TILT-UP CONCRETE STRUCTURES

Reported by ACI Committee 551

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Tilt-up concrete construction is commonly used in low-rise building construction. This report discusses many of the items that should be considered in planning, designing, and constructing a quality tilt-up project. Major topics discussed include design, construction planning, construction, erection, and finishes.

Keywords: Analysis; box type system; composite construction; connections; cranes (hoists); diaphragms (concrete); earthquake resistant structures; erection; finishes; inserts; lifting hardware; load bearing walls; moments; parting agents; panels; rigging; roofing; sandwich structures; stability; strongback; structural design; tilt up construction.

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ACI Committee Reports, Guides, Standard Practices, and Commentaries are intended for guidance in designing, planning, executing, or inspecting construction and in preparing specifications. References to these documents shall not be made in the Project Documents. If items found in these documents are desired to be a part of the Project Documents, they should be phrased in mandatory language and incorporated into the Project Documents.
The technique of site-casting concrete wall panels on a horizontal surface and then lifting or “tilting” them into place is referred to as tilt-up construction. Tilt-up construction uses less forming material than cast-in-place concrete construction and minimizes heavy equipment usage, which results in savings in time, equipment, and manpower. This efficient and cost effective method of construction has been used in the United States since the early 1900’s. Tilt-up has subsequently spread to many other countries around the world. The American Concrete Institute, recognizing the increasing interest in this type of construction, formed ACI Committee 551 in 1980. The Committee’s mission is to “study and report on the design and construction of tilt-up structures.”

This report is in conflict with ACI 318 in three areas. The first conflict is found in section 2.7.5 and deals with the distribution of concentrated loads. The second conflict is found in section 2.10.5, which discusses typical connection details between the panel, foundation, and slab-on-grade. The third conflict concerns the amount of shrinkage and temperature reinforcement required in a tilt-up panel and is found in section 2.15.5. At the time this report was prepared, these three conflicts were being discussed with Committee 318 in an effort to eliminate them.

1.2-Definition
The definition for precast concrete found in ACI 116R is “concrete cast elsewhere than its final position,” and includes tilt-up concrete. A more specific definition of tilt-up construction is “a construction technique of casting concrete elements in a horizontal position at the jobsite and then tilting and lifting the panels to their final position in a structure.”

1.3-History
In 1909, Aiken described an innovative method of casting panels on tilting tables and then lifting them into place by means of specially designed mechanical jacks. This technique was used for constructing target abutments, barracks, ammunition and gun houses, a mess hall, factory buildings, and churches (see Figs. 1.1 - 1.4). During this same time period, tilt-up concrete construction began to gain nationwide acceptance as techniques were refined. California led the way and Sun Belt states were quick to follow. Since that time, tilt-up buildings have been constructed in every state in the United States, and in other countries around the world.
1.4-Advantages

There are many advantages in tilt-up construction for low and even mid-rise buildings, including industrial plants, warehouses, office buildings, residential buildings, and commercial shopping centers. Examples of these types of buildings are shown in Figures 1.5 to 1.11. Some of these advantages are:

1) Elimination of expensive formwork and scaffolding
2) Fast, economical construction cycle time — from initial grading to move-in
3) Lower insurance rates that are typical for non-combustible construction
4) Wide variety of exterior finishes such as colored concrete, exposed aggregate, graphic painting and form liner finishes
5) Easily modified structures for building expansion
6) Durable, long-life and low maintenance building

Perhaps the greatest advantage of tilt-up is the ease and speed of construction. Panels can be tilted with high capacity mobile cranes and braced in less than ten minutes. It is possible to construct the complete building shell, from foundation through the roof, for a 100,000 ft² warehouse with office space in 30 days or less.

1.5-Disadvantages

1) Certain architectural treatment may become costly because of the construction techniques
2) Lack of availability of qualified personnel and contractors
3) Weight of the panels on certain soils
4) Available space to cast panels
5) Temporary bracing during construction
6) Availability of lifting equipment
7) Structural integrity requires careful consideration
1.6 Scope of report

This report includes current basic design procedures relating to slenderness, panel loading, connections, roof diaphragms, lifting analysis, temporary bracing, construction planning, construction procedures at the jobsite, erection, and safety procedures, along with a discussion of concrete mixture proportions and methods and types of finishes. Because of the concern for energy conservation a section devoted to the construction of insulated sandwich wall panels is also included.

Following the recommendations contained in this report will reduce the need for experimenting at the jobsite. The five steps of design, planning, construction, erection, and creating finishes are crucial to a successful tilt-up project. With ample preplanning between the owner, contractor, concrete subcontractor, erection subcontractor, accessory suppliers, and architect/engineer, and close adherence to the ideas and suggestions in this report, tilt-up concrete construction can provide a quick, economical, and versatile method of constructing low and mid-rise buildings.

CHAPTER 2 DESIGN

2.1 General

2.1.1 Slenderness — Tilt-up buildings are typically low-rise structures of four stories or less in height, with the majority being one and two stories. Wall panels for these buildings are generally designed as load-bearing beam-columns spanning vertically between the ground floor and the roof, or intermediate floors. Typically, these panels support vertical gravity loads in combination with lateral loads such as wind, seismic, or earth pressures. Often the panels are very slender; slenderness ratios of
Fig. 1.8-Service building

Fig. 1.9-Warehouse

Fig. 1.10-Office building
Fig. 1.11-Shopping center

$l/r$ of 140 to 200 are common. Bending moments due to applied loads can be magnified significantly by the effect of an axial load on the deflected shape. This increase in moment is generally referred to as the P-delta moment. P-delta magnification makes it necessary to take proper account of out-of-plane deflections.

2.1.2 Panel thickness — Panel thickness is often specified to conform to dressed lumber sizes, however, any thickness can be used. Thickness of 5% to 9% in. are commonly used.

2.13 Concrete — Either normal-weight or lightweight concrete can be used in tilt-up concrete panels. Because of exposure to weather and early loading during the erection process, concrete compressive strength of at least 3000 psi at 28 days is commonly specified.

2.2-Analysis

Slender tilt-up concrete walls must be analyzed as beam-columns. Design provisions in ACI 318 are applicable to walls where the slenderness ratio $(l/r)$ is less than 100. This is approximately equivalent to a height-to-thickness ratio $(l/h)$ of 30. Tilt-up walls will often exceed this limitation with $l/h$ ratios of 40 to 50 or more. These are permitted by ACI 318, but only where a detailed structural analysis, including long term effects, shows adequate strength and stability.

Several methods have been proposed for computing the load carrying capacity of tilt-up concrete wall panels. In 1974 the Portland Cement Association published a design aid for tilt-up load bearing walls. A series of design charts were produced based on a detailed computer analysis. Coefficients to determine the maximum axial loadings were given for several combinations of section thickness, reinforcing steel areas, lateral loading, panel height, and concrete strength.

Other variations of the design charts, including an expanded version of the PCA publication in 1979 were produced which made it easier to consider special loading conditions or variations in section properties. These require some interpolation and extrapolation.

Most designers prefer a simplified analysis method that gives reasonably accurate but conservative results. Such a method is provided by the Structural Engineers Association of Southern California (SEAOSC) in the “Yellow Book,” Recommended Tilt-Up Wall Panel Design and the “Green Book,” Test Report on Slender Walls. These and other methods of approximate analysis are used to compute the bending stiffness of the concrete section from which maximum panel deflection and, thus, P-delta moments can be obtained. It is left to the designer to select the rational method of analysis that best suits his own needs. In Section 2.6, an example problem is solved using three design methods.

2.3-Loads

2.3.1 Vertical loads — Tilt-up panels commonly support roof and floor joists. Joist spacing is usually five feet or less and the joist loads are considered as a uniformly distributed load on the panel. In most cases, these loads are applied at an eccentricity from the centerline axis of the panel.

Even if loads are intended to be concentric, a minimum eccentricity of one-third to one-half the panel thickness is generally used for design where the effect is additive to the lateral load, and zero where a reduction of total moment would otherwise occur. Eccentricity at the bottom of the panel is generally assumed to be zero.

2.3.2 Lateral loads — Usually wind pressures, as
specified by the local building code, control the design, although seismic accelerations are controlling in some areas.

Sometimes panels are required to resist lateral pressure due to soil in combination with vertical loads. These lateral loads can be significant and may limit the vertical span of the panel unless stiffening ribs are used for additional strength.

2.2.3 Self weight — The effect of panel self weight on the moment magnification can be approximated by assuming that a portion of the total weight acts at the top as a concentric axial load. For solid panels, the critical section for bending occurs at or above mid-height. It is therefore conservative to use one-half of the total panel weight. For panels with large openings, the location of the critical section 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 maximum design moment.

2.3.4 In-plane shear — In-plane shear forces on tilt-up panels can be significant for long-narrow buildings in seismic zones. These shear forces can result in significant panel overturning moments and increase the section and reinforcing requirements for panels with large openings and narrow legs. Horizontal reinforcement in the panels may be especially critical.

2.3.5 Load combinations — The following load combinations should be investigated. Lateral loads due to wind, earth, or seismic forces are usually predominant in determining the design moment:

\[ U = 1.4D + 1.7L \]
\[ U = 0.9D + 1.3W \]
\[ U = 0.9D + 1.3(1.1E) \]
\[ U = 1.4D + 1.7L + 1.7H \]
\[ U = 0.75(1.4D + 1.7L + 1.7W) \]
\[ U = 0.75[1.4D + 1.7L + 1.7(1.1E)] \]

2.4-Design bending moment

The design bending moment is the combined result of several effects including:

a) Lateral loads
b) Vertical loads applied at some eccentricity
c) Initial out-of-straightness
d) P-delta effects produced by vertical load

The maximum bending moment will usually occur at about mid-height of wall for panels spanning vertically. For panels with large vertical loads or large eccentricities the maximum bending moment may occur at a location other than mid-height.

The common practice is to combine the effects of all applied loads to obtain a maximum applied or primary moment acting on the panel. The P-delta moment is added separately as follows:

\[ M_u = M_a + P_u\Delta \]

Calculations for the P-delta moment are difficult in that they require a determination of the panel bending stiffness. The nonlinear properties of the concrete section make it difficult to precisely calculate the bending stiffness so approximate values are used. Effects of creep are typically ignored because of the transient nature of the predominant lateral loads. Where heavy vertical loads with large eccentricities are resisted, creep effects need to be considered.

2.5-Bending stiffness

Adequate bending stiffness is necessary for tilt-up panels in order to minimize out-of-plane deflections and the resulting P-delta moments. The bending stiffness of a reinforced concrete section varies with the following:

a) Geometry of the concrete section
b) Concrete modulus of elasticity
c) Flexural strength of concrete
d) Amount, grade and location of reinforcing steel
e) Axial compression force
f) Extent of cracking

Unless tilt-up panels are subjected to unusually large vertical loads, the bending component is generally dominant. Computer analysis of reinforced concrete sections has shown that for factored axial loads less than about 5 percent \( P_o \), the bending stiffness is almost independent of curvature after flexural cracking has occurred. In actual load tests conducted by the Southern California Chapter of ACI and the Structural Engineers Association of Southern California and by the Portland Cement Association (unpublished report) the panels tested were capable of supporting additional lateral load after cracking and after first yield of the reinforcement (see Fig. 2.1). In the ultimate design state the concrete flexural cracking stress will be exceeded along most of

\[ M_u = \text{total maximum moment} \]
\[ M_a = \text{applied moment} \]
\[ P_u\Delta = \text{P-delta moment} \]

![Fig. 2.1-Deflection at mid-height of panel](image)
the height of slender walls, and the cracked section stiffness is commonly used as a reasonably accurate but conservative approximation of the actual stiffness.

The design methods in References 6, 8 and 9 use the cracked section stiffness with modification to account for the effect of axial compression. The reader is referred to these publications for further detail.

Tilt-up wall panels are primarily bending members and as such are governed by the maximum and minimum reinforcing requirements of ACI 318 for flexural reinforcement.

2.6-Example

The design of a typical tilt-up panel for vertical and lateral loads follows. The panel reinforcement is determined by three different methods for comparative purposes. For additional design information and examples see: The Tilt-Up Design and Construction Manual.

Tilt-Up Panel Design

Sample Problem

\[ P_u / \phi = 0.83 / 0.89 = 0.93 k \]

(self weight of wall included in table)

\[ q_u / \phi = 25.5 / 0.89 = 28.65 \rightarrow \text{say 30 psf} \]

From Table A2:

Required Coefficient =

\[ \frac{P_u / \phi}{b h f_c'} = \frac{0.93}{12 \times 5.5 \times 4} = 0.0035 \]

\[ k_{lu/h} = \frac{1.0 \times 22 \times 12}{5.5} = 48 \]

For \( \rho = 0.25, \text{Coef.} = 0 + \frac{2}{10} (0.007) = 0.0014 \)

\( \rho = 0.50, \text{Coef.} = 0.007 + \frac{2}{10} (0.012) = 0.0094 \)

Required

\[ \rho = 0.25 + \frac{(0.0035 - 0.0014)/(0.0094 - 0.0014) \times 0.25}{0.316} \]

\[ A_s = 0.316/100 \times 5.5 \times 12 = 0.21 \text{ in.}^2/\text{ft} \]

SEASOC Method (Ref. 8)

\[ P_u' = 0.83 + 0.074 \times 22/2 = 1.64 k/\text{ft} \]

try

\[ A_s' = 0.22 \text{ in.}^2/\text{ft} \]

\[ A_s = (0.22 \times 60 + 1.64)/60 = 0.247 \]

\[ a = (1.64 + 0.22 \times 60)/(0.85 \times 3 \times 12) = 0.485 \text{ in.} \]

\[ c = 0.485/0.85 = 0.57 \text{ in.} \]

\[ M_y = 0.247 \times 60 [2.75 - (0.485/2)] = 37.16 \text{ in.} \times \text{k} \]

\[ = 3.10 \text{ ft-k} \]

\[ \phi M_y = 0.89 \times 3.10 = 2.76 \text{ ft-k} \]

\[ E_c = 3,120 \text{ ksi } n = 9.3 \]

\[ I_{er} = 9.3 \times 0.247 (2.75 - 0.57)^2 + 12 \times 0.57^3/3 = 11.6 \text{ in.}^4 \]

\[ A = (5 \times 37.16 \times 22^2 \times 12^2)/(48 \times 3120 \times 11.66) = 7.4 \text{ in.} \]

\[ M_u = (25.5 \times 22^2)/(8 \times 1000) + 0.83 \times 2.75/24 + 1.64 \times 7.4/12 = 2.65 \text{ ft-k} < 2.76 \]

\[ A_s = 0.22 \text{ in.}^2/\text{ft} \text{ is OK} \]
Table A2 — Load capacity coefficients of tilt-up concrete walls* (h = 51/2 in. and $q_u/\varphi = 30$ or 45 psf)

<table>
<thead>
<tr>
<th>$\rho$</th>
<th>$A_{y} \times 10^{4}$</th>
<th>$A_{x}/h$</th>
<th>$A_{w}/h$</th>
<th>$M_{y}/h$</th>
<th>$P_{u}/h$</th>
<th>$q_{u}/\varphi$ = 30 psf</th>
<th>$q_{u}/\varphi$ = 45 psf</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>0.438</td>
<td>0.278</td>
<td>0.030</td>
<td>-</td>
<td>49</td>
<td>0.438</td>
<td>0.110</td>
</tr>
<tr>
<td>2.75</td>
<td>0.078</td>
<td>0.011</td>
<td>-</td>
<td>-</td>
<td>39</td>
<td>0.067</td>
<td>-</td>
</tr>
<tr>
<td>6.25</td>
<td>0.013</td>
<td>0.005</td>
<td>-</td>
<td>-</td>
<td>39</td>
<td>0.012</td>
<td>-</td>
</tr>
<tr>
<td>1.00</td>
<td>0.438</td>
<td>0.278</td>
<td>0.030</td>
<td>0.020</td>
<td>**</td>
<td>0.438</td>
<td>0.218</td>
</tr>
<tr>
<td>2.75</td>
<td>0.096</td>
<td>0.028</td>
<td>0.007</td>
<td>-</td>
<td>49</td>
<td>0.087</td>
<td>0.019</td>
</tr>
<tr>
<td>6.25</td>
<td>0.024</td>
<td>0.014</td>
<td>0.004</td>
<td>-</td>
<td>49</td>
<td>0.023</td>
<td>0.010</td>
</tr>
<tr>
<td>1.00</td>
<td>0.438</td>
<td>0.278</td>
<td>0.030</td>
<td>0.035</td>
<td>**</td>
<td>0.438</td>
<td>0.218</td>
</tr>
<tr>
<td>2.75</td>
<td>0.118</td>
<td>0.046</td>
<td>0.019</td>
<td>0.007</td>
<td>**</td>
<td>0.111</td>
<td>0.038</td>
</tr>
<tr>
<td>6.25</td>
<td>0.040</td>
<td>0.027</td>
<td>0.013</td>
<td>0.006</td>
<td>**</td>
<td>0.038</td>
<td>0.020</td>
</tr>
<tr>
<td>1.00</td>
<td>0.438</td>
<td>0.278</td>
<td>0.030</td>
<td>0.050</td>
<td>**</td>
<td>0.438</td>
<td>0.218</td>
</tr>
<tr>
<td>2.75</td>
<td>0.139</td>
<td>0.063</td>
<td>0.031</td>
<td>0.014</td>
<td>**</td>
<td>0.134</td>
<td>0.056</td>
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<tr>
<td>6.25</td>
<td>0.055</td>
<td>0.039</td>
<td>0.022</td>
<td>0.012</td>
<td>**</td>
<td>0.063</td>
<td>0.035</td>
</tr>
</tbody>
</table>

*Observe the direction of ultimate transverse loads ($q_u$) and note the bending moments due to transverse loads are additive to those caused by the axial loads (Sec. 2.4). A dash indicates that the wall panel cannot sustain any load.

**Walls with slenderness ratios, $k_u/h$, greater than 50 are not recommended.

† This column gives the values of the slenderness ratios above which the walls have negligible load-carrying capacity.

Weiler Method (Ref. 9)

Applied Loading:

$P_u' = 0.83 + (74/1000) \times 22/2 = 1.64$ k/ft

$M_a = (25.5/1000) \times (22/2) + (0.83 \times 2.75)/(12 \times 2) = 1.64$ ft-k/ft

$P_u'/\varphi = 1.85 \quad M_a'/\varphi = 1.85$

Try

$A_s = 0.22$ in.$^2$

$A_s' = (0.22 \times 60 + 1.85) / 60 = 0.251$ in.$^2$

$\rho' = 0.251/12 \times 2.75 = 0.0076$

$\rho'n = 8.06 \times 0.0076 = 0.0613$

$k'd, = \sqrt{[0.0613]^2 + 2 \times 0.0613 - 0.0613}] \times 2.75 = 0.809$

$M_y = 0.251 \times 60 (2.75-0.809/3) = 37.4$ in.-k

or 3.11 ft-k

Stiffness $ EI = M/\Theta = (37.4)/(60/[29000(2.75 - 0.0809)]) = 35048$ k-in.$^2$

Bending $ k_b = (\pi^2 \times 35048/22^2 \times 10^2) = 4.96$ ft-k/ft

Stiffness

Magnifier $ \delta = l/(1-1.85/4.96) = 1.59$

Magnif. $M_u = M_a'/\varphi \delta = 1.85 \times 1.59 = 2.94$ ft-k

Mom't

Resisting $M_n = (0.251 \times 60)/12 (2.75 - (0.251 \times 60)/(1.7 \times 4 \times 12)) = 3.22 > 2.94$ ft-k

Min. $A_y = 0.21$ in.$^2$/ft

2.7-Special design considerations

2.7.1 General — Simplified design and analysis techniques, when used with engineering judgment, are satisfactory for the majority of tilt-up concrete panel conditions and configurations. However, special design considerations may be required along with a more detailed elastic analysis where simplified analysis assumptions are too conservative and not applicable.

2.7.2 Continuity — Simplified techniques in the design methods discussed generally assume the panel is pinned at points of support, typically at the floor slab and roof diaphragm. Often additional attachment at the footing or
at intermediate floors provides some degree of continuity. This continuity may be included in a thorough elastic analysis with careful consideration of the foundation and slab connections and lateral movement of the roof diaphragm.

2.7.3 Openings — Openings constitute the most typical special condition which must be considered in panel design. Careful panel joint location selection can minimize the effect of openings. Since tilt-up panels are able to redistribute loads well, single openings with a maximum dimension of two feet or less are generally ignored analytically unless located at areas of maximum stress in the panel. For these openings, diagonal corner reinforcement (two #5 x 4 ft long bars or reinforcement of equivalent area) is used to limit development of cracks as shown in Fig. 2.2.

Where larger openings occur, such as personnel doors, the horizontal and vertical loads applied over the width of the opening are generally distributed equally to vertical panel segments on each side of the opening. These segments are then designed for the increased vertical loads and moments uniformly distributed over the section. For these cases, reinforcing bars are commonly placed along each side of the opening (vertical and horizontal) in addition to the #5 diagonal corner bars. The horizontal and vertical bars should be #5 as a minimum and should extend at least two ft beyond the limits of the opening (see Fig. 2.3).

Where major openings in panels occur, such as at overhead doors, the horizontal and vertical loads are also distributed to segments on each side of the openings. These panel segments are then designed 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 panel
- Need for thickened pilasters
- Design of the panel above the opening for out-of-plane forces
- In-plane shear and frame action
- Possible need for strong-backing during erection (see Section 2.11)

Because the panel reinforcement around these openings, as determined by analysis, is often considerable, added crack control reinforcement may not be necessary (see Fig. 2.4).

2.7.4 Isolated footings — Simplified design analysis assumes continuous support, however, tilt-up panels may be used to span between isolated footings, pile caps, or caissons. This special case is similar to conditions of load concentrations or large openings in that the effective panel width is reduced. If pilasters are not used and the bottom of the panel is laterally supported by the floor slab, the total horizontal load may be assumed to act on the width of the vertical resisting elements. For design assistance for this condition see the Portland Cement Association publication Tilt-Up Load Bearing Walls.6

Special attention should begin to the horizontal reinforcement at the bottom of panel. This reinforcement resists panel shrinkage and thermally induced stresses in addition to flexural requirements, and should be developed at the edge of the foundation using hooks if required (see Fig. 2.5).

2.7.5 Concentrated loads — Concentrated loads on panels constitute a special condition which could invalidate assumptions of simplified design techniques. A series of concentrated loads such as roof or floor joists or purlins along a panel, are usually considered uniform for design purposes. Where reactions from major elements (such as in large beams or girders) produce load concentrations, the panel analysis must account for this effect.

ACI 318 allows a load concentration to be distributed to a width equal to the actual bearing width plus four times the panel thickness at the point of load. However, Committee 551 believes that the effective width to resist this concentrated load in tilt-up panels should be the width of bearing, plus a width described by sloping lines of one horizontal to two vertical on each side of the bearing to the critical design section in question (see Fig. 2.6). This vertical panel segment should be analyzed to provide suitable reinforcement for the full height of the panel. The horizontal load is considered to be that acting on the width of the segment in question. Special care is required when heavy loads occur at edges of panels (see Fig. 2.7). In this case the effective panel width is the width of bearing plus twice the distance from bearing edge to edge of the panel.

Panel reinforcement may be required in this vertical segment on both faces. Closed ties are required if reinforcement functions as compression steel.

Where load concentrations exceed the capacity of the panel segment, a pilaster or thickened panel segment may be used. A minimum of 3\(\frac{1}{2}\) in. added thickness is recommended to facilitate construction. Closed ties may be required. Where a pilaster is used its increased stiffness relative to the panel will attract a higher proportion of horizontal load than that acting on the remainder of the panel.

2.7.6 In-plane shear — Tilt-up panels are generally used as shear walls for building stability. Analysis of the panels should include in-plane shear stresses, panel stability, and floor and roof diaphragm connections. If panels must be connected to adjacent panels for stability, it is suggested that they be connected in groups with as few panels as needed to satisfy overturning requirements. See expanded discussion in Sections 2.8 and 2.10.

2.8 Building stability
2.8.1 General — Because tilt-up buildings are low- or
Fig. 2.2-Typical reinforcement at small openings

ADD 2-#5 x 4'-0"  
@ EA.CORNER

TYP. REINF

2'-0" MAX

Fig. 2.3-Typical reinforcement at personnel door

ADD 2-#5 x 4'-0"  
@ CORNERS TYP.

ADD #5 OVER- 
EXTEND 2'-0' 
BEYOND OPENING

Fig. 2.4-Typical reinforcement at major openings

HORL & VERT REINF. AS  
REQ'D BY ANALYSIS

TIES AS REQ'D BY DESIGN

Fig. 2.5-Typical reinforcement at isolated foundation

PROTECT AGAINST 
FROST OR EXPANSIVE 
GROUND

DEVELOP REINF.

DO NOT ATTACH PANEL 
RIGIDLY AT EACH END
mid-rise, lateral loads and building stability sometimes do not receive sufficient attention in their design. Due to the special nature of these structures, designers and constructors need to be aware of the bracing requirements necessary to insure a stable, safe structure during construction and for the life of the building.

2.8.2 Structural systems

2.8.2.1 Box-type system—Tilt-up buildings are predominantly classified and designed as box-type structures. Box-type structural systems carry loads through sets of planes. As such, lateral forces are resisted by the roof and floor systems resist lateral forces in the horizontal plane, and the wall panels act as shear walls in the vertical plane.

Wall panels, therefore, must support both gravity and lateral loads while also providing lateral stability to the structure. These types of structures are not stable until all structural elements are in place and connected. Special attention must be given to stability during construction. This means that wall panel erection braces should not be removed until the deck diaphragm is completely fastened to the structural systems, and all other permanent connections have been installed as detailed on the plans.

2.8.2.2 Rigid frame — Some tilt-up buildings are constructed using independent moment resisting rigid frames to resist all lateral loads. This sometimes is done when the panels are non-loadbearing and used mainly as a curtain wall system. This framing system allows for easy future expansion.

2.8.2.3 Combined system — Sometimes the box and rigid frame systems are combined with rigid frames resisting the lateral loads in one direction, while the wall panels resist the lateral loads as shear walls in the other direction. Other combinations are possible.

2.8.3 Lateral bracing systems — Tilt-up panels usually rely on the roof and floor levels for lateral support. This support can be accomplished in many ways. Typically, the floor or roof deck is designed and used as a structural diaphragm. This is an efficient and economical bracing system. Many common construction materials may be used to construct structural diaphragms such as cast-in-place or precast concrete, steel deck, or plywood sheathing. Traditional ‘x’-bracing at the roof level can also be used. Either type can be used in conjunction with rigid frames or shear walls. The bracing system that is used should be noted on the plans to aid the constructor.

2.8.4 Diaphragms—Typically, diaphragms are analyzed as large plate girders lying in the plane of the floor or roof, spanning horizontally between vertical shear resisting elements. The deck functions as the web to resist shear forces while perimeter or chord members function as flanges to resist the bending moment. Although this analysis is approximate, it is sufficiently accurate for most structures of this type.

The distribution of shear forces to the shear walls depends on the stiffness of the diaphragm. Diaphragms can be divided into five groups based on their shear stiffness moduli, $G'$, expressed in kips/in. of deflection. The typical diaphragm spans are indicated in the following paragraphs. Often these spans are limited by the aspect ratio (spans to width) of the diaphragm.

2.8.4.1 Very flexible—Very flexible diaphragms with an effective shear stiffness of less than 6.7 kips/in. such as straight and conventional diagonally sheathed wood diaphragms, will distribute forces in direct proportion to the tributary area supported. These types of diaphragms should not be used to support tilt-up concrete walls.

2.8.4.2 Flexible—Flexible diaphragms, with an effective shear stiffness of 6.7 kips/in. to 15 kips/in., such as special diagonal wood sheathing, plywood sheathing, and some lightly fastened light gauge steel decks, will distribute lateral forces in direct proportion to the tributary area supported. The span of flexible diaphragms is usually limited to a maximum of 200 ft when supporting tilt-up concrete walls, unless diaphragm deflections are calculated.

2.8.4.3 Semi-flexible—Semi-flexible diaphragms, with an effective shear stiffness of 15 to 100 kips/in., such as plywood sheathing and moderately fastened medium gauge steel decks, will distribute lateral forces primarily
in proportion to the tributary area supported. Most of the steel roof decks commonly in use fall into this category. The span of semi-flexible diaphragms is usually limited to a maximum of 400 ft when supporting tilt-up concrete walls unless diaphragm deflections are calculated.

2.8.4.4 Semi-rigid – Semi-rigid diaphragms, such as some heavily fastened heavy gauge steel decks, with an effective shear stiffness of 100 to 1000 kips/in., can exhibit large deflections under load yet will distribute the loads in proportion to the relative stiffness of the vertical shear elements. The span of semi-rigid diaphragms is usually not limited.

2.8.4.5 Rigid – Rigid diaphragms, with an effective shear stiffness greater than 1000 kips/in., such as cast-in-place concrete decks, will distribute lateral forces in direct proportion to the relative stiffness of the vertical shear elements. The span of rigid diaphragms is not limited.

2.8.4.6 Diaphragm connections — The strength and performance of the entire diaphragm bracing system is dependent on the use of proper details for connecting the diaphragm to the structural framing system and to the vertical shear elements such as the tilt-up wall panels. Proper edge distances between the structural fastener and edge of the diaphragm must be detailed to prevent the fastener from tearing loose. Because of the importance of diaphragm connections, they should be inspected if the deck is designed to function as a diaphragm.

2.8.4.7 Diaphragm opening — Openings in diaphragms should be framed with some type of structural member of sufficient strength to carry the required forces around the opening.

2.8.5 Lateral deflection – In addition to strength, the bracing systems must be stiff enough to limit lateral deflections to a range where the vertical elements will not be damaged. Lateral deflections are generally not a problem with at-grade tilt-up buildings because panels sitting on grade beams are essentially pin-ended and able to rotate about their base. When panels extend below the floor slab such as at truck back-up doors, a certain degree of fixity exists at the floor level. If the top of the wall is pushed outward or pulled inward by large deflections of the bracing system, high flexural stresses can develop in the panel at the floor slab causing cracking or crushing. Based on guidelines provided in Seismic Design for Buildings, it is suggested that diaphragm deflection be limited to:

\[ \Delta = \frac{l^2}{24h} \]

where
\[ \Delta = \text{lateral deflection in inches} \]
\[ l = \text{unsupported height of panel in feet} \]
\[ h = \text{thickness of wall panel in inches} \]

Tilt-up panels at loading docks are usually designed as a pinned condition at the roof and floor lines. This deflection, therefore, should be limited to control bending stresses and possible cracking of the panel near the floor level.

2.8.6 Stability – Wall panels function as supports for the horizontal bracing. They must, therefore, be designed to resist in-plane shear forces. Typically, the shear stresses are very low. However, because the structure is made up of many individual panels, the sliding resistance and overturning stability of each panel must be calculated to insure an adequate margin of safety. Many times in regions of low or no seismic risk, the weight of the panels is sufficient to safely resist these forces, requiring no connection to the foundation other than grout for a uniform continuous bearing. When greater stability is required due to loading and to moderate or high seismic risk, the panels may be interconnected or connected to the foundation and/or floor slab to provide the required resistance.

2.8.7 Joints – To limit the effects of building movements due to thermal and shrinkage forces on large structures, structural expansion/contraction joints are used. These joints must be carefully located in a diaphragm supported structure to maintain lateral stability.

2.8.8 Summary – The stability and safety of a tilt-up structure depends on interaction of many different parts of the structure. The structural system used to furnish permanent stability of the structure should be clearly noted on the design drawings so that there is no question when the temporary panel erection braces may be removed.

2.9-Tolerances

2.9.1 General – Until tolerances have been established specifically for tilt-up construction, it is the recommendation of the Committee 551 that the tolerances for precast nonprestressed elements in Standard Tolerances for Concrete Construction and Materials (ACI 117), be used for tilt-up elements.

The Building and Construction Industry Division of the Department of Labour in Australia has developed a code of practice for tilt-up construction. Their recommended maximum fabrication tolerances are:

**Length and Height:**
- Up to 3m (10 ft) \( +0, -10\text{mm} (\% \text{ in.}) \)
- 3m to 6m (10 ft to 20 ft) \( +0, -12\text{mm} (\frac{1}{2} \text{ in.}) \)
- Over 6m (20 ft) \( +0, -15\text{mm} (\% \text{ in.}) \)

**Thickness:**
- Overall \( \pm 5\text{mm} (\frac{3}{16} \text{ in.}) \)

**Straightness (deviation from intended line):**
- Up to 3m (10 ft) \( +10\text{mm} (\% \text{ in.}) \)
- 3m to 6m (10 ft to 20 ft) \( \pm 15\text{mm} (\% \text{ in.}) \)
- 6m to 12m (20 ft to 40 ft) \( \pm 20\text{mm} (\% \text{ in.}) \)
Skewness (measure as tolerance in length of diagonal):

- Up to 3m (10 ft): ±10mm (3/8 in.)
- 3m to 6m (10 ft to 20 ft): ±15mm (5/8 in.)
- 6m to 12m (20 ft to 40 ft): ±20mm (3/4 in.)

2.10-Connections

2.10.1 General - Tilt-up panels are generally incorporated into the overall building structural system supporting both vertical and horizontal loads, and also serve as external cladding. Connections must therefore be designed to adequately transmit forces from the roof and floor systems to the foundations.

In addition to the strength requirements, connections should be detailed to provide a degree of ductility for relief of temperature and shrinkage stresses, and for seismic energy absorption.

2.10.2 Types of connections - Details for connecting structural components to tilt-up panels are difficult to standardize. Variations in the type of roof and floor systems, combined with a designer or contractor’s own preferences, have resulted in a wide variety of connection types. Before making a decision on connection types, an investigation of local practices should be made.

The following discussion will highlight some of the common features of connections and illustrate typical examples of details. For a more complete discussion on connections see the Portland Cement Association publication Connections for Tilt-Up Wall Construction.15

Connections used in tilt-up construction can be categorized into four main groups:

- Welded embedded metal
- Embedded inserts
- Drilled-in anchors
- Cast-in-place concrete

Welded embedded metal is the most common tilt-up connection. Typically, a steel angle or plate with anchors is cast into the panel. Connections are made by field welding to the exposed metal surfaces. These connections are sufficiently strong for most applications, are fast and inexpensive, and can be designed with reasonable ductility. Care should be taken not to overheat and spall concrete surrounding embedded items during field welding. Smaller sized welds with multiple passes are generally preferred.

Embedded inserts such as the ferrule loop allow bolted connections to be made directly. These metal to metal connections are reasonably ductile and they eliminate the need for field welding.

Drilled-in anchors (post installed) are inserted into holes drilled in hardened concrete. Anchorage of the steel insert to the concrete is provided by mechanical means or bond with a chemical adhesive. For indepth information on drilled-in anchors see ACI 355.

Mechanical anchorage is obtained by radial expansion of the anchor. A force is applied on the walls of the hole by tightening the anchor to a specified torque. To insure capacity of the mechanical anchor proper, hole size and torque are necessary. The designer should investigate the cyclic load characteristics of any mechanical anchor which will be subject to seismic loads or heavy vibration.

Chemical anchors rely on adhesives which cure and bond with the surrounding concrete. Torque of the nut is not required to develop anchorage strength. The designer should investigate the effects of corrosive environments when using chemical anchors.

Powder-actuated fasteners are not recommended for structural applications.

Cast-in-place concrete connections are commonly used to connect wall panels to the slab-on-grade floor. Cast-in-place connections are also made by casting infill sections between erected panel components with overlapping reinforcement projecting from the ends of the panel (see Fig. 2.8). Cast-in-place connections between panels create restraint to thermal and shrinkage volume changes, and can result in cracking of the panel. In an earthquake, however, ductility after yielding of the reinforcement can be attained. Cast-in-place connections between panels are not common and the committee does not recommend their use as a general practice.

2.10.3 Roof and floor connections

2.10.3.1 Seat for steel joist - One type is a pocket recessed in the panel with an anchored angle seat (see Fig. 2.9). This connection must carry vertical gravity loads and transverse loads due to out-of-plane and in-plane wind or seismic forces. The steel joist is commonly field welded to the seat.

An alternate is a flat steel plate embedded flush with the panel face and with stud anchors embedded in the concrete (see Fig. 2.10). An angle seat is welded on after the panel is cast. Note that in both cases it is desirable to avoid projections beyond the surface of the panel to allow for easy screeding and finishing, or for stack casting one panel on top of another.
2.10.3.2 **Seat for steel beam** — Recessed pockets are sometimes used for beam connections. Alternatively, a corbel or full height pilaster can be considered in order to provide sufficient concrete bearing area (see Fig. 2.11). A large flush plate with embedded anchors may be used with an angle seat welded on after casting. Beams with large vertical reactions and/or large eccentric connections may cause bowing in the panel.

2.10.3.3 **Ledger for wood joist** — Wood roof and floor systems commonly use sawn timber joists supported on a wood ledger. The ledger is connected with bolts, cast into the panel, or threaded into embedded inserts. In seismic regions transverse steel strap ties are installed to prevent separation of the roof or floor deck from the panel (see Fig. 2.12).

2.10.3.4 **Seat for glu-lam beam** — This connection is similar to the steel beam seat. The anchored flush plate with welded shoe for supporting the beam is most common (see Fig. 2.13).

2.10.3.5 **Ledger for concrete hollow core** — Hollow core floor or roof slabs will normally sit on top of a tilt-up panel or on a continuous ledge of adequate width to include bearing size plus manufacturer’s tolerance. The slabs should rest on a leveling pad to even out the bearing. Lateral reinforcing ties can be cast into the topping or alternatively inside one of the cores (see Fig. 2.14).

2.10.3.6 **Support for precast beams** — Heavily loaded precast double tees have been carried directly on tilt-up panels. The double tees will normally bear on the top of the panel or on a continuous corbel. The tee legs should rest on bearing pads, which allow some rotational movement, and be tied in at the top by welding to embedded panel anchors or by dowels embedded in a concrete topping (see Fig. 2.15).

2.10.3.7 **Chord angle connection** — Panel connections to the perimeter steel chord angle transmit in-plane shear forces and provide a transverse tie for out-of-plane loadings. This connection will also carry small vertical loads.

Many designers use continuous chord angles connected to the wall panels. Other designers use a single

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**Fig. 2.9-Pocket for steel joist**

**Fig. 2.10-Seat angle for steel joist**

**Fig. 2.11-Beam seat on pilaster**

**Fig. 2.12-Wood joist ledger**
embedded connector plate located in the middle of the panel to transmit all the longitudinal shear. On either side of this plate, anchor bolts provide vertical and transverse load support only. Longitudinal slotted holes are sometimes provided in the chord angle to allow volume changes in the panel without significant restraint (see Figs. 2.16 and 2.17).

**2.10.3.8 Perimeter reinforcing bar chord connection** — This detail is popular with wood roof and floor systems. The wood ledger transmits vertical and longitudinal loads into the panel. The reinforcing bar chord is cast into the panel with a sleeve at a specified length to allow for panel expansion or contraction. A full strength splice is made in the reinforcing bar chord at panel joints by field welding. Requirements of the welding code, AWS D1.4, for welding reinforcing bars should be followed (see Fig. 2.18).

**2.10.4 Panel to panel connections** — There are wide differences of opinion on whether panels need be connected to one another. There are those who suggest that 2 or 3 welded connectors should be provided at each vertical panel joint, particularly in seismic zones. On the
other hand, there is a philosophy that panels should be free to expand and contract without the restraint of edge connections, and that unconnected panels will perform better in an earthquake (due to structural damping).

There is insufficient evidence to require arbitrary panel connections, and therefore the Committee believes that only those connections required for structural stability under prescribed loadings be provided.

When additional resistance to overturning moment is required, one solution is to connect adjacent panels in-plane. When this occurs, panels should be connected in pairs or at the most in groups of three. Additional horizontal reinforcement should be considered to control shrinkage cracking.

The type of connection used should have high static strength with good ductility under cyclic loading. Panel to panel connections are shown in Figs. 2.20 through 2.23.

2.10.5 Connections to foundations — In regions of low or no seismic risk friction is frequently regarded as providing sufficient restraint between the panel and footing without a mechanical connection. This is in conflict with requirements in ACI 318, however, experience in all areas in the United States indicate that a connection at the base of a panel is not necessary. In regions of moderate and high seismic risk it is important to have a good connection between tilt-up panels and the foundation. Seismic forces will be transmitted through the foundation and wall panel, and into the roof or floor
Fig. 2.20—Panels connected in pairs

Fig. 2.21—Panel to panel connection

Fig. 2.22—Embedment detail

Fig. 2.23—Alternative detail

diaphragms. A poor connection between foundation and panel could result in longitudinal displacement of the panel, a situation that would be especially critical for buildings supported on piles or pier foundations. It is essential, therefore, that a connection be provided to prevent this occurrence.

Commonly, the panel is also connected to the concrete floor slab on grade. This is achieved by casting the slab around dowels projecting from the panel, or by welding to embedded anchors. This connection is important in situations where the panel also acts as a grade beam as in Figures 2.24, 2.25, and 2.27. The connection restrains panel bowing due to earth pressure and reduces the unsupported length of the panel.

Panel to foundation details are shown in Figs. 2.24 through 2.27.

2.11—Sandwich panels

2.11.1 General — Tilt-up panels composed of two concrete layers or wythes separated by a layer of insulation are referred to as sandwich panels. These panels serve both structural and thermal functions. Sandwich
panels may be designed as load bearing or non-load bearing, and also function as columns, beams or shear components. The two basic types of sandwich panels are composite and non-composite.

With composite panels, the two concrete wythes act together to resist imposed loads. The wythes are connected by regions of solid concrete (concrete bridges) or by rigid ties through the insulation.

With non-composite panels, the two concrete wythes act independently. In some designs, both wythes support the loads. However, more commonly the interior wythe supports the applied loads including the exterior wythe.

2.11.2 Advantages — Tilt-up concrete sandwich panels provide energy-efficient, relatively maintenance-free walls that can be used wherever durable construction is desired. The two wythes are cast as flat slab construction. A separate labor crew is not required for the application of insulation or drywall.

2.11.3 Composite sandwich panels — In composite sandwich panels, the two concrete wythes are connected by special shear connectors and/or concrete connectors or bridges. These connections inhibit temperature and shrinkage movements of the wythes relative to each other, and can result in cracking of either or both wythes, particularly if the connectors run in both directions. Because of the tendency to crack the panels and reduction in insulation efficiency, internal concrete ribs in composite sandwich tilt-up panels are normally not used.

2.11.4 Non-composite sandwich panels — In some non-composite designs, both wythes resist loads, but in most, one wythe resists all loads and supports the other wythe. The structural wythe is usually thicker and located on the interior side of the panel to facilitate connection to the building and to take advantage of the thermal mass. The
noncomposite concept allows the exterior wythe to react to the environment without resistance or cracking. The sandwich panel must be designed to resist the external loads previously listed.

Connections between wythes must be designed for:

a) Seismic loads, both in plane and perpendicular to the surface
b) Compression from wind applied to the supported wythe and in tension from wind suction applied to the supported wythe. Peak wind suction near the top and corners of buildings should also be considered
c) Stress induced by weight and eccentricity of the supported wythe
d) Loads and forces during erection and handling, including bond stresses between the supported wythe and the casting bed
e) Thermal stresses caused by temperature differential between the inner and outer wythes

2.11.4.1 Thickness — Concrete wythes should be thick enough to provide sufficient cover for the reinforcement and allow adequate embedment for anchors connecting them together. A thickness of 2% in. for supported wythes reinforced with 6 x 6 - W2.9 x W2.9 mats is considered minimum. Textures or recesses should be in addition to these minimum thicknesses.

2.11.4.2 Connections — Anchors and ties between the two wythes should be designed to permit volume changes of the supported wythe due to temperature changes, shrinkage, or other applied loads. This can be accomplished by connecting the wythes for in-plane loads at locations that effectively resist these loads, and providing ties for loads perpendicular to the panel plane at other points. The ties should allow for in-plane movements but provide connections for movements perpendicular to the panel planes. The tie system between wythes typically is made from stainless steel or other non-corrosive materials to prevent corrosion in the event of sealant and/or insulation deterioration. It is recommended that the designer obtain information from the manufacturers of the various systems available.

2.11.4.3 Bottom detail — In order for the tilt-up panel to be rotated about its bottom edge into the vertical position, a solid rib of concrete connected to the structural wythe may be required. This solid 8 to 12 in. wide rib is located at the foundation where its effect on the insulation value is minimal, but it does prevent failure of the supported wythe during rotation. This rib can also be used to vertically support the nonstructural wythe, provided expansion and contraction are accounted for (see Fig. 2.28). An alternate detail is to provide a piece of structural grade lumber in place of the insulation at the bottom of the panel (see Fig. 2.29). Vertical support of the outer wythe is accomplished with in-plane anchors.

2.11.4.4 Construction procedure — The recom
mended construction procedure is to cast the supported wythe first. The insulation and structural wythe will be added later in successive stages. There should be no concrete-to-concrete surface except as discussed in Section 2.11.4.3. Pick-up inserts are placed in the second-cast structural wythe, negating the need for solid concrete shear blocks.

2.11.5 Insulation — Insulation can be any of a number of types, but should be closed cell, low absorbent, or have a water-repellent coating. The danger of toxic fumes caused by burning cellular plastic is minimized as the plastics are encased in concrete sandwich panels. However, consideration should be given to the use of non-combustible joint materials.

2.11.5.1 Thickness — Insulation thickness will be determined by thermal characteristics of the material and design criteria of the structure. Generally, ties or connector pins are pushed through the insulation, but in the case of some rigid insulation, it may be desirable to obtain it in widths to match the tie spacing, so the ties will occur in the joints.

2.11.5.2 Shear transfer — No shear transfer between the concrete and insulation is desirable, so a physical or chemical bond breaker is used between the concrete and insulation. A sheet of reinforced building paper or polyethylene may be used for this purpose.

2.11.5.3 Installation — When installing the insulation, it is important to seal the joints to prevent concrete placed on top from running down in the joints and forming concrete bridges. Any gaps or openings in the insulation around connectors or ties should be sealed or packed with insulation to avoid concrete bridges. Two thin layers of insulation with staggered joints may be considered instead of one thick layer to minimize joint leakage. If polyethylene sheeting is placed on the warm side to eliminate bonding, it can serve as a vapor barrier if all the penetrations for ties or connectors are also sealed.

2.11.6 Connections and joints — The entire sandwich wall system should be designed for durability, resistance to corrosion, and moisture protection. Some of the most vulnerable points are at connections and joints. Effects due to temperature and shrinkage must be considered when sizing sandwich panels and their joints. Allowance must be made for expected panel deformations, particularly at corners and panel openings.

2.11.6.1 Connection designs — Structural connection of tilt-up sandwich panels to the entire building must be designed for the same loads as a normal tilt-up panel. All connections must be to the structural wythe. To achieve this, it may be necessary to place openings in the supported wythe at locations where structural connections occur on that face of the panel.

2.11.6.2 Subdividing supported wythe — To minimize cracking and excessive warpage in large panels, it may be necessary to cut the supported wythe into several pieces and support them all from the same structural wythe. The supported wythes are cast down with joints between them. One structural wythe is cast over them. The unit is lifted as one piece, and intermediate joints are sealed the same as the main joints.

2.11.6.3 Joints — Joints between sandwich panels are sealed to prevent moisture from entering the building or reaching the insulation. These joints may also be insulated with compressible material to improve energy efficiency and allow joint movement (see Section 2.16.4).

2.11.6.4 Differential warpage — Differential warpage in two adjacent sandwich panels can lead to unsightly conditions. It is desirable, therefore, to design panels to react similarly to weather and temperature conditions. Corners, where movement and warpage occur in two different planes, are the most difficult to design. For mitered corners special consideration should be given to the effects of temperature and shrinkage on both wythes. A small concrete return on the fascia panel is easier to build, though one edge will be stiffer than the other and could result in differential deflection (see Fig. 2.30). A separate symmetrical insulated corner element may be the best design.

2.11.6.5 Top of panel — In sandwich panels, insulation frequently extends to the top, allowing moisture to enter, unless a waterproof cap strip is provided (see Fig. 2.31). It is sometimes desirable to stop the insulation and external wythes short of the top of panel. In this instance, a concrete rib can be cast integrally with the structural wythe and the horizontal joint sealed to the supported wythe (see Fig. 2.32). This has the disadvantage of forming a thermal bridge.

2.11.6.6 Frames — Frames for doors and windows should be connected only to the structural wythe. A joint should be provided in the supported wythe around the door and window frame (see Figs. 2.33 and 2.34).

2.11.7 Lifting — A complete discussion of lifting tilt-up panels appears elsewhere in this text, so this section will be limited to the differences for sandwich panels. The same type of lifting inserts that are used in regular tilt-up panels can be used in sandwich panels, provided that they are embedded in the structural wythe only. The section modulus used for determining lifting stresses will be that of the structural panel only.
2.11.8 Summary of recommendations

a) The supported wythe thickness should be as thin as possible, but not less than 2\(\frac{1}{2}\) in.
b) The structural wythe thickness should be properly sized to accommodate the additional load of the supported wythe
c) Do not allow any structural loads to be transferred to the supported wythe
d) Consideration must be given to thermal bridges and joints in design of non-composite panels
e) Provide a solid rib of concrete or wooden member at the bottom of the panel to facilitate rotation when the panels are being tilted from the casting bed
f) Cast the structural wythe on top to allow easy access to the lifting inserts
g) Use only stainless steel or other non-corrosive connectors between the two wythes
h) It is important that good curing practices described elsewhere are followed, since thin concrete sections are involved
i) It is essential that a quality bond breaker or method of breaking the bond is employed to minimize bond between the supported wythe and casting bed. Adhesion to the casting bed or attempts to break the bond with too rapid a load application can delaminate the two wythes. Wedging non-composite panels from the casting bed can cause spalling and collapse of the insulation, and is therefore not recommended

2.12-Lifting analysis

2.12.1 Introduction — Tilt-up panels are erected using a crane, and appropriate rigging connected to lifting inserts that were embedded in the upper face of the panel during casting. This is called a face lift. An edge lift, in which the rigging is connected to inserts embedded in the top edge of the panel, may be used occasionally. These erection practices subject wall panels and floor slabs to flexural stresses that often exceed the permanent structure’s service load stresses.

2.12.2 Obtain job information — The first and most important step in designing a panel for lifting is to obtain appropriate technical information such as:

1. A complete set of plans and applicable contract specifications documenting panel construction and erection
2. Specified concrete strength at time of lift
3. Yield strength of reinforcing steel to be used
4. Minimum cover for additional reinforcing steel if strongbacking is not permitted
5. Location of reinforcing steel in panels if not shown on plans
6. Panel thickness
7. Architectural features and surface, including weight and change in thickness of nonstructural finishes
8. Density of concrete
9. Type of lift desired
   a) Face lift
   b) Edge lift
   c) Both
10. Method of casting panels
    a) Inside face down
    b) Outside face down
11. Bracing Operation
    a) Lifting inserts
    b) Bracing inserts
    c) Strongback inserts, if required
12. The pattern of rigging system preferred by the contractor should be stated. Three wide or three high rigging systems are seldom used due to the complexity of the rigging
13. Use strongbacks where permitted to avoid overstressing of concrete, wood or steel strongbacks
14. Sequence of lifting
15. Other special requirements or instructions not covered

Having obtained the necessary job information, appropriate design/construction personnel should study the plans and other information carefully for special requirements.

2.12.3 Insert location

2.12.3.1 General — Engineers and contractors involved in the design and construction of tilt-up panels should understand the mechanics of tilting and lifting the panels. However, most accessories suppliers will perform the service of locating lift points and analyzing the panel stresses associated with the lifting operations. It is recommended that persons performing this analysis have experience in this type of work.

To properly position inserts, the center of gravity of the panel must be determined. Since tilt-up panels are not always uniform in weight, due to openings and architectural features, inserts are located to compensate for shifts in the center of gravity.

2.12.3.2 Number of inserts — To establish the number of lifting inserts required, the weight of each panel and its configuration must be determined. The preferred or required rigging patterns are carefully selected giving consideration to insert quantities, panel size, and center of gravity data. The basic insert pattern is positioned horizontally and vertically to maintain equalized insert loadings and minimal flexural stresses. Typical insert location and rigging is shown in Fig. 2.35.

Frequently basic insert patterns fall within openings complicating insert positioning. If an insert must be moved in a horizontal direction, the opposing (mirrored) insert usually must be adjusted by the same amount in the opposite direction. If an insert must be moved in the vertical direction, usually other inserts must be adjusted by proportional amounts. In some instances, inserts have to be moved in both directions requiring a combination of the above procedures. These procedures are not steadfast rules and judgment should govern.

To facilitate rotation, the final location of inserts should position the center of lift away from the center of gravity of the panel and towards the top of the panel. Inserts should be symmetrical, if possible, about a vertical line through the panel’s center of gravity. For panels that are to remain horizontal, inserts should be located superimposing the center of lift directly over the center of gravity of the panel.

2.12.4 Analysis — During erection of tilt-up panels, the tension load, normal to the panel, on lifting inserts
Fig. 2.35-Lifting inserts and riggings
will vary as the angle of the panel and rigging geometry changes. The rigging is arranged to equalize loading on inserts, keeping the resultant load on each insert the same. However, the tension and shear components on each insert will be a function of the angle between the panel and cable.

2.12.4.1 Vertical analysis — To determine the flexural stresses, the panel is treated as a beam supported by tension loads on the inserts and the ground reaction. Section properties of the beam are based on the net width of the panel and its structural thickness (overall thickness less architectural features and exposed aggregate). The gross concrete section of the panel is used in the lifting analysis. The load applied along the beam is the normal component of panel weight. Tension and shear loads on inserts vary as geometry in the rigging changes. Panel stresses are calculated at incremental points along the length of the panel and repeated at several angles of panel inclination to determine points of maximum stress. Maximum stress usually occurs at 0 deg and between 30 and 50 deg for two and four row lifts. If the allowable stresses are exceeded, additional reinforcement may be used to control crack width. As an alternative, strongbacks, which are covered in Section 2.12.5, using higher strength concrete, or another lifting arrangement should be considered.

The allowable flexural stress is a stress level less than the modulus of rupture of the concrete at time of lifting. For single wythe panels and noncomposite sandwich panels an allowable flexural stress of 5.5 to 6.0 $\frac{f_{c}}{4}$ yields satisfactory results for normal weight concrete. The value off, is the specified compressive strength at time of lift. It is recommended that field cured cylinders or flexural beams be used to confirm the flexural strength of concrete at lifting time. If flexural beam tests are used, a flexural stress of 8 to 10 $\frac{f_{c}}{4}$ will usually satisfactorily meet the strength requirement. Maximum stress determined by analysis does not include additional loads that may be imposed by bonding to the floor or impact of rapid debonding.

Maximum shear and tension loads on the inserts should be checked to insure that the allowable shear and tension capacity is not exceeded.

2.12.4.2 Horizontal analysis — Horizontal analysis is similar to the vertical analysis. The analysis need only be performed once at zero deg inclination because the sum of the insert tension loads acting on the panel in the horizontal direction is greatest at this point.

2.12.5 Panel strengthening

2.12.5.1 Vertical — If panel flexural stress exceeds allowable flexural stress, the concrete strength $f_c$ at time of lift must be increased, a different lifting arrangement considered, or the panel must be reinforced. Reinforcement is accomplished by adding external strongbacks or additional reinforcing steel in the tension zone of the panel.

2.12.5.2 Strongback application — Wood beams, steel channels, or aluminum channels are usually used for external strongbacking (see Figs. 2.36 and 2.37). Relative stiffness of strongback and panel should be used in the analysis of lifting stress. If strongbacks are used, care should be taken to insure that they clear the rigging, inserts, lifting hardware, and braces. To develop their strength, they should also be extended a sufficient distance beyond the location where they are not required. Weight and location of strongbacks should be considered when determining the center of gravity of the panel. Where strongbacks or extra reinforcement are required, it is normally sized to carry the entire bending moment at the critical section.

2.12.6 Computer aided design — With the aid of computers, a complete panel analysis for the lifting stresses can be performed quickly and accurately. Complex panel shapes and unusual panel finishes are easily accommodated with computers, thus allowing optimal solutions. Panel analyses without the services of a computer and software are usually laborious.

2.13-Temporary bracing

2.13.1 General — Once erected, tilt-up panels must be temporarily braced against wind and other lateral forces until all final structural connections are completed. The most common method of temporarily bracing tilt-up panels is the use of telescoping pipe braces. These braces are commercially available in a wide variety of lengths and sizes. They can normally be rented from the same accessory supplier that supplies pick-up inserts and lifting hardware.

2.13.2 Design criteria — Design criteria for lateral forces can vary from area to area. A commonly used service load is 10 psf. A windload of 10 psf will normally be produced by a wind velocity of approximately 45 mph. While this load may be adequate for many areas, local conditions regarding wind speed expectations must be considered in the temporary brace design. Local building codes or other governing agencies may also dictate design criterion. When calculating windload forces on a panel the designer should consider all panels as being solid for uniformity of bracing and ease of design.

2.13.3 Sub-braces — Depending upon type of brace used and height of wall, the bracing design may require that the main support brace be supported by a system of knee braces, lateral braces, and end or cross braces (see Fig. 2.38). When cross bracing is required it should be used at intervals that normally do not exceed 100 ft to prevent a chain reaction of brace failure. Such a sub-support system is designed to reduce the buckling length of the main brace and must have firm connections at all points. The knee brace must be connected at the bottom end to prevent the main brace from buckling downward or upward. Lateral bracing and end or cross bracing prevent the main brace from bending laterally. All elements of such a sub-support system must be used and properly connected. For example, a knee brace without end or lateral bracing results in a bracing system no stronger than if the knee brace was not provided.
2.13.4 *Brace supports* — Often the weakest link in the bracing system will be the attachment anchor that connects the main brace to the floor slab. A calculation of the induced pull-out force at the floor attachment should be a part of any brace design. Floor thickness and its concrete strength must be considered in determining proper anchorage. Typically drilled-in anchors are used to connect braces to the floor slab. Care in installation is essential to insure an adequate attachment.

2.13.4.1 *Deadmen* — The use of deadmen is common practice when a floor slab or footing is not available for attaching a brace. Deadmen can be any shape; round, square, rectangular or even a continuous grade beam depending on jobsite requirements. The same care and attention to detail regarding concrete strength and type of anchor attachment should be taken as though it were a normal brace point in a floor slab. Weight of the deadman should be at least 1.5 times the vertical uplift force.

2.13.5 *Removal* — Bracing should not be removed until all structural connections are completed including...
1" DIA. LBPT INSERTS TYP.

1" DIA. DOUBLE LBPT INSERTS TYPICAL AT LIFTING BRACKETS

NOTCH AS REQ'D.

1" X LAGS-IUD WITH FLAT WASHER TYP.

SHORE AS NOTED ON PANEL DETAILS

Fig. 2.37-Typical strongback with shore detail

WHEN NECESSARY PROVIDE END BRACE FOR LATERAL BRACE STABILITY AT EACH END OF LATERAL BRACING.

LATERAL BRACE (2 x 4) (MUST BE CONTINUOUS)

KNEE BRACE (2 x 4)

NAILING PLATE FOR LATERAL BRACE

Fig. 2.38a-Temporary bracing — elevation
2.13.6 Suppliers — Most tilt-up concrete accessory suppliers provide a detailing service whereby they will design a bracing system for a given project. Contractors often avail themselves of this service.

2.14 - Architectural/engineering documents

2.14.1 General — Architectural/engineering project drawings and specifications need to transmit, with completeness and clarity, the general and special requirements for tilt-up panels. In order for the contractor to properly fabricate these panels, information about panel size, openings, face treatment, edge conditions, reinforcement, connections, and lifting devices must be detailed. Some of this information, such as location of the lifting devices, may be generated by the contractor’s shop drawings.

2.14.2 Drawings — A set of architectural/engineering project drawings will include:

2.14.2.1 Elevations — Exterior architectural elevations showing panel dimensions, jointing, openings, areas of special treatment such as facing aggregates, reveals, form liners, and scuppers.

2.14.2.2 Details — Architectural details showing bevels, miters, chamfers, tapered recesses, door and window conditions, roofing, and flashing connections.
2.14.2.3 Panel elevation — Panel elevations drawn from the viewpoint of the fabricator (will panel be cast face up or face down) showing typical reinforcement and special reinforcement at major and minor openings. Recommended scale \( \frac{1}{8} \text{ in.} = 1 \text{ ft} \) and with each panel uniquely numbered.

2.14.2.4 Key plan — Key plan to indicate location of panels and panel designation.

2.14.2.5 Structural details — Structural details showing typical panel thickness (is facing aggregate and grout or architectural relief included in the structural thickness) and special thicknesses and widths of pilasters.

2.14.2.6 Reinforcement — Reinforcement details showing typical placement and clear cover requirements (note: vertical reinforcement is typically centered in the structural thickness and horizontal reinforcement offset to the outside face), pilaster reinforcement and tie configurations and dowels for slab connection.

2.14.2.7 Connection details — Connection details showing anchor devices, embedded structural steel, base grouting, and connecting materials.

2.14.2.8 Miscellaneous details — Other items include necessity for mechanical and electrical coordination openings, sleeves, conduits, and junction boxes.

2.14.3 Specifications — Specifications should include the specified compressive strength of concrete at 28 days, grade of reinforcement, minimum strength, and density of concrete at time of lift, and allowable lift stresses (see Section 2.12.4.1). Requirements, if considered necessary, of a sample panel to include finishes, miters, corners, and other details.

2.14.4 Shop drawings — The contractor should be required to submit shop drawings which depict each panel. See Section 3.8 for information.

2.15 Reinforcement

2.15.1 General — Reinforcement most frequently used in tilt-up panels is #4 through #6 Grade 60 deformed bars. Larger diameter bars may be used but are more difficult to handle at the jobsite. Prefabricated and welded wire fabric, or mats of deformed bars have been used successfully when panels are of uniform dimension and have few openings. Post-tensioning of wall panels is generally not economical and may limit the flexibility of cutting future openings. Fiber-reinforced concrete is not commonly used and is not discussed.

2.15.2 Concrete cover — Concrete cover provides protection of reinforcement from ordinary exposure conditions. It also reduces possible discoloration of the concrete surface. Cover is measured from the concrete surface to the outermost surface of reinforcement.

In practice, many designers choose cover dimensions for concrete tilt-up wall panels that are between the required minimum for precast and cast-in-place concrete.

2.15.2.1 Cast-in-place requirements — If the designer has concern for tolerances under field conditions, the minimum covers of ACI 318, may be used:

a) Concrete exposed to earth or weather, #5 bar and smaller — 1\( \frac{1}{2} \) in.

b) Wall not exposed to earth or weather, #11 bar and smaller — \( \frac{3}{4} \) in.

2.15.2.2 Precast requirements — If the designer has confidence that the tilt-up contractor can meet precast concrete construction tolerances for dimension control, reinforcement placement, aggregate size, concrete quality, and curing control, reinforcement may be detailed in accordance with ACI 318:

a) Wall panels exposed to earth or weather, #11 bar and smaller — \( \frac{3}{4} \) in.

b) Wall panels not exposed to earth or weather, #11 bar and smaller — \( \frac{5}{8} \) in.

Size of aggregate must also be considered in determining minimum cover requirements.

2.15.2.3 Architectural panels — Designers must pay particular attention to minimum cover of wall panels that vary in thickness due to architectural treatments. Reductions in panel thickness for reveals or rustication may require that the entire reinforcing bar mat be shifted to the interior of the panel section, particularly in areas where there are multiple layers of reinforcement in the section.

2.15.2.4 Edge cover — Experience has shown that it is good detailing practice to terminate ends of reinforcing bars a minimum of 2 in. from any exposed edge or opening. Reinforcing bars parallel to a panel edge or opening should maintain a minimum 3 in. clearance between the bar and edge or opening. Greater clearances should be maintained in areas of panels designed for future openings to allow for over-cutting of the concrete saw blade.

2.15.2.5 Corrosive environment and fire walls — Wall panels designed to withstand the effects of unusually corrosive environments must comply with cover requirements suitable for those conditions. Similarly, wall panels designed as fire walls should satisfy special requirements for thickness and cover.

2.15.3 Principal reinforcement — Generally, tilt-up wall panels are designed as beam-columns spanning from slab-on-grade to roof or intermediate floors. Therefore, the principal reinforcement in a wall panel is usually placed parallel to the vertical panel axis. Loads act on either surface of the panel and most designs employ a single mat of reinforcement at or near the center of the panel section. However, in panels supporting high concentrated loads such as beam or joist girder reactions and in panels with large openings, a double mat of vertical reinforcement is often required. The principal reinforcement should be continuous from top to bottom of panel, avoiding splices. In cases where loads are small, minimum requirements for temperature and shrinkage may be the controlling design condition.

2.15.3.1 Spacing — Spacing of bars is a function of design requirements for the imposed loads. However,
clear distances between parallel bars in a layer should not be less than one bar diameter (ACI 318) nor 1.5 times the maximum size of aggregate. Where parallel bars are placed in layers in the casting position with bars in the upper layer directly above those in the lower layer, the clear distance between layers should not be less than 1 in. (ACI 318) nor 1.5 times the maximum size of aggregate.

2.15.4 Supporting reinforcement — Reinforcing bars are supported in the wall panel by the use of high-chairs or slab-bolsters. These supports are usually manufactured from steel wires or plastic. Steel supports in contact with the panel’s exposed face should either be fabricated of stainless steel or have a durable plastic coating. If the surface of the panel is to be sandblasted, use all plastic chairs.

The single mat of vertical reinforcement may be supported by chairs directly, or more commonly, is tied to and supported by the horizontal mat. The normal recommendation for spacing of chairs is not more than 4 ft on centers in both directions. Horizontal bars are often spaced on 18 in. centers. Supporting every third bar or a 4 ft, 6 in. chair spacing has proven satisfactory.

In areas requiring a double layer of reinforcement, cages may be detailed with #3 ties and supported by slab bolsters. Another popular method for supporting a double layer of bars is to tie one level below the horizontal mat and stack the second layer on spacer bars above the horizontal mat.

2.15.5 Shrinkage and temperature reinforcement — Shrinkage and temperature reinforcement are required at right angles to the principal reinforcement to minimize cracking and to tie the panel together. Most commonly, this is horizontal reinforcement in a tilt-up panel.

Design requirements for shrinkage and temperature reinforcement fall in an area between precast and cast-in-place construction. When individual panels are less than 24 ft wide, a common practice is to provide an area of temperature and shrinkage reinforcement not less than 0.0015 times the gross concrete section. This has proven to be a successful compromise between the values of 0.0010 recommended for precast panels by the Prestressed/Precast Institute in their Design Handbook and the ACI code requirement of 0.0020 for cast-in-place concrete (ACI 318). For panels greater than 24 ft wide and for buildings in a dry climate, a higher minimum reinforcement ratio of 0.0020 is often used. If adjacent panels are connected greater amounts of reinforcement should be considered.

Consideration of how temperature and shrinkage stresses are likely to develop in a panel due to its shape, openings, connections, or bearing conditions is also important in determining the location of temperature and shrinkage reinforcement (see Figs. 2.2, 2.3, 2.4 and 2.5).

2.15.6 Construction considerations — In some instances, the tilt-up lift analysis will require additional reinforcement due to severe lifting stresses. These bars are to be placed as detailed and are in addition to reinforcement shown on the project drawings.

2.15.6.1 Inserts — Precise location of lift inserts in the panel is critical for a successful lift. Short pieces of reinforcement are frequently used to secure inserts to the reinforcing bar mat.

2.15.6.2 Tieing — Horizontal and vertical reinforcement should be securely tied at least at 50 percent of their intersections. Ties should be distributed uniformly throughout the reinforcing mat. Scrap tie wire and other foreign material should be removed before casting concrete to avoid corrosion stains on the panel surface.

2.15.6.3 Size and grade — Designers should be consistent in their selection of bar sizes detailed for vertical and horizontal reinforcement and should avoid mixing grades of reinforcing bars on the same job.

2.15.6.4 Bondbreaker — A bondbreaker should be sprayed on the floor slab before placing the reinforcing bar mat. Preferably the bondbreaker should not come in contact with the reinforcement.

2.16-Architectural considerations

2.16.1 General — Tilt-up concrete construction offers additional freedom to architects in the design of buildings. As with any construction medium, however, certain guidelines will maximize benefits and minimize limitations. If the flexibility of the building design and designer allow inclusion of many of the ideas presented in this section, economy of tilt-up construction can be enhanced. Concepts are presented here as a guide but are not meant to be all-inclusive.

2.16.1.1 Cracking — It should be recognized that cracks may occur in panels due to the normal behavior of a reinforced concrete section and also because of thermal and shrinkage movement. However, these cracks can be minimized and controlled by careful design and detailing of the panel, placement of openings, distribution of reinforcement, and use of rustication strips.

2.16.2 Shape — Rectangular panels are generally the most efficient to design, construct, and lift. However, other shapes such as slopes and in-plane curves have been used successfully in many projects. Openings within a panel can also be formed with considerable variation in shape. Architects should consult a designer with tilt-up experience when formulating their design to assure that the resulting panel is structurally sound.

2.16.2.1 Repetition — Greatest economy is achieved by repetition of shapes and details. Where site or slab area constraints dictate that panels be cast in stacks, constant size is important.

2.16.2.2 Top heavy panels — Avoid top heavy or laterally unbalanced panel configurations which may be unstable when erected. Long slender legs which extend to the bottom of the panel are particularly vulnerable to cracking during the lifting operation.

2.16.2.3 Discontinuity — Avoid designs where significant gravity or lateral load resisting elements are interrupted by openings or limited by design to an insufficient thickness. Long span lintels are sometimes con-
figured to support large girder reactions. This results in additional panel thickness and reinforcement.

2.16.3 Identifications and projections — Architectural variety can be accomplished using indentations or projections from the face plane of the panel.

2.16.3.1 Design — Horizontal slots, reveals, rustication strips, etc., may create a weakened section often at a point of maximum design moment. The reduced concrete thickness at this point controls the structural design and adds to overall thickness and cost. Vertical indentations have less effect on panel strength unless, of course, the panels are designed to span horizontally between supports or pilasters.

2.16.3.2 Architectural finish — Architectural finishes and aggregate surfaces should not be included in determining structural thickness. Coordination on this item is necessary to define the total thickness required and avoid important dimensional errors.

2.16.3.3 Casting procedure — The architect should be aware of how the panel is to be cast. If cast “outside face down,” a projection to the exterior would be difficult to fabricate and may require building formwork for a large area of the panel rather than the economical method of casting directly on a slab. If projections are required, they can often be accomplished after panel erection.

2.16.3.4 Out-of-plane construction — Difficult out-of-plane construction, which requires specialized formwork and erection techniques, such as curved panels, or round columns or pilasters, is possible but will be expensive to design, fabricate, and erect. Again, consult the engineer to assure structural feasibility.

2.16.4 Joints — Perhaps the area with the greatest potential to add to or detract from the economy and success of a tilt-up project is prudent and knowledgeable placement of panel joints. If the architect considers the following concepts when creating the panel joint pattern, many problems can be avoided.

2.16.4.1 Corners — Consider corners carefully. Mitered joints require special care in fabrication to avoid uneveness.

2.16.4.2 Details — Care should be taken in detailing joints using chamfers and sealants. The correct joint width is important in the proper functioning of the sealants. Joint widths of 1/2 to 1/4 in. are commonly used. Accenting the joint with an acknowledgment of its existence using vertical indentations is often more effective than trying to hide it with a detail requiring difficult construction precision.

2.16.4.3 Joint location — Avoid panel joints which coincide with structural framing members supported by the panels. Locate joints so that panel segments adjacent to openings are not too narrow. The engineer should be consulted to establish minimum dimensions. Generally, segment widths less than 24 in. should be avoided.

2.16.4.4 Chamfer — Chamfer of exposed corners of panels should be given consideration. Generally, the exposed face of the panel is cast down and without a chamfer in the corners can result in voids and honeycomb. A chamfered corner can eliminate this problem and improve appearance of the panel.

2.16.4.5 Lift weight — In selecting panel jointing and resulting panel widths, due consideration should be given to the lift weight of the elements. The heaviest panels will determine size of the crane required for erection and hence the cost.

2.16.4.6 Openings — Avoid joints that extend through openings and lintels. If windows or doors occur at a joint, panel movement may cause the window to crack or door to jam.

2.16.4.7 Fire walls — If a tilt-up concrete wall with jointing is expected to perform as a fire wall, special details to protect the joint are required.

2.16.5 Special considerations — Interesting effects in a building can be accomplished by attaching spandrels, eyebrows, fins, and other precast elements to the panels. These can often be site fabricated and tilted up in much the same manner as typical wall panels. However, considerable care is required when detailing connections to avoid exposure and rusting of steel embedded items. Also, bridging across panel joints with a concrete element which is rigidly connected to both sides may result in thermal cracking.

2.16.5.1 Supported panels — Architectural designs requiring panels to be supported atop each other require special attention, especially if the support point is not laterally restrained by a second floor or other structural element.

2.16.6 Finishes — Finishes are addressed in Chapter 6.

CHAPTER 3 — CONSTRUCTION PLANNING

3.1-Introduction

3.1.1 General — The nature of tilt-up construction dictates the need for thorough preconstruction planning. Much of the economy of tilt-up construction is realized by the ability to establish an efficient on-site production operation. Success of each construction sequence depends on the success of the preceding construction event. Errors are literally cast in concrete. Successful production requires organization and planning. This chapter is intended as a planning guide for the average tilt-up project but is not all inclusive.

3.2-Site access and jobsite conditions

3.2.1 General — Location of a jobsite may be such that special permits will be required to gain access to the site for heavy equipment needed for earth work, large cranes for panel handling, and large trucks that deliver roofing members. As an example, special permits are a common requirement for schools and churches. These are often built in residential areas where tonnage restrictions could exist.

It is advisable to investigate restrictions on early daily start-up times. Noise abatement and dust control
regulations are becoming more prevalent. Fencing around a project should be considered to reduce vandalism and prevent unauthorized access and possible injury.

3.2.2 Crane access — The panel contractor and erection sub-contractor should walk the jobsite and determine site access and building access for the crane. Any problems with uneven terrain should be noted, along with determining a suitable location for crane assembly and rigging make up. Some local governments will not allow this activity on public streets. Location of crane entrance and exit ramps at the building should be finalized, and if necessary, plans made to thicken the floor slab at those locations so the crane’s weight does not damage the slab.

3.2.3 Underground — Underground tunnels, trenches, and sewer lines are a very common occurrence. It is necessary to know the location of these underground lines, to avoid those that need strengthening to support the equipment. Location of underground hazards should be noted on the architect/engineer’s plan. Further investigation by the contractor should be made in an effort to discover unknown hazards.

3.2.4 Overhead — Overhead wires can be a common problem on both urban and rural jobsites. Chapter 5 on panel erection explains some of the problems involved when handling panels near or under overhead wires. In the early stages of construction planning it is important to be aware of such problems, particularly if it involves shutting off power or lifting panels on premium cost days (Saturdays, Sundays, holidays) when the power outage is least disruptive to surrounding property owners.

3.3-Coordination

3.3.1 Scheduling — Construction sequences and scheduling must be constantly monitored and tightly controlled. Subcontractors and other trades have a certain specified time slot in which to perform their function. If a subcontractor performs his function out of sequence it almost always involves costly delays and precludes the next construction sequence from progressing.

3.4-Sequence of construction

3.4.1 A typical construction sequence for an average tilt-up project follows:

1. Site preparation
2. Underslab plumbing and electrical
3. Cast and cure interior column footings
4. Cast and cure floor slab
5. Form, cast and cure panels
6. Form, cast and cure exterior footings (Steps 5 & 6 are often performed concurrently, keeping in mind the need for proper curing time of the footings)
7. Erect and brace panels
8. Construct the roof structure/diaphragm
9. Place concrete in pour strip between the floor slab and panels
10. Remove braces
11. Schedule other trades for: painting, landscaping, interior framing and interior finish

This is not a rigid sequence of events. There are many exceptions. A common occurrence that would cause this sequence to change would be a specification requiring the floor slab to be placed after the roof structure/diaphragm is constructed. In this case, temporary casting slabs located outside the building perimeter are necessary for panel construction. Also, deadmen will be needed for panel bracing.

3.5-Work platform

3.5.1 Floor slab — Quality of the floor slab is an important aspect in tilt-up construction. Panels are normally cast on the floor slab and any imperfections in the slab will be reflected in the panel finish.

A general rule of thumb is that panels can be cast individually on the floor slab, without stacking or going outside the building perimeter with temporary casting slabs, if the total square footage of panel area does not exceed 85 percent of available floor slab area.

3.5.1.1 Joints — Locate crack control joints to minimize unsightly lines being transferred to the panel. These lines will always be visible. Filling the joints with plaster, parafin, styrofoam rod, or covering with tape will often minimize costly surface repairs or finishing. Paint or coatings will not always eliminate the visual effects of casting panels on untreated joints.

3.5.1.2 Electrical and plumbing — Make plans for stubbing all electrical and plumbing below the finish floor surface. Doing so creates additional area for casting panels and an obstacle free area for crane movement. Projections interfere with screeding and can be a source of cracks.

3.5.1.3 Column blockout — Floor area at column blockouts can be utilized for a casting area. This can be accomplished by filling the area with sand to within 3 in. of the top and then placing a temporary filling of concrete finished the same as the floor.

3.5.1.4 Curing — Proper application of the curing compound on the floor slab is very important. The right time to apply curing compound is immediately after final hard troweling just as the slab is starting to lose the wet sheen. Recommendations found in ACI 308 and the manufacturer’s instructions should be followed.

3.6-Curing compounds and bondbreaker

Combination curing compounds and bondbreakers should meet ASTM C 309 requirements and are one of the most critical materials that will be used on a tilt-up project. Proper selection and application are essential to the success of a tilt-up project. Most projects require a cure and bondbreaker that will perform multiple tasks and allow future trades to work on the concrete surface. The contractor is looking for these characteristics:

1. Good curing qualities
2. Good bondbreaking qualities
3. Good drying qualities
4. Clean appearance
5. Compatibility with subsequent floor hardeners and/or coverings
6. Compatibility with panel finish such as paint, sealants, and adhesives

It is suggested that the same material be used to cure the floor slab as is used for the bond breaker between the slab and panel. Avoid using different brand products for the curing compound and bondbreaker. Compatibility between bondbreaker and curing compound is critical. There are instances where special sealers are specified for the floor slab. Manufacturers representatives may know if certain products are not compatible, otherwise, specific testing or evaluation may be required. When the concrete mixture design for tilt-up construction contains fly ash, it is desirable to check with the manufacturer of the cure and bondbreaker for any special precautions needed.

3.7-Lifting accessories
Concrete accessory suppliers offer a wide range of types and sizes of lifting inserts in a variety of load carrying capacities. Prior to construction, the panel contractor should consult with the supplier and erection subcontractor to discuss the proper type.

3.8-Shop drawings
Panel drawings can usually be found in the architect/engineer’s plans. However, they are often incomplete for the panel contractor’s purposes. Complete panel detail drawings are essential (see Fig. 3.1). These should include:

1. Panel identification
2. All dimensions
3. All physical characteristics including weight
4. Reinforcing
5. Location and identification of embedded items
6. Finishes and textures
7. Rigging and bracing information

3.9-Panel casting locations
3.9.1 Planning panel layout — To insure an efficient construction procedure consideration must be given to the casting location of panels. Two important criteria must be met:

1. Panels must be properly located for efficient casting
2. Panels must be properly located for efficient lifting

The contractor should consult with the erection subcontractor to help develop the casting layout. The erecto’s advice should be sought so that panels are cast in such a position that a properly sized crane can erect them.

3.9.2 Erection sequence — A typical panel erection sequence takes into consideration a number of factors:

1. Watch for special bracing conditions, particularly at corners and other interruptions of a straight building line. At corners, braces will be required to pass over or under bracing of a previously erected panel. Consideration of brace locations before casting can often reduce the time involved in placing braces in these situations.
2. Eliminate ‘fill-in’ panels wherever possible, Panels should, if possible, be erected consecutively, beginning at a corner.
3. 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 by lifting each panel cut-out by hand to insure that the erection sequence is compatible with the panel layout. This planning should be done with the erection subcontractor.

3.10-Erection subcontractor
3.10.1 Crane selection — Crane selection is primarily the choice of the erection subcontractor. This is also a good time to discuss the rigging, to be certain proper equipment arrives with the crane.

3.10.2 Erection from outside — If panel lifting will be done from outside the building perimeter, the area should be graded smooth and compacted so the crane will not be subjected to traveling over deep ruts or soft spots. Sudden movement during panel handling imposes a dynamic load on the crane and/or lifting inserts, possibly causing a serious overload.

Fig. 3.1-Typical shop drawing format
3.10.3 Site access — Although site access is often a minor consideration, access will be required for the crane and one or two accessory vehicles. The erection subcontractor will also need an area large enough to make up and break down the crane.

3.11-Final closure panel
An important consideration is the exit arrangements for the crane. Exit should serve to allow access by subsequent trades.

CHAPTER 4 — CONSTRUCTION

4.1-Introduction
This chapter emphasizes information of special importance to the contractor. A Construction Check List summarizing many of the items in the chapter is located in Appendix B.

4.2-Site, subgrade, and slab
4.2.1 Site — With tilt-up construction, the contractor should consider an all weather access to the site and to the building floor slab. The floor slab is the working table and should have permanent access during construction for heavy equipment and material delivery.

4.2.2 Subgrade — During initial grading of the site and building areas, the contractor should consider completing all subgrade work for the building floor, parking, and truck areas. At the same time, a road bed and ramp to the subgrade of the building for accessibility of equipment and material delivery can be installed. Consideration should be given to a well compacted subbase in the areas to be paved later. Materials can be stored on this subbase and be easily accessible on site.

4.2.3 Slab — The floor slab should be placed as soon as possible if it is to be used as the “work table” for all tilt-up panel forming, casting, bracing, and erecting. For best results, the floor slab should have a steel trowelled high quality finish because the panel face cast against the floor will mirror its surface. If the floor slab is not available for casting the panels, they can be “stack cast” one on top of the other at an accessible location near the perimeter of the building, or from the subgrade of the building.

4.3-Construction practices and workmanship
4.3.1 Tolerances — Refer to Section 2.9 for recommended reinforced concrete tolerances.

4.3.2 Underground installation — All underground installations, particularly in slab areas, should be completely installed, properly backfilled, and compacted and capped off below the floor slab prior to placing concrete. Keeping mechanical and electrical work below the top of the slab is a major safety factor, particularly when the floor slab is the work table.

4.3.3 Floor slab — Floor slabs should be cast according to plans and specifications. A temporary ramp should be considered for access of equipment and material delivery to the floor slab.

4.3.3.1 Placement — It is recommended that a well consolidated, low water-cement ratio concrete be placed. The floor slab should have a steel trowelled high quality finish. See ACI 302 for guidance and recommendations for slab-on-grade construction. Consideration should be given to casting bay width wide strips for the length of the building, and creating floor joints by using inserts placed in the fresh concrete or saw cutting the hardened concrete slab. It is also suggested that alternate bays be cast and then fill the areas in between.

4.3.4 Layout of panels — Once the floor slab is in place and cleaned, the panels are laid out directly on the slab and edge forms erected. Chalk lines should be sprayed with a sealer so weather will not wash the lines away. Plan layout of panels so that they are accessible to ready-mix concrete trucks for casting and to the crane for erecting. Panels should be placed as near as possible to their final location in the wall, and as many placed side by side as possible. Panels that cannot be cast near their final location should be carefully located so that they can be “walked” by the crane to the final position in the wall.

4.4-Shop drawings
4.4.1 Panels — If complete shop drawings are not prepared by the engineer, the contractor must prepare drawings detailing each panel. See Section 3.8 for further discussion.

Preparing shop drawings of individual panels on 8½ x 11 in. stock that can be kept in a loose leaf notebook is one common procedure. Standard forms can be prepared by the contractor to make details of each panel.

4.4.2 Lifting and bracing — After panels have been detailed showing architectural features, thicknesses, embedments, and reinforcement, the contractor should contact the designer of the lifting and bracing inserts with instructions to determine the location of lifting and bracing inserts for each panel. If contract drawings include a layout for lifting and bracing inserts, this step is not required.

4.5 Materials and equipment
4.5.1 Concrete — The concrete mixture proportions should be reviewed by the designer.

4.5.2 Form work — Form materials should be straight and true. Edge forms should be cut to design panel thickness. One recommended method is to make L-shaped brace forms on the site, then anchor them to the floor slab by drilling ¾ in. holes through the forms into the floor, and anchor with two double headed form nails wedged into the hole in the concrete. Holes can be patched with epoxy at completion of the work. Do not use stud guns. The stud could damage the slab.

4.5.2.1 Special care — Special care should be taken in constructing panel forms to insure that they are square and true. With panel heights typically 22 ft or more, slight variations in form measurements will affect the plumbness and joint dimensions.

If horizontal rustication or relief is used in the arch-
itectural treatment of the building, location of forms for this relief is critical. Special care should be taken in locating these forms to insure a good straight line from panel to panel.

4.5.3 Reinforcement — Reinforcing bar mats can be tied ahead of time and placed in the panel on supporting chairs. Reinforcing bar mats can be displaced during concrete casting so caution should be used to prevent this. Chairs should be made of plastic or if made of steel wire, have plastic tips. Additional reinforcing may be required around inserts for lifting and bracing.

4.5.4 Bondbreakers

4.5.4.1 Type — It is essential that a quality bondbreaker be employed. It is also essential to know the type of finish that will be required on the panel. There are three basic bondbreaker types:

a) synthetic petroleum, hydro-carbon, resin solutions
b) solutions of waxes with metallic soaps
c) solutions of organic esters and silicones

Since resin and wax-soaps rely on physical films for performance, possibilities exist for residue on both panel and slab. Although resins are designed to oxidize in 30 to 90 days under normal exposure, varying conditions may result in residue beyond that period of time. Wax-soap types resist oxidation, leaving residue, particularly with excessive application. Residues discolor and can prevent adhesion of paint, sealers, adhesives, and other treatments. Silicone-ester types leave little or no residue.

4.5.4.2 Compatibility and testing — It is important to select a curing compound that is compatible with the bondbreaker. Check this prior to casting the slab. Suitability of the bondbreaker may be checked by dropping small amounts of water on the surface to form spherical droplets, and also by physically feeling the material on the concrete casting bed or slab. Bondbreakers exposed to weather for more than three days, or that have had heavy rain exposure should be checked. It may be necessary to add another coat. Panel surfaces that stick can result in damaged and cracked panels, or pull out of lifting inserts with resulting job delays and panel replacement costs.

4.5.5 Inserts — Selection of lifting and bracing inserts should be determined prior to construction. There is a wide range of types of pick-up inserts including coil-bolt, quick release, and lanyard release. Size, height, and weight of panel should be considered in determining type selection. The contractor should also consider recommendations from the hardware and erection subcontractors.

4.5.6 Embedded items — Embeds, as they are generally called, should be on the jobsite prior to casting the concrete panels. It is important that embeds be securely anchored in place prior to casting and their location carefully checked. Wood forms and reinforcement can be used to either nail or anchor all embeds in place.

4.5.7 Finishes — There are a number of finishes that can be used on concrete panels including exposed aggregate, cast face up or face down; form liners, painted and unpainted; and sandblasting. More detail concerning finishes is discussed in Chapter 6.

4.5.8 Equipment — Equipment other than small tools should include rotary hammers, drills, rollers, and other items, as required. Heavy equipment should include a tractor with land-leveler and a front end loader, primarily for material handling. Lifting beams, rigging, and crane are generally furnished by the erection subcontractor.

4.6-Supervision

It is important that the supervisor check the forms for dimensions and thickness, reinforcement location, and insert locations prior to casting panels. A double check of all lifting inserts, bracing inserts, and all structural embeds, is again, important prior to casting structural concrete.

4.7-Casting

4.7.1 General — After panels are formed; bondbreaker applied; chamfer strips installed on all exterior edges; and reinforcing steel, lifting and bracing inserts installed; and all embeds are in place and anchored, the contractor is ready to cast the structural concrete. Casting is the final process in producing a successful end product.

4.7.2 Material — Concrete, in accordance with the specifications and ASTM C 94, should be delivered to the site. With preplanned accessibility to the panels, most concrete can be discharged directly from the ready mixed truck.

4.7.3 Consolidation — Concrete must be properly consolidated using an appropriate vibrator. For proper vibration equipment and techniques see ACI 309.

4.7.4 Interior finish — Interior finish of panels is often an owners preference. If panels are to be left exposed either a steel troweled or a light brooming is generally used. For uniformity of appearance the panels should all be finished in the same direction, either top to bottom or side to side.

4.8-Strip and clean panels

Prior to erection clean the surface of all panels including exposed embeds. Do any necessary rubbing and patching of concrete, then install braces to the panels if cast face down. Remember, work on the ground is less expensive and safer than working on the panel after it is erected.

For panels that are cast outside face up, the holes left by the lifting inserts must be patched. Patching of concrete is discussed in Chapter 6.

4.9-Seating on foundations

4.9.1 Layout and alignment — Prior to erection the panel should be laid out on the exterior foundations and the exterior wall line established.

One method of alignment is to mark the limits of each panel, then drill 1/4 in. holes into the foundation
approximately 5 in. deep. Install No. 5 dowels, two on each side of each panel. These dowels are helpful in placing the panels with minimum effort.

4.9.2 Leveling shims — Prior to erection of panels, install shims using a level so that the top of all panels are in line with necessary adjustments below grade.

4.9.3 Grout — After panels have been erected and aligned, grout as specified should be placed underneath all panels. Grout placement should be accomplished as early as possible after panel erection, and care should be taken to be sure the grout fills the void between bottom of panel and top of footing.

4.9.4 Bracing — The contractor is responsible for proper layout, safety, and temporary bracing of the panel. This should be discussed in detail with the panel erector. Bracing that must be installed on the panel after it has been erected, and while the crane is holding the panel in position is a costly procedure and places personnel in a hazardous position.

4.10-Backfill

4.10.1 Perimeter strip — When casting the floor slab, a perimeter strip 3 to 5 ft wide is often left out between the panel and edge of the finished floor. This portion of floor is not cast because of excavation for the footing, and inability to backfill until the tilt-up panels have been erected. This excavated area may be as deep as 5 or 6 ft and must be carefully backfilled and compacted. After backfilling, the floor strip is cast connecting the panel to the floor.

4.10.2 Connection — Dowels in the panel, or other types of mechanical arrangements, are often used to lap reinforcement in the floor slab to connect the panel to the floor. Prior to backfilling, place a strip of felt over the joint between adjacent panels below grade and pack with plastic roof cement. This will prevent dirt, mud, or water from leaking through the joint in the panels. As a safety precaution, when backfilling deep areas more than 2 ft, it is a good idea to connect dowels in the panel and floor slab together to prevent any bending or bowing in the panel during backfilling. After backfill is in place and properly compacted, cast the perimeter strip joining the panel and the existing floor slab.

4.11-Wall panel joints

As discussed earlier, chamfer strips are helpful in making uniform panels and clean, neat corners. Details of the corners should be carefully discussed with the owner and architect to give desired effect within the total building. At completion of all panel and roof structure work, and prior to painting, install backer rod to ½ in. and then seal and caulk the exterior with a good grade of sealant. Interior joints may be covered with regular sealant to give a clean uniform finish.

4.12-Safety

The most important time for safety precaution is during, and immediately after, erection of the panels. The following safety items should be considered:

1. Skilled personnel and supervision must be available
2. Particular attention should be given to overhead obstructions, safe road beds, and floor projections
3. Layout and accessibility of each panel
4. Braces must be safely anchored and checked daily until all structural connections supporting the panels have been completed
5. Use remote-quick release lifting hardware
6. Minimize use of ladders

4.13-Construction checklist

A construction checklist for the project manager for forming, casting, tilting, and temporary bracing of panels is given in Appendix B.

CHAPTER 5 — ERECTION

5.1-General

The most important phase during construction of a tilt-up building is erection of the wall panels. It is incumbent upon designers and contractors to plan and re-plan, directing their efforts to ensure that this important phase of tilt-up construction is performed safely and efficiently. Since there must be a close, cooperative relationship between the panel contractor and erection sub-contractor, it is advisable to select an erection sub-contractor during the early days of the project. The erection sub-contractor and crew should be well experienced in tilt-up, as panel tilting and handling is very specialized. This chapter highlights some of the major points that the panel contractor and erection sub-contractor should address.

5.2-Prior to construction

5.2.1 Crane selection — Crane selection should not be looked upon as merely routine. General rules for sizing the crane state that the crane capacity should be a minimum of two to three times that of the heaviest panel including weight of the rigging gear. However, in the final analysis not only panel weight, but also the crane’s position relative to the panel must be considered. The following questions must be answered before final determination of crane size can be established:

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?

The crane that is finally selected for the project should be properly certified. Many, if not all states have standards with which erection sub-contractors must comply. It is a prudent panel contractor that makes certain
they have available at the jobsite documentation attesting to the crane’s certification. They should also obtain from the erection sub-contractor a certificate of insurance.

5.3-Prior to erection day

5.3.1 Site inspection — After panels are cast and during curing, the panel contractor, erection sub-contractor, and tilt-up hardware supplier should again walk the site. Terrain upon which the crane will travel should be inspected and corrections noted. The contractor should request that the crane be rigged prior to starting time on the date of erection. The panel contractor should verify that the crane is in good working condition.

5.3.2 Panel preparation — Panel preparation must be checked. Are inserts properly located as shown in erection manual, and are they clean? Check all inserts with lift hardware. Are strongbacks properly installed? Has the in situ strength of concrete been attained? Strength of concrete noted in the erection manual refers to concrete strength at time of lift and not the 28-day strength.

5.3.3 Crane entrance and exit — Entrance and exit ramps should be checked. The entrance ramp should be built up so the crane descends slightly down onto the slab, not crawling up onto it. The exit ramp should be constructed in the same manner. On some buildings, architectural openings are large enough for the crane to exit. Do not let the crane’s weight bear at the extreme edge of the slab. This is of particular importance if the crane is walking out with the added weight of the closure panel.

5.3.4 Workplatform — Blockouts over interior column footings should not be broken out prior to the lift, particularly in rainy weather. Water under the slab could make the subgrade weak.

5.3.5 Equipment — The panel contractor and erection sub-contractor must itemize the rigging and equipment that will be needed for proper, safe lifting. The erection manual supplied by the erection accessory vendor or the erection plans will specify all the types of rigging configurations and cable lengths for the project. These details should be rigidly adhered to since they are an integral part of the erection stress calculations. The panel contractor should also make a list of required tools. They should include a compressor, drills, wrenches, expansion anchors, a bolt-on lift plate, ladders, and miscellaneous hand tools. A minimum of two sets of lift hardware should be on the job. It is prudent to anticipate material needs for last minute repairs.

5.3.6 Crew — The erection sub-contractor’s minimum crew should consist of the crane operator, rigger foreman, two journeyman riggers, and welders if required. This crew should be augmented by carpenters and laborers from the panel contractor’s workforce, primarily to handle braces. In areas where no crane erection subcontractors are available the minimum crew should be a crane operator and driver, foreman, and four to five laborers. Exception: stacked panels require an additional two to three laborers and welders if required. A properly staffed and well coordinated erection crew is the key to successful lifting. The crane operator must be a skilled journeyman, experienced in handling tilt-up panels. He must be able to control three motions of his crane: Hoist, swing, and boom hoist. It is quite normal to use all three of these functions simultaneously.

5.4-Safety meeting

5.4.1 General — A safety meeting with the erection crew is held before any lifting starts. Personnel are told to never place themselves under the panel while it’s being tilted or on the blind side of the panel when the crane is traveling with it. Personnel must never be placed between the crane and the panel. A conscientious erection sub-contractor will not allow play or unnecessary talking. A standard part of the safety meeting, which is usually conducted by the rigger foreman, should contain comments about the need to remain alert with each person depending on the other. The crew should be reminded that safety is everyone’s responsibility and that hard hats are required. It is advisable for the erection sub-contractor to create a check list to use during this safety meeting to be certain everything is covered. A cautious crane contractor will have crew members sign the check list.

5.4.1.1 Rigger foreman — The rigger foreman should be clearly identified at the meeting. This individual will be the one the crane operator will be looking to for all signals. The rigger foreman must be experienced in handling panels and be totally familiar with the precise set of hand and arm signals that will communicate his desires to the crane operator. Verbal instructions are almost impossible due to the noise level in the operator’s cab.

A competent rigger foreman will create and maintain a confident atmosphere during the lift, will remain alert to guard against over confidence, and will not allow the crew to become careless.

5.4.1.2 Demonstration — During this meeting the rigger foreman should demonstrate use of the lifting hardware, bracing hardware, and proper use of any tools and equipment that are to be used.

5.4.1.3 Teams — The crew is often broken up into teams for handling bracing, rigging, and hardware attachment. Each individuals’ function and responsibility is clearly defined. The panel contractor should furnish a person whose responsibility it is to clean the floor slab as soon as the crane has cleared the area. Regardless of how good a contractors housekeeping is prior to the lift, there is always a certain amount of debris left behind. This individual should also make certain that all leftover form nails are pulled from the slab.

5.5-During lift

5.5.1 Precautions — The panel contractor should provide a clean working area with all obstacles removed. The panel should be cleaned of all debris and loose
tools. Blow away all standing water from around the perimeter of the panels and remove any water that might be pooled in panel openings. Standing water prevents air from entering under the panel and creates extra loading needed to break the bond. Wind conditions should be considered prior to lifting a panel. A 40-ton panel will easily move in a slight breeze when hanging from a crane.

Panel erection should be accomplished in one continuous and smooth rotating motion to the vertical position. The bottom of the panel should not be dragged on the casting bed or ground during the rotating operation. The panel should not be swung while the bottom of the panel is in contact with the casting bed.

When the crane is walking with the panel most crew members will be looking up at the panel and rigging. The rigger foreman must be alert to all obstacles in the path of the crane and crew.

It is the rigger foreman’s responsibility to make certain all personnel not directly connected with the panel lifting be clear of the lifting area.

5.5.1 Special shapes or rigging — Extra precaution should be taken when lifting panels with special shapes or special rigging. The erection manual should be consulted for cautionary notes as to how a panel might act during lifting, and to again verify the rigging and insert locations. If possible, the tilt-up hardware supplier should be on the jobsite the first day.

5.5.2 Inspection — Panels should be inspected prior to lift for any reinforcing steel and/or ledgers that may be projecting beyond the panel edges that will create interference when the panel is being plumbed next to a previously erected panel. This happens most often at corners.

After all attachments are made to the panel, and as the rigging is being raised to take the slack out of the cables, but prior to initial loading of the inserts, all rigging gear must be inspected for proper alignment and to be free of snags. If nonswivel type sheaves are used, make certain the sheaves are properly aligned. Reattach hardware when cable twisting is present, and check winch brake before panel clears slab.

5.5.3 Sticking panels — Be alert for panels that may be stuck to the casting surface. Under such conditions loads transferred to the pick-up inserts could be more than doubled causing possible insert withdrawal. Carefully positioned wedges and pry bars can be used to help release the panel. As cables are being tensioned, they will invariably try to twist and possibly rotate the lifting hardware causing side loading on the hardware bale. The rigger foreman should be alert for the condition and if it does happen, should halt the lift and realign the hardware.

5.5.4 Braces — Braces are almost always attached to the panel prior to lifting. Caution must be taken to be certain that the braces will not be trapped by the rigging when the panel is in its final upright position, and braces are ready to be swung out and attached to the floor.

5.6-Plumbing panels

5.6.1 Precautions — Be alert when plumbing panels to their final upright position. Caution must be taken to make certain the panel being plumbed does not strike a previously erected panel. All personnel should be cleared of those critical areas around a panel when plumbing is being done. If a panel being plumbed is to be a closure panel, measurements should be taken prior to the lifting to be sure it will fit.

5.6.2 With crane — Tilt-up panels should be as plumb as possible prior to attaching the bracing at the floor point. Temporary out-of-plumbness should not exceed 4 in. All commercially available pipe braces have threaded adjusting units that allow for some in and out adjustment after they are attached. It is generally more practical to “fine tune” the panel plumbness with pipe braces after the lift is completed.

5.6.2.1 Special conditions — There are two commonly occurring conditions that dictate that panels be perfectly plumb prior to releasing the crane:

1) If the panel is going to support an adjacent spandrel or lintel panel, then the panel should be in an accurate final position to prevent having to readjust it later when it is supporting another panel

2) If the bracing design calls for a subsupport system of knee, lateral and end or cross bracing, then the panel should be accurately placed

It is recommended that panels requiring subsupport systems not be replumbed later as the brace subsupport system, if not removed, must at least be loosened to adjust the main brace, placing the panel in a dangerous position.

5.7-Bracing

5.7.1 General — Do not release the crane load if bracing does not appear adequate. Crane loads should always be released slowly, keeping an eye on the panel and bracing for any unusual activity. It is desirable that all bracing be complete before releasing the crane, that is, all knee, lateral, and end bracing, if required, be in place. This is not always possible. Often the crane’s position near the panel prevents the lateral bracing from being attached. Once the crane is clear of the area the panel contractor must complete the lateral and end bracing, and be no more than one panel behind the lift with this phase of the bracing. All bracing should be completed on all erected panels at the end of the work day.

5.8-Closure panel

Be alert with the closure panel. It is generally a blind pick and is usually handled while moving down a ramp. It is almost always a filler panel and should be measured for fit prior to lifting.
CHAPTER 6 — FINISHES

6.1-Introduction

6.1.1 General — Finishes may be obtained in many different ways, either by finish face up or finish face down for tilt-up concrete panels. Color and texture can be obtained by cements, colored admixtures, specialty aggregates, and mixture proportions. Surface texture and appearance can be developed through various mechanical methods, by special forming techniques, or through application of surface retarding coatings.

6.1.1.1 Variety of finishes — A wide variety of finish colors, intricate architectural shapes, and surface textures can be obtained for tilt-up. It is no longer necessary for tilt-up construction to be plain grey concrete with perhaps a painted finish. Panel areas can be divided or the pattern broken with the use of rustication strips. Concrete naturally has some texture or color variation. The effect of these variations on the architectural appearance can be minimized by the use of textured surfaces and rustication.

6.1.1.2 Problems and solutions — The more elaborate the shape and finishing techniques required, the more susceptible to problems the manufacturing process becomes to climatic conditions, a skilled labor force, quality control procedures, and higher initial costs. However, with proper planning, suitable specifications, and quality construction techniques, surface blemishes and repairs can be minimized. Over a 20-year cycle, the decreased maintenance cost of a building with natural architectural finishes may recover a large part of the higher initial cost.

6.2-Finish face up

6.2.1 General — Often tilt-up panels will be exposed to view from both sides. This necessitates a finish face up, as well as the more common face down methods. Face up finish may be grey or colored concrete in a light to heavy sandblast, a patterned or random broom type finish, an exposed aggregate surface, or a honed polished finish.

6.2.2 Special surfaces — For panels where aesthetics are a consideration, it is recommended that any smooth surface be lightly exposed with a chemical retarder or by sandblasting to minimize color variation and minor surface irregularities. An exposed face up aggregate surface can be obtained through the use of chemical retarders and low pressure water washing along with brushing of the plastic concrete. An exposed aggregate texture can also be obtained on the hardened concrete by the use of bush hammering, or sand or other abrasive blasting. Side forms should be removed prior to any surface treatments on the face up concrete. Face up finish will require repair of voids or recess pockets required for handling or erection hardware.

6.2.3 Extra care— Extra care is needed with mixture proportions, placing, and vibration of concrete when providing a face up finish. Nonuniform exposure can result due to either an uneven finish surface, poor distribution of aggregate, high paste content, or by poor consolidation. When an exposed aggregate surface is desired, better results can be obtained by additional seeding of coarse aggregate. This aggregate should be worked into the top surface of the plastic concrete prior to troweling. This procedure should be followed whether the surface is to receive a chemical retarder, bush hammer, sandblast, or polish. When a sandblasted surface is desired, the mixture proportions and the timing of the sandblast are very important.

6.3-Finish face down

6.3.1 General — A smooth surface can be obtained by placing the panel concrete against the cast-in-place slab or previously placed tilt-up panel. The face down surface will be a mirror image of the surface against which the freshly mixed concrete is placed. Therefore, any deformities in the casting surface such as cracks, voids, and blemishes will be mirrored in the surface unless repairs to the casting surface are made prior to the placement of concrete.

6.3.2 Form liners — Concrete may also be cast against a treated wood surface, or against form liners. Form liners with widely variable designs are being produced. Any form liner material must be sufficiently strong so as to minimize displacement or distortion during concrete placement and consolidation. It is recommended that a potential user contact the various manufacturers of these materials for detailed information.

Deep rib or other surface textures can be obtained through the use of plastic, metal, or elastomeric form liners. Adequate draft or provisions for form removal must be allowed in all sculptured or deep return surfaces.

6.3.3 Sealing surface — Depending on the level and surface finish of the casting slab, the finish face down will be the most uniform and dense surface of the tilt-up panel. The casting surface, whether wood, concrete, steel, etc., must be sealed if porous to prevent surface discoloration. Concrete and wood, as well as other form materials can cause uneven moisture absorption from the plastic concrete resulting in surface discoloration.

When the surface of the form material varies, a different release agent may be required for each different form surface. Whichever release agent is used initially should be used constantly throughout the project. Use only a non-staining cure and release agent (bondbreaker).

6.3.4 Exposed aggregate — Exposed aggregate surfaces can be obtained through three common methods; chemical retarders, sandblasting, and sand bed casting. After the tilt-up panel has been lifted into and secured in place, completion of the aggregate exposure can be accomplished by brushing, high pressure water, abrasive blasting, tooling, bushhammering or by polishing. High pressure water and polishing are not commonly used in concrete tilt-up construction due to the high cost and difficulties of obtaining uniform surfaces.
6.4-Concrete materials

6.4.1 Color — In smooth concrete, the color of cement and any color admixture are dominant. If color uniformity is critical, use the same brand of cement and keep a close control on the water cement ratio throughout the project. Retain a sample of the original cement for mortar control comparisons. Daily checks can be made for color control on the ready-mixed concrete being delivered to the job. Concrete mortar can be compared in color against a fresh mortar made using the original cement sample, color admixture, and fine aggregate.

6.4.1.1 Color admixture — Premixed color admixtures are available to provide the contractor with a wide range of concrete colors. These can be obtained with normal or retarded set characteristics. Care must be used to assure that the casting slab, forming system, workmanship, placing, and consolidation of concrete follow recommended procedures for architectural concrete construction. Follow any special recommendations of the color admixtures supplier.

6.4.1.2 Color variation — Color variation can be affected by the form surface, release agent, water cement ratio, consolidation procedures, and amount of cement used. When using a color admixture refrain from using fly ash. Fly ash may increase the normal color variation already present. In exposed aggregate surfaces, impact of cement and admixture color diminishes with each increase in the amount of aggregate exposure.

6.4.2 Aggregates — Surface area of the typical tilt-up panel on the project, as well as distance at which the panels are viewed, should determine size of the exposed aggregate. Since tilt-up panels generally use ready mixed concrete from a local plant, a wide selection of cement, sand, and coarse aggregates are usually not available without additional cost. Aggregates having iron pyrites or other reactive materials should be avoided.

6.4.3 Special face mix — The use of two separate mixture proportions is not recommended (a facing mix with special materials and a back-up concrete for structural consideration) for tilt-up construction. Unless concrete placement timing is carefully followed, there is the potential for differential shrinkage between the facing and back-up concrete. Control of water cement ratio, cement content, and placement timing can minimize this potential.

6.4.4 Admixtures — Air entraining admixtures are recommended. Integral retarders and superplastisizers have been used in tilt-up construction when it is desirable to modify properties of the concrete mixture. Calcium chloride accelerating admixtures are not recommended. Use of natural sand as opposed to manufactured sand for part or all of the fine aggregate will increase workability and is desirable.

6.4.5 Delivery — Standard delivery methods are satisfactory for most tilt-up concrete projects. Special considerations are required when architectural concrete is used. For discussion see ACI 303.

6.4.6 Proportioning — Proportioning of the concrete mixture is determined by the most practical combination of materials that will provide the desired qualities in the hardened concrete. Flexural strength for handling, early strength for lifting, durability, minimum volume change, as well as surface finish are all equally important. The required surface finish will determine the ratio of coarse to fine aggregate. In exposed aggregate panels, the amount of coarse aggregate may be higher than in normal ready mixed concrete. The sand/total aggregate (S/A) ratio will frequently be 0.34 to 0.36 for these exposed aggregate mixes rather than the more common 0.40 ratio. Preliminary test samples or a mock-up panel are recommended to help determine the final mixture proportion.

6.5-Method and types of finish

6.5.1 Exposing aggregate in plastic concrete — A combination of low pressure water washing and brushing must be done before the matrix becomes hard. This method is used for finish face up concrete having a medium to deep surface texture. When aggregate in the concrete is exposed, washing must begin shortly after initial set of the concrete has occurred. Care must be taken not to disturb the large aggregate at the surface by attempting too early removal of the matrix. A more uniform finish can be obtained if a brush is used with the water for obtaining the final finish. Exposure by water washing maintains the natural color of the aggregates.

6.5.1.1 Seeded surface — One method of exposing aggregate in plastic concrete is through seeding of coarse aggregate in the top surface of the panel. This involves spreading additional aggregate on the top surface of the panel when the concrete is still plastic. The construction sequence is to place the concrete in the forms and consolidate. Concrete is screeded or leveled to within 1/4 - 1/2 in. of the form top depending on size and amount of the architectural aggregate. Sufficient height should be left below form top to compensate for the volume of hand placed aggregate. After vibration and consolidation of the concrete, surface aggregate to be exposed is spread over the entire surface using a square ended shovel or a shaker hopper. Only one layer of coarse aggregate is recommended. Stone to be used may be a specialty aggregate rather than that used in the basic concrete mixture. Special care is needed in placement of the surface aggregate around corners, edges or at openings. Aggregate is worked into the concrete by using a bull float in the center and a hand float near the edges. Aggregate near edges should be worked in before the center portion as the edge of slab sets up first. Sometimes a vibrating screed or hand “jitterbug” may be used to embed the surface aggregate.

Surface aggregate must be worked until it is completely covered by concrete mortar. Concrete must have set sufficiently to support the surface aggregate without allowing too much aggregate to settle too deeply into the panel. Washing and/or brushing away the mortar to expose the aggregate surface should begin shortly after initial set of the concrete. Timing is critical. Generally, if
the surface can bear the weight of a man, leaving only a slight indentation, concrete will be close to its initial set.

The first step in exposing the aggregate is to use a stiff brush to loosen the cement/sand mortar around the aggregate. A light spray of water is then used in conjunction with additional brushing. Some hand placement of aggregate and final brushing will be necessary to obtain an acceptable uniform surface. After all brushing has been completed, the entire panel should be flushed with clean water to remove any remaining cement coating from the aggregate. A mild acid wash may be used for certain aggregates after the tilt-up panels have been properly cured.

A disadvantage of the face-up and seeding method is that patching will be required to fill surface voids left for the handling hardware. An experienced finisher is required who understands mixture proportioning for patching and technique of repair.

6.5.2.1 Finish face up — Chemical retarders applied to the top surface of freshly placed concrete are water based materials, which are usually sprayed on with garden type applicators with a fan nozzle. Prior to final troweling and spray application of a chemical retarder to the face up surface, some additional seeding of coarse aggregate may be done to obtain maximum aggregate density. This aggregate must be worked into the concrete surface until it is completely covered with mortar. As soon as the surface water disappears, retarder is sprayed on the top concrete surface. The top of the concrete is then covered with black polyethylene sheeting to retain the concrete moisture and prevent it from evaporating too rapidly. Later, the retarded mortar may be removed by brushing and washing, or through use of high pressure water washing.

6.5.2.2 Finish face down — Chemical retarders are now being successfully used in tilt-up construction for finish face down surfaces. Major field problems in the past have been poor retarder application and improper concrete placement. Care must be taken to prevent moving the retarder so that thicker and thinner concentrations are not created causing a non-uniformity of reveal when aggregate is exposed. Concrete should be placed in its final position in the tilt-up panel and not moved with a long shaft vibrator, held parallel to the casting slab. Training and planning are required for use of the retarder method, as is true for all quality concrete work. Protection from the elements should be provided during the interval after the chemical retarder is applied until the concrete is placed. The retarder applied surface should be kept dry as it is the water content in the concrete mix that activates the retarder.

Chemical retarders can be best used with small to medium sized coarse aggregate. Larger aggregates, over 2 in., can obtain better results with sandbed casting. After the panel has been lifted from the casting bed, the retarded surface is removed using an 800 psi pressure water spray from a fan type nozzle, by lightly sandblasting, or by wet blasting. Aggregate exposure procedure should begin as soon as possible after lifting since the retarded surface will harden after exposure. Light etch chemical retarders can be used in combination with medium or deep sandblast exposed surfaces to cut down on the time and labor used for this texture. Excellent results can be obtained through the use of chemical retarders if proper training of personnel and correct procedures are carried out.

6.5.3 Sand bed — The sand bed method is primarily used with 1.5 - 2 in. aggregates or larger. The sand bed method has been successfully performed with coarse aggregate up to 6 in. in size. These larger rocks must be hand placed in the sand. Large thin slices of stone used as a complete facing have also been used successfully in sand bed casting or by including a patented bonding agent process.

Best results are obtained when dry sand is used. 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 - 30 percent of the stone thickness. A square ended shovel should be used for spreading the sand. All aggregate to be exposed should be of one size gradation for uniform exposure. Final sand thickness depends on the thickness of stone being used. However, on an aggregate up to 3 in. in diameter the sand thickness should not exceed 45 percent of the coarse aggregate height. If the aggregate is larger, the sand thickness should be reduced to a maximum of 30 percent of the coarse aggregate height.

Special care should be taken to insure that adequate aggregate density is obtained around edges, corners, and openings. 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 to set the aggregate. Adjustment in sand thickness should be made and a fine spray of water used to settle the sand around the aggregate. Direct use of water from a normal nozzle may disturb the aggregate bedding.

In some instances a thin cement/sand slurry material may be placed over the aggregate and allowed to harden to insure that the aggregate is not dislodged when the normal back-up concrete is being placed.

Reinforcement is then placed into the forms, and ready mixed concrete carefully placed and consolidated. If a cement/sand slurry or grout is used to maintain aggregate position, ready mixed concrete should be placed within 2 - 3 hours. If this is not possible, provisions must be made to cure the slurry or grout. A curing compound should not be used since it may prevent bond with the concrete.

After the tilt-up panels have been cured and have obtained adequate strength, forms are removed, panels erected, and the sand is hand brushed or removed with water under low pressure, under 1000 psi.

6.5.4 hardened concrete — Smooth or textured flat surfaces are obtained by casting the concrete against a formed surface. In tilt-up, this most often is a concrete slab or a form liner placed inside the perimeter side forms.

If smooth hardened concrete is to be left exposed, care should be taken to prevent bleeding of water from the concrete under the edge forms. This loss of concrete mix water/mortar will cause discoloration and honeycomb - both difficult to repair on a smooth surface finish. Care in forming, materials selection, mix design, placement, and consolidation of concrete is required if a uniform surface appearance is to result.

When the surface is to have a coating applied, some blemishes or variations in color or texture will not be harmful. Rustication strips, form liners, or some other physical means should be used to subdivide large smooth surfaces into smaller segments for a more uniform appearance. These can also be used to divide two different surface textures within the same panel.

6.5.4.1 acid washing — Exposure of aggregate by acid washing or etching is generally not recommended for tilt-up construction.

6.5.4.2 sand blasting — Sand or abrasive blasting will often change the appearance of the aggregates by permanently “dulling” them. The degree of change will vary depending upon the type of hardness of the aggregates. Matrix strength of concrete will affect appearance and difficulty of sandblasting. Matrix strength of concrete in each panel should be approximately the same when it is sandblasted. Ideally, the 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 experiment on similar concrete to be used in tilt-up panel construction. Once a sandblast sand has been selected, do not change the manufacturer or grit size during course of the project.

Degree of uniformity obtainable 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 look acceptable on a small sample, but uniformity is difficult to obtain. It is recommended that a medium or medium/heavy sandblast finish be used for the typical large tilt-up panel. A face up sandblast finish can be done most efficiently while the panels are still on the ground. When casting panels that are to be sandblasted, care must be taken not to have any cold joints between ready-mix loads of concrete. It is important that the transition point between two loads of concrete be vibrated thoroughly to eliminate any evidence of jointing. Any cracks should be epoxy injected prior to start of sandblasting. Sandblasting will round the edges of any cracks not repaired and will amplify the crack size.

When panels are blasted in a vertical position, the operator should use a manlift or have sufficient staging to maintain a level position of the nozzle. Better 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. Due to pollution controls, some areas of the country may require wet sandblasting.

Sandblasted surfaces are normally classified as brush, light, medium, or heavy. These may be defined as:

1. Brush — Remove the cement matrix and expose the fine aggregate — No projection of the coarse aggregate from the matrix
2. Light — Sufficient to expose fine aggregate and occasional exposure of coarse aggregate reveal 1/16 in.
3. Medium — Sufficient to expose coarse aggregate with a slight reveal — Maximum aggregate reveal 1/4 in.
4. Heavy - Sufficient to generally expose and reveal the coarse aggregate to a maximum projection of a third of the coarse aggregate diameter — Reveal 1/4 to 1/2 in. This surface is rugged and uneven.

When a medium or heavy sandblast surface is required, it is recommended that a chemical retarder be used initially. This will provide greater uniformity and reduce sandblasting time. When sandblasted surfaces are required, only 100 percent plastic chairs should be used to support the reinforcing steel. The deeper the sandblast the more coarse aggregate is required in the mix design. This would normally be established in the design stage of the concrete mixture with mock-up panels. Deep exposure of coarse aggregate requires a finer abrasive to obtain uniform results.

6.5.4.3 bushhammering- Bushhammered surfaces are produced by pneumatic tools fitted with a bushhammer, comb, chisel, or multiple pointed attachment. The type of tool will be determined by the final surface
desired. Bushhammering is normally applied to well-graded mixtures with softer aggregates such as dolomite and marble, providing these aggregates are durable. Most bushhammering will remove 3/16 in. of surface material. Therefore, additional concrete cover must be provided for the reinforcing steel. Bushhammering works best with higher strength concretes. To minimize loosening of the aggregate during hammer operations, a minimum concrete age of 14 days is recommended. Bushhammering at corners tends to cause damage. Bushhammering is normally held back 1 to 2 in. from the corners. Corners should be done by hand tooling rather than using pneumatic hammers.

6.5.4.4 Special texturing — Tooling, broken rib (fractured fin), texturing with a needle gun are all surface treatments that produce textures somewhat different from all the above. Several different finishes may be produced on a single tilt-up panel. Orientation of special equipment for any of the above should be kept uniform throughout the finishing treatment for each project, if at all possible. All surface textures and finishes should first be performed on the full scale mock-up or on a panel of minor importance. This will develop the optimum equipment and field procedures.

6.6-Cleaning

6.6.1 Washing — Tilt-up panels must occasionally be cleaned and repaired after installation. If cleaning is required, exposed panel faces should be washed with trisodium phosphate dissolved in hot water or another cleaning product of equal efficiency. Panels should be thoroughly rinsed with clear water after washing. A good fiber brush should be used for cleaning. Individual panels are cleaned starting at the bottom and working up. After first washing from bottom to top, panels should be rinsed and then washed from top to bottom, followed by a second rinse with clear water. Cleaning solutions must never be allowed to dry on the concrete surface exposed to view. This procedure should result in an adequately clean panel for most purposes. Final finish should be clean, sound, and have exposed concrete free of all laitance, dirt, stains, smears, or other blemishes.

6.6.2 Stain — Stains of various kinds can mar the panels appearance. Staining may occur accidentally or through carelessness on new concrete or on old. The most common stains encountered on panels are copper/bronze, iron (rust stains), oil/grease, asphalt, roofing tar, efflorescence, paint, fire, or smoke. Stains from various causes may be removed by commercial stain removers, but some alteration of the concrete surface may occur.

An excellent reference for removing stains is the Portland Cement Association Publication *Removing Stains and Cleaning Concrete Surfaces*, PCA Code No. IS 214T. 18

Iron or rust stains may be caused by aggregate particles, embedded iron items in the concrete, or by water washed over iron building materials at the site. Remove the source of the stain immediately. Stains are more difficult to remove the longer they are allowed to remain.

6.6.3 Sandblasting and steam cleaning — Sandblasting and steam cleaning with pressure are also common methods to clean panels. Sandblasting is not recommended with certain quartz and other aggregates unless the method was used originally in exposing the surface of the panel. Sandblasting may dull the aggregate or change the color or texture so that it no longer matches the remainder of the structure. Sandblasting may also expose and exaggerate blemishes or cracks in the surface. An experienced sub-contractor should be engaged for sandblasting of tilt-up panels. A small area, preferably in the mock-up, should be tried and approved before proceeding.

6.7-Coatings

6.7.1 Coatings — Finishes can be altered, decorated, or surface uniformity obtained, by applying clear acrylic coatings, textured pigmented coatings, and by painting. Clear waterproofing compounds or sealers may also be used to give a natural appearance to any concrete tilt-up panel, but still minimize efflorescence or moisture movement that would alter the desired finish appearance. It is important to choose coatings manufactured for use on concrete and to follow recommended application instructions from the manufacturer. All coatings must be compatible with the form sealer and/or bondbreaker unless they have been previously removed. The same coatings, sealers, and bondbreakers should be used throughout the entire project.

6.7.2 Preparation — Concrete surfaces must be free of any substances such as dirt, dust, oil, bond breaking compounds, laitances, and efflorescence. Any preparations that are used to remove these substances must also be completely rinsed from the surface so a film does not interfere with adhesion of the coating.

6.7.2.1 Texturing surface — Extremely dense and glazed concrete surfaces should be roughened to insure proper bond. This can be achieved by acid washing or sandblasting with an abrasive. Broom finishes can have high concrete porosity. Additional applications of coating may be necessary on such a surface.

6.7.2.2 Weather — The best conditions for applying coatings exist when the weather is dry and ambient temperatures and concrete temperature are both above 50 F.

6.8-Cracking

6.8.1 Occurrence — Cracking can occur in any tilt-up concrete panel during erection operations. Certain finishes will accentuate cracks that may occur in concrete construction such as sand blasted exposed aggregate and certain paint finishes.

6.8.2 Control — In order to minimize cracking, designers should consider the shape and form of the tilt-up panel as well as size and location of openings. Special attention should be given to simulated joints, abrupt change of mass, unbalanced sections, and irregular outlines which may raise stresses at re-entrant corners. Ad-
ditional reinforcing in these areas will strengthen the tilt-up panel and control cracking.

6.8.3 Acceptability — The decision regarding acceptability must be made on an engineering basis as well as visual appearance. Repairs of cracks depend to a large extent upon their size, location, and engineering design problems, if any. Cracks that are nonworking in nature and which do not have significant structural problems may be repaired with a patch mix. Structural cracks may require epoxy injection or specialized repair techniques based upon evaluation by the structural engineer. Repair should be delayed as long as possible to allow the cracks to stabilize.

CHAPTER 7 — REFERENCES

7.1-Specified and/or recommended references

The documents of the various standards-producing organizations referred to in this document are listed below with their serial designations.

American Concrete Institute

116R Cement and Concrete Terminology
117 Standard Specifications for Tolerances for Concrete Construction and Materials
302.1R Guide for Concrete Floor and Slab Construction
303R Guide to Cast-in-Place Architectural Concrete Practice
308 Standard Practice for Curing Concrete
309R Guide for Consolidation of Concrete
318 Building Code Requirements for Reinforced Concrete
355 State-of-the-Art Report on Anchorage to Concrete

American Society for Testing and Materials

A 666 Standard Specification for Austenitic Stainless Steel, Sheet, Strip, Plate, and Flat Bar
C 94 Standard Specification for Ready-Mix Concrete
C 309 Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete

American Welding Society

AWS D1.4 Structural Welding Code-Reinforcing Steel

The above publications may be obtained from the following organizations:

American Concrete Institute
P.O. Box 9094
Farmington, MI 48333-9094

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103

American Welding Society
550 N.W. Le Jeune Rd.
Miami, FL 33135

7.2-Cited references


APPENDIX A — NOTATION

\[ A_s = \text{area of non prestressed tension reinforcement within width } b, \text{ sq in.} \]
\[ A_s' = \text{effective area of tension reinforcement within width } b, \text{ sq in.} \]
\[ b = \text{width of compression face of member, in.} \]
\[ d = \text{distance from extreme compression fiber to centroid of tension reinforcement, in.} \]
\[ D = \text{dead loads} \]
\[ E = \text{load effects of earthquake} \]
\[ E_c = \text{modulus of elasticity of concrete, psi} \]
\[ E_s = \text{modulus of elasticity of reinforcement, psi} \]
\[ f_c = \text{specified compressive strength of concrete at time of lift, psi} \]
\[ f_c' = \text{specified compressive strength of concrete at 28 days} \]
\[ f_y = \text{specified minimum yield strength of reinforcement, psi} \]
\[ G' = \text{shear stiffness of diaphragm expressed in kips/ in. of deflection} \]
\[ h = \text{overall thickness of member, in.} \]
\[ H = \text{lateral earth pressures} \]
\[ I = \text{moment of inertia of section resisting externally applied factored loads, in.}^4 \]
\[ k = \text{effective length factor for compression members} \]
\[ k_d' = \text{length of triangular shaped compression block, in.} \]
\[ l = \text{unsupported height of panel in ft} \]
\[ l_u = \text{unsupported length of compression member} \]
\[ L = \text{live load} \]
\[ M_a = \text{maximum factored moment or member neglecting effects of deflection} \]
\[ M_n = \text{nominal moment strength at section} \]
\[ M_u = \text{factored moment at section} \]
\[ M_y = \text{nominal moment strength of section at yield strength of reinforcement} \]
\[ n = \text{modular ratio of elasticity} \]
\[ P_o = \text{nominal axial load strength at zero eccentricity} \]
\[ P_i = \text{factored applied axial load} \]
\[ P_u = \text{total factored axial load} \]
\[ q_u = \text{factored lateral load} \]
\[ r = \text{radius of gyration of cross section of compression member} \]
\[ U = \text{required strength to resist factored loads} \]
\[ w_c = \text{unit weight of panel} \]
\[ w_{cu} = \text{factored unit weight of panel} \]
\[ W = \text{wind loads} \]
\[ \Delta = \text{panel deflection, in.} \]
\[ \delta = \text{moment magnification factor} \]
\[ \Theta = \text{rotation of member at yield of reinforcement} \]
\[ \rho = 100 A_/bh \]
\[ \rho' = 100 A_/bh \]
\[ \phi = \text{strength reduction factor} \]

APPENDIX B — CONSTRUCTION CHECK LIST FOR WALL PANELS

Forms:
- Use quality material
- Well oiled but no excess
- Straight, plumb and square
- Chamfer strips installed

Bondbreaker:
- Apply in two coats 90 deg. to each other
- Wipe off excess material
- Consider combination curing compound bondbreaker
- Be sure of compatibility with curing compound
- Concrete surface should not be wet when applied
- Reapply if exposed to rain if necessary

Inserts:
- Should be clean
- Check location, plumbness, orientation and fastening
- Check insert size for panel thickness

Reinforcement:
- Clean and free of materials that will adversely affect bond
- Check quantity, size and location
- Check miscellaneous reinforcement for tying inserts and around openings
- Check chairing and tieing
- Steel wire chairs should have plastic tips
- Clean out form before casting concrete

Casting Concrete:
- Verify concrete mix and slump
- Do not displace inserts
- Proper vibration and consolidation

Prior to Lift:
- Numbers or designation marked on panels
- Mark footing with panel locations
- Find brace inserts in floor slab if cast-in-place
- Find panel lift and brace inserts in panel
- Make sure all inserts and connections are completed and on panels
- Establish panel lines on footings
- Attach braces
- Set guide dowels or angles
- Set panel shims
- Mark thickness of shims on footings for later check by erecting crew

During Lift:
- Do not do final plumbing with crane
- At least 2 braces per panel before crane unhooks
- Workers should stand beside braces not behind during
lifting and plumbing operation
Do not walk under a panel leaning toward you
One person gives signals to crane operator
If inserting a panel between two previously set panels,
take it completely outside then bring it into place
from the bottom up
Use spacers between panels to establish joint spacing
If sub-bracing is required, complete before leaving site
at the end of a day

Post Erection:
Plumb wall panels
Grout under panels
Do not disturb braces in any manner
Do not adjust a panel brace to make floor or roof
structural steel fit
Do not remove bracing until all structural connections
and roof deck have been completed
Caulk panel joints before roofing is installed
Grout under all panels

METRIC CONVERSIONS

1 in. = 25.4 mm
1 ft = 0.3048 m
1 lb = 0.4536 kg
1 psf = 4.882 kg/m²
1 psi = 0.007 MPa
1pcf = 16.02 kg/m³
1kip = 4.448 kN
1ksi = 6.895 MPa
1kip in. = 0.113 kNn