Pressure on Wall and Column Forms

ACI issues new guidelines for the formwork designer

By M.K. Hurd

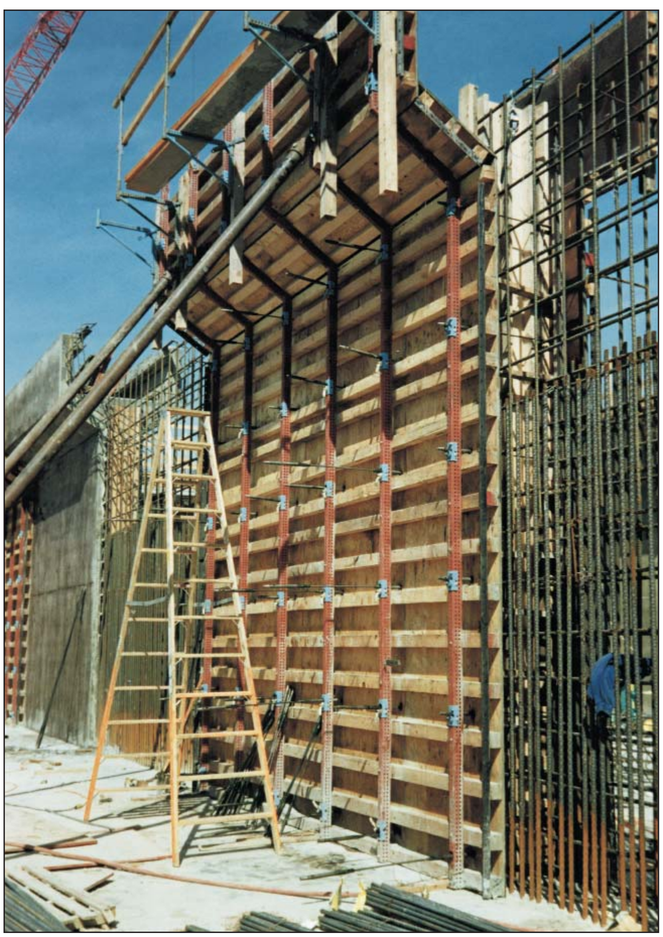
Who makes the rules for form design? The American Concrete Institute (ACI) Committee 347, Formwork for Concrete, is generally regarded as the standards-setting authority in the United States—not only for vertical formwork but also for deck forms, shoring, and reshoring. Using data available from field measurements at the time, Committee 347 came out with its first lateral pressure recommendations in 1958: pressure formulas that could be used for safe form design. Then, as now, the committee was a balanced group of contractors, engineers, industry suppliers, and educators concerned with both the contractor's need for economy and the workers' safety. Knowing that a dozen or more factors could influence the pressure of concrete against the forms, it identified the three most important variables as:

- concrete temperature
- rate of pour
- weight of concrete

The committee then developed simple formulas that form designers could apply, using values of these variables appropriate for their jobs. The underlying assumption was that freshly placed concrete, particularly under the influence of a vibrator, acts temporarily like a fluid, producing a hydrostatic pressure that acts laterally against vertical forms.

These original formulas were based on pressure measurements made during actual placement of concrete. In the past 40 years, concrete mixes have changed significantly. Development of

Tall walls may require heavy formwork to resist the lateral pressure of freshly placed concrete. On this form, the closely spaced horizontal wood members have been designed to support the plywood sheathing, limiting deflection to provide a smooth concrete surface.



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The variables used in the pressure formulas are defined as follows:

p = lateral pressure of concrete, psf (pounds per square foot)

h = depth of fluid or plastic concrete from top of placement to point of consideration, feet

w = unit weight of concrete, pcf (pounds per cubic foot)

R = rate of placement, feet per hour

T = temperature of concrete during placement, degrees F

C_w = unit weight coefficient

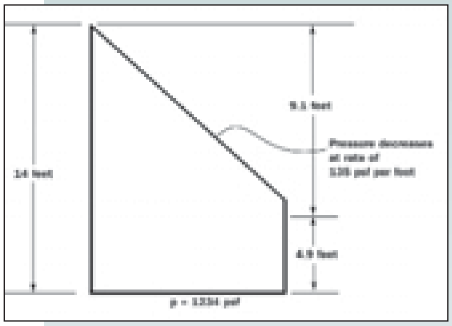
C_c = chemistry coefficient

Examples of pressure calculations

1. Wall form

Find the design pressure for a 14-foot wall, with concrete placed at 4 feet per hour (rate of rise in the form) and a concrete temperature of 60° F. The mix is lightweight concrete weighing 135 pcf, made with Type I cement and a retarding admixture. From Table 3, the base pressure value is 1060 psf. From Table 1, the weight coefficient is 0.5 (1 + w/145), or 0.5 (1 +135/145) = 0.97. The chemistry coefficient C_c is 1.2 for Type I cement used with a retarder. The maximum pressure, therefore, is 1060 x 0.97 x 1.2 = 1234 psf.

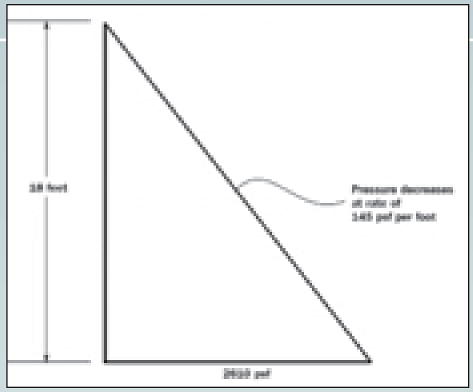
Since this is considered comparable to fluid pressure up to the time the concrete begins to stiffen, the pressure is assumed to increase uniformly at the rate of w psf per foot of depth (135 psf per foot in this example) until the maximum of 1234 psf given by the equation is reached. Any point within the first 9.1 feet below the top of the form (1234 psf/135 pcf) will have proportionally less pressure than the maximum. The 1234-psf maximum is used for design for all of the remaining 4.9 feet of the form below the 9.1-foot level.



The drawing shows what is called the *envelope of maximum pressure.* Since studs and sheathing are ordinarily uniform in size and spacing throughout their entire height, only the maximum value will be used for their design. However, the spacing of wales and ties may be increased in the upper part of the form to take advantage of the lower pressure.

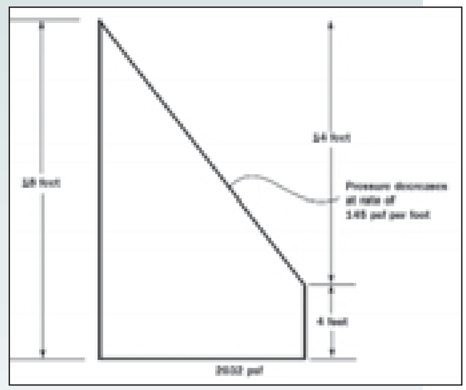
2. Column form

An 18-foot-high column form is filled at 12 feet per hour using a blended cement mix containing 30% fly ash but no retarder. The mix temperature is 50° F, and its unit weight is 145 pcf. From Table 2, the base pressure value is 2310 psf. From Table 1, the chemistry coefficient C_c is 1.2, and the unit weight coefficient is 1.0. So the maximum pressure for design is 2310 x 1.2 x 1.0 = 2772 psf. But this exceeds the wh limit of 18 x 145 = 2610 psf. Therefore the simple hydrostatic pressure distribution shown in the drawing is used for design.



3. Column form

Suppose the same column described in Example 2 is filled with concrete at a temperature of 70° F with all other factors the same. From Table 2, the base pressure value is 1693 psf. The chemistry and weight coefficients are the same so the design pressure is 1693 x 1.2 x 1.0 = 2032 psf. As in the wall example, this is assumed to be hydrostatic in the upper part of the form to a depth of 2032/145 = 14.0 feet. The maximum pressure of 2032 psf is then used for design of the bottom 4 feet of the form.



sophisticated admixtures that alter the workability and setting time of concrete, and the introduction of new cementitious materials such as fly ash, ground slag, and silica fume, have introduced the possibility of higher concrete pressures. The growing use of pumps for rapid placement has also created the potential for higher pressures. Over time, ACI Committee 347 attempted to adjust its formulas, but, unable to make a breakthrough to cope with all of the new conditions, finally came to a basic recommendation to design for full liquid head, $p = wh$ (see box for definition of terms), that is, to simply multiply the unit weight of the unhardened wet concrete by its depth in the form. The committee recommended use of the earlier formulas only if the concrete matched the working conditions under which the formulas were developed.

This very conservative approach led to what some considered punitively high pressures for taller forms—a 30-foot-high column, for example, filled by pumping might have to be designed for a pressure of 4500 pounds per square foot: 150 pounds/cubic foot (typical unit weight assumed for the concrete) times 30 feet. There were protests and differences of opinion as

Table 1. Coefficients to be used in pressure equations

Unit weight coefficient, C_w	
Concrete weighing less than 140 pcf	$C_w = 0.5 (1 + w/145)$ but not less than 0.80
Concrete weighing 140 to 150 pcf	$C_w = 1.0$
Concrete weighing more than 150 pcf	$C_w = w/145$
Chemistry coefficient, C_c	
Types I and III cement without retarders*	1.0
Types I and III cement with a retarder*	1.2
Other types or blends without retarders* containing less than 70% slag or less than 40% fly ash	1.2
Other types or blends with retarders* containing less than 70% slag or less than 40% fly ash	1.4
Blends containing more than 70% slag or 40% fly ash	1.4

* Retarders include any admixtures such as retarders, retarding water reducers, or retarding high-range water-reducing admixtures that delay the setting of concrete.

Table 2. Base values of lateral pressure on column forms,* psf, for various pour rates and concrete temperatures.
Multiply value from this table by unit weight and chemistry coefficients (see Table 1) to obtain pressure for design of column forms.

Rate of placement *R*, ft per hr	Concrete temperature during placement, degrees F					
	90° F	80° F	70° F	60° F	50° F	40° F
1	250	263	279	300	330	375
2	350	375	407	450	510	600
3	450	488	536	600	690	825
4	550	600	664	750	870	1050
5	650	713	793	900	1050	1275
6	750	825	921	1050	1230	1500
7	850	938	1050	1200	1410	1725
8	950	1050	1179	1350	1590	1950
9	1050	1163	1307	1500	1770	2175
10	1150	1275	1436	1650	1950	2400
11	1250	1388	1564	1800	2130	2625
12	1350	1500	**1693**	1950	**2310**	2850
13	1450	1613	1821	2100	2490	
14	1550	1725	1950	2250	2670	
16	1750	1950	2207	2550		
18	1950	2175	2464	2850		
20	2150	2400	2721			
22	2350	2625	2979			
24	2550	2850			3000 C_wC_c maximum governs	
26	2750					
28	2950					

* Base value of lateral pressure equals 150 + 9000 *R/T*
NOTE: Depending on coefficient values, the minimum pressure of 600 C_W may govern. Do not use pressures in excess of *wh*.

Table 3. Base values of lateral pressure on wall forms,* psf, for various pour rates and concrete temperatures.
Multiply value from this table by unit weight and chemistry coefficients (see Table 1) to obtain pressure for design of wall forms.

Rate of placement R, ft per hr	Concrete temperature during placement, degrees F					
	90° F	80° F	70° F	60° F	50° F	40° F
1	663	728	810	920	1074	1305
2	694	763	850	967	1130	1375
3	726	798	890	1013	1186	1445
4	757	833	930	**1060**	1242	1515
5	788	868	970	1107	1298	1585
6	819	903	1010	1153	1354	1655
7	850	938	1050	1200	1410	1725
8	881	973	1090	1247	1466	1795
9	912	1008	1130	1293	1522	1865
10	943	1043	1170	1340	1578	1935
11	974	1078	1210	1387	1634	
12	1006	1113	1250	1433	1690	
14	1068	1183	1330	1527	1802	
16	1130	1253	1410	1620	1914	
18	1192	1323	1490	1713	2000 C_wC_c controls	
20	1254	1393	1570	1807		

* Base value of lateral pressure equals 150 + 43000/*T* + 2800 *R/T*
NOTE: Maximum pressure is 2000 C_WC_c and minimum is 600 C_W. Do not use pressures in excess of *wh*.

to whether this was really appropriate or necessary (Ref. 1).

But then, in 1999, a new study that took into account both the original (1958) data and many more-recent pressure measurements in the United States and abroad was presented to ACI Committee 347. This work, by John Barnes and David Johnston at North Carolina State University (Ref. 2), was accepted by the committee and served as the basis for new pressure equations that are now available in ACI 347-01, "Guide to Formwork for Concrete" (Ref. 3).

Updated formulas

The updated formwork standard released in late 2001 provides two pressure formulas, one for walls and one for columns. It also introduces weight and chemistry coefficients, C_w and C_c, that make it possible to apply the formulas to a variety of mixes and concrete weights:

For columns:
$p = C_wC_c\,[150 + 9000\,R/T]$
with a maximum pressure of 3000 C_wC_c, a minimum of 600 C_w, but never more than *wh*

For walls:
$p = C_wC_c\,[150 + 43{,}400/T + 2800\,R/T]$
with a maximum pressure of 2000 C_wC_c, a minimum of 600 C_w, but never more than *wh*

For purposes of applying the formulas, ACI 347 defines a wall as a vertical element with at least one plan dimension greater than 6.5 feet and a column as a vertical element with no plan dimension larger than 6.5 feet. Although pressure at any given point within the form varies with time, the designer usually does not have to know the specific variation since the equations indicate the maximum pressure on the forms.

ACI 347-01 reverts to equivalent hydrostatic head ($p = wh$) when a form is filled full height in less than the time required for the concrete to begin to stiffen, or for conditions where the coefficients cannot be applied. For example, when forms are filled by pumping from the bottom, ACI 347 recommends using *wh* plus an allowance of at least 25% for pump surge pressure. The maximum and minimum pressures given by the formulas do not apply when $p = wh$ is used.

Table 1 gives values of C_w and C_c. Table 2 gives base values of lateral pressure on column forms—that is, pressures that can be used when both C_w and C_c are 1. Table 3 gives base values for lateral pressure on wall forms—again, pressures that can be used directly when both weight and chemistry coefficients are 1. The examples show how to use the tables and formulas.

Future of the pressure formulas

Based on Barnes and Johnston's work, ACI Committee 347 has introduced these modified formulas for lateral pressure, but this is not the end of the line. Johnston, who is chairman of the committee, believes that more field measurements of pressure are needed as changes in placement methods and concrete mixes continue. He hopes to get contractors involved in developing data that will lead to improved formulas and more accurate assessments of pressure. The advent of self-consolidating concrete alone will call for further pressure studies. SCC is making inroads in Japan and Europe and already enjoys widespread use in precast concrete (see CONCRETE CONSTRUCTION, January 2002). It is also expected to become a significant factor in cast-in-place work. Will the pressures with SCC be higher? What effect will new admixtures and cementitious materials have? The entire concrete industry will have to be involved in observing and measuring pressures if realistic standards are to be maintained. ■

References

1. Nadine Post, "Climbing the Walls," *ENR*, January 18, 1999, pp. 46–49.

2. John M. Barnes and David W. Johnston, "Modification Factors for Improved Prediction of Fresh Concrete Lateral Pressure," Institute of Construction, Department of Civil Engineering, North Carolina State University, Raleigh, 1999.

3. ACI Committee 347, "Guide to Formwork for Concrete (ACI 347-01)," American Concrete Institute, Farmington Hills, Mich., 2001.

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