Description of Tilt-Up Concrete Wall Construction

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Abstract: Tilt-up concrete wall construction is an alternative to cast-in-place, precast, or masonry methods of constructing building walls. The process involves more than just a cast and lift operation. Detailed planning, preparation, scheduling, and safety issues are constantly redefining the process. This paper describes the tilt-up process in step-by-step detail from the panel layout, to the setting of forms, to the concrete placement, and finally to the panel erection. A warehouse/office/shop tilt-up in Tempe, Ariz. is used as a case history of this construction method.

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Introduction

Concrete tilt-up wall construction is a method of building concrete interior and exterior walls without the use of vertical formwork. The high cost of formwork is the primary driver of this innovative concrete construction technique (Allan 1990). The process is used to reduce the cost of materials and labor in wall construction. The tilt-up wall panels can be designed to be load bearing, which is usually the case for the exterior walls, or non-load-bearing (Hornbostel and Hornung 1982). This building process works very well for shell-type buildings. The panels are formed, constructed, erected, and supported very quickly, as compared to other building methods. Like any process, proper planning is the key to success.

This case history describes the construction of a 3,716 m^2 (40,000 ft^2) warehouse/shop/office in Tempe, Ariz. The project was accomplished using the design/bid/build contracting method. Gerald Deines was the project architect and TLCP Structural, Inc. was the engineer for the building. The general contractor on the project was Mardian Contractors, Inc., based in Phoenix. All of the concrete work on the site, with the exception of the sidewalks, and site drainage, was performed by Jack Hatfield Concrete Incorporated of Peoria, Ariz. Hatfield constructed the slab-on-grade, and the interior and exterior building walls. The total project cost was $1.8 million.

Panel Description and Layout Pattern

The slab-on-grade building floor (floor slab) served as the casting yard for the tilt-up wall panels. This slab was 127 mm (5 in.) thick. A commercial concrete curing and bond-breaking compound (Clean Lift 90) was used as the curing compound for the floor slab. When used as a cure coat on a smooth-hard troweled surface, the coverage is approximately 9.8 m^2/L (400 ft^2/gal.). A second coating would be applied later to serve as the bond breaker between the floor slab and the tilt-up panels. The concrete used in the slab had a compressive strength of 20.7 MPa (3,000 psi) at 28 days (Table 1). By using the same compound for both purposes, the contractor simplified his materials management operations.

The casting floor slab is constructed so that there is a 0.5 m (1.5 ft) gap between its outside dimensions and the final interior face of the exterior tilt-up panels. This gap provides space for the construction of a strip foundation around the perimeter of the building. Fig. 1 shows the gap between the floor slab and the strip foundation on a similar project in the Phoenix area.

There were a total of 42 tilt-up panels used for the building shell/wall construction. They ranged in size from 8.2 to 9.4 m (27–31 ft) tall, and 6.1–9.1 m (20–30 ft) wide. An extra 0.9 m (3

Fig. 1. (Color) Gap between the floor slab and the strip foundation

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Table 1. Concrete Mix Designs

Material	Floor slab 20.7 MPa (3,000 psi) concrete		Tilt-up panel 27.6 MPa (4,000 psi) concrete	
	kg/m^3 (lb/yd^3)	m^3 (ft^3)	kg/m^3 (lb/yd^3)	m^3 (ft^3)
ASTM C 150, type II, low alkali	273 (460)	0.07 (2.34)	320 (540)	0.08 (2.75)
ASTM C 33, fine aggregate	847 (1,428)	0.24 (8.62)	791 (1,334)	0.23 (8.05)
ASTM C 33, number 5 coarse aggregate	593 (999)	0.17 (6.03)	601 (1,013)	0.17 (6.12)
ASTM C 33, number 7 coarse aggregate	485 (818)	0.14 (4.94)	492 (829)	0.14 (5.01)
Water	178 (300)	0.14 (4.81)	178 (300)	0.14 (4.81)
Air	—	0.01 (0.27)	—	0.01 (0.27)
ASTM C 494, type A water reducer	391 g (13.8 oz) WRDA-64		459 g (16.2 oz) WRDA-64	
ASTM C 494, type A water reducer	652 g (23.0 oz) Daracem		765 g (27.0 oz) Daracem	
Water/cement ratio	0.65		0.56	
Slump	17.8 cm±2.5 cm (7.00 in.±1.00 in.)		17.8 cm±2.5 cm (7.00 in.±1.00 in.)	
Concrete unit weight	2,375 kg/m^3 (148.3 pcf)		2,383 kg/m^3 (148.8 pcf)	

ft) of height was required for the exterior panels because they extend below the slab surface and rest on the strip foundation.

The width of the strip foundation around the perimeter of the building was approximately 0.9 m (3 ft). After the panels are erected, the gap between the outside dimensions of the floor slab and the final interior face of the exterior tilt-up panels is filled with concrete to complete the slab up to the wall. Reinforcing bars extended outward from the previously placed casting slab and the tilt-up panels so that when the concrete was placed in the space between the slab and the interior of the panel wall, the structural systems were tied together (Fig. 2).

The wall panels range in size from 2.3 m^3 (3 yd^3) of concrete weighing 5,441 kg (12,000 lb) to 11.5 m^3 (15 yd^3) of concrete weighing 26,298 kg (58,000 lb). The panels were reinforced with number 5, grade 414 MPa (60 ksi) reinforcing steel.

Blockouts for doors and windows were created in the panels. Diamond shaped blockouts (Fig. 3) were formed into the upper portion of some panels. These particular concrete void spaces later receive decorative windows. Knockouts were created in certain sections of some panels. In these areas, there is no reinforcement or electrical conduit. The outline of the knockout area is grooved 2.5 cm (1 in.) into the panel sections. The knockouts are created so that in the future if a tenant should choose to place a door in that panel, it is possible to easily remove the concrete section by saw cutting without striking any reinforcing steel or electrical conduits. The tilt-up concrete panels are designed to be structurally sound with the knockouts removed.

With tilt-up panel construction, the layout of the panels can be accomplished in many ways. All of the panels can be cast on the slab-on-grade if there is sufficient room. If there is not sufficient room, some of the panels can be cast on a false slab (temporary slab) that is constructed beside the project. If site conditions greatly restrict the available slab area, panels can be constructed on top of one another. This concrete contractor has performed stacked operations successfully, with up to eight panels piled one upon another. On this particular project, there was sufficient space for the placement of all of the wall panels on the building slab.

Each wall panel had a particular function and place that it belonged to in the overall structure. The goal was to cast the panels in close proximity to their position in the erected structure.

Fig. 2. (Color) Reinforcing bars extending outward from the previously placed floor slab and the tilt-up panels

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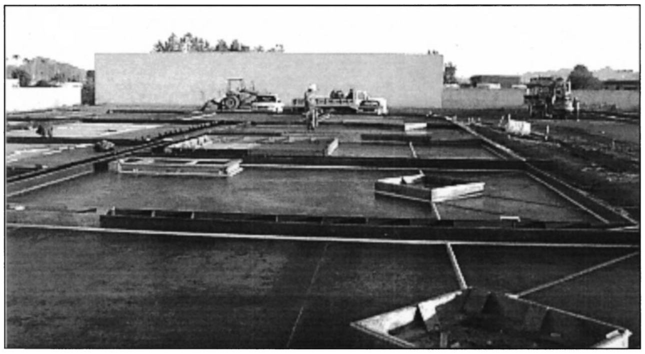

Fig. 3. Panel edge forms set on the slab on grade. Blockouts are shown for windows and doors.

They did not have to be directly adjacent to their final erected location, but they were laid out on the slab in a pattern that minimized crane time during the erection. The panels are usually erected in a clockwise rotation, starting from a chosen building corner. To ensure a proper placement sequence, the erection of certain panels at the correct place and time requires some panels to be rigged and hoisted over or around others that remain in their horizontal cast position on the slab.

Planning the panel layout is a critical part of this construction technique. The planning resembles a game of chess, and the proper strategy ensures that the erection of the panels runs smoothly. The technique requires good planning, because once the concrete is placed in the forms, it is very costly to change the operation. The goal is to erect the panels in an efficient manner.

Setting Forms

The wall panel forms are installed upon the building's slab-on-grade as soon as that concrete work is completed. This operation includes the panel formation, and the placement of reinforcing steel, cutouts, lift and brace points, ledger plates, and conduits for the electrical utilities.

A panel placement map is used to lay out the panels on the building slab. On this project, a spacing of at least 2 ft was used between the edge forms of the panels to allow for work in and around the individual panels. After the panels had been laid out on the slab, the wall panel edge forms were positioned accordingly. Steel concrete edge forms having an angle iron shape were used on the project. The legs of the angle had triangle shaped supports closely spaced horizontally. The concrete edge forms had 190.5 mm (7.5 in.) by 165.1 mm (6.5 in.) legs. The panels that formed the walls were required to be 203.2 mm (8 in.) in thickness. Since the forms were not that tall, 12.7 mm (0.5 in.) pieces of plywood were placed underneath the forms to provide the increased height. RAWL nails were used to hold the forms in place (Fig. 4). In this case, the nails were double headed 6.4 mm (0.5 in.) by 70 mm (2.75 in.) spikes. They were hammered into holes that had been predrilled into the floor slab. Because of the double head, they can be easily removed with a crowbar.

Blockouts for windows, doors, overhead doors, and guttering were formed inside the edge forms (Fig. 3). The locations for the knockouts were marked at this time. Some of the window blockouts and most of the gutter blockouts were placed along one edge of the panel. These windows and gutter locations were at locations where the panels would be spliced together. Some of the

Fig. 4. (Color) 6.4 mm (0.5 in.) by 70 mm (2.75 in.) double headed RAWL nail

gutter blockouts were divided between two panels, so that when the panels were erected the vertical seam would be hidden behind the gutter piping mounted on the panel exterior. Chamfer strips were positioned along each panel edge. The chamfer strips are 45° angle 2.5 cm (1 in.) wood slats. The chamfers are used so that when the panels are lifted and placed, the concrete is not damaged along its edges. For architectural purposes, medium density fiberboard slats were embedded on three of the diamond shaped windows' four corners. These slats create small but noticeable grooves in the concrete to add aesthetic variation and texture to an otherwise flat exterior wall surface.

To prevent the wall panels from adhering to the concrete slab-on-grade, a commercial concrete curing and bond-breaking compound was applied to the surface of the slab (Clean Lift 90). This was the same compound that had been used previously as the curing chemical for the floor slab. A bond breaker prevents the panel concrete from bonding with the slab, thus permitting the lifting of the wall panels from the slab-on-grade without damage to either. Before the bond breaker can be applied, the slab surface must be cleaned and allowed to dry. To clean the slab, it was first swept with a broom. A vacuum was then used to collect any standing water. Finally, compressed air was used to remove any remaining small dirt or dust particles. The bond breaker is applied with sprayers at a coverage of approximately 9.8–14.7 m^2/L (400–600 $ft^2/gal.$). If the bond breaker is applied and subsequently the slab surface gets dirty or rained upon, the process of applying the compound must be repeated.

Once the bond breaker is applied, the crew has to be very careful not to contaminate the surface. All materials brought onto the casting area atop the slab-on-grade must be thoroughly cleaned. It is important to expedite the work once the bond breaker is applied. The placement of the concrete must follow as quickly as possible, so nothing can contaminate the coating. If everything is installed, reinforcing steel, blockouts, and electrical

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Fig. 5. (Color) B-75 coil insert used to temporarily attach wall panel braces

Fig. 6. (Color) Super Lift III insert, which is installed in the wall panel to form a hoisting point

conduits, and then it rains before the concrete is placed, the bond breaker must be reapplied. This can be a significant schedule and cost issue. It the bond breaker must be reapplied, extra precautions must be taken not to contaminate any of the reinforcement, ties, supports, conduits, lifting inserts, and ledgers.

After applying the bond breaker, the next step is the placement of the electrical conduits. Following placement of the conduits, the lifting and anchoring inserts, reinforcing steel, and ledgers can be added. During the form setting process, the inserts were added to the wall section so that the panel can be lifted, erected, and then temporarily supported until the roof diaphragm is installed. On this project, B-75 coil and the Super Lift III inserts were used. Each insert has its own particular end use. The coil insert is used to attach braces that run between the floor slab and the panel once it is positioned and erected vertically. The number of inserts depends on the size of the panel. The coil insert is a single bolthole insert that is 1.9 cm (0.75 in.) in diameter, and has 0.6 cm (0.25 in.) threads (Fig. 5). There is a plastic blockout extension that sticks out of and above the panel slab when the concrete is placed, so that the insert can easily be found when needed.

The other inserts installed in the wall panel form are for the crane hoisting operation. On this project, four lift inserts/anchors (Super Lift III) were placed in each panel (Fig. 6). They were placed in sets of two along the long dimension of the panel (the vertical dimension when erected). The lower inserts were placed about four-sevenths from the top of the panel, and the upper inserts were about one-seventh from the top of the panel. The lift insert has a plastic half-moon void former on the anchor. When the plastic is removed, the metal loop anchor is exposed. The lift insert must not be tipped more than 20° in any direction or protrude above the surface of the concrete, because the lifting bail must bear on the void that is formed in the concrete. The void that is formed must match the smooth surface of the plastic former. After the concrete is placed, the void former is stripped and the void is cleared of debris and checked for smoothness to ensure that it provides the proper bearing area. If it is correct, then the void is ready to be used for lifting. If the formed surface is not smooth, then the void must be repaired using nonferrous nonshrink grout.

The inserts were set in designated locations in the panel. Their locations had been calculated so that when lifted, the panel hangs vertically. The position of the inserts cannot vary by more than 0.3 m (1 ft) from the calculated location. The lift bail must attach to the inserts within this area, or the panels could fail simultaneously during hoisting. With the size and weight of the tilt-up panels, it only takes one mistake, such as incorrect insert installation, to cause an unstable and potentially dangerous lifting situation. After the inserts were set into the panel forms, the reinforcing steel and ledgers were placed.

The reinforcing steel was number 5, grade 414 MPa (60 ksi). It was placed horizontally and vertically across the panels in a single layer (Fig. 7). The reinforcing steel was tied, with number 4 ties, and separated 76 mm (3 in.) from the floor slab by plastic spacers. Reinforcing steel was installed in the entire tilt-up panel, with the exception of those areas that were intended to be knock-

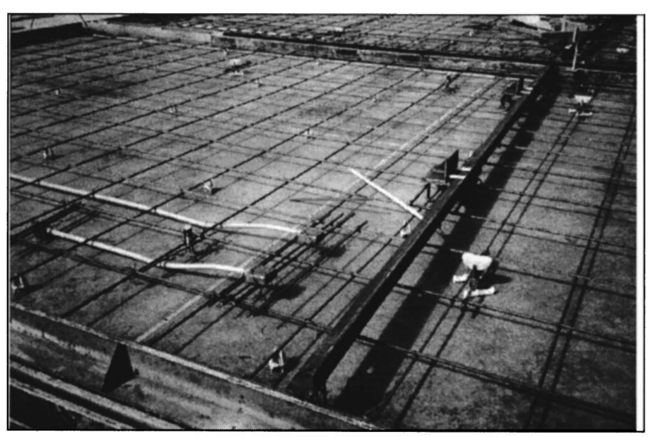

Fig. 7. Formwork with reinforcing steel, electrical conduits, inserts, and ledger plates in place

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Fig. 8. (Color) Concrete tamp like the one used during the tilt-up panel concrete placement

outs. One-meter (3.1 ft) vertically standing reinforcing steel was installed along the bottom of the panel. This reinforcing steel was to be overlapped with the reinforcing steel protruding from the floor slab (Fig. 1). When the tilt-up panel is erected in the trench, and the floor slab-wall gap is filled with concrete, this reinforcing steel provides continuity between the wall and the slab.

The other items to be placed in the formwork were the ledger plates and delivery door protectors. The metal ledger plates, which are partially embedded in the concrete, provide bearing support for the roof trusses and girders. The delivery door protectors were pieces of angle iron that were placed at the bottom threshold of the overhead door blockouts. The metal protectors are used to keep the concrete edges from being damaged by delivery trucks and any other traffic that might in the future strike the edge of the door's bottom concrete surface.

Concrete Placement

The next step in producing tilt-up concrete wall panels is concrete placement. On this project, concrete placement began at 2 a.m. The placement was performed in the early morning for two reasons. First, in Arizona, the temperature would be too high during other parts of the day. Second, that time was chosen to minimize conflicts between city traffic and the ready-mix trucks delivering concrete. The concrete was placed with a Schwing concrete pump truck having a 52 m (170 ft) boom. The pump truck had two chutes by which the concrete from the ready-mix trucks discharged into the pump. The ready-mix trucks carried 7.6 m^3 (10 yd^3) of concrete, and the pump had a capacity of pumping 163 m^3/h (213 yd^3/h). Two ready-mix trucks could be stationed behind the pump at the same time. The trucks would sequentially discharge concrete into one of the hoppers. The placement of the concrete was limited by the truck delivery rate, which was approximately 46 m^3/h (60 yd^3/h). The pump was, in fact, capable of pumping concrete faster than it could be delivered.

The concrete used in the panels was 27.6 MPa (4,000 psi) at 28 days (Table 1). During concrete placement, slump tests were performed on a regular basis. The concrete was designed having a 17.8 cm (7 in.) slump.

A crew of 15 men and a foreman placed the concrete in the forms. Due to the large panel sizes, a large crew was needed.

Fig. 9. (Color) Burke braces temporarily supporting erected wall panels

There was one pump operator who used a handheld remote to control the boom and the flow of concrete. There was one laborer who guided the end of the boom hose trunk. The placement started furthermost from the outside edge of the forms of the panel, and the laborer worked his way across and back in a zigzag manner to fill the interior of the tilt-up panel forms. Three men worked spreading the concrete. Two laborers used vibrators with 5 cm (2 in.) heads to consolidate the concrete. Whenever inserts, anchors, or other types of units are embedded, it is necessary to achieve good consolidation of the concrete around each item. Without good consolidation of the concrete, the embedment could possibly pull out at well below its expected load.

Two screed and rod laborers followed the pump/distribution operation. To knock down the concrete, they used a 10.9 m (36 ft) long 2 by 4 that stretched across the width of the panel. They made several passes over the panel or parts of the panel before moving to the next panel. After the screed laborers left an area, one man using a concrete tamp (Fig. 8) followed. He walked backward through the concrete in a zigzag manner, completing the tamping.

The final members in the concrete placing crew were the four floaters and finishers. Two men operated ''bull'' floats; they accomplished the final finishing atop the interiors of the placed panels. The last two finishers in the crew used magnesium floats. The 15th member of the crew was the spotter. The spotter was responsible for ensuring that the reinforcements, conduits, and

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Fig. 10. (Color) Extendable end of a Burke brace

Fig. 11. (Color) Spreader bar with pulleys attached at each end

inserts that had been placed in the forms were not damaged or displaced during concrete placement. The project foreman directed the concrete operation and helped individual crew members as necessary.

For a typical 9.1 by 7.9 m (30 by 26 ft) panel, the concrete placement required a little more than 10 min, from the start of the placement to the final finishing. The whole process ran sequentially, with each individual operation following the other. The laborer who guided the pump boom periodically required the pump operator to slow the concrete pumping rate because the ready-mix truck delivery volume was received at such a rate that it tended to create large piles.

The crew members coordinated their multiple concurrent work activities. Everyone maintained a good sense of position and did not step on or knock over any of the knockout markers, surface electrical items, inserts, or reinforcements, thereby producing high-quality precast tilt-up panels.

After the concrete was placed and finished, the concrete cure and bond breaker Clean Lift 90 was applied to serve as a curing seal. The curing duration was seven days. Additionally during the curing period, the concrete was periodically wetted. The holes for the brace bolts and ring clutches in the inserts and electrical devices were cleaned of concrete the next day. The yellow plastic extensions from the coil inserts and void formers for the lift inserts were removed. The formwork for the doors, windows, and overhead doors was also stripped the next day.

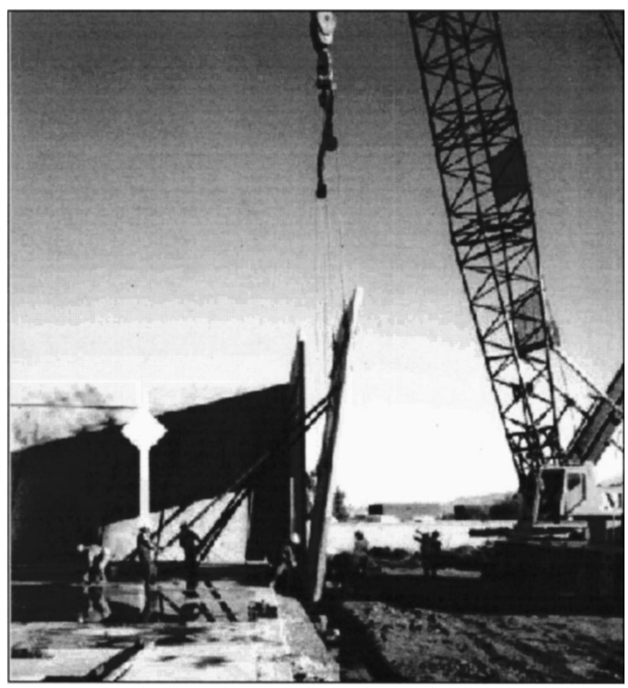

Fig. 12. Mobile lattice boom crane (300 t) erecting panels

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Fig. 13. (Color) Finished building

Erecting Panels

The final phase in the concrete tilt-up panel construction process is the panel erection. After the panels had cured for seven days, the edge forms were removed and Burke braces were attached (Fig. 9). The Burke brace is a metal rod, extendable at each end (Fig. 10). These are used to support the panel temporarily when it is positioned vertically. They are removed when the panel is permanently fixed in place. The braces are bolted into the designated holes and laid on top of the panel until the panel is lifted.

The hoisting of the panels required the use of a 300-t mobile lattice boom crane. The crane began the wall panel erection sequence by hoisting panels at the northeast corner of the building, and moved in a clockwise direction around the floor slab, lifting each panel. The panel lifting and temporary securing process required three days. Since the crane is expensive to rent and operate, it is imperative that the proper lifting sequence be followed, so that the crane can erect as many panels as possible without having to be repositioned. Following the planned lifting sequence maintains both project safety and the schedule.

Erection Cycle

The first steps in an erection cycle were to (1) position the crane to hoist the selected panel; and (2) attach the specialized rigging system to the wall panel. The crane lowered a spreader bar, which had a pulley attached at each end (Fig. 11). A single wire rope passes over each pulley, and each end of that rope is connected to one of the two anchors along one edge of the panel. This provides a self-adjusting mechanism, which allows the panel to swing from the horizontal to the vertical position as it is lifted from the floor slab. The shackles are used to attach the wire rope to lift bails, and each lift bail is attached to a ring clutch. The ring clutch bears on the concrete at the top of the void created by the plastic void former of the Super Lift III insert, and at the same time engages the anchor eye of the Super Lift III embedment. The manufacturer of the ring clutches, which are reusable hardware, recommends a safety factor of 5 to 1. For the lifting anchors, the recommended safety factor is 4 to 1.

Each lift bail has a handle with a specialized release mechanism that can be operated by a connecting chain or rope. When everything is connected, the panel is lifted from the slab. The top of the panel lifts first, and slowly the panel is rotated/hoisted to the vertical position.

The 10-man erection crew included a crane operator and oiler, and seven men and a foreman on the ground handling the panels. Two men handled the Burke braces. They hand carried the trailing end of the braces behind the moving panel so the braces did not damage the concrete floor slab or adjacent tilt-up panels still lying on the slab. Two more men, positioned one on each side of the panel, helped direct and guide it into position. They aligned the panel into the foundation trench, or the marked spot on the interior slab, and next to the previously erected panel (Fig. 12).

Once the panel was leveled and plumbed, the braces were attached to the slab by two laborers, one man to each of the two panel braces. The braces were designed to maintain the panels upright and to resist the forces of a 100 km/h (60 mph) wind load.

It is not recommended to hoist panels into position if the wind is blowing in excess of 33 km/h (20 mph), due to the fact that the panel will move like a large sail. Also, with the exception of the rigging crew, no personnel are allowed within 1 $\frac{1}{2}$ times the panel height, so that if an incident should occur, there is a safe work perimeter.

Once the brace had been extended to the proper length and had come into contact with the ground, the two men positioned next to the braces drilled holes into the slab and then placed 19 mm (0.75 in.) expansion bolts in the slab to anchor the braces (Fig. 9). After the braces had been firmly attached to the slab, the crane rigging system was detached from the panel by a laborer who pulled on the handles, which released the ring clutch from the panel.

After the tilt-up panels are erected, the roof system is placed on the structure. At the same time, the trench at the bottom of the panels is filled with concrete, securing the panels to the foundation. Once both of those operations are completed, the temporary Burke braces can be removed.

Conclusion

Tilt-up concrete wall construction is an innovative construction technique. It may seem like a simple process of placing concrete into a form, letting it cure, and then simply lifting the panels into place. However, the process requires careful planning and prepa-

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ration. A great deal of attention to detail is necessary. All work activities including the crane movement between individual picks must be planned. The planning, scheduling, and safety issues on these types of projects are being continuously improved. The final building is a high-quality, aesthetically pleasing structure (Fig. 13).

Acknowledgments

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References

Allan, E. (1990). *Fundamentals of building construction materials and methods*, 2nd Ed., Wiley, New York.

Hornbostel, C., and Hornung, W. J. (1982). *Materials & methods for contemporary construction*, 2nd Ed., Prentice-Hall, Englewood Cliffs, N.J.

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