Erectors have reported incidents in which precast concrete members have rolled uncontrollably during erection.

PCI issued an alert regarding this phenomenon in December 2008.

This article provides reliable methods to determine the cause of panel instability and discusses ways to anticipate and avoid panel instability.

Erecting long, vertical precast concrete members with one crane and two operating lines

Donald R. Logan

The most common procedure to erect long vertical precast concrete members is to rotate the members in midair from their as-delivered flat position to their final vertical position in the structure. To keep member stresses during lifting within acceptable limits, this procedure normally involves supporting the member at three points. One point is at or near the top of the member, and the two lower reactions are supported by slings threaded through rolling blocks, one end attached near the bottom of the member and the other end close to its midheight (Fig. 1).

Erectors have reported incidents that occurred while using this common erection procedure in which precast concrete members suddenly rolled from an apparently stable tilt angle to the vertical position. These incidents often cause damage to the member and erection equipment and can endanger the safety of erection personnel (Fig. 2). Erectors have expressed concern that they have no reliable method to determine the cause of this instability, how to anticipate it, and how to avoid it.

While the concepts described herein apply to all long vertical precast concrete members, the discussion and figures address long non prestressed wall panels. These are potentially subject to detrimental visible cracking in critical architectural finished surfaces that may result from using handling techniques that address erection safety only. Thus, tensile stresses at an impact factor of 1.2W are
checked for each lifting-layout configuration against the recommended maximum of

\[ 5\sqrt[5]{f'c} = 354 \text{ psi (2.44 MPa)} \]

where

\[ f'c = \text{concrete compressive strength at erection} \]
\[ = \text{assume 5000 psi (35 MPa)} \]

\( W \) = weight of panel
\( R_R \) = right lifting reaction
\( R_L \) = left lifting reaction

**Figure 1.** A panel can be erected with one crane using two operating lines. Note: c.g. = center of gravity; \( R_L \) = left lifting reaction acting at centerline of rolling block; \( R_R \) = right lifting reaction acting at right end of panel; \( W_{(c.g.)} \) = panel weight acting at c.g. of panel.

c. Crane operator tilts panel by raising top end allowing lower sling to rotate through rolling block.

b. Crane operator lifts panel in horizontal position until truck pulls away.

a. Panel arrives on truck in horizontal position.

b. Panel feels “light” to crane operator. Top line appears to be going slack.

a. Crane operator tilts panel by raising top line. Panel feels stable to crane operator.

Figure 2. Panels can experience instability during tilting toward vertical. Note: c.g. = center of gravity; $R_L$ = left lifting reaction acting at centerline of rolling block; $R_R$ = right lifting reaction acting at right end of panel; $W_{(c.g.)}$ = panel weight acting at c.g. of panel.
Since the mid-1980s, the third edition of the *PCI Design Handbook: Precast and Prestressed Concrete* and PCI’s *Erector’s Manual: Standards and Guidelines for the Erection of Precast Concrete Products* have addressed this issue, providing a formula intended to protect against sudden rollover of long wall panels (Fig. 3).

Formula in PCI Erector’s Manual and Design Handbook. Purpose is to protect against erection instability.

\[ e > \frac{L}{2} - \frac{\sqrt{L^2 - b^2}}{2} - a \]

Panel will be stable during erection if:

\[ e > \frac{L}{2} - \frac{\sqrt{L^2 - b^2}}{2} - a \]

Figure 3. The current PCI stability equation shown with Fig. 5.6.2 on page 5-24 of the sixth edition of the *PCI Design Handbook: Precast and Prestressed Concrete* is incorrect. It is necessary for the c.g. of the precast concrete component to be between the two main crane lines for all angles during the rotation. Note: \( a \) = distance from up face of panel to center of gravity of the panel; \( b \) = distance between lower lifting devices; c.g. = center of gravity; \( e \) = distance from the center of gravity of panel to centerline of rolling-block reaction with panel in horizontal position; \( L \) = length of panel; \( R_L \) = left lifting reaction acting at centerline of rolling block; \( R_R \) = right lifting reaction acting at right end of panel; \( W(c.g.) \) = panel weight acting at c.g. of panel.
However, erectors have indicated that even if the panel lifting points conform to the dimensions derived from the PCI formula, there have been instances in which unexpected sudden rollover has occurred.

The author encountered this problem in 1995 during the erection of a long wall panel produced by Stresscon Corp. for the Soundtrack project in Denver, Colo. In an analysis of the incident, the basic concept of safe handling of long wall panels was recognized and Stresscon adopted a procedure for three-point lifting, imposing restrictions on the location of the lower sets of lifting devices.

**Basic instability concept**

As illustrated in Fig. 4, with the panel in its horizontal position, the rolling-block lifting reaction $R_L$ is centered between the two lower sets of lifting devices. Its vertical alignment is located at a distance $e_o$ from the center of gravity c.g. of the panel toward the lower end of the panel. As the panel is tilted to its vertical position, $R_L$ shifts toward the c.g. of the panel and its distance $e_o$ decreases.

As the tilt angle increases further, $e_o$ may decrease to zero so that $R_L$ aligns with the c.g. of the panel. At that point, $R_L$ carries the entire weight of the panel, the top reaction carries no weight, and the panel becomes unstable, swinging rapidly to the vertical position as illustrated in Fig. 2 and 4.

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![Diagram](image)

**Figure 4.** These diagrams show the fundamental issues as the tilt angle increases. Note: $b =$ distance between lower lifting devices; c.g. = center of gravity; $CG_L =$ distance from left end of panel to c.g. of panel; $CG_R =$ distance from right end of panel to c.g. of panel; $e_o =$ distance from the center of gravity of panel to centerline of rolling-block reaction with panel in horizontal position; $e_{\Delta} =$ horizontal projection of distance from centerline of center of gravity to centerline of rolling-block reaction with panel in tilted position; $L =$ length of panel; $R_L =$ left lifting reaction acting at centerline of rolling block; $R_R =$ right lifting reaction acting at right end of panel; $W =$ weight of panel; $W$(c.g.) = panel weight acting at c.g. of panel; $\alpha =$ angle between sling leg and surface of panel; $\Delta =$ tilt angle of panel in tilted position ($\Delta$ as a subscript identifies horizontal projection of dimensions with panel in tilted position).
The safeguard against instability is to locate the lower sets of lifting devices so that throughout the tilting of the long panels, the rolling-block reaction $R_L$ is prevented from aligning with the c.g. of the panel.

As indicated in Fig. 5, both of the lower sets of lifting devices are located below the c.g. of the panel. Thus at all tilt angles, $R_L$ is prevented from aligning with the c.g. of the panel.

There are other considerations that must be addressed, even with this conservative procedure. As the panel is tilted, the load carried by $R_L$ increases and the loads applied to the lifting devices increase accordingly, changing from primarily tension to primarily shear. These loads are applied to the lower lifting devices at steep angles, potentially exceeding their allowable shear capacity.

As shown in Fig. 6, the conservative layout of the lower lifting inserts causes the moment in the upper portion of the panel to dominate. The consequent tensile stresses in the bottom face of the panel (usually the architectural finished face) may result in visible cracking of this critical surface. Concentric prestressing is often required for long panels erected using the three-point procedure.
Figure 7. This figure shows the lifting-device layout for the illustrated panel in this article and the consequent balanced positive and negative moments during loading on trucks for delivery to job sites. Note: K = kip; M = moment; R = reaction; \( W' = \) weight of panel modified by impact factor (1.2 \( W \) in examples). 1" = 1 in. = 25.4 mm; 1' = 1 ft = 0.305 m; 1 psi = 6.895 kPa; 1 kip = 4.448 kN; 1 kip-ft = 1.356 kN-m.

\[ W' = 55.5K \]

Panel 6.94' × 44.42' × 1.0'

\( W' = 46.25 \times 1.2 = 55.5K \)

Max. Tensile Stress = 80 psi

4-Point Lift - Stripping & Loading

Figure 8. This figure shows the moments and maximum tensile stress using the conservative three-point lifting-insert layout shown in Fig. 6. Note: K = kip; M = moment; R = reaction; \( W' = \) weight of panel modified by impact factor (1.2 \( W \) in examples). 1" = 1 in. = 25.4 mm; 1' = 1 ft = 0.305 m; 1 psi = 6.895 kPa; 1 kip = 4.448 kN; 1 kip-ft = 1.356 kN-m.

\[ W' = 55.5K \]

Panel is stable at all Tilt Angles

Max. Tensile Stress = 620 psi > 354 psi

3-Point Lift - Shift Point 2 to Point 2

Conservative Layout

Figure 9. This figure shows the moments and maximum tensile stress resulting from three-point lifting using a single line from the top of the panel and the slings and rolling blocks attached to points 1 and 3 of the four-point lifting configuration. Note: K = kip; M = moment; R = reaction; \( W' = \) weight of panel modified by impact factor (1.2 \( W \) in examples). 1" = 1 in. = 25.4 mm; 1' = 1 ft = 0.305 m; 1 psi = 6.895 kPa; 1 kip = 4.448 kN; 1 kip-ft = 1.356 kN-m.

\[ W' = 55.5K \]

At Tilt Angle = 60°

Panel unstable w/sling line = 30 ft.

Panel barely stable w/sling line = 40 ft.

Max. Tensile Stress = 513 psi > 354 psi

3-Point lift at points 1, 3 & top

Figure 10. This figure shows the moments and maximum tensile stress resulting from attaching the rolling-block lines to point 3 and a modified location of point 1, farther from the bottom of the panel. Note: K = kip; M = moment; R = reaction; \( W' = \) weight of panel modified by impact factor (1.2 \( W \) in examples). 1" = 1 in. = 25.4 mm; 1' = 1 ft = 0.305 m; 1 psi = 6.895 kPa; 1 kip = 4.448 kN; 1 kip-ft = 1.356 kN-m.

\[ W' = 55.5K \]

At Tilt Angle = 60°

Panel unstable w/sling line = 30 ft.

Panel stable w/sling line = 40 ft.

Max. Tensile Stress = 305 psi < 354 psi

3-Point Lift - Shift Point 1 to Point 1
Analytical methods to reduce tensile stresses

Figures 7 through 10 study the effects on panel moments and stresses resulting from varying the lifting-device locations. The layout of lifting devices for long panels is dictated by the condition at stripping of the panels when the concrete strength is low. The PCI Design Handbook shows the recommended layout of lifting devices using four-point handling of long panels in the horizontal position for stripping and loading on trucks. (This is referred to as eight-point lifting in the PCI Design Handbook because there are two devices at each lift point location along the length of the panel.) For the panel in this article, Fig. 7 shows this lifting-device layout and the consequent balanced positive and negative moments during loading onto trucks for delivery to jobsites.

Figure 8 repeats the moments and maximum tensile stress using the conservative three-point lifting-insert layout shown on Fig. 6 for comparison with the modified layouts shown in Fig. 9 and 10. Figure 9 shows the moments and maximum tensile stress resulting from three-point lifting using a single line from the top of the panel and the slings and rolling blocks attached to points 1 and 3 of the four-point lifting configuration. This results in a reduction in tensile stress from 620 psi (4.3 MPa) to 513 psi (3.5 MPa), but the analytical stability calculation presented in this article indicates that the panel becomes unstable at a tilt angle of about 50 deg with a sling length of 30 ft (9 m). Even with a sling length of 40 ft (12 m), there is insufficient margin of safety against instability at the critical tilt angle.

In this article, sling length S is defined as the length of the cable attached to a lifting device running diagonally through the rolling block and diagonally back to the companion lifting device that shares the rolling-block reaction. It includes the lengths of hooks and any shackles within that length of line.

Figure 10 shows the moments and maximum tensile stress resulting from attaching the rolling-block lines to point 3 and a modified location of point 1, farther from the bottom of the panel. The tensile stress reduces further to 305 psi (2.10 MPa), but the analytical stability calculation shows that the panel is only marginally stable at the most critical tilt angle, using a sling length of 40 ft (12 m). Increasing the sling length to 50 ft (15 m) in both of the previously described cases would ensure stability at all tilt angles.

The section “Analytical Study—Shifting of Rolling-Block Reaction” and the sidebar “Erecting Long Precast Concrete Members” show two analytical methods that establish the safe location of lifting devices. However, it must be understood that the length of the sling running through the rolling block is a critical variable in these analytical methods, and that using a shorter sling than indicated may cause sudden instability of the panel, even though the lifting-device locations are unchanged.

This raises an important caveat that must be considered by designers who use this less-conservative layout. It is essential that the designer be in a position to ensure that the erection crew is properly notified and understands the critical importance of using the minimum specified sling length. If not, this less-conservative layout method may potentially put members of the erection crew at serious risk and should not be used.

The conservative layout procedure for three-point lifting (Fig. 5) is not subject to this risk and is recommended for use in any situation in which close supervision of the erection crew is not available.

Four-point lifting with two sets of rolling blocks

Another method to reduce tensile stresses in the critical face of the panel is to use a four-point layout of lifting devices and two sets of rolling blocks. As illustrated in Fig. 11, both the lower and upper reactions are carried by rolling blocks with upper-block slings engaging the two upper lifting devices and the lower-block slings engaging the two lower devices in the conservative locations shown in Fig. 8.

Figure 11 also shows the moments and maximum tensile stress for the same panel for comparison with those indicated from Fig. 7 through 10. Although this method significantly reduces tensile stresses in both faces of the panel, it is also more expensive and requires additional erection equipment and extra erection labor to install and then disengage for each panel lifted.

However, as indicated in Fig. 11, the panel remains stable through all tilt angles from its horizontal position to its vertical position. The demonstration photograph sequence in Fig. 12 further illustrates the stability and clearly shows the shifting of the rolling-block reactions as the panel is rotated through all tilt angles.

Check validity of the PCI Design Handbook formula

As discussed in the “Background” section, four editions of the PCI Design Handbook and the Erector’s Manual present a formula that is intended to protect against sudden rollover of panels being tilted to their vertical position. Erectors have reported to the author that some long panels that have lifting-device locations conforming to this formula suddenly became unstable during erection.
Figure 11. This figure shows the four-point lifting layout with rolling blocks at both ends of the panel. Note: $K = \text{kip}; M = \text{moment}; R = \text{reaction}; R_L = \text{left lifting reaction acting at centerline of rolling block}; R_R = \text{right lifting reaction acting at right end of panel}; \Delta = \text{tilt angle of panel in tilted position (\Delta as a subscript identifies horizontal projection of dimensions with panel in tilted position)}$. $1' = 1 \text{ ft} = 0.305 \text{ m}; 1 \text{ psi} = 6.895 \text{ kPa}; 1 \text{ kip} = 4.448 \text{ kN}; 1 \text{ kip-ft} = 1.356 \text{ kN-m}$.

Figure 12. This demonstration shows the tilting of a panel with a four-point layout and rolling blocks at both ends of the panel.
**CHECK VALIDITY OF FORMULA IN PCI HANDBOOK AND ERECTORS MANUAL. DOES IT PROTECT AGAINST INSTABILITY?**

**Panel Instability Incident: Soundtrack project, June 1995 (Stresscon)**

**PCI Formula**

If \( e > 2.55' \), stability OK

Actual \( e = 6.0' > 2.55' \)

**Analytical Model**

At \( \Delta = 60^\circ \)

\( R_L \) shifts to right of c.g.

\( R_L \) carries entire weight of panel > 52k

\( R_K \) would require downward pull = 510#

to keep panel from rolling

**Panel actually rolled in June 1995**

As predicted by Analytical Model

PCI FORMULA DID NOT PREDICT INSTABILITY

**Figure 14.** This figure compares the formula \( e \) with the actual \( e \) in an unstable panel. Note: c.g. = center of gravity; \( e \) = minimum distance from the center of gravity of the panel, with the panel in its horizontal position, to protect the erection-crew members against the unexpected sudden rollover of the panel; \( a \) = horizontal projection of distance from centerline of center of gravity to centerline of rolling-block reaction with panel in tilted position; \( R_L \) = left lifting reaction acting at centerline of rolling block; \( R_K \) = right lifting reaction acting at right end of panel; \( W \) = weight of panel; \( W(c.g.) \) = panel weight acting at c.g. of panel; \( \Delta \) = tilt angle of panel in tilted position; \( # \) = pound. 1” = 1 in. = 25.4 mm; 1’ = 1 ft = 0.305 m.
To evaluate the validity of this formula, the panel used for the following example is the Soundtrack wall panel, which became unstable during tilting. Figure 13 shows the formula along with the corresponding dimensions of the lifting-device locations, panel thickness, and location of the c.g. of the panel. The length of the rolling-block sling was 40 ft (12 m).

The PCI Design Handbook formula calculates the minimum $e$ required to protect the erection-crew members against the unexpected sudden rollover of the panel when it is in the horizontal position. In this case, the actual $e = 6.0$ ft (1.8 m), which comfortably exceeds the minimum $e = 2.55$ ft (0.78 m) derived from the formula.

However, as indicated in Fig. 14, the analytical method shows that, with the sling length of 40 ft (12 m), the panel becomes unstable at a tilt angle of 60 deg. In fact, the Soundtrack panel became unstable during erection. The bottom end hit the ground abruptly, and the panel was severely damaged. Fortunately, all erection-crew members escaped without injury. With a sling length of 50 ft (15 m), the analytical methods show that the panel would probably have been stable throughout the tilting process.

Erectors have also reported to the author other documented rollover incidents wherein the dimensional information and sling lengths were available. In each case, the PCI Design Handbook formula indicated that the formula-derived lifting-device locations should have protected the panel from sudden rollover, whereas the analytical methods, which include sling-length effects, predicted the instability that was actually encountered.

In its present form, the PCI Design Handbook formula does not include the critical sling-length variable and therefore does not provide its intended protection against instability. Instead of addressing possible modifications to the PCI Design Handbook formula, this article provides the analytical methods described in the section “Analytical Study—Shifting of Rolling-Block Reaction” and the sidebar “Erecting Long Precast Concrete Members,” which directly model the shifting location of the $R_L$ reaction and enable the designer to vary the length of the sling for any case studied.

At the time this article was written, PCI had transmitted a technical bulletin to the industry on December 19, 2008, then published the bulletin in the Spring 2009 edition of the PCI Journal, indicating that the formula in its present form “is incorrect and may not provide stability for all conditions when rotating a precast concrete component in the air.” PCI has further initiated action to remove the formula from future editions of both the PCI Design Handbook and the Erector’s Manual and to recommend that the conservative layout shown in Fig. 5 be used for three-point lifting of long vertical precast concrete members.

However, design engineers are hereby cautioned that the PCI Design Handbook formula, in its present form, is represented in current and past editions of these publications as providing protection against sudden rollover, and precautionary procedures should be instituted to ensure against its use without a verified modification that incorporates the sling-length variable.

**Conclusion**

**Beneficial effect of longer sling lengths**

Through studies of various hypothetical conditions and analyses of incidents that resulted in the sudden rollover of members while using the three-point pickup, it became apparent that increasing the length of the slings would often protect against this condition. Based on these studies, it appears that a simple rule may be applicable in cases in which the erector is confronted with having to evaluate the potential for sudden rollover of long vertical precast concrete members already cast with lifting devices in place.

**Erectors’ quick rule**

For the three-point lifting procedure, it is suggested that the minimum sling length be greater than twice the distance between the two lower lifting devices to which it is attached. For example, if that distance is 25 ft (7.5 m), a minimum sling length of 50 ft (15 m) plus 10 ft (3 m), or a total minimum sling length of 60 ft (18 m), is suggested. However, to verify the safety of this quick rule, for any specific case it is critical that the resulting sling length be checked and verified by analytical methods, such as those presented in the section “Analytical Study—Shifting of Rolling-Block Reaction” and the sidebar “Erecting Long Precast Concrete Members.”

**Recommendations to designers**

The analytical methods shown in the section “Analytical Study—Shifting of Rolling-Block Reaction” and the sidebar “Erecting Long Precast Concrete Members” are also recommended to be used to establish lifting-device locations in situations in which the designer elects not to conform to the recommended conservative lifting-device layout in Fig. 5.

However, the following must be emphasized:

- The designer must be in a position to guarantee that the sling length required by the calculation is actually used by the erection crew.
- The location of the c.g. of the member must be clearly defined. A wall panel with openings near the top of the panel or with the top portion thinner than the
bottom shifts the c.g. toward the bottom, which may result in the panel becoming unstable if the calculation is based on the c.g. being at midheight of the panel.

- While the analytical methods are capable of calculating the eccentricity between the vertical alignments of the c.g. of a member and the rolling-block reaction through all tilt angles, engineering judgment should be exercised in establishing a required minimum value for this eccentricity to ensure that it is increased by an adequate factor of safety to account for manufacturing tolerances and other imperfections.

The analytical methods should also be used to calculate the loads in the slings and the angles to which they apply loads to the lifting devices, particularly in cases in which the rated capacity of a lifting device is less in shear than in tension.

**Analytical study—shifting of rolling-block reaction**

This method compares the vertical alignment of the rolling-block reaction with the vertical alignment of the c.g. of long precast concrete members at any selected tilt angle. If at any tilt angle the rolling-block reaction aligns with the c.g., that reaction will carry the entire weight of the member and the member will become unstable.

**Figure 15** illustrates this method. The input data utilize values given for each of the notations illustrated on **Fig. 16** with the panel in the horizontal position. Those input data are shown in the highlighted boxes in the example.

The notations at any tilt angle $\Delta$ are shown on **Fig. 17**. During the tilting of a member, the horizontal components of the loads $T$ in the two legs of the rolling-block sling $(T \sin \theta)$ must be equal and opposite. Thus the angle of inclination $\theta$ of each leg with respect to the vertical alignment of the rolling-block reaction must also be equal and opposite.

At any tilt angle $\Delta$, the method requires the selection of trial values of $\theta$, calculates the consequent values of dimensions $q_s$ and $p_s$, until, through successive approximations, $\tan \theta = q_s/p_s$. At that value of $\theta$, the method calculates the horizontal shift of the vertical alignment of $R_{r,s}$ and its eccentricity $e_s$ with respect to the vertical alignment of the c.g. of the member.

If, at any selected tilt angle, $e_s$ approaches zero value or becomes negative, the panel becomes unstable and will roll suddenly and uncontrollably.

If the value of $e_s$ remains positive through all tilt angles, the member will remain stable. However, it is emphasized that the selected sling length $S$ is a very important variable and its length must be established and controlled so that this or any other analytical method may be relied on to ensure the safe erection of these long members.

In the example, this method is applied to the long wall panel that rolled suddenly during erection on the 1995 Soundtrack project. The required input data are taken from the panel dimensions with the panel in its horizontal position and are highlighted in yellow. The sling length used to erect the Soundtrack panel was about 40 ft (12 m).

Figure 17 illustrates the panel at tilt angle $\Delta$. The value of $\Delta$ is checked at 60 deg in the example, and the value of $\theta$ is varied until $\tan \theta = q_s/p_s$. The resulting value of $\theta = 18.2$ deg, and at that value the vertical alignment of the rolling-block reaction $R_s$ has shifted beyond the vertical alignment of the c.g. of the panel. The value of $e_s$ becomes negative by 1.54 in. (39 mm), and the panel becomes unstable.

The calculations in the example show that at $R_s$, a downward pull of 0.51 kip (2.3 kN) would be required to keep the panel stable, and $R_s$ carries the entire weight of the panel. The tension in one of the two sling lines would be 13.56 kip (60 kN) applied at the lower lifting device at angle $\alpha = 11.8$ deg with respect to the panel surface.

This method also checks the validity of the PCI Design Handbook formula and calculates the minimum value of $e = 2.55$ ft (0.78 m) with the panel in the horizontal position, at which point the panel should be stable. However, the actual value of $e$ is 6.0 ft (1.8 m), but the panel has become unstable at a tilt angle $\Delta = 60$ deg, with a sling length $S = 40$ ft (12 m). Thus the PCI Design Handbook formula did not predict the instability of the panel.

If the sling length $S$ is changed to 50 ft (15 m), the method will show that the panel remains stable at all tilt angles. However, engineering judgment should be exercised with respect to establishing a safety factor to increase the minimum required eccentricity at the critical tilt angle to account for manufacturing tolerances and other variables associated with the erection process.

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Diagrams were put into digital form by Austin Bryan of CAD Prototypes LLC.
LIFTING ANGLE EFFECT ON PANEL REACTIONS

Notations Illustrated on Figs. 16 and 17

SOUNDTREEK 1995-STYROCORE PANEL 10 FT x 54.33 FT;
3 POINT PICKUP, b(Lower) = 25.00 ft
THICKNESS = 12.00 in.
a = 0.500 in.

THICKNESS =

SELECT Δ = 60.00 deg

sin.Δ = 0.866  a*sin.Δ = 0.433 ft
sin.Δ = 0.500

a = 0.500 in.

bΔ = b*cos.Δ = 12.500 ft
pΔ = b*sin.Δ = 21.651 ft
tΔ = f*cos.Δ = 3.250 ft
tf = f* - (a*sin.Δ) = 2.817 ft
CG(R) = [CG(R)*cos.Δ] – a*sin.Δ) = 13.317 ft

TRY θ = 18.211 deg

jΔ = pΔ*cosθ = 22.792 ft
kΔ = (SL Δ jΔ)/2 = 8.604 ft
mΔ = kΔ*sinθ = 2.689 ft
qΔ = bΔ – 2mΔ = 7.122 ft
nΔ = kΔ*cosθ = 8.173 ft
eΔ = mΔ – fΔ = -0.128 ft; * 12 = -1.538 in. UNSTABLE

CHECK
qΔ/pΔ = tanθ = 0.329  tanθ = 0.329

SHIFT = b/2 – mΔ = 3.561 ft ; *12 = 42.73

W = 52 K ; ALPHA = 90 – Δ – θ = 11.79 deg
RRL = WΔeΔ/(CG(L)Δ + eΔ) = -0.51 K downward*
RRΔ = [W*CG(L)Δ/(CG(L)Δ + eΔ) = 5251 K vertical*
Line Tens. (4 components) = Rl/(4*cosθ) = 13.82 K resultant

* NOTE: THE Rl Δ REACTION LINE HAS SHIFTED PAST THE CG LINE AND Rl CARRIES ENTIRE PANEL WEIGHT; RRL < ZERO KIPS. PANEL IS UNSTABLE.

Figure 15. This Microsoft Excel diagram shows the lifting angle's effect on panel reactions. Note: b = distance between lower lifting devices; L = length of panel; SL = S = sling length, defined as length of cable attached to lifting device, running diagonally through rolling block and diagonally back to companion lifting device that shares rolling-block reaction, includes lengths of hooks and any shackles within that length of line; W = weight of panel; Δ = tilt angle of panel in tilted position (Δ as a subscript identifies horizontal projection of dimensions with panel in tilted position); θ = angle of inclination. 1 in. = 25.4 mm; 1 ft = 0.305 m.
Figure 16. Notations are given for the panel when it is in the horizontal position. Note: $a$ = distance from up face of panel to center of gravity of the panel; $b$ = distance between lower lifting devices; $e_o$ = distance from the center of gravity of panel to centerline of rolling-block reaction with panel in horizontal position; $L$ = length of panel; $R_L$ = left lifting reaction acting at centerline of rolling block; $R_R$ = right lifting reaction acting at right end of panel; $S_L = S =$ sling length, defined as length of cable attached to lifting device, running diagonally through rolling block and diagonally back to companion lifting device that shares rolling-block reaction, including lengths of hooks and any shackles within that length of line; $W =$ weight of panel; $\alpha =$ angle between sling leg and surface of panel; $\Delta =$ tilt angle of panel in tilted position ($\Delta$ as a subscript identifies horizontal projection of dimensions with panel in tilted position).

Panel in horizontal position showing notations
Refer to Fig. 15 for specific dimensions
of unstable Soundtrack panel – 1995
Panel instability at tilt angle $\Delta$ illustrated
Refer to Fig. 15 for specific dimensions of unstable Soundtrack panel – 1995

Figure 17. Panel instability is shown for tilt angle $\Delta$. Note: $a =$ distance from up face of panel to center of gravity of the panel; $b =$ distance between lower lifting devices; $e =$ horizontal projection of distance from centerline of center of gravity to centerline of rolling-block reaction with panel in tilted position; $R_i =$ left lifting reaction acting at centerline of rolling block; $W =$ weight of panel. $\Delta =$ tilt angle of panel in tilted position ($\Delta$ as a subscript identifies horizontal projection of dimensions with panel in tilted position).
References


Notation

\( R_L \) = left lifting reaction acting at centerline of rolling block

\( R_R \) = right lifting reaction acting at right end of panel

\( S \) = sling length, defined as length of cable attached to lifting device, running diagonally through rolling block and diagonally back to companion lifting device that shares rolling-block reaction, including lengths of hooks and any shackles within that length of line

\( T \) = tension in the rolling block sling

\( W \) = weight of panel

\( W' \) = weight of panel modified by impact factor (1.2\( W \) in examples)

\( W(c.g.) \) = panel weight acting at c.g. of panel

\( \alpha \) = angle between sling leg and surface of panel

\( \Delta \) = tilt angle of panel in tilted position (\( \Delta \) as a subscript identifies angles and dimensions with panel in tilted position)

\( \theta \) = angle of inclination between sling legs and centerline of rolling block reaction
Erecting long precast concrete members

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This sidebar shows the method that Concrete Technology Corp. uses to evaluate the stability of long precast concrete members lifted using three points during erection. This method is based on the law of cosines and is simple to understand and incorporate into a spreadsheet.

In the horizontal position, the panel hangs as shown in Fig. S1. The only information required as input for the method is:

- \( d_{cg} \) = distance from up face of panel to c.g. of panel
- \( h_{cg} \) = distance from bottom of panel to c.g. of panel
- \( h_1 \) = distance from bottom of panel to lowest set of lifting devices
- \( h_2 \) = distance between lower two sets of lifting devices
- \( L \) = length of panel
- \( S \) = sling length, defined as total length of lifting sling from lowest set of lifting devices through the rolling blocks to middle set of lifting devices

In the horizontal position, the length of the lower leg of the sling \( S_1 \) and the upper leg of the sling \( S_2 \) are both \( S/2 \). During all angles of rotation, \( S_1 + S_2 = S \). When the panel reaches vertical, \( S_1 = S - (S - h_2)/2 \) and \( S_2 = S - S_1 \). By varying \( S_1 \) between the possible extremes, the stability of the panel during rotation can be investigated.

Figure S2 shows the panel in a tilted position. Because the distance between the lower two sets of lifting devices \( h_2 \) is fixed, angles \( A \) and \( B \) can be found by the law of cosines for any assumed value of \( S_1 \).

\[
A = \cos^{-1} \left( \frac{S_1^2 + S_2^2 - h_2^2}{2S_1S_2} \right)
\]

\[
B = \cos^{-1} \left( \frac{h_2^2 + S_2^2 - S_1^2}{2h_2S_2} \right)
\]

**Figure S1.** The panel hangs like this when it is in the horizontal position. Note: c.g. = center of gravity; \( d_{cg} \) = distance from up face of panel to c.g. of panel; \( e_h \) = distance from c.g. of panel to \( R_l \); \( h_2 \) = distance from bottom of panel to c.g. of panel; \( h_1 \) = distance from bottom of panel to lowest set of lifting devices; \( h_3 \) = length of panel minus \( (h_1 + h_2) \); \( R_l \) = left lifting reaction acting at centerline of rolling block; \( R_r \) = right lifting reaction acting at right end of panel; \( S \) = sling length, defined as total length of lifting sling from lowest set of lifting devices, through the rolling blocks, to middle set of lifting devices; \( S_1 \) = the length of the lower leg of the sling; \( S_2 \) = the length of the upper leg of the sling.

**Figure S2.** The panel is in a tilted position. Note: \( A \) = angle; \( B \) = angle; \( C \) = angle; \( e \) = eccentricity; \( R_l \) = left lifting reaction acting at centerline of rolling block; \( R_r \) = right lifting reaction acting at right end of panel; \( S_1 \) = the length of the lower leg of the sling; \( S_2 \) = the length of the upper leg of the sling; \( d_{cg} \) = distance between the bottom up-face corner of the panel and the vertical crane line reaction \( R_r \); \( \theta \) = angle of panel rotation from horizontal.
The results of this method on the example illustrated in the section “Analytical Study – Shifting of Rolling-Block Reaction” are tabulated in Table S1. The values designated \( \Delta \) are used to modify \( S_1 \) for the entire range of rotation. The mesh of \( \Delta \) values decrease as the panel rotation angle increases because instability is more likely to occur at higher tilt angles. At \( S_1 = 31.40 \text{ ft} (9.6 \text{ m}) \), \( \Delta \) has been manually adjusted to result in a panel tilt angle \( \theta \) of 60 deg. The resulting \( e = -0.13 \text{ ft} = -1.54 \text{ in.} \) (39 mm) agrees with the results of the method shown in “Analytical Study—Shifting of Rolling-Block Reaction.” However, actual instability will begin at roughly \( \theta = 50 \text{ deg} \).

Due to the free rotation of the rolling blocks, angle \( A \) is bisected by the crane line resisting \( R_l \) at all angles of rotation. Consequently, the angle of panel rotation \( \theta \) can be found using

\[
\theta = 90 - \left( 180 - \frac{A}{2} - B \right)
\]

The distance between the bottom up-face corner of the panel and the vertical crane line reaction \( R_l \) can be found using

\[
x_{\text{lift}} = \cos \theta (h_1 + h_2) - \sin \frac{A}{2} (S_2)
\]

The distance between that same bottom up-face corner and the c.g. of the panel, adjusted for the depth of the c.g. below the up face, is

\[
x_{cg} = \cos \theta (h_{cg} + d_{cg} \tan \theta)
\]

The panel will remain stable as long as \( e = x_{cg} - x_{\text{lift}} \geq 0 \)

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The mathematical method presented herein is straightforward. However, engineering judgment should be exercised with respect to a minimum required eccentricity (greater than zero) to account for manufacturing tolerances and other imperfections associated with the erection process.
About the author

Donald R. Logan, P.E., is principal of Logan Structural Research Foundation in Colorado Springs, Colo. He was founder and CEO of Stresscon Corp. from 1967 to 2007. He is a PCI Fellow and was named a Titan of the Industry in 2004. Logan received the Martin P. Korn Award and the American Society of Civil Engineers’ T. Y. Lin Award for his 1997 paper on strand-bond acceptance criteria and the Korn Award again for his 2007 paper on eccentrically loaded L-spandrels. He serves on the PCI Research and Development Committee.

Synopsis

Erection of long, vertical precast concrete members from their as-delivered horizontal position to their vertical position in the structure involves devising handling procedures that protect the safety of the erection personnel while preventing the precast concrete member from cracking during the tilting procedure. The author investigates the most commonly used procedures, three-point and four-point rolling-block lifting systems, and identifies a common instability condition that causes sudden, uncontrolled rolling of the members as they are being tilted toward their vertical position. Methods are devised to detect in any member the potential for such instability, to establish safe location of lifting devices and minimum lengths of crane slings to prevent this condition from occurring, and to analyze and control tensile stresses from causing cracking of long precast concrete wall panels as they are lifted from their horizontal position, rigged for the tilting operation.

Keywords

Erection, long members, rolling block, safety, stability, tilting, wall panel.

Review policy

This paper was reviewed in accordance with the Precast/Prestressed Concrete Institute’s peer-review process.

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