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Tilt- Up Construction and Design Evaluation and Methodology

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Tilt – Up Construction and Design Evaluation and Methodology

by

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Dedication

En Memoria de mi Abuelo Roberto Schuldes Niebl

To my parents Roberto and Natalia Schuldes

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by

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The University of Texas at Austin, 2012

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Tilt-up construction basically involves job-site prefabrication of concrete building members under controlled and relatively economical conditions. This master's report presents tilt-up design procedures, along with construction procedures and planning at the job-site, erection, finishing and architectural treatments. It is intended to bring together the five steps of design, planning, construction, erection, and finishing which are crucial to a successful tilt-up project.

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Chapter 1: Introduction

Tilt-up, tilt slab, or tilt wall is a type of building and a construction technique using reinforced concrete. Descriptions of tilt-up construction abound throughout history and some experts believe that tilt-up construction originated more than 2,000 years ago when Roman architects discovered the ease of casting a slab of concrete onto a graded ground surface and tilting it into position [10]. It was in the early 1900's, when concrete was rapidly becoming the most popular building material, that engineer Robert Aiken introduced the construction method now known as tilt-up construction. Aiken was designing and building reinforced retaining walls at Camp Logan Rifle Range in Illinois. Instead of using the traditional method of cast-in-place concrete walls, Aiken poured the walls on a casting slab flat on the ground and tilted the panels into position. Aiken then used steel rods to anchor the walls into the concrete footing until the entire structure and roof diaphragm was in place. Aiken soon realized that this building method would be advantageous if implemented correctly and used it in several buildings throughout Illinois. The first complete tilt-up building was a concrete factory near Zion City, Illinois.

Although tilt-up construction had been known for a long time, it was not until the late 1940's that it really started gaining popularity with the introduction of the mobile crane. The mobile crane facilitated the panel erection process and allowed for larger panel construction. Ready-mix concrete also started to become available, allowing tilt-up construction to become more efficient and cost effective [10].

These innovations could not have come at a better time. After World War II, business in the United States was booming, subsequently increasing the demand for commercial and industrial structures. Because tilt-up construction allowed contractors to offer high quality projects at a cost effective price and with a reduced construction schedule, the process quickly became increasingly popular. Since that time, tilt-up construction has undergone many more innovations and refinements, and has now developed into a building method commonly used by many concrete contractors and general contractors in the construction industry [1].

Chapter 2: Design of Tilt-Up Panels

Tilt-up construction basically involves job-site prefabrication of concrete building members under controlled and relatively economical conditions. It consists of prefabricating concrete wall panels or slabs horizontally on the floor slab or a temporary casting surface, then tilting and lifting them up using a crane and setting them in place, where they will eventually become an integral part of the structure.

Numerous design options are available for tilt-up construction varying from project to project. In the design of a tilt-up structure, the panels themselves should always be designed to withstand the in-place loads, lifting loads, and whatever features that the wall will have. Architectural features such as color, finishes, exposed aggregate or rustications should also be incorporated in the design. The designer should also take into account the lifting inserts layout; usually it is done after all other aspects of the design are complete. The following criteria should be considered when designing a tilt-up panel:

Loads

Wind loads usually control the design of tilt-up panels, although seismic accelerations may be occasionally significant, especially in areas of high seismic activity. Building codes like the ACI Building Code Requirements and the Canadian Code for Concrete Structures should always be consulted to meet all design requirements. It is suggested that the design lateral pressure should never, in any case, be taken to be less than 0.5 kPA (10 psf) neither in the positive nor negative direction [4].

Axial loads can be considered to act as uniformly distributed loads along the top of the panel. If heavy point loads occur, they should be distributed over the load length plus 12 times the panel thickness. The effect of the panel weight can be approximated by assuming that a portion of the total weight acts at the top as a concentric axial load. Since the critical section is generally at or above the mid-height, it is conservative to use 1/2 the panel weight. For panels with large openings, the location of the critical section for bending will change and engineering judgment is required in determining the effect of P-delta. Changes in panel stiffness and application of loads will each affect the location of the maximum design moment [12].

Axial loads are always applied at some eccentricity from the center line axis at the panel, either intentionally or due to irregularities. Even if loads are intended to be concentric, a minimum eccentricity of 1/3 to 1/2 the panel thickness is recommended for design computation where the effect is additive to the wind load, and zero were the reduction of total moment would otherwise occur. Eccentricity at the bottom is generally zero. Load combinations are specified in the relevant codes; wind and load combinations often govern [12].

Bending Moments

The design bending moment is the result of several effects, including lateral loads, vertical loads applied at some eccentricity, initial out-of-straightness, and P-Delta effects produced by vertical loads. The maximum bending moment usually occurs about mid-height of the wall panels. Bending moments occur at a location other than mid-height when panels have large vertical loads or large eccentricities. Common practice combines the effects of all applied loads to obtain the maximum moment acting on the panel. The P-Delta moments are very difficult to calculate because they require the determination of the panel bending stiffness, which is difficult to calculate due to the nonlinear properties of concrete. For this reason it is common to use approximate values [12].

Effective Height

It is highly recommended that all panels be considered to be pinned at each end, unless the bottom of the panel is fixed so that all rotation is prevented. In that case, a reduced effective height in the order of about 85 percent of the clear distance between supports may be used. For panels continuous over a horizontal support such as a floor slab, the mid-height moment may be assumed to be less than that corresponding to simple support conditions. However, in view of the uncertainty of the exact degree of constraint provided by the footing, this moment should correspond to an effective height of at least 90 percent of the actual height. The point of inflection should not be assumed to be more than 10 percent of the height above the floor [14].

Creep and Initial Deflections

Long-term deflections associated with creep are generally not considered since dead load deflections are significantly smaller when compared to those from wind load deflections. Initial deflections or unevenness of the walls caused by shrinkage or by casting on uneven floor slabs, or casting slabs can be approximated by adding a small deflection at mid-height when calculating the primary bending moment.

Deflections at roof level, caused by the flexibility of the roof diaphragm, have no influence on slenderness effects unless there is fixity at either the top or bottom of the panel.

Panel with Openings

Panels with openings are becoming more and more popular. These panels can be analyzed by finite element methods, but this is a very expensive and time consuming process. An approximate analysis generally provides results that are sufficiently accurate for most designs. Local codes should be consulted to meet requirements.

Where openings occur, the lateral and axial loads, including self-weight, on the entire panel must be carried by the continuous vertical legs on each side of the openings. If there is more than one opening, vertical legs should be able to carry all loads. Often, it is only necessary to increase the loads acting on the legs by the ratio of the total panel width to the leg width. Some designers may assume point loads are exerted by door and window frames.

When the remaining panel width besides the opening is significantly large, the width of the leg carrying the additional loads should be restricted to approximately 12 times the panel thickness in design calculations. The use of a greater width may fail to detect the danger of buckling. For very wide openings, it is recommended to design the panel legs or segments as beam columns extending the full height of the panel. In some cases design loads may be substantial. Items to consider in the design are:

- Use of additional reinforcement on both faces of the vertical and/or horizontal panel segments and use of closed ties
- Effective width of the segment
- Bearing stress limitations at base of the panel
- Need for thickened pilasters
- Design of the panel above the opening for out-of-plane forces
- In-plane shear and frame action

Since the panel reinforcement around the openings, and determined by analysis, is often considerable, added crack control reinforcement may not be necessary [4].

Intermittent Footings

Panels are often supported on isolated footings at their ends. The designer can handle this by assuming that the reaction at the footing spreads into the panel at some angle to the vertical direction. The axial compression then increases linearly from the top to the bottom of the panel; the effect can be modeled by assuming an effective self-weight [4].

$$W_s = W_s \frac{BL}{2A} + P\left(\frac{B}{2A} - 1\right)$$

Where	W_s	=	actual wt/unit area of wall
	B	=	length of wall
	L	=	height of wall
	A	=	length of each of two isolated footings
	P	=	total value of load on panel top

Half of this effective self-weight is then added to the applied load on top of the panel [4]:

$$Total\ Load = P + \frac{1}{2} W_s$$

$$= P + W_s \frac{BL}{4A} + \frac{P}{2}\left(\frac{B}{2A} - 1\right)$$

In-Plane Shear

Tilt-up panels are generally used as shear walls for building stability. In-plane shear is significant for high, narrow panels with substantial shear loads applied at the top. Analysis of the panels should include in-plane shear stresses, panel stability, and floor and roof diaphragm connections. Shear load may be converted into an effective self-weight at the outer edge of the panel. In most cases, this involves applying one-half of the total effective self-weight at the top of the panel. If the edge is stable under the combination of this load with the lateral wind force, then no further bracing is necessary. If this is not the case, a thickened edge beam may be added or panels can be connected together so that the compression edge of one panel is tied to the tension edge of another panel. If panels must be connected to other panels to increase stability, it is suggested that they be connected in groups with as few panels as needed to satisfy overturning requirements [12].

Lifting Stress

As the tilt-up panel is picked up for erection, it is immediately subjected to bending that causes both compressive and tensile stresses which must be resisted by the panel. Manufacturers of inserts locate the picking points so that the overhanging portions of the panel will reduce the bending moments between pickup points, therefore reducing the compressive and tensile stresses in the concrete. The flexural stresses can be determined by treating the panel as a beam supported by tension loads on the inserts and the ground reaction. The gross concrete section of the panel is used as lifting analysis. The load applied along the beam is the normal component of the panel self-weight. The tension and shear loads on insets vary as geometry in the rigging changes. Maximum stress usually occurs at 0 degrees and between 30 and 50 degrees for two and four row lifts [12]. In the case that the allowable stresses are exceeded, additional reinforcement, higher strength concrete, strongbacks, or another lifting arrangement should be considered.

The value of allowable tensile stress in the concrete is a function of the modulus of rupture and the safety factor used at the time of lifting. For single panels and noncomposite sandwich panels an allowable flexural stress of 5.5 to 6.0 $\sqrt{f^c}$ yields satisfactory results using normal weight concrete. To analyze horizontal tension loads you only need to calculate insert tension loads at 0 degree inclination, because loads acting on the panel on the horizontal direction are greatest at this point [4].

Temporary Bracing

Once the panels are erected in place, tilt-up panels must be temporarily braced against wind loads and other lateral forces until all final structural connections are completed. The most commonly used method for bracing tilt-up panels is the use of telescoping pipe braces [12].

Chapter 3: Construction Planning and Construction of Tilt-Up Panels

Construction Planning

Good planning is a key part of all successful construction work, but it is especially critical in tilt-up construction if all the cost, schedule, and safety benefits are to be realized. As mentioned in the ACI 551-R Tilt-Up Concrete Structures, "Success of each construction sequence depends on the success of the preceding construction event." Successful construction of tilt-up panels requires careful organization and planning.

It is recommended to check site access and the jobsite conditions as an early step of construction planning. It is common for permits to be required by different entities depending on the location of the jobsite. For example, special permits are required for schools and churches since these are usually built in residential areas where tonnage restrictions, noise abatement, and dust control regulations could exist. The contractor and erection sub-contractor, if any, should determine site access and the building access for the crane. Problems with uneven terrain or obstruction from other construction trades should be noted and solved beforehand. Additionally, a suitable location for crane assembly and rigging should be determined. Some local governments will not allow this activity on public streets. In the early stages of construction planning it is important to be aware of overhead wire problems. In some cases it might be necessary to shut off power or lifting panels on premium costs days (Saturdays, Sundays, and Holidays) when the power outage is least disruptive to surrounding property owners.

Panel drawings can usually be found on the architect's /engineer's plans. Complete panel drawings are essential. Plans should include panel identification, dimensions, physical characteristics, reinforcing, location and identification of embedded items, insulation (if applicable), finishes and textures, and rigging and bracing information.

To insure an efficient construction procedure, consideration must be given to casting location of panels and erection sequence. The contractor should develop a panel casting layout, which can include temporary casting slabs or the floor slab, which will ensure the most efficient casting and lifting of the panels. Panels must be properly located to have efficient construction access and to minimize crane movement. Prior to panel erection, it is important to watch for special bracing conditions, particularly at corners and other interruptions of a straight building line. Cross-bracing will be required at the corners, where braces will be required to pass either over or under the braces of the previously erected panel. Avoid "fill in" panels where possible. It is recommended for panels to be erected in a consecutive way were possible. A casting layout and erection sequence plan should be made by drawing the floor plan and placing on it cut-outs of the panels in their proposed casting locations. Use the cut-outs to evaluate the panel erection sequence and identify any possible cause of delay [12].

Casting Surface

The concrete floor slab is usually the most convenient place for casting tilt-up panels. It is recommended for the floor slab to be placed as soon as possible as it used as the "work table" for all tilt-up panel forming, casting, bracing, and erecting. If the floor slab is not available or there is simply not enough space available for casting the panels, panels can be "stack-cast" one on top of another or in a temporary casting platform or casting bed on an accessible location outside of the building. Figure 2 illustrates the floor slab being used for casting tilt-up panels during the Gupton Stadium project in Austin, Texas.

The floor slab must be level and smoothly troweled for a high quality finish. A smooth surface is important to prevent mechanical bonding and is necessary for clean cleavage when lifting. A properly constructed floor slab should have a compacted subgrade with adequate strength and thickness to carry the loads of material trucks and heavy mobile cranes that may be needed in the erecting process. Floor slab jointing should be located between panels whenever is possible. If the floor contains openings for pipes or other utilities, a ¾-inch skin coat over sand fill can be used to close up the openings temporarily [13].

Edge Forms

One of the advantages of tilt-up construction is the savings in form material and labor. Panel edge forms, which are a relatively easy form to erect, should be securely bolted or weighted down to the casting surface. Top and bottom edge forms need to be braced and squared (See Figure 1). A recommended method for securing panel edge forms, is to make L-shape forms on the site or use prefabricated steel angles, then anchor them to the floor slab by drilling 3/8-inch holes through the forms (prefabricated steel angles should already have these holes) into the casting slab, and anchored with double headed form nails wedged into the hole in the concrete. Using pieces of plastic wedged between the nail and the concrete also facilitates the stripping of the forms when removing the nails from the casting bed. Holes can be patched with epoxy at completion of the work [12].

In constructing panel forms it is important to avoid variations in form measurements and insure a good straight line in the panel sides and from panel to panel. It is recommended to use a chalk line for laying out the forms, and

Figure 1: Tilt-Up Panel Forms at Cedar Creek High School, Austin, Texas

Figure 2: Casting Slab and Tilt-Up Panels at Gupton Stadium, Austin, Texas

spraying a sealer over the chalk so weather will not wash the lines away. Slight variations in form measurements will result in plumbness variations and will affect joint dimensions.

Windows and door openings in panels are usually not a problem to form. The common method used by contractors of including windows or doors in a tilt-up panel is to cast directly against the steel sash or frame. All opening forms should be held down on the casting slab with either weight or by the method described above. Exposed surfaces of sash or frame should be given a coat of bond-breaking compound to prevent concrete adhesion.

Bondbreakers

Curing and finishing of the concrete floor slab or casting slab is important to obtain a uniform surface and prevent dusting and plastic shrinkage cracks. Cracks present on the casting slab should be covered using epoxy, for they will directly translate into the panels. A good bondbreaking agent is also essential in tilt-up construction to obtain an easy lift from the floor slab. There are three basic bondbreaker types [12]:

- Synthetic petroleum, hydro-carbon, resin solutions
- Solutions of waxes with metallic soaps
- Solutions of organic esters and silicones

It is important to be aware of some of the effects each bondbreaker might have on the final appearance of the panels. For example, some bondbreakers leave residue, especially when applied excessively to the casting surface. Residues affect the coloration of the panels and can prevent adhesion of paint, adhesive, sealers, or any other treatments. If the possible effects of the bondbreaker on the panels are unknown, it is recommended to consult the manufacturer before using it.

It is very important to test the bondbreaker agent with the curing agent for compatibility, usually before casting the slab. The bondbreaker coat should be applied prior to placement of the reinforcing steel. It is recommended to apply two light coats evenly at about 600 square feet per gallon, sprayed at right angles 15 minutes apart [12]. Care should be taken to ensure that the bondbreaker is not sprayed over dirt, sawdust, dew, frost, or surface water. To avoid staining, puddles formed by the bondbreaker should be wiped off. An easy method for testing separation is to sprinkle water on surface were the bondbreaker was applied (after it dried). If the water beads as on a newly waxed floor, the panels will separate. If the water is immediately soaked into the floor, the panels need re-spraying. Bondbreakers that have been heavily exposed to rain or to weather for longer than three days should be checked. Re-spraying might be necessary. Bondbreakers not applied correctly will result on panel surfaces that stick. Not being able to separate the panels can result in damaged and cracked panels, pull out of lifting inserts, or exceed crane load capacity creating schedule delays and panel re-construction costs.

Reinforcement

The usual building code requirements for wall reinforcement call for a steel area from 0.0015 to 0.0025 times the cross-sectional area of the concrete. Number 4 deformed bars, 16-inches on center for a 6-inch panel are common [13]. Around openings, reinforcement bars are added to strengthen the corners and edges. In the locations were wire fabric is the principal reinforcement, dowel bars should be provided

Figure 3: Panel Reinforcement at Cedar Creek High School, Austin, Texas

Figure 4: Panel Reinforcement at Gupton Stadium, Austin, Texas

where panels and columns are tied together. To provide for clear cover, mats of reinforcement should be lowered onto plastic chairs [12]. Chairs made of steel wire should have plastic tips. Check specifications and design plan for additional reinforcing requirements around inserts for lifting and bracing. Figure 3 and Figure 4 illustrate reinforcing bar arrangements for different projects in Austin, Texas. If the panel dimension allows, bar mats can be tied outside of the form and placed in position once they are completed (See Figure 3 and Figure 4).

Insulation

There are a number of options for insulating tilt-up panels but the most economical method is to cast normal weight concrete directly over rigid, low density insulation which is laid in the form. Panels constructed this manner have to be cast face up with lifting inserts located on the outside surface. Another method is to install insulation panels or apply insulation directly to the inside wall surface after placing the wall panel in a vertical position.

A wall panel of sandwich construction is preferred for many buildings [13]. Sandwich panels consist of two wythes of reinforced concrete bonded together to a core of rigid, low density insulation. Sandwich panels can be load bearing or non-load bearing. It is common for sandwich panels to consist of one layer of structural concrete and the other of lighter-weight architectural concrete. The concrete layers help provide thermal mass. That is, the concrete is able to store significant amounts of thermal energy and delay heat transfer through the building walls. According to the Fundamentals Handbook of the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE), this delay leads to three important results:

- Slower response time tends to moderate indoor temperature fluctuations under outdoor temperature swings.
- In hot and cold climates, energy consumption is significantly reduced over that for a similarly sized low mass building.
- Because the mass is adjacent to the interior of the building, energy demand can be moved off-peak periods because energy storage is controlled through correct sizing of the mass and interaction with the HVAC system.

Figure 5: Panel Insulation at Cedar Creek High School, Austin, Texas

Figure 6: Panel Insulation and Connectors at Charlie Rouse High School, Austin, Texas

The first step in sandwich panels is to pour and level the exterior layer of concrete. Then the insulation panels or sheets are arranged on top of the unhardened concrete according to the individual panel drawings (See Figure 5). The insulation panels can be pre-fabricated and pre-drilled by the manufacturer. Connectors are inserted through the insulation sheets (See Figure 6). Most connectors are made from a fiber composite material consisting of continuous glass fibers and vinyl ester polymer. In the past, it was common to use steel to hold the panel together, but testing has proved that fiber composite connectors are better suited for sandwich wall construction because steel conducts heat energy at a rate over 50 times greater than that of fiber composite ties. The connectors hold the wall together by developing a keying action within the concrete wythes using specially designed notches. Connectors provided by THERMOMASS (See Figure 7) have been tested to have pullout capacities in concrete exceeding 5,000 lbs, shear capacities as great as 2,500 lbs each, and a tensile strength up to 140,000 psi [5]. It is recommended to space the connectors at 18-inch on center transversely and 16-inch on center longitudinally. Depending on panel dimensions and loading conditions, special spacing may be specified. When using fiber composite connectors, a minimum concrete wythe thickness of 2 inches is required. After placing the insulation sheets, connectors, lifting devices, bracing inserts and reinforcement, the structural or interior wythe is poured [5].

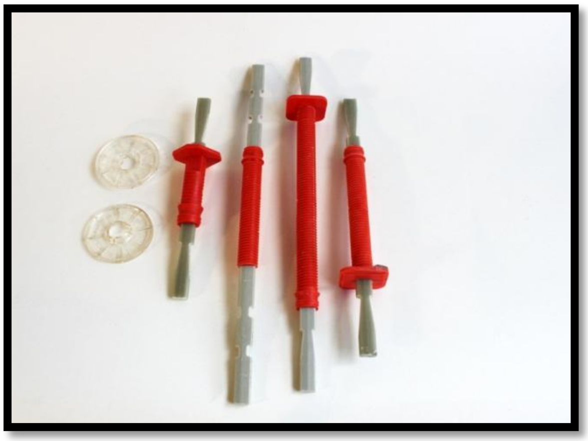

Figure 7: THERMOMASS Fiber Composite Connectors

Concrete Placement and Curing

The concrete is placed the same way as the floor slab. Care must be taken to prevent rock pockets along the bottom of the edge forms and to prevent damage to the bondbreaking material. Concrete must be properly consolidated using an appropriate vibrator. Avoid any contact between the vibrator head and the casting slab; this will affect the bondbreaking surface resulting in lifting problems. Additionally, it can damage the appearance of the exterior surface.

Layout, Alignment, Leveling, Bracing and Connecting

Prior to erection the panels should be labeled for identification, laid out on the exterior foundations, and establish the exterior wall line. A commonly use method of alignment requires the contractor to mark the limits of each panel and drill ¾-inch holes into the foundation approximately 5-inches deep. Then install #5 dowels, two on each side of the panel. This process is helpful when placing the panels as it reduces the effort in keeping the panels aligned [12].The day before erection of the panels, install shims using a level to avoid placing the panel in a tilted position and more importantly setting the panels at the wrong elevation. A simple and commonly used method is to set up the shims to

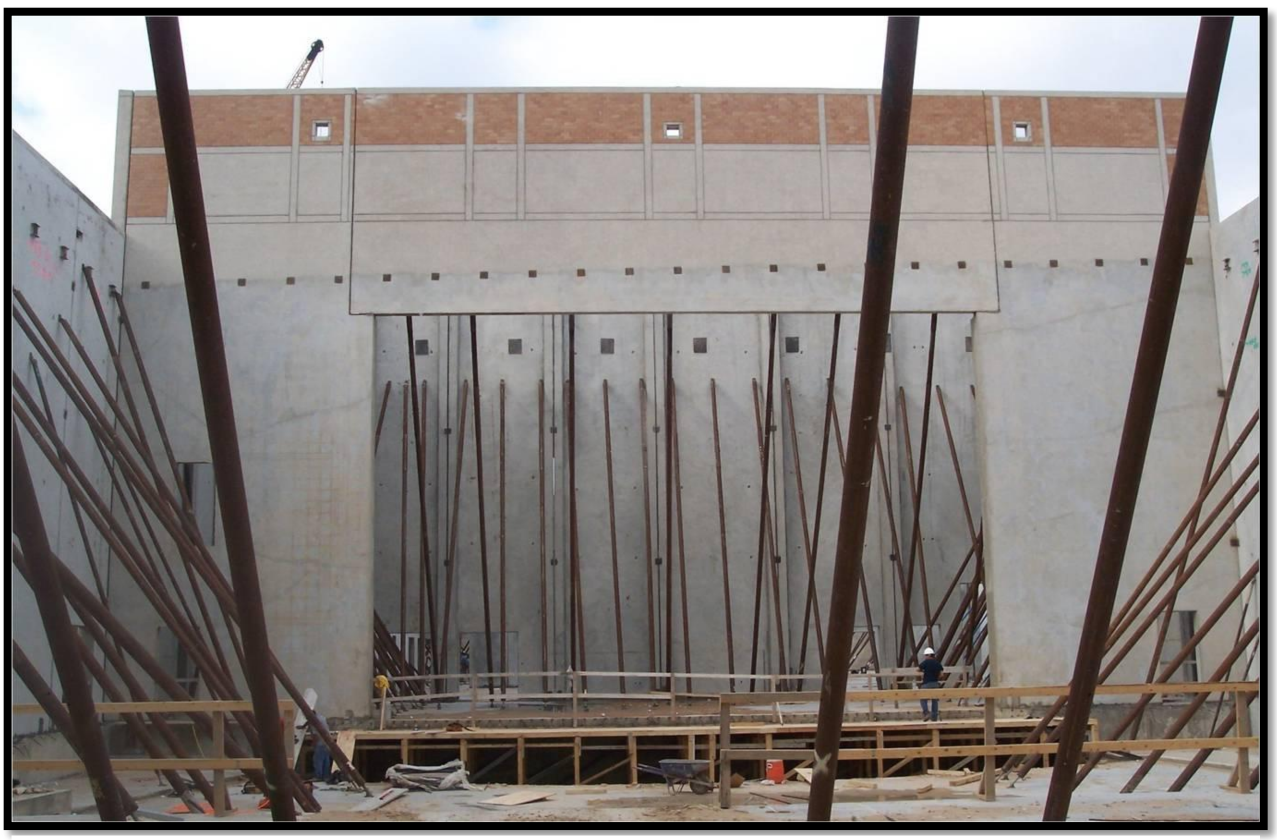

Figure 8: Complex Bracing at Charlie Rouse High School, Austin, Texas

a desired or specified elevation below finish floor or grade. After panels have been erected, it is important to backfill and compact the perimeter strip. The perimeter strip is a 3ft to 5ft wide and 4ft to 6ft deep strip at the edge of the finish floor [12]. After backfilling, grout is used to fill the voids between the panels and the finish floor.

Bracing should be done prior to erection of the panel. Bracing done after erection and while the crane is holding the panel in position is a costly procedure as it requires the use of additional equipment such as lifts or temporary scaffolding. Additionally, it places personnel in a hazardous position. Figure 9 below illustrate how complex the bracing layout can be on a given project. The braces should be adjustable and positively anchored to imbedded inserts of sufficient strength to resist both horizontal and vertical forces acting on the panel. The angle between the brace and the finish floor should be between 45 degrees and 60 degrees, all connecting bolts must be checked to ensure tightness and prevent movement of the braces [12] (See Figure 9).

After erecting all panels and completing the roof structure, it is recommended to install backer rod, spray water-proof foam and then seal and caulk all wall panel joints. If the panels are not to be painted, a cleaning agent and a sealant can be used to provide protection.

Figure 9: Panel Erection at Wiley Middle School, Austin, Texas

Chapter 4: Erection of Tilt-Up Panels

Erection of the panels is a critical phase during tilt-up construction. It is imperative that the designer, contractor, and usually an erection sub-contractor plan and check all rigging and tilting procedures carefully to ensure that the tilt-up phase is done safely and efficiently. Not planning for erection and not taking the necessary safety precautions can be fatal.

The correct crane should be selected prior to construction and based on the panel design. The general rule for sizing the crane is that the crane capacity should be a minimum of two or three times that of the heaviest panel including the weight of all the rigging gear. In addition to the general rule for sizing the crane, the American Concrete Institute recommends the following three questions to be answered before determining the crane size:

1. How far must the crane reach to lift the panel?
2. How far will the crane have to travel with the panel?
3. How far will the crane have to reach to set the panel?

After selecting the correct crane, alternative crane positions should be considered to make the erection phase as efficient as possible. When the wall panels are to be erected before construction of the structural frame or roof diaphragm, it is recommended that the crane operates on the floor slab. If this is the case, panels can be formed and casted beside each other in rows or "stack-casted" to allow a substantial amount of panels to be erected while minimizing crane movement. Before rigging the contractor should provide a clean working area and the panel should be cleaned of all debris and loose tools.

Figure 10: Panel Erection at Charlie Rouse High School, Austin, Texas

Rigging

Cables for lifting sling need to be long enough to provide at least a 60-degree angle from the plane of the panel, and the rigging should provide approximately equal stress on all inserts [8]. An even number of lifting points is recommended unless panels with special shapes require different rigging procedures like a modified M or in the case where some sort of automatic equalizing system is being used [6]. Panel erection should be done in a continuous and smooth motion to avoid overloading. It is important to make sure that the bottom section of the panel is not dragged on the casting bed or ground during erection, as this can damage the panel (See Figure 10 and Figure 11).

Figure 11: Panel Erection at Charlie Rouse High School, Austin, Texas

It is important to use wedges and pry bars to help release the panel. Panels stuck to the casting bed can double the load on the pick-up inserts causing possible withdrawal. As lifting starts and cables start to get tensioned, they will inevitably try to rotate. A rope can be used to prevent undesired rotation and to keep the panel aligned. Ropes should also be used to prevent braces from getting trapped by the rigging when the panel is being set in its final position. Braces that get trapped can damage the floor slab or cause the insert to snap, permanently damaging the panel. Braces can be very heavy depending on the size of the panel, so make sure enough personnel is assigned to this task (See Figure 12).

Figure 12: Panel Placement at Charlie Rouse High School, Austin, Texas

Placement

Avoid striking a previously erected panel or the floor slab while setting the panel to its final position. If it is a closure panel, measurements should be taken prior to lifting the panel to make sure it will fit correctly. Tilt-up panels should be as plumb as possible before attaching the braces to the floor. Temporary out-of-plumbness should not exceed 4-inches. A theodolite can be used to “fine tune” the final panel plumbness by making sure the panel is in a 90 degree angle with the floor. All pipe braces are designed to have threated adjusting units; this can be used to position the panel as plumb as possible even after the braces have been attached to the floor.

Chapter 5: Finishing and Architectural Treatments for Tilt-Up Panels

A wide range of colored coarse aggregates and sands, several possible colors of cement, and many other architectural available applications offer an owner and designer an array of possible colors and textures which can be applied to tilt-up panels. In the United States there are four or five commonly used methods for obtaining various finishes on tilt-up panels. These methods include exposed aggregate that is usually obtained by sandblasting, the seeding method, the sand bed method, and finishes obtained by using a textured liner [7]. Decorative patterns and even stone-face can also be added to obtain the desire design.

Sandblasting

The main classifications for sandblast finishes are light blast, medium exposed aggregate, and to fully exposed aggregate. This can be obtained by varying from fine to coarse sand and applying various pressures. It is recommended to sandblast the face-down of a panel because a higher concentration of aggregate, as gravity tends to move aggregate towards the bottom. Additionally, the face-down surface does not have any lifting or bracing inserts which are very difficult to patch in order to match the surrounding surface. The most commonly used finishes are light to medium exposed aggregate. The reason for this is that concrete in the panels has to reach sufficient strength to avoid creating stress and bending cracks when tilting the panels. Most contractors allow the concrete to reach at least 3000 psi before tilting, while normal sandblasting should be done before the concrete reaches 1500 psi to 2000 psi, heavy sandblasting is required making this a more costly operation [13].

When the face-down side is going to be the finished side, additional care should be taken when finishing the casting bed as the face down surface will be a mirror image of the surface on which it was casted. Subsequently, all deformities such as cracks, voids, and blemishes should be corrected to make sure they will not mar the exposed finish.

The sandblaster operator should be wearing proper protective clothing and equipped with an air-fed protective helmet. Different locations have different environmental regulations which should be thoroughly investigated. It is recommended to provide the proper dust control methods and to sandblast during the night, when there is less or no personnel working on-site. To produce the most uniform results the contractor should provide the proper equipment. This includes a compressor, rotary or screw type, which deliver uniform pressure at the nozzle.

In selecting abrasives, the flint and hydrocarbon type abrasives usually cost more than silica sand, but their properties allows for faster cutting and therefore increasing productivity. A rule of thumb is to consider that the particle size of the abrasive will work on a similar size particle on the concrete surface. For this reason a medium or coarse abrasive should be selected when a lightly blasted finish is desired. On the other hand, a finer abrasive should be selected when a deeper exposure of the aggregate is desired as the finer abrasive attacks the smaller particles in the mortar fraction of the concrete rather than aggregate. Caution has to be taken when sandblasting concrete at an early stage, as some of the abrasives may become imbedded in the concrete creating some discoloration. Also, large pieces of the concrete surface can "break-off" while sandblasting at this stage [7].

Seeding Method

To create the desired exposed aggregate finish, the aggregate can be either seeded over the fresh concrete or hand placed on a wet mortar. The method chosen typically depends on the aggregate size. To accomplish this, a structural concrete mix can be poured in the forms and consolidated to a level of 1/8-inch to 7/16-inch below the desired finish which allows for the volume of the selected aggregate to be seeded [7]. Once the structural concrete has been screeded to the proper level and consolidated, the aggregate is seeded carefully by shovel or by hand to completely cover the concrete layer.

The aggregate can be embedded into the concrete surface by using a bull float over the center areas of the panel and a darby or a straightedge along the edges and the openings. Sometimes a rolling device, like a large pipe, can be used to help embed the aggregate into the concrete surface. The contractor should regularly check the concrete mix when using the seeding method. A wet mix will allow too much of the aggregate to settle deeply into the panel while a dry mix would make it very difficult to properly imbed the aggregate. It is recommended to begin the exposure of the aggregate as soon as the concrete surface can withstand the weight of a man leaving a slight to no indentation. Weather conditions and admixtures should be considered by the contractor as they play a big role in the time and the rate in which the concrete sets. For example, in the heat of the summer, if the process is started too late, it becomes extremely difficult to get proper exposure or to finish embedding the aggregate completely as the concrete becomes drier at a faster rate. Retarders can be successfully used under proper conditions to increase the productivity by exposing a larger area per man.

The most common method for exposing the aggregate after embedment is by washing and brushing the surface. The process usually begins by using a stiff brush to remove the concrete/mortar followed by a combination of spraying water and brushing until a uniform exposure is obtained. Hand work might be necessary to accomplish the correct exposure. Sometimes it is necessary to clean the surface using a mild acid solution after the panels have properly cured. The acid helps remove any cement film that may have not been completely removed during the washing process and also helps to highlight the color of the aggregate.

The use of proper protective clothing should be worn to prevent accidents. Additionally, refer to the specifications to make sure that the cleaning agent being used meets all requirements. When special or decorative aggregates are being utilized, a sealer can be applied after the panels have been cleaned to further highlight the color and, in some cases, give the aggregate a wet and glossy appearance.

Sand Bed Method

The sand bed method is recommended when the aggregate selected for exposure is 1-inch or more in diameter. This includes large field stone materials. The two most common methods of utilizing the sand bed method to expose aggregate are: (1) Place the aggregate on the casting bed and sprinkle sand between the aggregates and (2) spread a layer of fine sand over the bottom of the form and then imbed the aggregate. The (1) method is rarely used in tilt-up construction so it is not explained with further detail.

For method (2), a layer of fine sand should be sprayed at the bottom of the form to about 1/3 the diameter of the aggregate being used. Uniform-size aggregate is preferred as it produces a more uniform exposed surface. The aggregate is pushed into the sand, tightly, to obtain the densest coverage possible. This is generally done by hand and the contractor should take caution to insure that the adequate aggregate density is obtained around the edges, corners, and openings [7].

When the aggregate is in place a fine spray of water can be used to settle the sand around the aggregate so that each piece is held securely in place. In some cases, a thin cement slurry layer can be placed over the aggregate and allowed to dry to insure that the aggregate is not dislodged when the normal concrete is being placed.

After the aggregate is imbedded, the reinforcement steel, lift and brace anchors, and all other items are placed in the form. As on any exposed concrete surface, all reinforcement support that might become in contact with the surface should be either plastic or galvanized steel. Another option is to hang the reinforcing steel and all other items from the top of the form, subsequently eliminating the need for chair support and their exposure to the surface after the panel is in place. Finally, all sand clinging to the exposed aggregate surface can be removed by brushing and washing with a high pressure hose once the panel has been erected.

Textured Line

A variety of patterns may be produced in large tilt-up panels by using plastic materials as form liners. Common liners used are vacuum-formed thermoplastics, fiberglass-reinforced plastics, or plastics formed into shape by heat and pressure. Some advantages of using this method is that liners can eliminate the extra care of preparing the casting bed so that joints, cracks, block-outs, etc… will not be reflected in the panel. Liners also provide a wide range of textures and appearances. Finishes obtained with liners include simulated sandblast, ribbed finishes, boarded textures, bush-hammered finished, and many more.

The use of liners in tilt-up construction is usually limited to larger projects where higher utilization of liners can be obtained. Liners are expensive and usually require a minimum of three to four uses to be economically comparable with other finishes. An important aspect to consider is that plastic does not bond to concrete, so parting agents are frequently not needed.

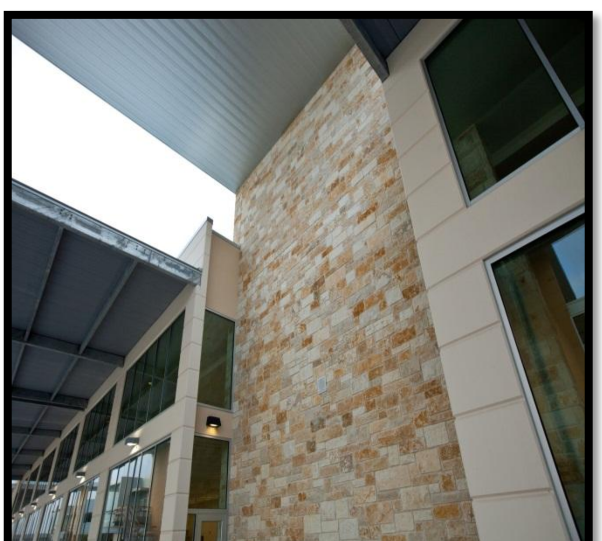

Figure 13: Cedar Ridge High School, Austin, Texas

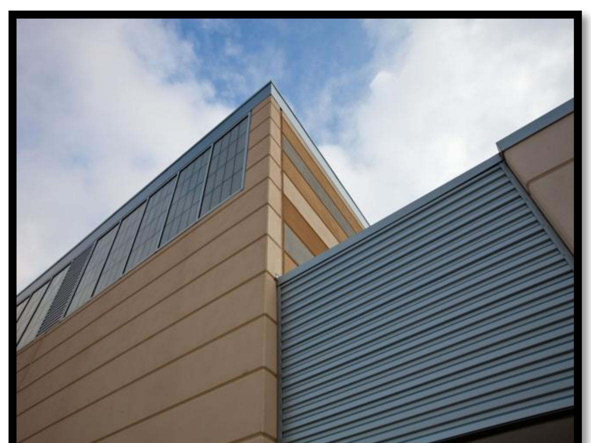

Figure 14: Cedar Ridge High School, Austin, Texas

Figure 15: Cedar Creek High School, Austin, Texas

Figure 16: Stone Finish at Cedar Creek High School

Figure 17: Charlie Rouse High School, Austin, Texas

Figure 18: Liner at Wiley Middle School, Austin, Texas

Figure 19: Liner at Charlie Rouse High School, Austin, Texas

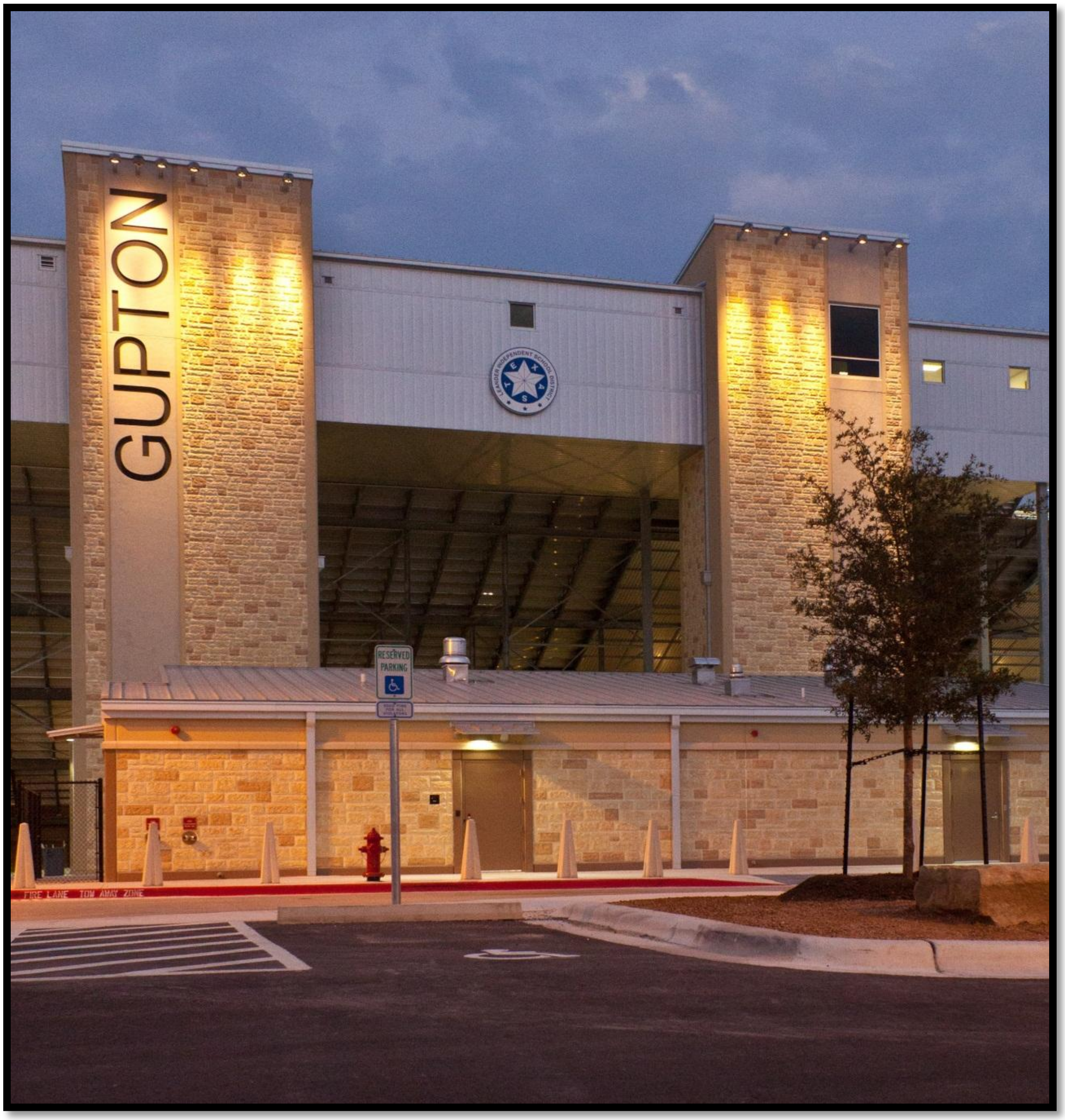

Figure 20: Gupton Stadium, Austin, Texas

Figure 21: Panel Placement and Painting at Gupton Stadium, Austin, Texas

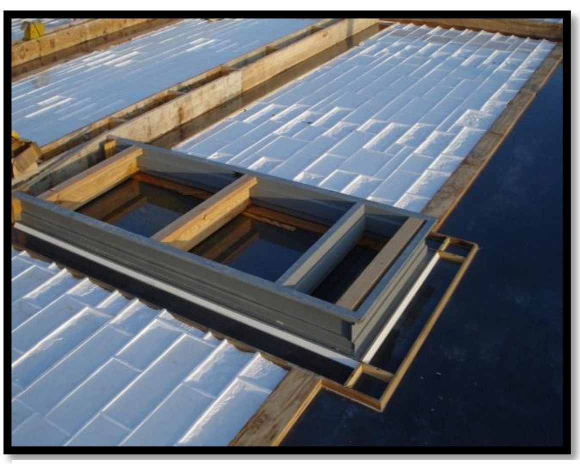

Figure 22: Textured Concrete Finish at Gupton Stadium, Austin, Texas

Chapter 6: Why Tilt-Up Construction?

Building using tilt-up construction brings cost benefits that are more favorable to the owner when compared to other building methods. Tilt-up construction will save money and building time, two powerful reasons in making the decision of methods to use. To build with tilt-up construction benefits the owner, the designer, and the contractor or builder.

Owner Benefits

To really see the benefits of tilt-up construction, the owner has to see the advantages of concrete buildings overall. Concrete is a rugged, strong material that is both impact proof and abrasion resistant. This means that concrete will not wear out even when exposed to the heavy service imposed by the industrial and commercial sector. In addition, the solid tilt-up panels are almost impossible to penetrate offering added security to vandalism and breaking in.

Tilt-up panels can be easily designed to provide a 2 to 4 hour or more fire rating [13]. Good protection against fire eliminates any problems with compliance with the requirements of a local building and city codes. A good fire rating allows for maximum use of the site when locating the building with respect to property lines. It also helps to reduce changes in fire insurance rates.

There is an array of almost unlimited aesthetic treatments available for tilt-up construction. Panel color, texture, and pattern can be varied with the selection of plain walls, exposed aggregate walls, painted walls, sculptures walls, textured walls, and a combination of surface finishes. All of these choices are available at any location since tilt-up construction is done using local materials. An additional advantage of tilt-up construction is that it helps reduce the cost of heating and air conditioning of the entire facility. Concrete mass in tilt-up panels not only slows down heat transfer, it also stores heat during the daylight hours and releases it during the cooler night hours. Because of the concrete greater mass, the thermal resistance requirements of tilt-up walls average about 30 percent less than the thermal resistance of lightweight walls [13]. This translates in the need of less costly and more efficient heating and cooling equipment. Tilt-up panels also provide for an excellent enclosure for passive solar designs, because of the concrete's heat storage properties. In addition, the concrete greater mass also helps reduce the outside noise coming into the building.

Tilt-up buildings can go up faster than buildings constructed using more conventional methods, giving the owner the earliest building occupancy and reducing the risk of losing profit due to delayed start-up of the facility. Tilt-up buildings also have the possibility of expanding if required by the owner. Connections can be detailed so that it is easy to remove, reset, and reuse panels.

Contractor Benefits

Tilt-up construction can become more attractive to the contractor or builder as this method saves on construction time, labor, and materials. All of the concrete work is done in an accessible horizontal surface. The crews work at ground level, increasing labor productivity in pouring, finishing, and curing the concrete. No scaffolding is required as wall heights get higher, reducing the indirect costs of renting temporary structures or equipment and increasing safety. At the job site, foundation work can be going on at the same time as panel fabrication.

Tilt-up is a relatively simple construction method that can be done by semiskilled and unskilled workers reducing the overall labor costs. The materials used – concrete and reinforcing steel – are also relatively inexpensive, and the amount of formwork (edge forms only, rather than wall faces) is at a minimum. Additionally, by casting the panels as close to their final position as possible, erection time can be reduced as the crane will only need to handle the panels once when setting them in the final position.

Designer Benefits

The advantages that benefit the owner and the contractor also benefits the architect/designer. Tilt-up offers freedom when selecting the size and shape of the panels and this provides flexibility and rewards innovation in the preliminary design stages. The designer has an almost limitless choice of architectural treatments, offering the owner an array of colors, patterns, and textures to choose from.

In addition to aesthetic advantages, tilt-up construction also gives some advantages in structural performance. Design tables are available that enable the designer to use tilt-up panels as bearing walls providing good support for roof systems, elevated slabs, and floor slabs. The procedure used to analyze tilt-up panels takes into account the influence of the variable moment of inertia on member stiffness and the effects of deflections on moments and forces. The elimination of columns and beams to support the roof loads around the periphery of the building contributes to reducing the costs of a tilt-up building. Tilt-up panels can also act as shear walls, providing excellent resistance to lateral forces of wind and earthquakes. Tilt-up panels can also rest on any type of foundation support such as isolated pad footings, caissons, pile caps, floating slab, continuous ribbon footing, formed and cast foundation walls, and retaining walls.

Chapter 7: Summary and Conclusion

Tilt-up construction has been around for a long time, but it was not until the late 1940's that it really started gaining popularity with the introduction of the mobile crane. Since then, tilt-up construction has undergone many innovations and refinements, and has now developed into a building method commonly used by many concrete contractors and general contractors in the construction industry.

In the design of a tilt-up structure the panels should always be designed to withstand the in-place loads, live loads, wind loads, and most importantly, lifting loads. The designer should take into account the lifting inserts layout and all architectural features incorporated into the final design of the structure. The designer can refer to building codes such as ACI 551 and ACI 319 for additional guidelines and requirements in the tilt-up design.

Good planning is the key part to all successful construction work, but it is especially critical in tilt-up construction if all the cost, schedule, and safety benefits are to be realized. To insure an efficient construction procedure, consideration must be given to the casting location of panels and erection sequence. It is important for the contractor to develop a panel casting layout to ensure the most efficient casting and lifting of the panels. For tilt-up construction, the concrete floor slab is usually the most convenient place for casting tilt-up panels. The floor slab can be used as the "work table" for panel forming, casting, bracing, and erecting. If there is no accessibility to the floor slab, temporary casting slabs can be used instead for casting tilt-up panels. It is important to understand the main construction process for tilt-up construction, which includes: edge form, bondbreaker, reinforcement, insulation, lifting, bracing and connecting. The lifting or erection of the panels is a critical phase during tilt-up construction. It is imperative that the designer, contractor and usually an erection sub-contractor plan and check all rigging and tilting procedures carefully to ensure panel erection is done safely and efficiently. The correct crane should be selected based on the panel design. The general rule for sizing the crane state that the crane capacity should be a minimum of two or three times that of the heaviest panel including the weight of all the rigging gear.

A wide range of colored coarse aggregates and sands, several possible colors of cement, and many other architectural applications available offer an array of possible colors, textures, and finishes that can be applied to tilt-up panels. The most commonly used methods to create the desired panel appearance include sandblasting, seeding method, sand bed method, and finishes obtained by using textured liners.

Tilt-up construction is a simple construction method that offers benefits directly related to meeting specific costs, schedule, and performance requirements. New and innovative architectural design techniques have given tilt-up more versatility. Tilt-up construction also benefits the owner, the designer, and the contractor or builder. For example, all the concrete work in tilt-up construction is done in an accessible horizontal surface, increasing labor productivity in forming, pouring, finishing, and curing the concrete. Since no scaffolding is required, this method reduces the indirect costs of renting temporary structures. Additionally, the materials used - concrete and reinforcing steel – are also relatively inexpensive, and the amount of formwork (edge forms rather than wall faces) is kept at a minimum.

In conclusion, tilt-up construction basically involves job-site prefabrication of concrete building members under controlled and relatively economic conditions. Tilt-up construction is generally identified with industrial and commercial building, but has been increasingly been used in other types of buildings such as parking lots, residences, shopping centers, and churches. It is important to recognize the opportunities and advantages tilt-up construction has to offer. Even though tilt-up is not a new idea, it has been proven to be one of the most efficient and cost effective construction methods known to date.

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Vita

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