2 in. error can cause havoc in the field. Nearly every problem that occurs during erection is the result of a dimensional error. It is best to check the panel dimensions, and then check them again. It is important to have someone else check the work, as one often does not catch personal errors. Errors, while costly, are typically much easier to correct while the panel is on the ground.

SELECTING THE ERECTION CONTRACTOR

Planning, experience and training make the difference between a smooth, error-free lifting operation and one that is disorganized and takes much longer than it should. The experience of the erection contractor, along with a proven ability to plan the panel erection carefully, should be the most important criteria for selection. Not just price.

Many Tilt-Up subcontractors develop a working relationship with one erection contractor they use exclusively. In most cases, panel erection is a team effort, with the general contractor supplying carpenters and laborers to assist the erection crew (which generally is comprised of the crane operator, oiler/driver, two riggers and an erection foreman) and with the contractor’s superintendent closely watching. This familiarity in working together is a very desirable factor.

Sometimes the lifting operation is competitively bid upon. In these cases, each crane company selected to bid looks over the plans to determine how many panels will be lifted, how many may be difficult to erect (such as L-shaped and lintel panels), how much access there is to the site and maneuvering space during lifting, and other factors that affect their time on the job. With this information, they estimate how long it takes to complete the job, prepare the estimate and submit the bid. If the contractor is unfamiliar with the low bidder, references are checked, to determine how many Tilt-Up jobs they have completed and whether they were without mishap.

It is possible that no one in your area has Tilt-Up experience. If so, enterprising crane contractors or operators can learn by cautiously taking that first job. Lifting hardware suppliers can provide coaching, allowing the crane operator to mentally plan each step of the operation carefully. In addition, use a rigging crew who also wants to acquire the experience.

A crane operator in one area of the country may be willing to coach operators in other areas by telephone. In some cases, operators with no experience in Tilt-Up have flown to an active Tilt-Up area to watch, talk to those involved and return with the confidence to try their first job. Therefore, lack of experience should not be a deterrent.

When the crane subcontractor (the terms "crane subcontractor" and "rigging subcontractor" are used interchangeably, meaning a combination of crane and rigging crew) is selected, he or she meets with the general contractor and concrete subcontractor to review the casting layout of the panels. This allows all parties to verify the panels are placed on the slab as close as possible to their final position to minimize crane time. This part of the planning process was discussed in the *Section 4: Panel Layout and Forming*; however, the rigging subcontractor plays a leading role in determining where the panels are cast on the floor slab.

PLANNING FOR LIFT DAY

There is a considerable amount of work that precedes lift day, and it is this effort that minimizes time wasted during the erection operation.

Before the start of lifting, the erection plan should be reviewed. If panels are to be erected from outside of the building, the perimeter should be cleared and inspected for safe crane operation. If panel lifting will be from the inside of the building, suitable crane access should be provided. The casting and erection sequence plan should be reviewed to verify that all panels have been cast and are in their correct locations. Items that have changed from the original plan should be addressed.

When planning for lifting, the following items should be part of your preparation checklist:

1. Locate and clean out the lifting points.

2. Attach and support temporary wind bracing.

3. Determine the size and location of strong-backs (if required).

4. Prepare the rigging, per the lifting manual and hardware documentation.

The rigging subcontractor also carefully pre-plans so that when the crane and crew arrive on lift day, everything is ready—and in the right place.

There are many decisions to be made and items to check before lift day arrives. The site inspection is key to progress of the plan. Underground and overhead hazards such as wires, rough terrain and soft or eroded subrades must be identified. The path of the crane is imperative to this search to make sure the operator and the crew are fully aware of the surrounding conditions they must maneuver around.

The crane is ultimately the work-horse for this stage of the process, and it must be thoroughly inspected and verified to be in good working condition prior to the erection day. This means confirming the condition of cables, tracks, tires, engine operation and hydraulics. The operator must verify that the equipment is checked and prepared to proceed. The contractor must also verify that the crane is the proper size to do the work at the given conditions. Although a crane has the capacity to ultimately lift the panel, can it make the lift at the angle and distance that must be maintained for the specific site? A rule of thumb typically used is that the crane capacity is two to three times the weight of the heaviest panel to allow for variation in boom angle and distance.

Connecting the crane to the panels is a series of cables, bars and pulleys varying in design based on the company who owns the equipment or has produced the design. All lifting inserts (embedded connections in the panels) must be checked for proper alignment and be able to cleanly attach with the lifting clutches to the rigging. The cables must be inspected for any damage or excessive wearing. Subsequently, the lifting beam that gathers the loads from the multiple attachment points to the panel and concentrates those loads to the single crane cable must be checked for fatigue and proper connection.

A final check of the site prior to erection day should be made and re-checked the morning of erection to make sure the site is clean of debris and free of standing water. This will ensure that the paths taken during the maneuvering of the panel will not cause the crew to stumble and fall into an unsafe position, as well as making sure that excessive force is not needed to pull the panel from its resting position.

The following checklist is one example a rigging subcontractor follows while walking the job site with the crane operator, several days prior to lifting. This checklist is expandable and customizable by individual contractors as experience dictates:

1. Access to the site for the crane.

2. Access onto the floor slab by a properly constructed ramp so the edge of the slab won't crack.

3. Levelness and load capacity of the terrain traveled by the crane.

4. Any overhead wires (OSHA requires 10 ft. minimum horizontal separation between power lines and any part of the crane or rigging). Arrangements with the utilities company should be made to shut off power if necessary.

5. Underground hazards that could cause a problem such as insufficiently compacted trenches or old sewer lines.

6. With the job superintendent and concrete subcontractor, discuss the lifting sequence and the path the crane will follow so nothing will be in the way. This discussion should also involve the crane operator.

7. Also discuss with the job superintendent thickening the floor slab (if not already placed) at points where the crane enters and exits to minimize the possibility of cracking the slab.

8. Make sure all forms are stripped and debris removed.

9. Make sure lifting and brace connection inserts are accessible and placed correctly, and braces are in place on the panels.

10. Make sure footings and grout pads are ready.

11. Make sure all tools are ready (shovels, bars, shims, hammers, drills, wrenches, etc.).

12. Make sure the contractor's personnel will be available (carpenters and laborers).

13. Review schedule for crane move-in and start of lifting.

14. Read and review the Erection Manual. This is the manual prepared by the hardware supplier and shows each panel, locating pick-up points, brace connection points, cable lengths and other items of information.

In addition, prior to lift day the crane subcontractor selects the crane for use on the job. Most crane subcontractors rent their cranes. Cranes are selected based upon the weight of the heaviest panel and the maximum reach required to set a panel. (*See Section 4: Crane Types and Capacities Available*). The subcontractor also chooses the crane operator -- a most important team member -- with confidence, as most crane subcontractors began their careers as crane operators.

Safety planning is part of every construction project, but Tilt-Up construction requires some additional planning. The planning process includes a meeting before panel erection between the superintendent, crane operator, rigging foreman and all personnel involved in the erection process. Crew members should be assigned specific tasks for handling braces and hardware attachment. Only those individuals directly involved with the erection process should be anywhere near the panel being erected. No one should be permitted to walk under a panel while it's being tilted, on the blind side of the panel when the crane is traveling with it, or between the crane and the panel. The crew should remain alert and look out for fellow workers.

The rigging foreman is the individual that the crane operator looks to for all signals. Rigging foremen should be experienced in handling panels and completely familiar with the precise set of hand and arm signals used to communicate with the crane operator. The rigging foreman should be able to demonstrate proper use of all lifting hardware, bracing hardware and any tools or equipment that may be necessary.

HOLD A SAFETY MEETING!

Safety procedures are a critical part of the erection process and should be reviewed in a safety meeting before panel erection. Before any equipment is started or any preparations are made, lift day must start with a safety meeting. It is imperative that each crew member understand his/her responsibility for the day. Everyone involved must know that only one person is to communicate with the crane operator (panel foreman), and that individual must be confident that the signals to be used are easily understood by the operator. Crew size is also important—maintaining a minimum crew size (i.e. a crane operator, rigger foreman, two journeyman riggers and welders only as required) will reduce the chance that a person is out of position when panels begin to move. It is also highly recommended that the safety meeting involve individual safety cards/checklists that can be signed by the crew member and entered into the job record.

During the safety meeting, crew members must understand that no one is to ever be positioned under a panel. No one is to be on the blind side (side not visible by the crane operator) of the panel while it is moving and no one is to be between the crane and the panel or between the panel and an adjacent panel either on the ground or in the air. Crew members must remain alert at all times

and look out for each member of the team. Finally, without the proper protective clothing (e.g. gloves, hardhats, steel-toed shoes), no one should be in the vicinity of the lift.

Further, the crane operator must be present at the safety meeting. As stated before, he/she must understand the signals that will be given only by the rigging foreman. The crane operator must be in the line of sight of the rigging operator at all times.

Quality-minded contractors make a mandatory safety meeting the first order of business on the day of lifting. Worker Safety Checklists—a wallet-size handout—can be purchased from the TCA for distribution at these meetings. For use during the meetings, the TCA also offers a tear-off pad checklist that serves as a referable document for OSHA records. Items to discuss during the safety meeting include:

1. The person selected as rigger-foreman is the only person to signal the crane operator.

2. No unnecessary talking or horseplay is permitted.

3. Demonstrate the lifting hardware and brace installation procedures.

4. Nobody is ever behind or under a panel while it is being lifted.

5. Nobody gets between a panel being lifted and the crane cab.

6. Review each person's responsibility.

7. Reemphasize safety, alertness and the importance of teamwork.

In addition to safety issues discussed in *Section 2: Planning the Tilt-Up Building*, special attention should be paid to the quality of the crane and rigging. Qualifications of the operators should be reviewed. Items such as crane access and crane support, quality control of placement, and attachment of lifting inserts to lifting hardware and rigging should also be monitored.

ABOUT CRANES

Cranes are rated in tons of lifting capacity. The lifting capacity is the maximum load that can be lifted, boomed up tight, while on outriggers. A typical capacity crane used for Tilt-Up erection varies from 140 to 300 tons.

Selection of crane lifting capacity is based upon the weight of the heaviest panel lift, how far the boom must reach and how far a crane may be required to carry or “walk” a panel. Selection of the boom length, similarly, is based upon the panel heights, the required boom reach to pick and set the panels, and the length of slings required to pick the panels.

In the past, the most commonly used crane for erecting Tilt-Up panels was a truck crane. A truck crane is mobile and can legally travel down the highway to a job site. Once on the job, the crane is prepared in about one hour.

Increasingly, crawler type cranes are used for their greater lifting capacity (250 to 300 tons is typical) and their ability to work off the slab.

These crawler cranes operate on steel tracks and have the capability of “walking” with a panel that weighs in excess of 100 tons. However, crawler cranes are transported to the jobsite on trailers and assembled, sometimes requiring an additional crane. Costs for moving crawlers in and out of the jobsite can

reach $10,000 or more. To purchase a new 300 ton crawler crane and supply all of the additional equipment needed for Tilt Up, such as spreader bars, blocks, slings and shackles, be prepared to spend upwards of $2,000,000. To recapture this investment, the crane with a full Tilt-Up crew (operator, oiler and three riggers), would rent for around $750 per hour.

In the past, when panels weighed over 50 or 60 tons, two cranes would work together (in tandem) to set the large panels. Today, when large panels are picked, it is quite common to employ the use of a crawler crane. Smaller hydraulic cranes are used for the site walls on a project. See *Section 2: Other Site Uses For Tilt-Up* for examples of site wall types.

To stabilize a truck crane during lifting, hydraulically controlled outriggers are extended out from the crane with pads (also called "floats") at the end to set on the floor slab. During lifting, nearly all of the weight is carried by these pads, or on the eight rear tires while "walking" a panel. Assuming a crane weight of 150,000 pounds and a panel weighing 80,000 pounds, and 80% of the crane load on the pads, each pad then supports a load of 100,000 lbs. or 25,000 lbs. per tire while walking a panel. This is why the design is so important, as discussed in *Section 3: The Floor Slab and Foundations*.

It is preferable that the panels are cast on the slab as closely as possible to their final position to minimize time for repositioning the crane.

If a crane must be moved to set a panel, more time will be required and the possibility of unforeseen problems related to crane movement increases.

CRANE SELECTION

As a rule of thumb, the heaviest panel up to 30 ft. high should not weigh more than one-half the lifting capacity of the crane, and the heaviest panel more than 30 ft. high should not weigh more than one-third the lifting capacity of the crane. This reduction is necessary because the boom is often extended (reached out) to lift and set a panel.

Crane manufacturers provide charts to determine the lifting capacity for varying reach distances. Crane contractors refer to these to determine the adequacy of the crane for the panels, and to decide how far out they can reach to pick up a panel.

In addition to selecting a crane with the proper capacity, other items to verify include:

1. The crane must have regular inspection records by OSHA certified companies.

2. The insurance certification is proper.

3. The experience of the crane operator with Tilt-Up work.

RIGGING FUNDAMENTALS

“Rigging” refers to the devices necessary for lifting, setting and bracing the panels.

All rigging should be sized to accommodate the lifting loads. Cable lengths and rigging layout should be compatible with the lifting design.

The devices typically used for erecting the panels, starting from the crane hook down, include:

1. The spreader bar. As its name implies, this beam spreads apart the cables from which subsequent loads are suspended. They have holes along their length for positioning the lift cables. Sometimes, a second set of spreader bars are required, resulting in four lift points. Unless specifically instructed to offset for an unusual type of lift, the center of lift of the spreader bar is aligned with the center of gravity of the panel, and the load to each spreader equalized.

2. Sheaves (“Pulleys” or “Roller Blocks”) are used to handle two lift points with one connection to the spreader bar, maintaining an equal load on each lifting insert.

3. The cables (slings) are normally sized by the crane contractor and are usually a minimum of 1 in. wire rope.

4. Lifting hardware is used at each lift point to transfer the load from the cable to the lifting insert.

5. Lifting inserts are embedded in the panel and are used to connect the lifting hardware to the cables.

6. Floor brace inserts are used to connect the temporary braces to the floor slab.

7. Wall brace inserts are embedded in the panel and are used to connect the temporary braces to the Tilt-Up panel.


Left: The lifting bar is selected specific to the job and should have flexibility for multiple panel widths.

Middle: "Below the hook" is the responsibility of the contractor beginning with the cable or band connecting to the lifting bar.

Right: Cables connect the rigging to the panel and must be inspected to be at the proper angles and not twisted.

8. Pipe braces are normally provided by the general contractor for temporary support of the Tilt-Up panels until all structural connections are made.

RIGGING SAFETY

When the lifting begins, the rigging foreman must start by looking up. Hundreds of thousands of pounds in tension is applied by the crane through this rigging to the panel. If cables are twisted or out of position, the entire system may fail due to the stress. Since the erection crew has been identified, all other personnel around the site must stay clear of the operation. The crane operator's responsibilities are to maintain complete control of the crane. This includes fully-extended outriggers and proper cribbing. Charts available to the operator will show the capacity reductions for any condition less than full extension of the outriggers or unstable outrigger positions. The crew will be connecting rigging to each panel according to the established sequence. Prior to tensioning the system, the clutches must be checked for clean operation and the rigging itself must be inspected for proper alignment per the design provided.

The operation is simple but stressful. The crane applies a load. If the panels do not release under that load, the crew will be required to apply ground force to the panel by way of pry bars or wedges. These must be placed in-line with the lifting inserts where the additional reinforcement exists to handle that stress. Once the panel has separated from the slab, there will be movement in a designed direction. The path of travel, whether the crane is to move or not, must remain clean and clear of obstacles—

especially crew members. As the panel is set into position, there will be necessary crew responsibilities to verify alignment and setting position on the temporary shim stacks that will support the panel. Braces that were connected to the panel before the lift began will be extended to the proper angle location on the slab or to the exterior and secured. At no point in this process is any equipment to be put in service that shows signs of damage, such as bent braces or excessive wear on bolts.

THE RIGGING CREW

The rigging crew typically consists of the crane operator, driver/oiler, two riggers and a rigger foreman. Assisting them are several carpenters and laborers supplied by the general contractor for setting braces, drilling and installing the post-installed floor brace inserts, cleaning panels and floor slab, shimming and other miscellaneous tasks.

PANEL PREPARATION

Panel preparation includes removing formwork, locating and cleaning out lifting and brace inserts, testing each lifting insert with the lifting hardware, attaching braces and cleaning debris from around and on the panels. Any standing water around the panels and within openings should be removed. Standing water prevents air from entering under the panel and creates additional loading needed to break the bond. Locations of lifting and brace inserts should be checked with the erection manual. It is good practice to clean out blockouts for framing connections before erecting panels because of the easy access. Attachment of shelf angles and beam seats to embedded plates is also easier at this stage.

Panel concrete strengths (flexural and compressive) should be determined according to

ASTM C78 and C39 procedures before erection. These strengths are obtained from tests performed by the testing agency, which should be accredited to ASTM E 329, on the cylinder and beam specimens fabricated during casting of the panels. The field tests should be performed by an ACI Certified Concrete Field Technician. The erection manual specifies the strengths needed for lifting the panels. Panel erection may be postponed if strengths are inadequate.

LIFTING INSERTS AND HARDWARE

The lifting hardware attaches the cables to the lifting inserts that are embedded in the panel. The components of the rigging also include the spreader bar, sheaves and the cables. The crane contractor customarily provides the latter, whereas the vendor of the hardware provides the lifting hardware.

Prior to the moment of lifting, inserts should be located, cleaned out and tested with the intended hardware to ensure effectiveness.

The number of lifting inserts required for a given panel is not always based on the weight of the panel. Many times additional lifting inserts are needed to reduce bending in the panel as it is lifted into position. Excessive bending can cause cracking or failure of the panel.

An engineer experienced in this type of work should design the number, type and location of lifting inserts. The lifting hardware supplier typically provides the lifting analysis and lifting insert details. Special or odd-shaped panels may require strongbacks. Strongbacks may be required to prevent panel cracking during lifting and should be installed as detailed by the lifting insert engineer.

Many factors are involved in the design of the lifting inserts. They include: panel size, thickness, weight, insert type, panel shape, concrete compressive and flexural strengths at time of lift, panel reinforcement, panel openings, and panel finish.

The number of lifting inserts is usually an even number and normally in pairs with one cable attached to two inserts. The cable runs over a sheave that is connected to the spreader beam. This arrangement equalizes the load on each of the two lifting inserts.

The number of insert pairs required depends upon the panel weight, concrete compressive strength, and the flexural strength of the concrete at the time of the lift. Some panels require only two inserts. Others require four, and some eight and some very large panels require as many as 16 inserts.

Lifting insert design went through quite an evolution since the early days of Tilt-Up. In those days, the standard insert was a large sleeve nut filled with paraffin to keep concrete out of the threaded hole, and with rebar welded to the nut to anchor it into the concrete. Today's lifting inserts are truly high-tech. They require only a few seconds to attach the rigging to the panel. A ground release feature disengages the cables, after the panels are set and braced, by merely tugging on a lanyard from the ground. Before, workmen climbed ladders to disconnect the lifting hardware from the lifting inserts.

Plastic caps over the inserts took the place of the early-days paraffin. To make the inserts easy to find after the concrete is placed, these caps have narrow, plastic antennae that stick up above the panel surface. The concrete accessory hardware vendors supply these inserts.

Also embedded in the panel are inserts for attaching the temporary pipe braces. These inserts are supplied by the concrete accessory hardware vendor, and are generally supplied with a coil thread. A self-cleaning, threaded bolt is used with the coil inserts as the attachment bolt.

All inserts should be cleaned and checked to make sure all hardware operates correctly in the insert at least a day before lifting. Any problems can then be remedied without the crane waiting while repairs are made.

Although not the typical process, a crew secures braces to panel once it is vertical and then connects to brace foot on the floor slab before the crane disconnects.

BRACING THE PANELS

Prior to lifting a panel, temporary pipe braces are attached to the face. The braces will be anchored to the floor slab or other foundation system after the panel is lifted and placed in its final position and before the crane releases it. These pipe braces hold the panel plumb and prevent it from falling over.

Typically, the engineer designing the lifting inserts will also design the temporary panel bracing. The number, size and placement of the braces are based on wind loads and panel location and size, with a minimum of two braces per panel. If knee braces are required, lateral bracing with intermittent "X" bracing will also be needed to reduce the brace's unsupported length. If a strip of floor slab is left out until the panels are erected, deadmen for anchoring the braces may be required until permanent connections are made. The crane should not be released until the bracing designer's recommendations have been satisfied. The TCA Bracing Guidelines should be used. Braces are selected based on their lengths and capacity to resist wind loadings, usually using a safety factor of 1.5. Depending upon their length and diameter, some pipe braces are themselves braced at their mid-length to prevent buckling. This is accomplished with a sub-support bracing system of knee, lateral and end bracing.

Above: Brace feet are often connected to the slab with a drill-in anchor once panel is vertical.

Below: Brace inspection is important on the job site to ensure no damage has occurred in shipment to either the pipe or the feet.

When pipe braces require a sub-support bracing system to prevent buckling, and since a round pipe can buckle about any axis, they are braced in each direction and require that the knee, lateral and end bracing is securely fastened to prevent movement. To avoid having to install this sub-support bracing system, a larger capacity brace is required.

Two braces per panel are a minimum — frequently more are required. For large panels or in high wind areas, three or four braces per panel may be needed to reduce the risk of a panel falling.

Two types of pipe braces are available, fixed-length and telescopic. Both types have approximately 18 in. of threaded adjustment at their bottom end. This is used for plumbing the panels. Both brace types are used with extensions to increase their length and in some cases require knee, lateral and end bracing to develop the required load capacity.

The upper end of a pipe brace connects to an embedded wall brace insert by means of a 3/4 in. diameter coil, threaded bolt, and the lower end usually attaches to the concrete slab with a 3/4 in. diameter post-installed bolt. This bolt threads into an insert that is pre-installed (See *Section 5: Reinforcement, Inserts and Embeds* for more information), post-installed or cuts threads into the concrete itself. Frequently, this connection is specifically designed for this use.

A word of caution -- some expansion type anchors, those that were not originally designed for use in Tilt-Up construction, have failed; either by shearing off the bolt, spalling of the concrete or by pulling out a cone of concrete. Needless to say, this is not an area where the decision to purchase is based on price alone. Post-installed expansion anchors that are specially designed for attaching pipe braces should be cyclic tested to insure they will resist windy loading conditions.

The temporary pipe braces are connected to the panel above mid-height with a normal angle to the slab of approximately 54 to 60 degrees. Brace types, quantities, lengths and locations are normally specified by concrete accessory hardware vendors as a part of their service, but the braces are generally rented and provided by the general contractor.

Introduced in 1998, the Tilt-Up Concrete Association's Guideline for Temporary Wind Bracing of Tilt-Up Concrete Panels During Construction is the industry standard for determining the appropriate brace loading for wind.
Braces are laid out, adjusted to proper length and connected to the panel before the panel is lifted. Little time is lost when the panel is raised and set into position — the braces hang free and are quickly fastened to the floor slab. The connection of the brace to the floor slab usually takes less than two minutes.

The normal process is one worker holds the brace in the desired position while another worker drills the proper size hole in the floor slab for the post-installed insert that is used to secure the brace. Alternatively, the brace is connected to a cast-in-place floor brace insert.

Sometimes the floor slab is unavailable to anchor the bottom of the brace. This is due to the fact that the floor slab is placed at a later date, or bracing is installed to the outside of the building. In these cases, the brace is anchored to a deadman, which is normally a mass of concrete sufficient to safely resist the push or pull from the brace.

It is good practice to have spare lifting and bracing hardware on site in case the primary hardware is damaged or malfunctions. Emergency lifting plates should also be readily available. These are used when the lifting insert is mislocated or knocked over during panel casting. The plate is bolted to the panel where the insert should have been located. The plate and connection bolts should have the same load capacity as the cast-in lifting inserts and should be specified or otherwise approved by the lifting engineer.

Now that the panels are in place and secured by braces, the final safety measures are taken. Although very rare in the Tilt-Up industry, the few safety issues that do happen occur when panels are moving or when they are assumed to be "properly braced" or connected. The panel bracing is designed to hold the panels in a vertical

position for the normal design wind speeds for the local climate. Although bracing designs can be attained to secure the panels in more damaging winds, this brings excessive cost and risk to the project when life safety would not be of concern. TCA will continue examining the performance of bracing and the elements of safety that are attributed to this system and others in future articles.

STRONGBACKS

Strongbacks are sometimes used to lift an odd-shaped panel, or one with large openings that would otherwise be difficult or impossible to lift. In effect, a strongback stiffens and bridges over openings or weak points in a panel. An example is an inverted "L" shape, which would not have enough bottom edge about which to rotate as the panel is lifted.

Although strongbacks are often wood members (usually double 4x12s or 4x14s), strongbacks fabricated of double steel or aluminum channels are widely available. Strongbacks are normally designed to resist the entire bending moment that is induced into the panel during the erection process. If this is not done, the panel cracks.

THE LIFTING SEQUENCE

Panel erection should progress in one continuous and smooth operation. The rigging should first be inspected for proper alignment after the rigging and lifting hardware have been attached to the panel and the slack has been taken out of the cables but before initial loading of the inserts. If the cables twist or the hardware tries to rotate, the lift should be halted and the hardware realigned. The lifting hardware should not normally be subjected to a significant amount of side loading. The manufacturer's recommendations should be followed.

The following is the typical sequence of events when an experienced crew lifts, sets and braces a wall panel:

1. With the lifting crew assembled (normally two riggers, a foreman, several carpenters

and laborers), the crane operator lowers the spreader bar, with rigging attached, and the riggers connect the cables to the lifting inserts. The lifting hardware is quickly connected in a matter of seconds; normal elapsed time is two minutes or less.

2. As the riggers straighten out any tangles in the cables to prevent snags during lifting, the carpenters or laborers make certain the braces hang loose as the panel is lifted. Typical elapsed time is another two minutes.

3. The crane cable line is vertical to the panel surface and directly over the center-of-lift of the panel from left to right, so the load is balanced. The crane line bisects the sling angle throughout the lift matching the insert loads and stresses calculated. If the crane line slopes toward the top of the panel, called “high” or “over booming,” the load to some of the inserts is less, and the ground reaction increases. This causes higher positive bending stresses in the panel and, if too far off vertical, the panel slides away from the crane. If the crane line slopes toward the bottom of the panel, called “low” or “under booming,” the load to the inserts is increased and the ground reaction decreases. This causes higher negative bending stresses in the panel and, if too far off vertical, the panel slides toward the crane. Incorrect booming has an effect on the panel through the entire lift, but primarily from original lift through 60 degrees. All Tilt-Up panel lifts are made so the bottom of the panel does not slide in any direction because the erection design assumes no sliding or drag forces which could cause the panel to break.

4. The foreman gives the crane operator the signal to lift. When the cables are taut, the operator gives a tug on the panel to break the suction bond and the panel slowly lifts, pivoting about the lower edge resting on the floor slab. Often some pieces of scrap lumber or plywood are thrown under the panel for support if it is lowered for any reason (not recommended). This also prevents scratching the floor slab if the panel slides during lifting. Lifting continues until the panel is nearly vertical and off the floor. Typical elapsed time is two minutes. Note: Workmen should never be allowed under the panel!

If the panel does not readily break free from the casting surface, wedges and pry bars can be used to help release the panel. As the panel rotates and lifts off the slab, crew members should support the free end of the braces above the slab so the braces do not bind or hang up on other panels or construction materials. The crane operator should lift the panel without dragging the bottom edge along the slab or striking any previously erected panels.

5. If the panel cannot be set within reach of the crane, the crane carries the panel (called

“walking the panel”) to a location close enough to set the panel without booming out too far. Prior to walking the panel, the crane pulls the panel in close and retracts the outriggers. The outriggers are again set when the crane is ready to boom out to set the panel. Typical elapsed time is three to ten minutes.

6. The panel is lowered so it rests on the pre-leveled grout pads. The riggers use pry bars and wedges to move the panel so it rests in the proper position on the snap lines. Some contractors put a 1x4 wood stake in the bottom edge form, one near each end of the panel, so the resulting notch provides spaces for pry bars. To get the panel in just the right position can sometimes take ten minutes or more. Typical elapsed time is three to fifteen minutes.

7. With the panel securely resting on the pads, the braces are connected to the floor slab. With the crane still holding the panel, the braces are adjusted (using their integral turn-buckles) until the panel checks plumb. The panel can be roughly plumbed with the crane before attaching the braces to the slab. A 4 ft (1.2 m) level may be sufficiently accu-rate for this initial plumbing. It is important to

plumb the panel left to right (side-to-side) before plumbing it "in and out." If the panel is plumbed "in and out" first, it can become jammed against the footing. Adjustments in the plane of the panel are accomplished by adding or removing plastic shims at the setting pads. A transit is often used to verify that the vertical edges of the first panel set are plumb. Subsequent panels can be adjusted relative to the first panel by providing a uniform joint width between panels. Minor panel adjustments in or out can be accomplished with the brace's threaded adjusting mechanism enabling the brace to be lengthened or shortened after it is attached to the slab and the rigging is released.

Minor plumbing adjustments can be made until panels are grouted or framing is erected. Once the panel is grouted and connected at its base, its position cannot be adjusted by other trades. If a panel supports another panel (often called a spandrel or lintel panel), however, the supporting panel should be plumbed (in and out, and in the plane of the panel) before spandrel panel erection.

8. With the braces secure and the panel plumb, the crane slackens the cables and the riggers disconnect the lift hardware from the panels. This is usually done using the "ground release" type, so they release by tugging on them with a

Panel foreman (looking up) is responsible for all movements of the panel and only person to communicate with the crane operator.

lanyard. Typical elapsed time is two minutes.

9. Crane and crew gather tools and move to the next panel.

For a trained crew and typical panels, the total elapsed time is approximately 10 and 20 minutes. Setting panels that are L-shaped (which require strongbacks or temporary columns) and lintel panels take longer. While there are much higher records for the number of panels lifted in one day, it is not unusual to lift as many as 60 on a simple rectangular warehouse type building. With size, multiple corners, lintels and special features, the production rate reduces considerably until a full day may be required to place one panel.

BRACING CONNECTION ALTERNATIVES

There are times in tilt-up construction when conventional bracing to floor slabs is not possible or desired. Historically, concrete deadmen, temporary footings used to anchor the lower end of a brace where there is no floor slab at the time of bracing, have been used to secure the brace foot for the temporary wind load conditions. These elements are both expensive and time consuming as well as often times questionable in their effectiveness. Although deadmen

Properly-submerged deadman for brace foot connection outside of the slab.

are still used on occasion, helical ground anchor systems have steadily improved the performance and reliability of non-floor bracing systems. In many ways, they also surpass the performance of bracing to floor slabs since they can deliver significantly higher connection loads for stronger wind resistent schemes.

Deadmen are auger-drilled holes filled with reinforced concrete, continuous temporary concrete footings, a cubicle mass of concrete or one of several mechanical devices which are drilled or buried in the soil. The top surface is a maximum of 6 in. above grade. Provisions are made for attachment of the braces or a post installed expansion bolt is used to connect the braces to the deadman.

The design of deadmen requires knowledge of the lateral and vertical bearing capacity of the soil involved or a very conservative assumption is made.

After the brace loading, spacing and soil conditions are known, the concrete accessory supplier's engineer determines the design of the deadman.

In general, the weight of a concrete deadman is nearly as much as the wind load in a brace. For example, a panel with an 8,600 lbs. total brace load, with two braces, requires a deadman that weighs approximately 4,300 lbs. at each brace. This is a conservative estimate that may be reduced.

Helical systems are pre-engineered systems that consist of helix plates welded to steel shafts.

Certified or trained installers mechanically install the anchors by screwing them into the ground and applying a constant downward force. The holding capacity of the anchor is proportionate to the final installation torque.

These systems have revolutionized Tilt-Up construction by providing contractors with economical and efficient alternatives to the cumbersome concrete deadmen.

Helical systems also deliver a more environmentally friendly solution to the site with no concrete waste and they are designed for reuse.

PANEL BRACE MAINTENANCE

Panel brace connections at the floor and at the panel should be checked daily and tightened in accordance with the manufacturer's recommendations. Because wind vibration may work connectors loose, connection bolts should be checked and re-torqued daily.

BRACE REMOVAL

Panel braces should remain in place until the panel is fully connected to the stabilized building structure. The structural engineer of record should verify when temporary wind braces can be removed.

The most critical instruction given to workers on the job site is that the temporary bracing absolutely, positively cannot be removed until the connections are made and inspected by the engineer-of-record and the engineer approves removal of the bracing. The engineer-of-record is the only person who can make this determination--not the bracing manufacturer, not the owner of the construction company, nor the certified supervisor. Removal of bracing prematurely is taking the lives of workers into your own hands.

WHEN TO RELEASE THE PANEL

The crane must not release the panel until the braces are installed, including knee, lateral and end or cross bracing, and the panel is plumb. Some adjustment of the braces are made after release (by turning the threaded portion), but the top of the panel should be within 4 in. of plumb before release.

Before the crane releases the panel it also must be level longitudinally, that is, each end is at the same elevation so the joint between panels is a uniform width. If the panel is not level, it is raised and shims are added until it is level. This is rarely a problem, as the setting pads under the panel are checked for precise elevation before erection.

TOLERANCES

For the purpose of this discussion, the applications and monitoring of tolerances are addressed. The panels should be plumb to within 1/2 in., and the top of a panel should not be more than 1/4 in. out of alignment with its adjoining panel. And the joint between two panels, which is usually either 1/2 in. or 3/4 in., should not vary by more than 1/4 in. from top to bottom. With careful forming of the panels, setting of the foundation pads, and checking, these tolerances are not difficult to attain. For more information on tolerances, refer to ACI 117.

FOOTING PREPARATION

Several items are required to prepare footings for panel erection. Setting pads should be properly located both in plan and elevation. Grout setting pads require sufficient time to reach their specified strength. High spots in continuous footings should be ground down to allow panels to bear on the setting pads. If the panel bears on a high spot in the footing, the panel may not be plumb and the footing may be overloaded.

Normally, the setting or grout pads under each end of a panel is set at precisely the correct elevation. But if not, shims can be used. These temporary leveling devices serve to make up the difference between the top of the footing and the bottom of the panel. The shims, which can be combined in multiples to obtain the desired thickness, are accurately placed in predetermined locations with the use of a transit. Imagine, if one end of a 20-foot by 40-foot tall panel is ¼-inch lower than the other end, it would translate into a discrepancy of two times that amount at the top of the panel. A joint that was supposed to be ½-inch wide would be 1-inch wide on one side and the tops of the panels would be touching on the other.

The shims, which typically leave a space between 1 inch and 2 inches below the panel, are only intended to support the panel for a short period of time. In most instances, neither the panel nor the footing is designed to support the resulting point loads. If additional load is placed on the panel or if they sit too long, cracks could develop in the panel, or the footings could crack between the bearing points due to either too high a load on the soil or weakness in the top of the footing. The point loads are eliminated with a "foot pack" or grouting. A cement-based grout material is either packed or flowed underneath the panel filling the void. A standard grout mix is suitable since any shrinkage would be so small that it would not result in excess stress in the panel. The grout material should completely fill the void beneath the panels and should be installed as soon as possible after the panels have been secured and plumbed. A completely filled void is evident when grout protrudes from the opposite side of the panel.

Another use for shims, which is strongly recommended, is under the panel at its midpoint, or at the third points. A frequent problem occurs when the weight of a panel, which is imposed on the footing at each end of the panel, causes the footing to bow upward in the middle due to overloading the soil at the support points. To avoid this, the shims are used to distribute the panel's weight along the length of the footing.

Later, the space between the bottom of the panel and the top of the footing is grouted (*Section 8: Connections and Finishing Touches*) to provide uniform bearing under the length of the panel, but this does not alleviate the temporary overload condition that develops during the construction process.

Steel plate shims should not be used since they can corrode and they have too much frictional resistance when the panel shrinks. This can result in diagonal shrinkage cracks near the ends of the panel. One method used to reduce this tendency is to provide additional horizontal reinforcing at the bottom of the panel.

Prepackaged plastic shimpaks are obtainable from concrete accessory hardware vendors. They come in sets with an overall thickness of 11/16 in. These shimpaks are made up with 1/16-in., 1/8-in. and ¼-in. individual shims. They are usually available in 4x4 or 4x6 sizes. The plastic used in these shimpaks is specially formulated to provide high compressive strength with no appreciable deformation when loaded.

WHAT IF A PANEL STICKS?

Occasionally, they do.

Frequently, the "sticking" is just the suction resistance of water that penetrates under the panel and is broken by driving a wedge under the panel edges. Blowing out any openings in the panel or ponding water at the panel edges before lifting so any remaining water evaporates, can reduce water intrusion.

Sticking also occurs when the panel bonds to the casting surface caused by inadequately applied bond breaker. Either the bond breaker was not applied in sufficient quantity, (according to the manufacturer's instructions) was scuffed off, or its effect otherwise negated. Carefully follow the manufacturer's recommendations with regard to coverage and compatibility with other chemicals, such as curing compounds and floor hardeners, and protect the floor from excessive scuffing during the construction operations.

If a panel sticks to the floor slab and the crane is able to pull it loose, it sometimes pulls up a piece of the floor too. In some cases, the panel and floor is repairable. If not, then the panel is discarded and another panel recast and the damaged section of the floor is sawed out and re-cast.

ERECTING UNUSUAL PANEL SIZES AND SHAPES

The ability for Tilt-Up to offer creative solutions has lead to a dramatic increase in the variety of panel shapes. No longer rectangular with simple openings like the manufactured precast counterparts, Tilt-Up panels frequently have configurations with protruding arms or legs, sloped or arched outlines, and are often bowed or curved in-plane. Other popular features include dramatic variations in thickness to create architectural features and graphics or to allow for glazing systems or other materials to be set in place. The variety that is not regularly featured in the architectural variety of Tilt-Up panels does pose challenges to the panel design team. Experienced and expert panel engineers have responded with effective means of calculating essential panel characteristics such as the panel's center of gravity, positioning of reinforcement for maximum erection stresses, and effective locations for the lifting inserts and brace connections. This response is evidence of the craftsmanship and experience required from all involved in the Tilt-Up process to effectively plan and deliver the measure of creativity to which the industry has become known.

The wider the panel, the more complex a configuration of lifting beams is required. Note the scale of this panel, the longest spandrel on record, in relation to the number of crew members holding braces.

ERECTING LINTELS

Lintel panels span across openings, such as over recessed entries. They are very effective architectural features and do not present problems if certain guidelines are followed. Lintel panels are generally 4 to 10 ft. high and from 20 to 40 ft. long. Longer lintels are used—some of them are from 60 to 80 ft. long—but they can become unwieldy to erect and the designer should avoid using them. Shrinkage cracks are also more likely to occur in long lintels. Instead, the designer can split the span into two lintels.

End connections or support details for lintels provide for bearing as compared to a bolted or welded connection, since the latter requires the crane to hold the panel while the connection is made. Bearing type connections have an embedded steel plate in both the lintel corner and the concrete support upon which the lintel rests. The two plates are welded later provided that shrinkage, expansion, and contraction are accommodated elsewhere. Often, however, lintels will frame perpendicularly into other walls and require the bolted or welded connection or be set on haunches, columns or pilasters at the abutting panels. It is important to visualize the set condition for these panels ahead of the pick to be prepared for the duration of the sequence.

Unless the lintel is taller than approximately 10 ft., it can be “edge picked,” that is, picked up by lifting inserts embedded in the top edge rather than the face of the lintel. This causes the lintel to hang plumb, which makes for easier setting.

The pre-attached braces on a lintel panel are so long that they extend below the panel during lifting so they are frequently rotated to lie within the panel when it is first lifted and then rotated to the floor for final setting. Braces are connected above the mid-height to provide better stability against wind and prevent rotation. The lintel is connected to its supports to prevent movement as soon as possible.

For deep lintels, or where end connections are difficult or time-consuming, strongbacks with attached post shores are used to provide better vertical support for the panel, and to speed erection.

Although no longer common due to the availability of large cranes throughout markets today, tandem cranes have been used for projects with unusually large or wide panels.

TANDEM PICKS

This is when two cranes are used to lift a panel and an inverted spreader beam is used to connect each crane hook to a common lift point, from which the normal spreader beam and rigging are hung.

Two cranes are sometimes used when panel weights exceed about 60 tons—120,000 pounds. This assumes that the panel cannot be divided into two panels of less weight each. But sometimes, for various reasons a single panel is lifted as one component, such as the panel shown here. Most contractors will prefer to use crawler cranes of greater capacity, if they are available, rather than two smaller cranes.

The crane operator cannot see the connections to the panel, referred to as a “blind” pick.

REVERSE PICKS

A reverse pick, or blind pick, is one where the crane operator cannot see the up face of the panel (where the hardware is attached) when lifting the panel. This should be avoided for obvious reasons, but a reverse pick is sometimes necessary, such as when panels are erected from outside the building, or when the last panel is erected and when the crane has exited the building (this is called setting the “walkout panel”).

This panel is being positioned using a suitcase pick; all lifting inserts positioned across the top edge of the panel to ensure it hangs vertically plumb for a tight setting location.

SUITCASE PICKS

Suitcase picks are also called “end picks", "edge lifts", or "top picks”. They are normally used for lintel panels and small panels such as panels for trash enclosure walls or fences. The lift inserts are located in the top of the panel rather than the face. After the panel top is lifted off the ground it spans under its own weight between the lower edge resting on the floor, and the top of the panel. The maximum height for an edge-picked panel is limited. As a rule of thumb, don't use edge-picking if the height of the panel is more than 10 ft. for a 5½-in. panel, 13 ft. for a 6½-in. panel, 13 ft. 8 in. for a 7¼-in. panel, or 14 ft. 6 in. for an 8-in. panel. Instead, check with the concrete accessory suppliers’ engineer.

STACKED PANELS

When panels are stack cast on top of another panel, additional time will be required for panel erection. Forming lumber below the first panel erected should be removed before erecting the next panel. Lifting inserts should be located and cleaned out, and panel braces attached. This process will often double the time required to erect these panels. In addition, the crane operator should exercise caution when lifting stacked panels, because the crew members supporting the braces may have to walk over the panel on which the panel being erected was cast.

ERECTING YARD WALL PANELS

These are the panels used for such purposes as sidewalls for depressed truck loading wells, trash area enclosures, and yard walls.

They are end-picked (as described above), usually the full length of the wall, unless it is over approximately 30 ft. They set on concrete footing pads under each end of the panel. Reinforcing extends from the bottom of the panel for connection to the footing. The continuous footing, excavated under the panel location before it is set, is then filled with concrete.

SOME LIFTING PROBLEMS

Nearly every lifting problem can be avoided by proper planning. Here are some problems that can occur, listed in general order of declining incidence:

Panel sticks to the floor slab. Driving a steel wedge under the edge to break it loose, or just a bit more tugging by the crane usually relieves this. It can be caused by water seeping under the panel and causing a suction bond. Very rarely does the bond breaker fail causing a part of the floor slab to cling to the panel when it is lifted. When this occurs, the slab concrete is chipped off once the panel is erected, or the panel is replaced. If the panel bonds to the floor over a large area, both the panel and underlying floor slab are cut out, removed, and replaced.

Panel doesn't hang plumb. This is caused by the contractor not placing the lift points in the correct position, improper rigging configuration or the hardware supplier's miscalculating the location of lift points. If the panel cannot be manhandled into position, it is lowered and an emergency bolted-on lift plate attached to better balance the panel. The crane operator should always carry these emergency bolt-on lift plates for just such emergencies. These emergency lift plates are available from the concrete accessory vendors.

Panels crack during lifting. This is usually due to low-strength concrete, improper rigging, misplaced location of the lift points, insufficient or misplaced reinforcing, an inadequacy in checking the panel for erection stresses, or due to jerking the panel loose from the floor. Most cracks of this nature close after the panel is in place, however, occasionally they remain visible. If they are a structural concern, they are patched with grout or epoxy-injected. Very rarely the cracking permanently deforms a panel requiring removal and replacement.

Crane capacity inadequate. This is usually the result of underestimating the weight of the heaviest panel, or booming out farther than anticipated. Ballast is added to the crane to counteract its tendency to tip, or a larger capacity crane is brought to the job site. Both of these options are costly and can be prevented with more careful planning.

Cables tangle during lifting. This is relatively easy to fix quickly by the riggers. This is usually caused by too much haste or too small cables.

Panel doesn't fit. One example is a panel that is too long to fit into its position in the wall. The panel is lowered onto wood timbers, the offending edge sawed off and the panel raised again and set. The panel often hangs crooked during the second erection as the lift points are not centered about the new center of gravity. When a panel is too short, put in an emergency call to the structural engineer and architect to see if a "stitch strip" can be formed and poured later to close the gap or if the panel is to be discarded and replaced.

Footing settles causing the panel to be out of level horizontally. Most frequently this is the result of too much pressure on the footing under the end of a panel, at the setting pad. This is why it's a good idea to use shims at the third-points under the panel to spread out the load along the footing. Usually the soil is compact enough so this does not occur, even when intermediate shims are not used, but use of the latter is advisable. If footing pads under the ends of the panels are used instead of continuous footings, this also solves the problem. Another cause is water that soaks under the footing to lessen its bearing capacity. Don't set panels until the soil under and around the footings is dry.

Slab breaks under outriggers. This is more likely to happen if there is a soft spot under the slab or if the outrigger is put down too close to the edge of the slab, or near a joint. If an area is suspect, timber cribbing under the pad can help.

Lift inserts break loose. With the high-tech inserts used today and careful engineering, this occurrence is extremely rare. When it does occur, it usually is the result of miscalculating the loads on an insert, rather than the fault of the insert itself.

WALKING A PANEL

While it makes efficient use of crane time not to carry a panel across a portion of the site, it is sometimes the only way to complete the structure. Walking a panel means picking up the panel, retracting the outriggers, driving ("walking") the panel to a location where its position in the wall is reachable, then re-setting the outriggers and finally, setting the panel. One of the corner panels, for example, is usually cast on the interior of the floor, requiring walking it to its position.

Since approximately 80% of the crane's total weight including the panel is carried on the rear axle while walking a panel—which could result in tire loads as high as 25,000 lbs.—the operator uses care to travel over slab areas where the chance of cracking is minimized. While traveling, the panel is tethered and guided by a rigger.

The walk-out panel set here and leaning against an adjacent panel is both improper and unsafe. Brace loads are not designed for the additional weight of a leaning panel.

THE WALK-OUT PANEL

Assuming the crane sets the panels from inside the building, one of the panels is set after the rigging subcontractor exits. This last panel is called the “walk-out panel,” or the “closure panel,” and is set as a blind pick with the crane outside the building. Just so they don’t forget, rigging subcontractors usually mark the top face of this panel: “walk out panel.”

CRANE ACCESS RAMPS

Just as the crane must exit, it must also enter to start the lifting operation. For this purpose, a ramp is constructed either of dirt or scrap timbers, not only to get the crane onto the floor, but also to cushion the edge of the slab so it won’t crack. If made of earth, it should be at least 12 in. thick or more over the top of the slab and not much less if made of scrap lumber.

Some contractors thicken the slab at the edge where the crane enters and exits (not necessarily the same location) to minimize this risk.

THE ERECTION MANUAL

The erection manual is the "law" of the lifting operation and is obtained from the concrete accessory supplier. The alternative is to design the lifting procedure yourself, which although it occasionally is done by the general contractor, is not usually cost-effective since the concrete accessory suppliers have the experience and software. They also generally accept liability if their design or product does not work properly.

The erection manual includes a drawing of each panel showing among other things: location of lifting inserts, location of brace inserts, center of gravity of the panel in each direction, type of inserts to be used, location and details of any strongbacks needed, added reinforcing, if necessary for lifting, weight of the panel, cable lengths, concrete strength required before lifting.

It is important to note the erection manual may include panel heights, widths, and opening dimensions, but these dimensions should not be used to build the panel forms. Instead, the dimensions in the architectural and structural drawings should be consulted for construction of the panel forms.

SECTION 8 CONNECTIONS AND FINISHING TOUCHES

The braces must remain in place until the entire supporting diaphragm is connected and inspected by the engineer of record.

Lifting panels is always the most exciting time on a Tilt-Up job, but what comes after lifting is perhaps even more important to the proper performance of the structure. The very nature of a Tilt-Up building, or any rigid wall flexible diaphragm structure, is the interaction between the walls, the roof structure, and the floor or foundation. That's what makes the building perform when high wind, seismic, and other forces act on the structure. A variety of panel connections and finishing touches are discussed in this section.

This section introduces typical connections to the designer and contractor who are new to Tilt-Up. It does not recommend one connection over another, nor is it all-inclusive. The details shown are pictorial representations of connections that have been successfully used in construction. The structural engineer of record, the specialty engineer, or both, are responsible for designing and detailing connections and the contractor is responsible for proper execution. All permanent connections must be made before the removal of the temporary wind braces or as directed by the structural engineer of record. In addition, the PCA offers the publication Connections for Tilt-Up Wall Construction. After the panel is shimmed and plumbed, it should be grouted as soon as possible and connected at the base as required by the structural engineer of record. The contractor should verify the locations of embedment plates for permanent connections. Any discrepancies should be brought to the engineer's attention for immediate resolution.

After the panels are erected, the remaining steps include:

1. Making the required (if any) connections between panels.

2. Casting the pour-back strip between the panels and the floor slab by backfilling and placing concrete.

3. Caulking the joints between the panels.

4. Removing form liners.

5. Patching the exterior surface.

6. Filling holes on the interior surface.

7. Erecting the roof and floor structures and connecting them to the panels.

8. Removing the braces when the lateral resisting system is fully completed and all connections are made.

9. Finally, the surfaces may be sandblasted or painted depending upon project requirements.

CHORD BAR CONNECTIONS

In areas of high seismic activity, connection design and construction is especially critical to the integrity of the structure. Wall anchorage to the roof structure is very important and today's building codes have much higher strength requirements for this anchorage than in the past. In addition, special inspection requirements are commonplace in areas of high seismic activity.

In areas of high seismic activity, high wind activity, or where diaphragm action results in chord forces which are resisted at the roof line by connections between panels, the required continuity is achieved by welded connections between abutting chord bars (or steel ledger angles) or by external means of continuous steel chord members such as steel angles, WT members, or tube sections. When panel-to-panel chord bar connections are used, these connections are usually made soon after the panels are erected. It is best to delay this welding as long as possible to give the walls more time for shrinkage to occur and for the strength of the panels to increase. Delaying the completion of these chord connections reduces the likelihood of diagonal cracks at the

upper corners of the panels (as will sleeved chord bars -- see *Section 5*).

A recent code change for areas of high seismic activity requires that traditional forms of precast concrete construction emulate monolithic behavior. Tilt-Up concrete's unique panel-type construction is primarily a precast shear-wall system and is not subject to this provision intended for precast frames.

OTHER CONNECTIONS

Lintel panels, corners, and other conditions may call for welded connections between panels. Typically, panel-to-panel connections are not required in low and moderate wind and seismic regions. One advantage Tilt-Up panels have compared to precast panels is the Tilt-Up panels are not width-restricted like precast panels. Precast panels are limited in that they can only be as wide as allowed by transportation along the highways. Wider panels create greater resistance to lateral overturning forces and are less likely to require panel-to-panel connections.

Corner panel-to-panel connections are typically a good idea to prevent the caulked joint from failing prematurely. Corner conditions create a unique condition where opposing panels deflect at perpendicular angles to each other. This deflection is a result of thermal bowing of the panels and is generally not re-

The "closure" strip or "leave-out" strip often exists between the interior face of the panel and the slab edge to permit structural connections once the panels are secured with bracing.

lated to structural performance of the panels. Without restraint these deflections eventually deteriorate the caulking between the corner panels.

Most details for panel-to-panel connections call for recessing the embeds and plates into the panel and filling the recess later with grout. These connections are detailed and constructed with enough space to reach the area with a welding rod or the equipment required to complete the connection.

GROUT THE SPACE BENEATH THE PANELS

Grout the space beneath the panels as soon as possible after the panels are erected to prevent settlement of the footing and to reduce shrinkage cracks at the lower corners of the panels (due to the panel shrinking between constraining setting pads). Some designers may design the footing for the concentrated loads; however, most consider this a question of means and methods and exclude it from their consideration.

The space beneath the panel is usually 1 to 2 in. and is completely filled with grout for bearing under the entire length of the panel. A low-slump grout mix is placed from the chute of a ready-mix truck as it circles the building or other convenient methods. A vibrator is recommended to assure good penetration under the panel. Complete penetration of the grout is evidenced by the grout emerging from the opposite side of the panel.

PLACE THE CLOSURE STRIP

Slab closure strips are those areas of the slab between the initial slab pour and the erected panels.The closure strip of concrete ties the panel to the floor slab. These strips occur at loading docks when panels extend 4 to 6 ft (1.2 to 1.8 m) below the finished floor elevation or around the entire building perimeter if the

panels and slab are connected together. The initial slab pour will usually have reinforcement projecting through the construction joint to be lapped with panel reinforcement dowels. For dock conditions, polyethylene sheeting can be used to protect the exposed subgrade from erosion. Once panels are erected, braced, and plumbed, the area behind them is backfilled with sand, compacted fill soil, or a dense, graded aggregate. It is important to compact the backfill to the same requirements as the subgrade. Loosely placed backfill settles and causes the slab to crack, particularly at doors subject to forklift traffic.

It is best to place strips of building paper over the joints between panels to prevent dirt and concrete from entering the panel joints. If the depth of the backfill is more than a few feet, caution should be exercised in the backfill operation to prevent pushing the panel outward from the pressure exerted by the backfill and the compaction operation. Bracing the exterior of the panel or utilizing the dowels projecting from the panel and tack welding them to those extending from the floor slab into the closure strip are both successful methods at resisting these forces. The next step is to place the concrete. The closure strip is finished and cured the same as the floor slab, and crack control joints are sawed to prevent random slab cracking in the closure strip.

Polyethylene sheeting and backfilling are not required for at-grade panels. The closure strip is then cast with the same materials and methods used for concrete and finishing and curing procedures used for the initial slab. Slab control joints should continue across the closure strip to the panel. At door openings, it is important that the closure strip is slightly depressed at the opening so water drains to the exterior of the facility.

REMOVING FORM LINERS

If bond breaker was applied to the form liners prior to casting operations, then they are easily removed by prying them loose. Foam plastic form liners are also pried off but often require water blasting to completely remove them.

REMOVE THE TEMPORARY BRACES

Remove the temporary braces only after the complete lateral load resisting system is installed and is operational. This includes, but is not limited to, roof-to-panel connections, floor slab-to-panel connections, panel-to-panel connections, panel-to-footing connections, and any internal bracing systems required for instakkation. If temporary braces need to be removed prior to complete installation of the lateral load resisting system, consult the structural engineer of record for guidance.

Once the braces are removed, the holes left by the bolt connections for the braces are filled with grout, if required by the project specifications.

ROOF AND ELEVATED FLOOR CONNECTIONS TO THE WALL

Roof and supported floor connections usually consist of embedment plates with headed studs or reinforcing bars. A continuous angle or seat angle is welded to the embedment. Seat angles can also be attached to the panel with expansion bolt fasteners. A recessed pocket with an embedment angle or plate is commonly used for heavy loads such as joist girders.

Connections for roof and floor members are most likely cast into the wall so that it is only necessary to bolt or weld them to the panel. Typical roof and floor connections could be joist and joist girder connections, deck bearing angle connections, beam connections, or brace support connections where roof or floor members run parallel to the panel.

Steel beams and joist girders are bolted to shear plates projecting from the embedded connection, seated on an embedded plate or angle in a beam pocket, or bearing on a support angle welded or bolted to an embed placed on the backside of the panel.

Steel bar joists are typically connected to the panel at bearing pockets or along the panel face. Embedded steel plates at these locations

are welded to angles that are then welded or bolted to the bar joists. The steel deck is carried between bar joists by a continuous steel angle welded to embedded plates in the face of the panel. Glued-laminated or sawn wood beams are usually set into U-shaped buckets which are welded onto an embedded plate.

Roof and floor diaphragms are continuously connected to the walls by means of ledgers. Ledgers are either wood or steel and are set onto the panel before it is poured, with the anchor bolts embedded into the concrete. For some conditions, it may be easier to make attachment after the panels are erected, using drilled inserts or welded connections to an embedded plate or angle.

PANEL TO FOOTING CONNECTIONS

Foundation connections can be as simple as a projecting reinforcement bar or dowel cast into the foundation. Alternatively, a welded embedment plate connection or a field-drilled mechanical connection can be used. Corrosion protection should be added to all connection elements exposed to the elements. For this reason and due to the difficulty in inspecting and maintaining them, these connections are generally not recommended. In many cases, connections to the footings can be eliminated entirely, except for grout under the panels when there is no calculated tension at the panel base and the panel is anchored to the floor slab in accordance with ACI 318 Section 16.5.1.3.

There are instances where panel to footing connections are required to provide lateral resistance to lateral loads or prevent the panel from lifting off the foundation. Typical conditions for panel to footing connections are at dock high walls (typically 4 ft. or more below finished floor), low walls (typically 1 to 2 ft. below finished floor), or panels with excessive overturning moments that cannot be resisted by the dead weight of the panel and any applied dead loads.

The connections at dock high walls are beneficial to prevent the lateral soil loads behind the panel from displacing the base of the panel.

Low wall panel to footing connections are effective in eliminating the dowel bars required from the panels to the floor slab. By eliminating the panel to slab dowels, the floor slab is cast all the way to the inside face of where the future Tilt-Up panel is located. This eliminates the backfilling and slab infill operations required around the panel braces to fill in the closure strip.

When a Tilt-Up panel is resisting excessive lateral forces, there may be a requirement to provide tension tie downs at the outside edges of the panel. These connections transfer the tension forces induced from the excessive overturning moments from the lateral loading condition.

The current building code requires that at a minimum, Tilt-Up panels are attached to the footing or the floor slab. There is no requirement to attach a panel to the footing and the floor slab; however, at a minimum the panel is attached to one of them. When a panel is attached to the foundation and not the floor slab, the current code requires a minimum tension resistance of the connection.

When detailing steel connections between the panels and the footing, one important consideration is the protection of the connection from corrosion. Many times connections to the footings are detailed on the outside face of the panel, below grade. In this location, the connection is subject to accelerated corrosion. Placing a small concrete section over the steel connection does not protect the connection since the cold joints around the perimeter still leak water. The small section of concrete is also prone to cracking.

PANEL TO SLAB ON GRADE CONNECTIONS

There are several methods used to make panel to slab on grade connections such as dowel bars or threaded inserts cast in the panel during concrete placement, dowel bars epoxied into a cast panel, welded embedded plates or angles cast into the panel and the floor slab and then connected together to eliminate the need for the slab closure strip, or an angle bolted to the panel and the floor slab. The most common way to provide lateral stability at the base of a panel is with bent reinforcement dowels cast into the panel and lapped with reinforcement cast into the floor slab closure strip. Dowels can be drilled and epoxied into the panel as an alternative. Panel to floor slab on grade connections utilize the frictional resistance between the floor slab and the subgrade to provide resistance to the lateral loading. Most times it is a requirement to provide dowels that cross the construction joint at the pourback strip. These dowels provide continuity across the joint to engage the next slab panel for lateral resistance. Reinforcing or welded-wire fabric is required in the pourback strip and any slab panel required to provide lateral resistance. This slab reinforcement provides the tension resistance required in the slab panel to resist the tension induced from the lateral loads on the panel.

PANEL TO PANEL CONNECTIONS

In the past, it was common practice to connect all panel joints with rigid embedment plates welded together. Subsequent panel shrinkage and other panel movement resulted in cracking or even total failure of these connections. Many designers avoid panel-to-panel connections except where required to meet structural requirements for wind or seismic loads. Joint alignment is seldom an issue, except in outside corners where panel bowing can result from temperature variations due to differential sun exposure.

When panel to panel connections are required for Tilt-Up construction, they may be used to provide additional panel width to resist overturning forces, laterally stabilize two adjacent panels that need to remain flush, provide a direct connection for lintel bearing panels to their supports, or connect corner panels to prevent differential joint movement. Where panel-to-panel connections are required, they should be designed with some degree of ductility to accommodate panel shrinkage and thermal expansion and contraction. Reinforcing bar anchors are preferred over short, headed studs. Welding of these connections should be delayed as long as possible to allow for the majority of panel shrinkage to occur. This will reduce the risk of cracking around the embedment.

Panel to panel connections are not as common in Tilt-Up construction as they are in precast construction. Precast construction utilizes panel to panel connections to provide additional resistance to overturning forces, aid in the bracing of their panels during erection, provide additional continuity to reduce the effects a lateral loading, and to prevent the differential displacement of panels that are adjacent to each other.

Panel-to-panel connections can be made with chord bar connections, tube sections, or even a ledger angle. Connections that allow horizontal movement (such as chord bar connections) can be made soon after the panels are erected. Welded connections, however, should be delayed as long as possible in order to give the respective panels additional time to dry and shrink. Panel shrinkage around a rigid connection can induce tremendous stress into the panel resulting in cracking.

Corner panel-to-panel connections are recommended to increase the life of the caulk joint. Corner panels create a unique condition because of the deflection resulting from thermal bowing. Adjacent panels usually deflect at right angles to one another, which puts additional stress on the caulk joint.

The most important factor in designing and detailing panel to panel connections is not to restrain any more movement with the connection than structurally required. Allow for joint movement between panels to prevent shrinkage and thermal cracking.

SURFACE PREPARATION

Before repair of any blemishes on wall panels, they should be thoroughly cleaned of all bond breakers or form release agents, oils, dust, mold, and mildew. Any repair material applied over the bond breaker will not adhere to the panel. Power washing with detergent is usually the most effective and economical means of removing chemically active bond breaker residue. Sand blasting may be required to remove non-chemically active bond breaker residue. Bond breaker manufacturers provide recommendations for removal of their product. After drying, concrete should change color to a relatively uniform gray color. If heavy applications of bond breaker are present, additional cleaning may be necessary.

PATCHING THE EXTERIOR SURFACE

Once panels are cleaned, surface defects can be repaired. Just about every blemish on the floor slab appears on the panel surface when it is erected. In addition to cracks or joints in the floor slab, even markings on the floor for panel numbers often show up mirror-imaged on the panel surface. Floor slab construction and contraction joints, column blockouts, utility blockouts, and any cracks or voids should be filled or concealed before casting the panels.

If a joint is not filled beforehand, concrete goes into the recess and results in a fin or projection on the surface. Grind these off prior to further finishing. A rubbing stone generally works best for this operation, but power grinding may be necessary. Filling joints before panel casting can greatly reduce the amount of repair required. Fins left along panel edges and reveal strips should be knocked off with a rubbing stone.

Most other blemishes are hidden by painting or sandblasting. For sandblasting, however, cracks are accentuated since the sandblasting rounds the edges of a crack thereby highlighting it. There is not much you can do about this but it is recommended that you meet with the building owner so they understand the finish quality you are providing. The TCA's Guideline Specifications shown in Appendix B provide recommended language for varying the level of finish quality based on viewing distance.

To “patch and sack” the exterior surface, put a worker on a manlift with a can of water, hand grinder, mortar-consistency grout mix, steel trowel, and a sponge rubber trowel. The worker can grind off any fins with the grinder. For cracks, dash on some water, then spread grout mix with the rubber trowel and scrape off flush. When it starts to dry, steel trowel to get a smooth surface.

Formed edges around doors and windows usually require the most repairing, but care in forming these edges can eliminate much of this work. Caulking around formed edges and reveal strips can also reduce the amount of subsequent repairing and finishing.

Crew members cut off the steel dowels that secured a strongback to the panel.

The repairing process involves filling bugholes, cracks, or honeycombed areas on the panel surface and exposed edges. Tile grout makes a good repair material. Grout should be applied to a dampened surface with a rubber trowel and then scraped off flush. Steel troweling the grout when it begins to dry will produce a smooth surface. The repair material should be allowed to cure sufficiently before painting. When a textured paint is to be used, small imperfections in the panel surface can be ignored.

Tilt-Up has become an architecturally sophisticated form of construction, and finishing methods have matured with it. Cement manufacturers have developed new compounds that are one-component premixes designed to be trowel-applied. The new method is considerably faster and more productive with both mixing and application being accelerated. It is less tiring for workers, so productivity remains high day after day. Eliminating the loose sand and powder released by rubbing techniques is healthier for workers. It is also less wasteful of materials and eliminates the costly damage of sand getting into lift machinery controls.

Since the new materials were developed, the level of finish quality has continued to rise. Architects are even specifying exposed concrete Tilt-Up buildings. This actually complicates finishing, because the tilt-up casting process still produces flaws that are not necessarily part of the architect's vision. The blemishes have to be fixed, but in a way that blends in completely and doesn't compromise the 'concrete look.'

Some features of the new products are similar: they tend to be single component, trowel-applied, and fairly fast-setting. They are developed for strong adhesion. They all advertise smooth finishes and application down to featheredge thinness. However, applicators say there are some distinct differences between products. Of the major brands that publish their ingredients, most are made with "graded silica aggregate" or "graded aggregate" (i.e. sand), a material that puts a hard limit on the smoothness of texture that is achievable. One product advertises a finely ground sandable aggregate, and applicators report that it can produce a finish almost as smooth as glass. Caution should be given to using any exterior repair product that contains calcium sulphate (gypsum). Gypsum lowers the cost of repair mortars, but unfortunately also reduces the rain resistance.

To remove stains on concrete, refer to PCA's publication: *Removing Stains and Cleaning Concrete Surfaces*.

WHAT TO DO WITH LARGER CRACKS

Fortunately, most cracks close up after the panel has been erected, and those remaining can usually be hidden by patching as described above. This will usually take care of larger cracks, too. If they're too large or are of structural concern, they may need to be filled with epoxy or comparable joint filler to restore the structural integrity of the panel or provide resistance to water penetration.

Cracks in Tilt-Up panels are usually caused by either concrete shrinkage or lifting of the panel. If the concrete mixture is too wet or improperly cured, cracking can occur throughout the panel surface because of restrained drying shrinkage. Cracking can also occur at corners of openings or where contraction caused by drying shrinkage is restrained. For example, wide spandrel panels rigidly attached to the supports can crack diagonally at or near the support, unless the design allows for some stress relief. Cracks occurring during lifting usually occur at locations in the panel with reduced section (opening locations or reveals) or at the lifting inserts. Causes of cracks during lifting include low concrete strength, mislocation of lifting inserts (whether by design or construction), improper rigging configuration, or by poor bond breaker performance. The width of the crack (determined with the use of a crack comparator) determines the type of repair. Small cracks, less than 0.013 in. (0.38 mm) can be grouted as previously described or filled with latex caulk by pressing it in by hand. (Caulk should be compatible with the paint to be used.) Elastomeric paint or quality primer can sometimes be used to span the crack. Large or structural cracks, wider than 0.013 in. (0.33 mm), should be examined by an engineer before any repair. Usually the crack can be repaired by pressure injection with a structural epoxy performed by a qualified applicator. If cracks are of structural concern, they can be epoxy injected if they are at least 0.01 in. up to about 1/4 in.

CAULKING JOINTS BETWEEN PANELS

This is an extremely important operation since the joint must remain watertight over a long period time and remain flexible to accommodate movement of the joint from expansion and contraction of the wall.

Panel joints should also be thoroughly cleaned. The same factors that can prevent paint adhesion can also prevent caulk or other joint sealants from adhering to the panel.

The most common problem with caulked joints is failure due to lack of proper adhesion of the sealant to the concrete. To prevent this, the contact surface must be thoroughly cleaned to remove any remaining bond breaker or laitance that reduces bond. A good test to see if laitance is present, is to apply masking tape and then lift the tape to see if any white powder is evident.

Many water infiltration problems can be traced to bad joints between panels. Caulking may become brittle and crack from expansion and contraction, or the caulk may pull away from the panel. The latter may be due to improper preparation of the panel edge. Dirt, grease, or form release agent not cleaned off the panel edge will prevent proper adhesion of the caulk. As mentioned in Section 8.1, power washing, wire brushing, or even sandblasting may be required to prepare the surface.

Polyurethanes, polysulfides, or silicones have all been used as joint caulking for Tilt-Up buildings. Many contractors use polyurethane caulks for their economy and performance. Also, many polyurethanes do not require the panel surface to be primed. For best results, use a caulking that conforms to ASTM C 920-95 for Type S (single-component) or Type M (multi-component); Grade NS (non-sagging when applied between 40 °F [4 C] and 122 °F) [50 C]; and class 25 (withstands 25 % increase or decrease in joint width).

The joint itself consists of a foam backer rod of the appropriate size for the gap between the panels and the caulk.

SANDBLASTING

Sandblasting or pressure washing, combined with the use of a retarder, is the typical method to obtain an exposed-aggregate finish. The abrasive action of high pressure air and sand against the surface dislodges the small particles between the aggregate to achieve the texture. Sandblasting is classified as brush, light, medium, or heavy. Light sandblasting only removes about 1/16 in. from the surface, enough to give a texture to the exposed fine aggregate, but only slightly exposes the coarse aggregate. Medium sandblasting goes deeper to expose the coarse aggregate which will project about ¼ in. from the sandblasted surface.

Heavy sandblasting exposes up to one-third of the aggregate diameter, resulting in an aggregate projection of ¼ in. to ½ in. For medium or heavy sandblasting, a chemical retarder is often used to facilitate sandblasting. For heavy sandblasting, a coarser aggregate should be used. The deeper the sandblasting, the higher the cost since more time is required. Medium sandblasting is usually quoted at the rate of about 2,000 sq. ft. per hour. Sandblasting accentuates cracks because the sand rounds the edges of the cracks to highlight them.

Proper retarder application and concrete placement are critical to obtaining a uniform appearance with exposed-aggregate finishes.

Once the panel forms are placed, the retarder is applied to a properly sealed casting surface, eliminating the possibility that the retarder will be absorbed by the casting surface. The retarder should be checked for compatibility with the curing compound, sealer, or both. Care should be taken to avoid heavy or light concentrations of the retarder, resulting in non-uniformity of the aggregate exposure. Select a retarder with an etch depth compatible with the size of aggregate used. Protection from the elements should be provided during the time period after the chemical retarder has been applied until concrete is placed, because the retarder is activated by water. Joints and cracks should be covered or filled to prevent the absorption of retarder or moisture from the concrete mixture. Care should also be taken when installing panel reinforcement, lifting inserts, and other embedded items to avoid scraping the retarder off the casting surface.

Concrete should be deposited as close as possible to its final position in the panel and not moved about with the vibrator. Otherwise, segregation may occur resulting in a non-uniform surface finish. Once panels have been cast, the edges should be protected in the event of rain. Rainwater drawn under the panel could activate the retarder, producing an uneven finish.

After the panel has been lifted into place, the retarded surface is removed by light sandblasting, or by water blasting. Aggregate exposure should begin as soon as possible after lifting (within two to three hours) because the retarded surface will start to harden due to ultraviolet exposure. Light etch chemical retarders can be used in combination with medium or deep sandblasting of exposed surfaces to minimize time and labor. Proper procedures and trained personnel are critical in obtaining desirable results.

Sand or abrasive blasting with or without chemical retarders may change the appearance of aggregates by permanently "dulling" them. The degree of change will vary depending upon aggregate type. Concrete matrix strength will affect the final appearance and ease of sandblasting. Concrete matrix strength in each panel should be approximately the same when it is sandblasted. Ideally, concrete should be less than 14 days old. Diameter of the venturi nozzle, air pressure, and type of sandblast sand used should be determined by a trial procedure on concrete similar to that used in the actual Tilt-Up panel. Once a sand has been selected, the source and grit size should not be altered during the course of the project.

The degree of uniformity is generally in direct proportion to the depth of exposure. The deeper the sandblast exposure, the greater the uniformity. A brush or light sandblast finish may appear acceptable on a small sample, but uniformity on a large panel is difficult to obtain. To mask some non-uniformity of the sandblasted surface, reveal strips can be used to divide the surface into smaller areas.

When casting panels that are to be sandblasted, care should be taken to properly vibrate the concrete between loads of concrete, to avoid cold joints. Sandblasting will round the edges of any cracks and will amplify the apparent crack size.

The sandblasting operator should use a manlift or have sufficient staging to maintain a level position of the nozzle. Best results are obtained if a constant distance is maintained from the nozzle to the surface being blasted. Sandblasting is generally more uniform if the nozzle is moved in a circular motion rather than strictly vertically and horizontally. Wet sandblasting may be required for conformance with environmental regulations.

Sandblasted surfaces are normally classified as follows:

Brush. Removes the cement matrix and exposes the fine aggregate — No projection of the coarse aggregate from the matrix

Light. Sufficient to expose fine aggregate and occasional exposure of coarse aggregate reveal 1/16 in. (1.5 mm)

Medium. Sufficient to expose coarse aggregate with a slight reveal — Maximum aggregate reveal 1/4 in. (6 mm)

Heavy. Sufficient to generally expose and reveal the coarse aggregate to a maximum projection of one-third the maximum size of coarse aggregate diameter — Reveal 1/4 to 1/2 in. (6 to 13 mm). This surface is rugged and uneven.

When a medium or heavy sandblast surface is specified, it is recommended that a chemical retarder be used. This will provide greater uniformity and reduce sandblasting time. When sandblasted surfaces are required, only 100 % plastic, pointed chairs should be used to support the reinforcing steel. The plastic tips on steel chairs can come off resulting in rust stains on the panel. The deeper the sandblast the more coarse aggregate is required in the mixture proportion. Deep exposure of coarse aggregate requires a finer abrasive to obtain uniform results.

BUSH HAMMERING

Another type of exposed aggregate surface, though less common than sandblasting, is produced by bush hammering. Bush hammered surfaces are produced by pneumatic tools fitted with a bush-hammer, comb, chisel, or multiple-pointed attachment. The type of tool will be determined by the final surface desired. Bush

hammering is normally applied to well-graded mixtures with softer aggregates such as dolomite and marble, provided these aggregates are durable. Most bush hammering will remove 3/16 in. (5 mm) of surface material. Bush hammering works best with higher strength concrete. To minimize loosening of the aggregate during hammer operations, a minimum concrete age of 14 days is recommended. Bush hammering at corners tends to cause damage unless special care is taken. Corners should be completed with hand tools rather than pneumatic hammers.

PAINTING

The recommendations of ACI 515.1R should be followed when painting Tilt-Up panels. Painting should proceed after the panels have been cleaned and allowed to dry a sufficient period of time to allow as much excess water as possible to leave the panel. Any dirt or dust blown onto the panels from other construction operations should be removed with wire brushes or compressed air before painting. Panel pH should be checked before painting. A value of 7 to 10 is preferred, but the paint manufacturer should be consulted for optimum requirements. Panel moisture content should also conform to the paint manufacturer's requirements. Paint systems should consist of a primer coat and at least one finish coat. Application of paint may be applied by either sprayer, roller. or a combination of both.

The prime coat may be either water based or solvent based. If their use is allowed, solvent-based primers are more effective as an adhesion promoter. Many contractors recommend a 100% acrylic latex top coat. Use of alkyd and oil-based paint has declined because they contain esters that react with alkalis in the concrete to form water-soluble soaps. As a result, these paints have a strong tendency to blister and lose adhesion, which is also known as burning. Acrylic coatings of 100% methyl methacrylate provide the best results with up to 10 years of life expectancy. The paint and joint caulk should also be compatible or the paint may not adhere to the joint caulk. Some caulks come in different colors to match the paint color.

The most commonly used paints for concrete surfaces are acrylic latex paints. Styrene modified acrylic copolymer paints and elastomeric coatings are also popular but provide a lower life expectancy compared to 100% methyl methacrylate acrylic paints and coatings. Smooth paints and coatings are generally self-cleaning with rain, but require the use of smooth patching materials and tighter patching procedures to minimize the appearance of surface imperfections. Heavily textured paints and coatings tend to catch air pollutants and appear dirty sooner.

Before applying the sealer, the exposed surface is thoroughly cleaned of any excess form liner, dirt, dust, efflorescence, or any other bond-inhibiting material. Sandblasting, wire brushing, or pressure washing with trisodium phosphate is recommended.

Painting does not take place during periods of extreme heat or when the temperature is below 50 degrees Fahrenheit without using a cold weather additive. The panels are also not painted when surface moisture is too high. Follow the manufacturer's mixing and application recommendations.

A properly applied coat of paint should last a minimum of 6-8 years before requiring repainting. Some paints can last in excess of 10 years.

Additional information can be obtained from the TCA's Tilt Tips - Painting Tilt-Up Panels. Reference can also be made to PCA's publication: *Painting Concrete.*

INTERIOR INSULATION SYSTEMS

Several forms of interior applied insulation systems are available. These systems may be acceptable where a less durable interior finish is acceptable and where fire and moisture are not of concern. All interior systems isolate the thermal mass inherent in concrete from the conditioned space, lessening the benefits of thermal mass.

Interior systems are either fiberglass, mineral wool, or polystyrene. The first two types, fiberglass and mineral wool, are typically backed with some form of vapor-resistant coating. The coatings range from a thin flexible plastic or paper liner to a rigid plastic or metallic board. The insulation strips are usually secured with some type of spline or cap that is attached to the wall. The systems are inexpensive, quick to install, and can be applied after the building is erected.

EXTERIOR INSULATION FINISH SYSTEMS

Exterior Insulation Finish Systems (EIFS) are used extensively in construction because of their relatively low cost and the ability to accommodate complex forms. These systems consist of a cementitious coating over a base of expanded or extruded polystyrene. The base material and the composition and thickness of the coating can produce dramatic differences in the quality of these systems.

Finishing systems can be used in conjunction with Tilt-Up construction, either directly on the Tilt-Up panel or in conjunction with Tilt-Up and other forms of construction. Unless higher quality systems are used, applications should be limited to fascias and other elements that are less susceptible to damage from things such as lawnmowers and vandalism. Simple reveals and patterns can be easily applied to the panel, depending on the coatings used. The combination of the two systems can add new dimensions to the finished building.

SOME PROBLEMS AND REMEDIES

In spite of precautions taken, cracks do appear in panels after erection. Most of the cracks that become visible are due to lifting stresses or are induced by shrinkage. Most originated while the panels were still on the ground. Although most cracks are due to shrinkage and are not structurally significant, any cracks that appear extensive or extend through the panel, or to the edge of the panel, or are otherwise atypical, are assessed by the structural engineer. Common finish problems are described below.

Waffle cracking. This is a gridwork of cracks which occurs over reinforcing, sometimes over a large area of a panel. These cracks are caused by excessive shrinkage, whereby the bars create a weakened plane, particularly if they are close to the surface. This type of cracking seems most prevalent in hot weather and it is thought that the concrete is weakened where it contacts the hot rebar, thereby accentuating the weakened plane. The cure is often lower slump concrete and fog spraying to reduce surface water evaporation. Also spraying the bars to cool them just prior to pouring will help.

Vertical cracks near the center of the panel. These are usually due to shrinkage in a longitudinal direction. This is quite common and usually not of structural significance.

Horizontal cracks near mid-height. These cracks are caused by a variety of forces including excessive shrinkage in tall panels, too-high erection stresses, and wind or seismic loads, since they are at the point of highest stress in bending. Some of these cracks have been observed after earthquakes. Horizontal cracks often occur at reveals due to the decreased thickness (acts like a crack control joint).

Diagonal cracks at the upper corners. These are the result of shrinkage of the panel which is resisted by the chord bar splices. These cracks are minimized by sleeving the chord bars in from the end of the panel about 4 to 5 ft. Lower slump concrete also helps.

Diagonal cracks at the lower corners. These are usually the result of longitudinal shrinkage when the ends of the panel are restrained from movement by the setting pads. This is mitigated by placing setting pads in from the edges of the panels, such as one-quarter of the panel width. The use of neoprene pads, lower slump concrete, and adding additional horizontal reinforcing near the bottom of the panel also lessens the potential for diagonal cracking.

Dark splotches on panels. These are the result of a low water/cement ratio in a localized area, causing water to draw away by the dry slab upon which the panel was cast. This happens when insufficient bond breaker is applied. The dark spots are actually denser, harder concrete.

Misaligned or missing connections. When these occur, due to dimensional or layout errors, a fix is required. The structural engineer designs a replacement connection. Do not field modify a misplaced connection without input from a structural engineer. Many times field corrections made without the input from a structural engineer can cause more damage than the original misplaced connection.

Bowing of a panel. Occasionally this is caused during erection of the panel, with the bow remaining in the panel. A remaining bow may be an indicator that the panel is also cracked horizontally and the reinforcing has yielded locally. The panel is straightened using additional braces. The cracks in the panels are filled with injected epoxy, which will hold the panel straight. Bowing may be the result of thermal stress, whereby a temperature differential exists between the outside face and inside face of the panel, causing the panel to bow in or out. This is generally only a problem if the bowing is different between adjacent panels and at the building corners. (See the discussion on corner angles.) More likely, however, it is the result of the panel curling after it was cast and the subsequent appearance of the bow due to the release of curling stresses after the panel is erected. Creep of concrete is an unlikely cause of bowing. Any bowing of a panel is investigated by the structural engineer to determine the cause and assess its significance.

Slab Damage From The Crane- "Who Pays?"

This is a much-debated issue. Structural engineers could design floors for stated wheel loads. However, in reality this is impractical since structural engineers are not in a position to design for construction loads. Crane contractors are directed to put their cranes on slabs and are therefore unwilling to accept responsibility for any resulting damage. In nearly all cases, contractors take responsibility since they direct cranes on the slab to erect the panels. To avoid this issue and to protect floor slabs, some contractors do not permit cranes on slabs.

APPENDICE TCA'S GUIDELINE SPECIFICATIONS in Standard 3-part CSI Format

This publication is intended for the use of professional personnel competent to evaluate the limitations of its content and who will accept responsibility for the application of its contents. It necessarily addresses the specification of site-cast Tilt-Up construction of a general nature. The professional using this publication is solely responsible for the application of its content to project documents and for determining when its content is not applicable. The Tilt-Up Concrete Association makes no representation, warranty or guarantee in connection with this publication, and expressly disclaims any and all responsibility for the accuracy or application of this guideline, and for any loss or damage resulting from its use.

The Tilt-Up Concrete Association is not undertaking to meet the duties of employers, manufacturers or suppliers to properly train, warn and equip their employees, or others, to comply with applicable federal, state or local regulations or laws.

PREFACE

The original Tilt-Up Concrete Association (TCA) Guideline Specification for Tilt-Up Concrete Construction was drafted and offered in 1994. TCA has revised this document to incorporate the current state-of-the-art practices for site-cast Tilt-Up panels, as well as to incorporate the improved technology that has been made available to the market over the past 10 years.

Substantial changes occur throughout this document, including the addition of tolerances, grades of finish, sandwich panel values and revised quality control requirements, among others. The specifier is instructed to review this document thoroughly, taking care to notice areas that have been added to offer choices to the project based on the specific architectural or performance requirements for the intended construction.

The TCA has provided additional comments and key information throughout this document that may be deemed necessary for the inclusion in section 03470 or other key sections. This commentary is not to be considered a part of the standard specification unless added within the specification proper.

NOTES TO THE USER

The Guideline Specification for Tilt-Up Concrete Construction is available in electronic format from the TCA. The document is formatted in a one-column layout for the main body of the specification. Commentaries on the content and suggested sections for additional consideration are added on the right-hand side of the pages in notes boxes. The user is encouraged to review these, although they are not to be considered a part of the actual specification document unless added by the author.

To add this specification to your document, you may select portions of the text body using standard word processing procedures and then paste these into your project documentation. It is recommended that you use “Paste Special” for “Unformatted Text” to allow the text to conform to your formatting. The author may also choose “Select All” from the “Edit” menu to add the entire document. This will not add the text that is in the comment boxes, as the boxes are graphic items. To add text from these boxes, the author must select each section of text individually and paste it into the document accordingly.

PART 1 – GENERAL

1.1 SECTION INCLUDES

A. Site-cast Tilt-Up concrete panels.

B. Site-cast Tilt-Up concrete units other than panels.

C. The Project Architect/Engineer has not been retained to design the wall panels or the floor slab to resist the stresses caused by erection of the wall panels, nor to determine the means and methods to be used for erection and bracing until permanent bracing is in place.

D. It shall be the Contractor’s responsibility to erect the panel in a manner that will be both safe for personnel and property, and to brace and otherwise protect the panels against wind and other forces that may occur during construction and until connections to the permanent structural system are completed.

E. It shall be the Contractor’s responsibility to ensure that a suitable slab has been prepared to provide for the level of finish that has been established within this specification.

F. It shall be the Contractor’s responsibility to coordinate the slab finishing, including saw cutting of all joints with the panel forming to minimize the impact to the architectural finish of the panels.

1.2 RELATED SECTIONS

A. Section 03100 – Concrete Formwork: Formwork Requirements.

B. Section 03200 – Reinforcing Steel: Reinforcing Steel and Welding Requirements.

C. Section 03300 – Cast-in-Place Concrete: Requirements for Slab on Grade Design and Construction, and General Requirements for Concrete Used for Panels.

D. The latest editions of the following building codes having jurisdiction should be included in Section 01010 – SUMMARY OF WORK
- Uniform Building Code (UBC)
- Standard Building Code (SBCCI);
- National Building Code (BOCA);
- International Building Code (IBC),
- National Building Code of Canada (NBC) or applicable provincial governing codes and/or standards;
- Applicable local ordinances and amendments.

E. Section 05500 – Miscellaneous Metals.

F. Section 07920 – Sealants and Caulking: Fire-resistant Blanket and Sealant Materials.

G. Section 09900 – Painting: Finishing of Panels.

The latest editions of the following building codes having jurisdiction should be included in Section 01010 – SUMMARY OF WORK
- Uniform Building Code (UBC)
- Standard Building Code (SBCCI);
- National Building Code (BOCA);
- International Building Code (IBC),
- National Building Code of Canada (NBC) or applicable provincial governing codes and/or standards;
- Applicable local ordinances and amendments.

1.3 REFERENCES

A. AWS D1.1- 2002 “Structural Welding Code – Steel”

B. AWS D1.4- 98 “Structural Welding Code – Reinforcing Steel”

C. ASTM A123 – Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel.

D. ASTM A184/A184M – Specification for Fabricated Deformed Steel Bar Mats for Concrete Reinforcement.

E. ASTM A185 – Specification for Steel Welded Wire Fabric, Plain, for Concrete Reinforcement.

F. ASTM A496 – Standard Specification for Steel Wire, Deformed, for Concrete Reinforcement.

G. ASTM A497 – Specification for Steel Welded Wire Deformed Fabric for Concrete Reinforcement.

H. ASTM A615/A615M – Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement.

I. ASTM A706/A706M – Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement

J. ASTM C31/C31M – Method of Making and Curing Concrete Test Specimens in the Field.

M. ASTM C78-00 – Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).

N. ASTM C94 – Specification for Ready-Mixed Concrete.

O. ASTM C143 – Test Method for Slump of Portland Cement Concrete.

P. ASTM C150 – Specification for Portland Cement.

Q. ASTM C293 – Standard Test Method for Flexural Strength of Concrete (Using Simple Beam With Center-Point Loading).

R. ASTM C309-98a – Specification for Liquid Membrane-Forming Compounds for Curing Concrete.

S. ASTM C330 – Specification for Lightweight Aggregates for Structural Concrete.

T. ASTM C595M – Specification for Standard Specification for Blended Hydraulic Cements.

U. ASTM C1157 - Standard Performance Specification for Hydraulic Cement.

V. ACI 117 – Standard Specifications for Tolerances for Concrete Construction and Materials.

W. ACI 301 – Specifications for Structural Concrete.

X. ACI 305 – Specification for Hot Weather Concreting.

Y. ACI 306 – Specification for Cold Weather Concreting.

Z. ACI 315 – Standard for Details and Detailing Concrete Reinforcement.

AA. ACI 318 – Building Code Requirements for Structural Concrete.

BB. CRSI Manual of Standard Practice.

CC. CRSI Specifications for Placing Reinforcement.

DD. BSR/ASHRAE/IESNA 90.1-1999

EE. ASHRAE Handbook of Fundamentals 1997

FF. American Association of State Highway & Transportation Officials (AASHTO)

1.4 SUBMITTALS

A. Submit under provisions of Section 01300

B. Shop Drawings: Submit Panel Shop Drawings and Erection Drawings detailing all work of this section, including temporary bracing. Reinforcing bars shown on the project drawings do not allow for lifting and erection stresses.

C. Quality Control Submittals:

1. Test Reports: As directed by the Contract Documents, submit certified laboratory test reports confirming physical characteristics of materials used in the performance of the Work of this Section.

2. Manufacturer's Instructions: For manufactured items used, submit the manufacturer's current recommended methods of installation, including relevant limitations and safety precautions.

D. Material Submittals:

1. Concrete mix designs for each mix specified.

2. Sample of Interior and/or Exterior Surface Treatment.

3. Manufacturer's literature for bond breakers.

4. Mix design for structural grout for panel support.

1.5 QUALITY ASSURANCE

A. Regulatory Requirements: Comply with applicable codes and regulations of governmental agencies having jurisdiction. Where those requirements conflict with this Specification, comply with the more stringent provisions.

B. Qualifications for Field Personnel: Contractor shall show evidence of competence in site-cast Tilt-Up concrete construction. Workers shall be proficient in production and erection operations and shall be under the direct supervision of qualified personnel.

C. Qualifications for Welding: Qualify welding processes and welding operators in accordance with ANSI/AWS D1.4. Provide certification that welders to be employed in the Work have satisfactorily passed AWS qualification tests within the previous 12 months.

1.6 TOLERANCES

A. Dimensions of the finished panels, at the time of erection in the structure, shall conform to the casting tolerances stated below, unless otherwise specified or approved by the Project Architect/Engineer.

1. Height & Width of Basic Panel
   a. Up to 20 feet 1/4 inch
   b. 20 feet to 30 feet 3/8 inch
   c. Each additional 10-foot increment in excess of 30 feet 1/8 inch

Section 07900 – JOINT SEALANTS
The author is advised that the Manufacturer's literature for sealants and caulking used for the treatment of the joints between panels and any other penetration should be added to the submittal requirements for this section.

The Tilt-Up Concrete Association (TCA) through the ACI has established a Tilt-Up Supervisor Certification Program. The author should consider with the project team the inclusion of further language such as: "Provide certification that supervisor to be employed in the Work has been ACI certified, meeting Site-Cast Tilt-Up Supervisor qualifications" to be added to this section, item A if it is verified that there are suitable companies meeting this qualification available in his area.

SECTION 1.5 – QUALITY ASSURANCE, Item D:
When projects call for finished appearances incorporating exposed aggregate, sandblasted surfaces or other architectural finishes, the author is encouraged to add part or all of the following section:

D. Job Mock-up Panel for Architectural Finishes
1. Prepare minimum 4' by 8' panel using forming system and construction methods

to be used on project. Prepare one panel for each level of finish shown on the drawings.

2. Incorporate edge and reveal conditions as detailed on the project drawings.
3. Painted and Textured Concrete Finishes
   a. Utilize full range of color as specified.
   b. Utilize full range of textures variation as specified.
4. Sandblast or Colored Concrete Finishes
   a. Utilize full range size and colors in aggregate.
   b. Utilize full range of color in grout.
   c. If sandblasting is specified, it shall match degree specified.
5. Architectural Liner or Cast-In Brick Finishes
   a. Utilize full range of color sampling for brick specified.
   b. If liners are to be used, sample shall consist of section showing integration of both horizontal and vertical liner joints.
6. Maintain approved mock-up for comparison with finish work.
7. Dispose of mock-up when project is completed or when directed by Project Architect/Engineer.
8. Cast mock-up over slab joint or column joint if actual panels will be affected by these conditions.

2. Note: Tolerances referenced here may be further restricted by joint width tolerances listed in section 1.5.2a.

3. Thickness 3/16 inch

4. Note: The tolerance listed is for the average variation of panel thickness through any horizontal or vertical crosssection of the panel.

5. Skew of Panel or Opening
   a. Per 6 feet of dimension 1/8 inch
   b. Maximum difference 1/2 inch

6. Note: The tolerance listed is the measured difference in length of the two diagonals.

7. Openings Cast Into Panel
   a. Size of Opening 1/4 inch
   b. Location of Centerline of Opening 1/4 inch

8. Location/Placement of Embedded Items
   a. Inserts, Bolts, Pipe Sleeves 3/8 inch
   b. Lifting and Bracing Inserts Per Manufacturer's Specs
   c. Weld Plate Embeds (Lateral Placement) 1 inch
   d. Weld Plate Embeds (Tipping & Flushness) 1/4 inch

9. Deviation of Concrete Reinforcing Steel Cover: Shall be in accordance with ACI 318, and in no case less than specified elsewhere.

B. Dimensions of the erected panels shall conform to the erection tolerances stated below unless otherwise specified or approved by the Project Architect/Engineer.

1. Joint Width Variation
   a. Panels up to 20 feet tall 1/4 inch
   b. For Each 10-foot Increment in Excess of 20 feet tall 1/8 inch
   c. In no case should the variation in joint width be increased or decreased more than 50% from the specified joint width.

2. Note: The tolerance listed is measured between the panels at the exterior face of the panels at the joint.

3. Joint Taper
   a. Panels up to 20 feet tall 1/4 inch
   b. For Each 10-foot Increment in Excess of 20 feet tall 1/8 inch
   c. Maximum for Entire Length 3/8 inch

4. Note: The tolerance listed is the measured difference in joint width, indicating the panel edges are not parallel.

5. Panel Alignment

a. Alignment of Horizontal and Vertical Joints 1/4 inch
b. Offset in Exterior Face of Adjacent Panels 1/4 inch

1.7 PROJECT CONDITIONS

A. Job Conditions: The provisions of this section are supplemental to the scope of ACI 305 and 306.

B. Do not construct formwork, place reinforcing steel or concrete, or erect panels during adverse weather unless approved measures are taken to prevent damage. During periods of dry winds, low humidity, and other conditions causing rapid drying, protect fresh concrete with an evaporation retardant (monomolecular film) or fine fog spray of water applied immediately after screeding and bull floating. Maintain protection until final finishing and curing compounds are applied.

C. For cold weather conditions, adequate equipment shall be provided for heating concrete materials and protecting concrete during freezing or near-freezing weather. Concrete materials and reinforcing steel, forms, fillers and ground with which concrete is to come in contact shall be free from frost. If shelters are used, the type of fuel used for heating shall not weaken the concrete surface. Frozen materials or materials containing ice shall not be used. Also refer to ACI 306 - Specification for Cold Weather Concreting.

D. For hot weather conditions, proper attention shall be given to concrete materials, production methods, handling, placing, protection, and curing to prevent excessive concrete temperatures or water evaporation that may increase shrinkage and impair required strength or serviceability of the member or structure. Also refer to ACI 305 - Specification for Hot Weather Concreting.

PART 2 – PRODUCTS

2.1 MANUFACTURED ITEMS

A. Lifting hardware, inserts, braces and related embedded and attached items shall be manufactured specifically for site-cast Tilt-Up construction.

2.2 PANEL MATERIALS

A. Forms:

1. Forms shall contain blockouts required to provide openings detailed on Drawings. Coordinate all openings with other trades.

2. Panel boundary forms shall be rigidly constructed and well-braced steel or wood forms, straight and with precise corners. Design to withstand stresses resulting from the casting process. Consideration should be given to exposed formed surfaces. All forming surfaces shall be smooth and clean prior to pouring of concrete.

The author and design team may wish to consider the following text as an added item in this section where non-intrusive means for connection of forms to the slab due to floor requirements is necessary. Consider the following: "Forms shall be attached to the slab using non-intrusive glues and/or adhesives wherever possible in lieu of nails and bolts."

3. Panels may be stacked for ease of casting, in forms as specified above.

4. When panels are stack-cast, maintain a continuous sound and smooth surface with forming and plaster at all openings.

5. Bond breaker must be compatible with curing compound and other finishes, including paint and floor finish.

B. Reveal Materials: All material used for creating reveals or relief in the exterior face of the panel must be of adequate strength to withstand construction traffic/loads without damage.

C. Concrete Materials:

1. Cement: Portland cement, conforming to ASTM C150, C595 or C1157 Type ___.

2. Fine and coarse aggregates shall consist of clean, hard, strong and durable inert material, free of injurious amounts of deleterious substances, conforming to ASTM C33 for normal weight concrete and ASTM C330 for lightweight aggregate concrete.

3. Concrete shall be a design mix approved by Project Architect/Engineer.

4. Mixing water shall be free of any acid, alkali, oil or organic material that may interfere with the setting of the cement.

5. Admixtures shall be approved by Project Architect/Engineer.

6. All concrete shall be produced and delivered in accordance with ASTM C94.

D. Quality of Concrete

1. Ready-mixed concrete shall conform to ASTM C94.

2. Concrete shall have a minimum compressive strength at 28 days as indicated on the project drawings and as required for panel erection, or specified and tested according to ASTM C39.

E. Sacking Materials: Portland cement and water, mixed to a uniform creamy paste.

F. Dry-pack Materials: In accordance with requirements specified in Section 03300 — Cast-in-Place Concrete.

G. Steel Reinforcement:

1. Reinforcing bars shall conform to ASTM A615/A615M, Grade 60, or ASTM A706/A706M. For reinforcing bars conforming to ASTM A706, which will be welded, furnish a report of the chemical analysis for each heat of the bars.

2. Welded wire reinforcement shall conform to ASTM A185 or A497 based on type and

location and shall be of the style shown on the project drawings. Welded wire reinforcement shall be supplied in flat sheets.

3. Bar mats for concrete reinforcement shall conform to ASTM A184.

H. Fibers:

1. The use of fibers is only applicable for reduction of plastic shrinkage and thermal expansion/contraction. They shall not be used as flexural reinforcement in structural panels. Consult the manufacturer's literature for proper material quantities and application procedures.

I. Miscellaneous Metals:

1. Metals shall conform to requirements of Section 05500 – Metal Fabrications.

2. Provide all inserts, dowels, and other items to be cast in panels, including items required for erection and bracing.

3. Steel that will be exposed to the exterior or damp environments in finished panels shall be plastic-tipped, hot-dipped galvanized or protected by other means to prevent corrosion or oxidation of the metal after fabrication in accordance with ASTM A123.
   a. Selection of plastic-tipped treatments: Ensure that the plastic will not create stress concentrations within the thin sections of concrete when located near a surface from differential thermal expansion and contraction, ultimately resulting in local shear failure of the concrete surface, producing surface blemishes.

J. Facing Aggregates:

1. Material: ________________________

2. Gradation: ______________________

3. Color Range: ___________________

4. Sand-Cement-Grout
   a. Mix: ________________________

   b. Slump range _____ in. to _____ in.

K. Supports for Reinforcing Steel:

1. Supports may consist of metal, all-plastic and/or concrete materials.

2. Metal supports shall be either galvanized after fabrication or plastic-tipped. No galvanized or plastic-tip metal support shall be used on panels to receive exposed or sandblasted finish.

3. All-plastic supports should be of such design as to adequately support reinforcement, provide minimal surface contact, and be of such coloring as to not be distinguishable on any surfaces. Minimal surface contact is defined as having a total contact surface area not to exceed 0.10 square inches (64.5 mm²) per contact point. Refer to CRSI Manual of Standard Practice.

4. Concrete supports may only be used in situations where surface contact is not visible.

2.3 CONCRETE CURING MATERIALS

A. Liquid Membrane-Forming Curing Compound:

1. Liquid-type membrane-forming curing compound shall comply with ASTM C309-98a, Type I and I D, Class B.

2. It is preferred that the curing compound/bond breaker be the same product or compatible, and that only one manufacturer's product is used.

3. Concrete Curing of Casting Beds: All concrete in and around those areas to be used for casting shall be cured after finishing, as soon as the free water on the surface has disappeared and no water sheen is visible, but not so late that the liquid curing compound will be absorbed into the concrete. The cure and/or bond-breaking compound should be applied at the manufacturer's recommended coverage to achieve minimum moisture loss.

B. Reusable wet cure covers:

1. Impregnated fiber mat with a white or light-colored backing having low permeability with high moisture retention to maintain the proper moisture content during the concrete curing process shall be used.

2. Product must comply with AASHTO Specification M-171 for reflection and moisture retention.

2.4 SANDWICH INSULATION SYSTEMS

The current form of ASHRAE 90.1 permits the additional consideration of thermal mass to the building envelope balance calculation. The author may wish to consider altering the language of item A of this section to allow for both a minimum material R-value based on ASHRAE 90.1 or the applicable Energy Code and a submittal demonstrating energy balance under the provisions of ASHRAE 90.1.

A. The insulated concrete sandwich panels must be constructed to maintain the effective acceptable material R-___ of the panels with less than one (1) percent reduction due to penetrations and connection detailing. The reduction in thermal performance must be calculated using the Isothermal planes method of R-value calculation as provided by ASRHAE 90.1-1999. Install in accordance with manufacturer's recommendations.

2.5 SEALANT AND CAULKING MATERIALS

A. Sealants: In accordance with Section 07920 – Sealants and Caulking.

2.6 BOND BREAKER

A. Liquid Dissipating Membrane-Forming Curing Compound.

1. The bond-breaking material shall also be a dissipating membrane-forming material complying with ASTM C 309-98a, Type I and I D, Class B.

2. The bond-breaking compound shall be applied with adequate time to dry prior to placement of reinforcing steel.

3. The bond-breaking compound shall dry in 30 minutes or less at 100°F to reduce panel clean up.

4. Material must be compatible with curing material.

5. The bond breaker used must be compatible with any coating specified for interior or exterior concrete panels and slab.

B. Refer to manufacturer's instructions for proper procedures for post applying a liquid floor hardener or sealant to areas where bond breaker is present.

PART 3 – EXECUTION

3.1 GENERAL

A. Coordinate site-cast Tilt-Up operations with Work of other trades in order that Work may be expedited and omissions and delays avoided.

B. Concrete shall be so handled as to prevent segregation. Mixers, chutes, conveyors, pump hoses and other handling equipment shall be kept clean and free of foreign matter.

3.2 CASTING SURFACES

See ACI 301 or 302 for more detailed specification information for the Slab on Grade that the Project Architect/Engineer may wish to consider for Section 03300 — Cast-In-Place Concrete.

A. The information contained in this section consists of general recommendations for the design and construction of the Casting Slab.

B. Casting Slab Preparation:

1. Casting slab shall be cured. Saw cuts, cracks, joints or defects in the casting bed shall be filled so as to minimize transfer of the joint line to the panel face.

2. Waste slabs, if used, shall be of sufficient thickness and strength so as not to crack with the weight of the panels.

3. Contractor shall be responsible for compatibility of curing agents, sealants and releasing agents utilized in the Work. If panels are to be stacked, the troweled surface shall be considered the casting bed and shall be treated as the same.

4. Isolation pockets shall be formed in such a manner as to minimize the transfer of the pocket to the finished appearance of the panel.

C. Bond breaker should be applied in accordance with manufacturer's printed instructions for the applicable condition.

D. After placing reinforcing steel for panels, check casting slab surfaces for continuity of film. Touch up or recoat worn or damaged areas, taking care to prevent application of coating on reinforcing steel and inserts.

E. Coordinate installation of inserts and anchorages required to be set into concrete slabs prior to casting of panels.

F. Where reveals are specified in panels, ensure that forming strips are straight and securely fastened to prevent movement or floating during placing operations and that alignment between adjacent panels is correct. Reveal tolerances shall comply with the provisions of Section 3.7 of this document.

3.3 FORMING PANELS

A. The Contractor shall lay out the panels for casting in a manner that minimizes the locations of floor joints, column isolation joints and other construction joints in the panel faces. The Contractor shall prevent the layout of the panels over temporarily poured casting surfaces such as pre-formed columns and pits unless deemed absolutely necessary.

B. Forms shall be designed to maintain the perimeter of the panel as shown on the project drawings within 1/4" maximum deflection during pouring.

C. All formed blockouts for openings in the panels shall be designed to limit the deflection during pouring to a maximum of 1/8".

During the placing, the concrete should be consolidated in accordance with ACI Standard Practice for Consolidation of Concrete (ACI 309). This document is intended for use by individuals competent in evaluating the significance and limitations of its scope and recommendations as stated by ACI and should be discussed as a pre-construction meeting item if appropriate.

3.4 PLACING CONCRETE

A. Concrete shall be thoroughly worked around reinforcement and embedded items, and into corners of the forms.

B. Cold joints shall not be permitted in an individual site-cast Tilt-Up panel.

In general, the concrete should be cured and protected in accordance with ACI Standard Practice for Curing Concrete (ACI 308). See the commentary note above for section 3.4, restricting the inclusion of this as a part of this specification but relying on discussion of this during pre-construction meetings if appropriate.

3.5 CURING AND PROTECTIONS

A. Protect freshly placed concrete from premature drying and excessive cold or hot temperatures, and maintain without drying at a relatively constant temperature for the period of time necessary for hydration of the cement and proper hardening of the concrete.

B. Apply liquid membrane curing compound in accordance with manufacturer's recommendations.

C. Underlying panels in a stack-cast arrangement shall be cured in the same manner as casting beds.

A. When moist curing is provided as an alternative to the use of liquid membrane:

1. Cover panels completely with burlap strips immediately after finishing. Lay as many lines of soaker hose as needed. Quickly and completely wet the entire exposed surface.
   Cover panels completely with 4-mil polyethylene, transguard or burlene to prevent evaporation. The panels must be kept wet for 7 days. Do not allow alternate wetting and drying. The polyethylene shall be turned over and down the edge of the forms and securely fastened.
2. In panels or areas to be cured, weight the polyethylene, transguard or burlene with enough weight to prevent normal winds for the area from blowing it off the panels. Keep panels wet until erection begins or approved by the Project Architect/Engineer.

WARNING: The Project Architect/Engineer should add a warning to the drawings regarding the point-loading fatigue of the footing during construction and cover this in a pre-construction meeting. The Project Architect/Engineer typically designs the footings for service loading. If this design is not to consider construction loading, the following note is suggested: "Per the structural engineer, add a third shim set under the panel immediately after panel is plumbed and braced to reduce point loading, allowing grouting to occur later." As an alternative, the Structural Engineer should verify the footing design for point loading of panel supports during construction.

3.6 HANDLING AND ERECTION OF PANELS

A. Design panels for erection stresses. Selection of lifting system and hardware shall be by the Contractor.

B. Minimum strength of panels at time of erection shall be in accordance with the lifting design.

C. It is recommended that the Contractor take extra test specimens and field cure to verify concrete strength of panels.

D. Before starting erection operations, Contractor shall check relevant job site conditions to ensure they are ready for the erection of panels. Each element shall be properly marked to correspond with the designation indicated on the approved Shop Drawings.

E. Protect elements to prevent staining, warping or cracking.

F. Patch or repair defects in panels in a manner acceptable to the Project Architect/Engineer.

G. Use erection equipment that will prevent damage to existing construction, permanent floor slabs and panels. Damage to Work shall be repaired or replaced at the Contractor's expense and in a manner acceptable to the Project Architect/Engineer prior to painting or coating.

H. Set panels in the position assigned. Place panels evenly on prepared setting pads or proper-capacity shims. Grout space under panels for full bearing or provide additional support until grouting takes place.

I. Panels not attached to the building frame at the time of erection shall be braced in position using a bracing system designed to resist wind and other loads that may reasonably be determined until all structural connections have been made. There shall be a minimum of two braces per panel. Design of bracing shall be the responsibility of the Contractor. Panel bracing connection shall be maintained daily by Contractor to assure tightness.

J. After panels are erected, Contractor shall check all connecting bolts at the floor and panels daily to ensure tightness.

K. Dry-pack grout installation and preparation for weld pockets and other panel blockouts not cast in during pouring shall be performed as follows:

1. Remove laitance down to sound concrete.
2. Surface to receive grout shall be rough and reasonably level.
3. Surface shall have been properly wet cured.
4. Do not use curing compounds.
5. Clean surface of oil, grease, dirt and loose particles.

ADDITIONAL ITEM
The author may wish to consider restrictions on the timing of the welded connections between panels. The following note is recommended in this situation, although it should be noted that there are other characteristics of the construction that may be altered or sacrificed with this consideration.

A. Panel-to-panel connection should be designed in such a way as to allow minor movement in panels for thermal expansion and contraction and continuing curing of panels (shrinkage). Perform welding required to attach panels to building frame and to each other, in accordance with ANSI/AWS D1.4.
    1. Wait a minimum of 28 days from panel casting before making any panel-to-panel welds.

It is strongly recommended that the Project Architect/Engineer carefully consider the finish specified, as it will impact the cost of the project. They should also note that it is acceptable and recommended to specify different levels of finish for the project using a key plan. Further restrictions can be made to the provisions of the finish grades of this section with the understood implication to the related cost increase potential of the project.

6. Remove free water from concrete and bolt holes immediately before grouting.

L. Protection of the erected elements shall be the responsibility of the Contractor.

M. Temporary panel bracing shall not be removed until roof diaphragm is completely welded and installed.

N. After the panels are erected, dismantle panel erection devices and patch panels as required for a uniform appearance.

O. After panels are erected, patch holes or other blemishes in casting slab that were caused by the panel casting and erection processes in a manner acceptable to the Project Architect/Engineer.

3.7 PANEL FINISH

A. The Contractor shall consult with the Project Architect/Engineer and the Owner prior to initiating the project to determine the expectations for the project appearance.

B. Exposed surfaces of panels shall be finished as indicated on the project drawings. This shall include both the front and back of the panels as well as any exposed edges as defined below.

C. Visible surfaces of the panels, when in place, shall be free from surface defects for as defined below for a ____________ finish. Refer to Section 1.4 (D) of this document for finish sample requirements.

1. Grade A - Architectural: Projects designed for the circulation of people within a distance of 10 feet to 25 feet

    a. All panel surfaces will be free of all voids, holes, pockets and other surface deformations greater than 1/8".

    b. Surfaces of panels must not project reinforcing patterns, floor joints or other projections or voids from the casting surface.

    c. Cracks are not permissible in excess of 1/32".

    d. All surface repairs must be performed in such a way as to prevent the projection of repair strokes through the intended finish.

    e. All holes shall be filled with patching material to present a smooth surface ready for painting, unless the designed finish is to result in exposed aggregates, whereby the patching material shall match the intended color and texture.

    f. Reveals must be maintained in their designed positions. Deviation from any horizontal or vertical line shall not exceed 1/8" over 10'.

2. Grade B - Standard: Projects designed for the circulation of people within a distance greater than 25 feet while retaining an emphasis on quality finishes and aesthetic detail

a. All panel surfaces will be free of all voids, holes, pockets and other surface deformations greater than 1/4”.

b. Surfaces of panels may be repaired sufficiently to prevent excessive projection of blemishes through the intended finish.

c. Cracks are permissible as naturally resulting from curing. Cracks are not permissible as caused by erection forces.

d. Surface repairs shall improve the appearance of the panels within the descriptions above, provided they do not result in additional blemishes that are visible within the distance set.

e. All holes shall be filled with patching material to present a smooth surface ready for painting, unless the designed finish is to result in exposed aggregates, whereby the patching material shall match the intended color and texture.

f. Reveals must be maintained in their designed positions. Deviations greater than 1/4” from any location will not be permissible.

3. Grade C - Utility: Projects designed for remote areas with little or no public interaction and/or projects designed specifically for interior use with little or no emphasis toward the exterior design

a. Panel surfaces showing voids, holes, pockets and other surface deformations are permissible, provided they do not weaken the structural integrity of the panel or the finish of the panel and provided they do not exceed ___ inch

b. Cracked surfaces are permissible, provided the cracks are not resulting from structural weakness or failure, and provided they do not present the potential for failure of the finish over the life of the building.

D. Surfaces to be painted shall be prepared to receive paint finish as specified in Section 09900.

3.8 SEALING OF PANEL JOINTS

A. Clean the panel joints of contaminants, including form-release agents and concrete laitance. Dust and loose particles shall be blown out or otherwise cleaned to provide proper bond. Apply sealants in accordance with manufacturer’s recommendations.

B. Install fire-resistive blanket where indicated.

C. Install joint insulation where indicated to consist of a limited expansion polyurethane insulation or an approved equal as provided in accordance with Section 07200 – Insulation.

D. Install back-up rod, primer, paint and sealant in accordance with Section 07920 – Sealants and

Caulking.

Should consider a strong statement for joint treatments on both sides of the wall in applications like schools, etc.

3.9 FIELD QUALITY CONTROL

A. Testing:

The TCA has added the requirements for both cylinder and beam tests. The embedment strength of the lifting inserts is related to the concrete compressive strength determined by the cylinders. The ability of the concrete to resist cracking during panel rotation is related to the modulus of rupture strength determined by the beams. Proceeding without either one of these tests may jeopardize the success and ultimately the safety of the project.

1. Take not less than four cylinders and four beams for each class of concrete, for each 150 cu. yd. (114.7 cu. m.) or fraction thereof, for each day concrete is cast, or not less than once for each 5,000 sq. ft. (464.5 sq. m.) of panel area. The specimens shall be field cured.

2. Of each set of four beams, at least two shall be tested prior to panel erection. The average of the two beam results shall be the tested flexural strength. Ensure that the specified flexural strength has been met. The other beams shall be kept in reserve if additional testing is needed.

3. Casting, curing and testing of beams shall be in accordance with ASTM C78.

4. Of each set of four cylinders, two shall be tested at 7 days and two at 28 days.

The Designer may also wish to consider adding some or all of the information for testing found in ACI 318 Chapter 5, Section 5.6.5.

5. Casting and curing of test cylinders shall be in accordance with ASTM C31.

6. Test cylinders and test reports shall accurately indicate in which panel, by number and concrete delivery tag, the concrete represented by each test cylinder was placed.

7. Copies of test reports shall be distributed to Owner, Project Architect/Engineer, Building Official and Contractor. Reports shall indicate location of tests, dates, technician and other pertinent information.

The Designer may wish to include information from ACI 318 Chapter 5, Section 5.6.5 here.

B. Deficient Compressive Strength

1. In the event that concrete tests indicate a 7-day or 28-day strength below that which was specified, the Contractor, with the agreement of the Project Architect/Engineer, shall have the mix adjusted so that subsequent concrete will comply with the minimum strength requirements. The owner may require core specimens to be taken and tested, at the Contractor's expense. If core tests fall below minimum requirements, as determined by the Project Architect/Engineer, the concrete in place will be deemed to be defective. This concrete shall be removed and replaced or strengthened in a manner acceptable to the Owner and Project Architect/Engineer, at the Contractor's expense. Any demolition or repair of other materials or systems as a result of repair or replacement of defective concrete shall be at the Contractor's expense.

3.10 CRACKED AND DAMAGED PANELS

A. Panel damage that occurs during erection, cracks readily visible per the requirements specified in Section 03470.3.6.2, permanent bowing occurring from erection, and spalls, shall be repaired or replaced to the satisfaction of the Project Architect/Engineer, appropriate to the type and location on the building.

3.11 CLEANING

A. When Work of a Section has been completed, remove trash, debris, surplus materials, tools, and equipment from site.

3.12 PROTECTION

A. During the period after this Work has been completed, the General Contractor shall protect finished site-cast Tilt-Up concrete surfaces from damage by subsequent construction operations.

PHOTO INDEX

Express Scripts Building 3 Photography:

Images courtesy of photographer Matthew McFarland and TCA Sustaining Member Concrete Strategies.

Matthew McFarland specializes in architecture, industrial, and travel photography. For him, photography is not just a profession; it is an instrument to contribute to his other passions: architecture, travel, and his love for the ocean. He is perpetually inspired by dramatic and dynamic spaces, places and the process of building. Architecture and design have been fascinations of his for as long as he can remember. He started going to design classes with his mother at the age of seven traveling around the country doing high-end interior design & development. He has worked with some of the best architects, designers, and builders of award winning projects. His photos and designs have appeared in Architectural Record, Dwell and other trade and design magazines. Over the past few years he has photographed close to one hundred projects all over the US.

Express Scripts Building 3 – Saint Louis, Missouri, USA
7, 25-27, 37, 93-94, 99, 116-117, 121, 128-129, 134-149, 151, 154, 156-164, 173, 178, 181, 184-185,189

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Thank you to the membership and committees of the Tilt-Up Concrete Association, their support makes important industry resources like this publication possible.

The first edition of "The Tilt-Up Construction and Engineering Manual, authored by Hugh Brooks in 1988 was intended to cover, in one volume, nearly everything one needed to know to design or build a Tilt-Up building. Building upon that strong foundation of information, the Tilt-Up Concrete Association has been able to expand upon Brook's work and keep it relevant and useful for today's Tilt-Up Professional. His contribution to this industry was incredible and continues to be present in this book today.

TILT-UP CONCRETE ASSOCIATION