A P A

The Engineered Wood Association

DESIGN/CONSTRUCTION GUIDE

CONCRETE FORMING

A P A

The Engineered Wood Association

DO THE RIGHT THING RIGHT™

Wood is good. It is the earth's natural, energy efficient and renewable building material.

Engineered wood is a better use of wood. It uses less wood to make more wood products.

That's why using APA trademarked I-joists, glued laminated timbers, laminated veneer lumber, plywood, and oriented strand board is the right thing to do.

A few facts about wood.

- ***We're not running out of trees.*** One-third of the United States land base – 731 million acres – is covered by forests. About two-thirds of that 731 million acres is suitable for repeated planting and harvesting of timber. But only about half of the land suitable for growing timber is open to logging. Most of that harvestable acreage also is open to other uses, such as camping, hiking, hunting, etc.

- ***We're growing more wood every day.*** American landowners plant more than two billion trees every year. In addition, millions of trees seed naturally. The forest products industry, which comprises about 15 percent of forestland ownership, is responsible for 41 percent of replanted forest acreage. That works out to more than one billion trees a year, or about three million trees planted every day. This high rate of replanting accounts for the fact that each year, 27 percent more timber is grown than is harvested.

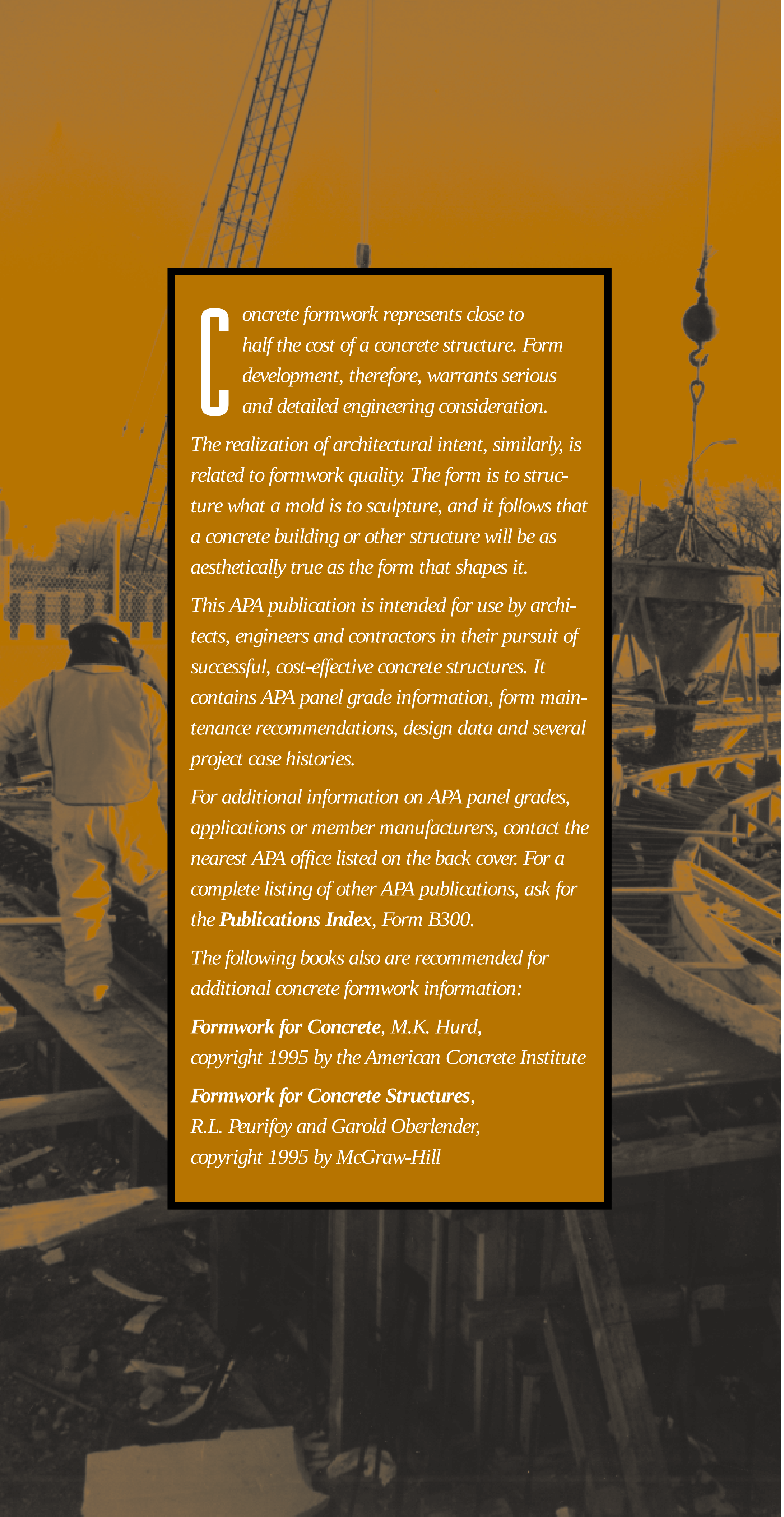
- ***Manufacturing wood is energy efficient.*** Wood products made up 47 percent of all industrial raw materials manufactured in the United States, yet consumed only 4 percent of the energy needed to manufacture all industrial raw materials, according to a 1987 study.

Material	Percent of Production	Percent of Energy Use
Wood	47	4
Steel	23	48
Aluminum	2	8

- ***Good news for a healthy planet.*** For every ton of wood grown, a young forest produces 1.07 tons of oxygen and absorbs 1.47 tons of carbon dioxide.

Wood. It's the right product for the environment.

NOTICE:
The recommendations in this guide apply only to panels that bear the APA trademark. Only panels bearing the APA trademark are subject to the Association's quality auditing program.



Concrete formwork represents close to half the cost of a concrete structure. Form development, therefore, warrants serious and detailed engineering consideration.

The realization of architectural intent, similarly, is related to formwork quality. The form is to structure what a mold is to sculpture, and it follows that a concrete building or other structure will be as aesthetically true as the form that shapes it.

This APA publication is intended for use by architects, engineers and contractors in their pursuit of successful, cost-effective concrete structures. It contains APA panel grade information, form maintenance recommendations, design data and several project case histories.

For additional information on APA panel grades, applications or member manufacturers, contact the nearest APA office listed on the back cover. For a complete listing of other APA publications, ask for the ***Publications Index****, Form B300.*

The following books also are recommended for additional concrete formwork information:

Formwork for Concrete*, M.K. Hurd, copyright 1995 by the American Concrete Institute*

Formwork for Concrete Structures*, R.L. Peurifoy and Garold Oberlender, copyright 1995 by McGraw-Hill*

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SELECTING AND SPECIFYING CONCRETE FORM PANELS

General

Virtually any Exterior type APA panel can be used for concrete formwork because all such panels are manufactured with waterproof glue. For concrete forming the plywood industry produces a special product called Plyform® which is recommended for most general forming uses. The term is proprietary and may be applied only to specific products which bear the trademark of *APA – The Engineered Wood Association.* All Plyform panels are Exterior type made with C or better veneer and waterproof glue.

MDO and HDO are names the plywood industry uses to describe overlaid surfaces. MDO means "Medium Density Overlay" and HDO means "High Density Overlay." During plywood production, these overlays are bonded to the plywood under high heat and pressure in a press. The function of the overlay is to add stability, repel foreign substances from the surface and provide a smoother and more durable forming surface. The thermo-set resins used in overlay production are hard and resist water, chemicals and abrasion. HDO is most often specified where the smoothest possible concrete finish and maximum number of reuses is desired.

Plywood Grades

Plyform is Exterior-type plywood limited to certain wood species and veneer grades to assure high performance. Products bearing this specific identification are available in two basic grades: Plyform Class I and Plyform Class II.

Each may be ordered with a High Density Overlaid surface on one or both sides. Plyform Class I is also available as Structural I Plyform when additional strength is needed.

Plyform Class I

Class I Plyform has Group 1 faces for high strength and stiffness. See Tables 3 and 4 for load capacities.

Structural I Plyform

This concrete forming panel is made with Group 1 wood species throughout – the strongest. All other factors being equal, it will support the highest loads both along and across the panel. It is specifically designed for engineered applications and is recommended where face grain is parallel to supports. See Table 5 and 6 for load capacities.

Plyform Class II

Class II Plyform may have Group 2 faces but still provides adequate strength for most forming applications. Check with supplier for availability.

B-B Plyform

Nonoverlaid Plyform is usually made with B grade veneer face and back and referred to as "B-B Plyform." It is available as Structural I, Class I or Class II. The panels are sanded on both sides and treated with a release agent at the mill (called "mill oiled") unless otherwise specified.

Unless the mill treatment is reasonably fresh when the panels are first used, the plywood may require another treatment of release agent. It is also important to apply a top-quality edge sealer before the first pour. Plyform panels can be ordered edge-sealed from the mill. Five to ten reuses of B-B Plyform are common.

HDO Plyform

This Plyform panel meets the same general specifications as Plyform Structural I or Class I or Class II. All classes of HDO Plyform have a hard, semi-opaque surface of thermo-set resin-impregnated material that forms a durable, continuous bond with the plywood. The abrasion-resistant surface should be treated with a release agent prior to its first use and between each pour to preserve the surface and facilitate easy stripping.

HDO Plyform is most often specified when the smoothest possible concrete finishes are desired, because the panel has a hard, smooth surface. It can impart a nearly polished concrete surface. Both sides of HDO are moisture resistant but cannot always be used to form concrete with equal effectiveness unless specifically made for that purpose. Scratches and dents in the backs caused by fastening the panels to the supports may make the use of both sides impractical. Various grades of HDO Plyform may be available; check with your supplier. With reasonable care, HDO Plyform will normally produce 20 to 50 reuses or more. Some concrete-forming specialists achieve 200 or more reuses with good results.

Medium Density Overlay

Special proprietary grades of MDO are available for concrete forming. *Regular MDO is intended for use as a paint surface and should* ***not*** *be used for concrete forming.* Panels are typically overlaid on only one side, although they can be produced with MDO on both sides. Proprietary MDO concrete form plywood is normally factory-treated with a release agent and edge-sealed to protect the edges from water absorption. The abrasion-resistant surface should be treated with a release agent prior to its first use and between each pour to preserve the surface and facilitate easy stripping. MDO form panels create a matte or flat finish on the concrete surface.

Related Grades

Additional plywood grades specifically designed for concrete forming include special overlay panels and proprietary panels. These panels are designed to produce a smooth, uniform concrete surface. Some proprietary panels are made of Group 1 wood species only, and have thicker face and back veneers than those normally used. These provide greater parallel-to-face grain strength and stiffness for the panel. Faces may be specially treated or coated with a release agent. Check with the manufacturer for design specifications and surface treatment recommendations.

Special Textures

Plywood is manufactured in many surface textures, ranging from the polished High Density Overlaid plywood to patterned board-and-batten siding panels. Working with these special panels, and with field-applied patterns, virtually any texture can be created.

Exterior-type textured plywood usually is applied in two ways in formwork design: (1) as a liner requiring plywood backing so that the liner delivers texture, but contributes little to the structure of the formwork, or (2) as the basic forming panel. In the second case, the best reports come from projects where the number of pours required is limited, because the textured surface can increase necessary stripping forces and, therefore, the possibility of panel damage in the stripping process. Film-coatings, such as lacquer, polyurethane or epoxy, can be used with a release agent to make stripping easier.

Plywood Tolerances

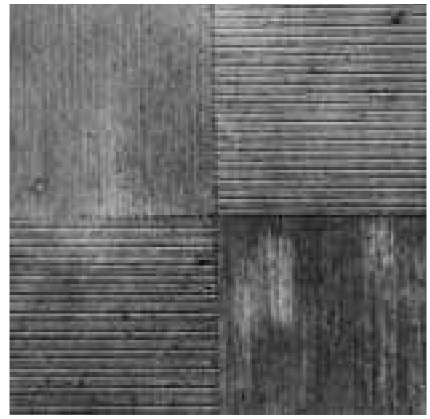
Plywood is an engineered product, manufactured to exacting tolerances under U.S. Product Standard PS 1-95. A tolerance of plus 0.0 inch and minus 1/16 inch is allowed on the specified width and/or length. Sanded Plyform panels are manufactured with a thickness tolerance of plus or minus 1/64 inch of the specified panel thickness for 3/4 inch and less, and plus or minus 3 percent of the specified thickness for panels thicker than 3/4 inch.

Overlaid Plyform panels have a plus or minus tolerance of 1/32 inch for all thicknesses through 13/16 inch. Thicker panels have a tolerance of 5 percent over or under the specified thickness.

For squareness, the Product Standard requires panels to be square within 1/64 inch per nominal foot of length when measured corner to corner along the diagonal, for panels 4 feet and greater in length.

For edge straightness, panels must be manufactured so that a straight line drawn from one corner to an adjacent corner shall fall within 1/16 inch of the panel edge.

These tolerances and consistent levels of quality required by *APA – The Engineered Wood Association* help minimize the time and labor required in building forms. Good construction practices dictate an awareness of the tolerances at the jobsite. In an extreme case, two 3/4-inch sanded panels, both within manufacturing tolerances, could form a joint with a 1/32-inch variation in surface level from panel to panel. Realignment of panels and shimming are quick, easy solutions.



Concrete Surface Characteristics

Surface dusting of concrete has occasionally been observed in concrete poured against a variety of forming materials, including plywood. There appears to be no single reason – the soft, chalky surface has been traced to a variety of possible causes, including excess oil, dirt, dew, smog, unusually hot, dry climactic conditions, and chemical reactions between the form surface and the concrete.

There may be other factors involved in dusting. The problem appears to occur at certain seasons of the year and in specific localities and with certain concrete mixes. Dusting during cold weather pouring may result from additives used in the concrete to protect against freezing. Too much water in the mix can cause laitance which, in effect, is dusting. Excess vibration can contribute to the same problem.

Various means of rectifying the problem have been successful. Preventive measures include proper form storage (cool, dry conditions) and cleanliness (avoiding needless exposure to dust, oil and weathering). If dusting occurs, a fine water spray is reported to help speed surface hardening. The State of California Department of Transportation reports that "…rather than attempt to employ inconvenient methods of preventing dusting, final results will be satisfactory if affected areas are subsequently cured for a few days with water in a spray fine enough not to erode the soft surface." Other concrete specialists have recommended surface treatment solutions such as magnesium fluorosilicate or sodium silicate.

Staining is occasionally observed on concrete poured against HDO plywood forms. The reddish or pinkish stain is a fugitive dye, and usually disappears with exposure to sunlight and air.

Where sunlight cannot reach the stain, natural bleaching takes longer. Household bleaching agents such as Clorox or Purex (5% solutions of sodium hypochlorite), followed by clear-water flushing, have been found effective in hastening stain removal.

On rare occasions, other discolorations have been observed in new concrete. For example, iron salts resulting from iron sulfides and ferrous oxides in slag cement have been found to stain concrete a greenish-blue color, particularly when large, continuous, smooth and airtight form surfaces are used.

Both occurrence and intensity of color seem to be related to the length of time between application of release agents to forms and pouring of concrete, as well as to the length of time before the forms are stripped. It has been suggested that loosening or opening the forms at the earliest possible time after placing the concrete would prevent the occurrence of discoloration in slag concrete. The discoloration usually fades and disappears with time. Hydrogen peroxide solutions have been reported useful in removing the color, particularly when applied to the concrete immediately after form removal.

Suggested Method of Ordering

The best method of ordering Plyform is to state the Class, number of pieces, width, length, thickness and grade. For example: "APA Plyform Class I, 100 pcs. 48 x 96 x 5/8 B-B Exterior type, mill oiled." Concrete form panels are mill treated with release agents unless otherwise specified. Even so, it is good practice to indicate treatment requirements when ordering.

When ordering overlaid plywood, the basic descriptions should be specified – High Density Overlay (HDO), for example. The number of pieces, size and thickness should be noted in the same way as Plyform.

Special surface requirements should be stated after the standard form of the order. Weights of surfacing material include High Density 60-60 (standard weight) and other variations such as 90-60, 120-60, or 120-120.

Metric Conversions

Metric equivalents of nominal thicknesses and common sizes of wood structural panels are tabulated below (1 inch = 25.4 millimeters).

PANEL NOMINAL DIMENSIONS (WIDTH X LENGTH)

ft	mm	m (approx.)
4 x 8	1219 x 2438	1.22 x 2.44
4 x 9	1219 x 2743	1.22 x 2.74
4 x 10	1219 x 3048	1.22 x 3.05

PANEL NOMINAL THICKNESS

in.	mm
1/4	6.4
5/16	7.9
11/32	8.7
3/8	9.5
7/16	11.1
15/32	11.9
1/2	12.7
19/32	15.1
5/8	15.9
23/32	18.3
3/4	19.1
7/8	22.2
1	25.4
1-3/32	27.8
1-1/8	28.6

GRADE-USE GUIDE FOR CONCRETE FORMS*

Use These Terms When You Specify Plywood	Description	Typical Trademarks	Veneer Grade		
			Faces	Inner Plies	Backs
APA B-B PLYFORM Class I & II**	Specifically manufactured for concrete forms. Many reuses. Smooth, solid surfaces. Mill-treated unless otherwise specified.	APA THE ENGINEERED WOOD ASSOCIATION PLYFORM B-B CLASS 1 EXTERIOR 000 PS 1-95	B	C	B
APA High Density Overlaid PLYFORM Class I & II**	Hard, semi-opaque resin-fiber overlay, heat-fused to panel faces. Smooth surface resists abrasion. Up to 200 reuses. Light application of releasing agent recommended between pours.	HDO • B-B • PLYFORM I • 60/60 • EXT-APA • 000 • PS 1	B	C-Plugged	B
APA STRUCTURAL I PLYFORM**	Especially designed for engineered applications. All Group 1 species. Stronger and stiffer than Plyform Class I and II. Recommended for high pressures where face grain is parallel to supports. Also available with High Density Overlay faces.	APA THE ENGINEERED WOOD ASSOCIATION STRUCTURAL I PLYFORM B-B CLASS I EXTERIOR 000 PS 1-95	B	C or C-Plugged	B
Special Overlays, proprietary panels and Medium Density Overlaid plywood specifically designed for concrete forming.**	Produces a smooth uniform concrete surface. Generally mill treated with form release agent. Check with manufacturer for specifications, proper use, and surface treatment recommendations for greatest number of reuses.				
APA B-C EXT	Sanded panel often used for concrete forming where only one smooth, solid side is required.	APA THE ENGINEERED WOOD ASSOCIATION B-C GROUP 1 EXTERIOR 000 PS 1-95	B	C	C

* Commonly available in 19/32", 5/8", 23/32" and 3/4" panel thicknesses (4' x 8' size).
** Check dealer for availability in your area.

FORM MAINTENANCE

Stripping

Metal bars or prys should not be used on plywood because they will damage the panel surface and edge. Use wood wedges, tapping gradually when necessary. Plywood's strength, light weight and large panel size help reduce stripping time. Cross-laminated construction resists edge splitting.

Cleaning and Release Agent Application

Soon after removal, plywood forms should be inspected for wear, cleaned, repaired, spot primed, refinished and lightly treated with a form-release agent before reusing. Use a hardwood wedge and a stiff fiber brush for cleaning (a metal brush may cause wood fibers to "wool"). Light tapping on the back side with a hammer will generally remove a hard scale of concrete. On prefabricated forms, plywood panel faces (when the grade is suitable) may be reversed if damaged, and tie holes may be patched with metal plates, plugs or plastic materials. Nails should be removed and holes filled with patching plaster, plastic wood, or other suitable materials.

Handling and Storage

Care should be exercised to prevent panel chipping, denting and corner damage during handling. Panels should never be dropped. The forms should be carefully piled flat, face to face and back to back, for hauling. Forms should be cleaned immediately after stripping and can be solid-stacked or stacked in small packages, with faces together. This slows the drying rate and minimizes face checking.

Plywood stack handling equipment and small trailers for hauling and storing panels between jobs will minimize handling time and damage possibilities. During storage, the stacks of plywood panels should be kept out of the sun and rain, or covered loosely to allow air circulation without heat build-up. Panels no longer suited for formwork may be saved for use in subflooring or wall and roof sheathing if their condition permits.

Specially coated panels with long-lasting finishes that make stripping easier and reduce maintenance costs are available. They should be handled carefully to assure maximum number of reuses.

Hairline cracks or splits may occur in the face ply. These "checks" may be more pronounced after repeated use of the form. Checks do not mean the plywood is delaminating. A thorough program of form maintenance including careful storage to assure slow drying will minimize face checking.

Coatings and Agents

Protective sealant coatings and release agents for plywood increase form life and aid in stripping. "Mill-oiled" Plyform panels may require only a light coating of release agent between uses. Specifications should be checked before using any release agent on the forms.

A liberal amount of form release agent, applied a few days before the plywood is used, then wiped so a thin film remains, will prolong the life of the plywood form, increase its release characteristics and minimize staining.

A "chemically reactive" release agent will give overlaid panels the longest life and should be applied prior to the first pour. Diesel oil and motor oil degrade HDO and MDO severely and should never be used as release agents on overlaid panels. Some concrete additives can also degrade overlays. Check with the manufacturer.

The selection of a release agent should be made with an awareness of the product's influence on the finished surface of the concrete. For example, some release agents including waxes or silicones should not be used where the concrete is to be painted. The finished architectural appearance should be considered when selecting the form surface treatment.

Plywood form coatings, such as lacquers, resin or plastic base compounds and similar field coatings sometimes are used to form a hard, dry, water-resistant film on plywood forms. The performance level of these coatings is generally rated somewhere between B-B Plyform and High Density Overlaid plywood. In most cases the need for application of release agents between pours is reduced by the field-applied coatings, and many contractors report obtaining significantly greater reuse than with the B-B Plyform, but generally fewer than with HDO plywood.

Mill-coated products of various kinds are available, in addition to "mill-oiled" Plyform. Some plywood manufacturers suggest no release agents with their proprietary concrete forming products, and claim exceptional concrete finishes and a large number of reuses.

FORM DESIGN

Introduction

This section presents tables and shows how to use them to choose the right Plyform thickness for most applications. It also includes tables for choosing the proper size and spacing of joists, studs, and wales. See pages 17-20 for technical information of interest to the form manufacturer or the engineer who must design forms having loading conditions and/or deflection criteria not included in the following tables.

Though many combinations of frame spacing and plywood thicknesses will meet the structural requirements, it is probably better to use only one thickness of plywood and then vary the frame spacing for different pressures. Plyform can be manufactured in various thicknesses, but it is good practice to base designs on 19/32", 5/8", 23/32" and 3/4" Plyform Class I, as they are most commonly available. Plywood thickness should be compatible with form tie

TABLE 1

CONCRETE PRESSURES FOR COLUMN AND WALL FORMS

Pour Rate (ft/hr)	Pressures of Vibrated Concrete (psf)[a][b] 50°F [c] Columns	50°F [c] Walls	70°F [c] Columns	70°F [c] Walls
1	330	330	280	280
2	510	510	410	410
3	690	690	540	540
4	870	870	660	660
5	1050	1050	790	790
6	1230	1230	920	920
7	1410	1410	1050	1050
8	1590	1470	1180	1090
9	1770	1520	1310	1130
10	1950	1580	1440	1170

(a) Maximum pressure need not exceed 150h, where h is maximum height of pour in feet.
(b) Based on concrete with density of 150 pcf and 4 inch slump.
(c) See page 16 for additional information on concrete form pressures.

TABLE 2

DESIGN LOADS FOR SLAB FORMS

Slab Thickness (in.)	Design Load (psf) Nonmotorized Buggies[a]	Design Load (psf) Motorized Buggies[b]
4	100[c]	125[c]
5	113	138
6	125	150
7	138	163
8	150	175
9	163	188
10	175	200

(a) Includes 50 psf load for workers, equipment, impact, etc.
(b) Includes 75 psf load for workers, equipment, impact, etc.
(c) Minimum design load regardless of concrete weight.

dimensions. For large jobs or those having special requirements, other thicknesses may be preferable, but could require a special order.

Concrete Pressures

The required plywood thickness, as well as size and spacing of framing, will depend on the maximum load. The first step in form design is to determine maximum concrete pressure. It will depend on such things as pour rate, concrete temperature, concrete slump, cement type, concrete density, method of vibration, and height of form.

Pressures on Column and Wall Forms

Table 1 shows the lateral pressure for newly placed concrete that should be used for the design of column and wall formwork. This pressure is based on the recommendations of the American Concrete Institute (ACI). When formwork is to be designed for exterior vibration or to be used in conjunction with pumped concrete placement systems, the design pressures listed should increase in accordance with accepted concrete industry standards.

Concrete form design procedures are based on ACI standard 347R-88, which recognizes the use of a large number of variables in modern concrete designs. These variables include the use of various cement types, admixtures, design slumps, concrete placement systems, etc. The lack of test data on the effects of variables on concrete design pressures prompted the ACI to publish more conservative design equations when non-traditional concrete mix designs are used.

Concrete pressure is in direct proportion to its density. Pressures shown in Table 1 are based on a density of 150 pounds per cubic foot (pcf). They are appropriate for the usual range of concrete poured. For other densities, pressures may be adjusted in direct proportion.

Loads on Slab Forms

Forms for concrete slabs must support workers and equipment (live loads) as well as the weight of freshly placed concrete (dead load). Normal weight concrete (150 pcf) will place a load on the forms of 12.5 psf for each inch of slab thickness. Table 2 gives minimum design loads which represent average practice when either motorized or nonmotorized buggies are used for placing concrete. These loads include the effects of concrete, buggies, and workers.

Curved Forms

Plyform can also be used for curved forms, as illustrated on page 8. The following radii have been found to be appropriate minimums for mill-run panels of the thicknesses shown when bent dry. Tighter radii can be developed by selecting panels that are free of knots and short grain, and/or by wetting or steaming. Occasionally, a panel may develop localized failure at these tighter radii.

MINIMUM BENDING RADII

Plywood Thickness (in.)	Across the Grain (ft.)	Parallel to Grain (ft.)
1/4	2	5
5/16	2	6
3/8	3	8
1/2	6	12
5/8	8	16
3/4	12	20

TABLE 3

RECOMMENDED MAXIMUM PRESSURES ON PLYFORM CLASS I (psf)[(a)]
FACE GRAIN ACROSS SUPPORTS[(b)]

Support Spacing (in.)	Plywood Thickness (in.) 15/32		1/2		19/32		5/8		23/32		3/4		1-1/8	
4	2715	2715	2945	2945	3110	3110	3270	3270	4010	4010	4110	4110	5965	5965
8	885	885	970	970	1195	1195	1260	1260	1540	1540	1580	1580	2295	2295
12	355	395	405	430	540	540	575	575	695	695	730	730	1370	1370
16	150	200	175	230	245	305	265	325	345	390	370	410	740	770
20	–	115	100	135	145	190	160	210	210	270	225	285	485	535
24	–	–	–	–	–	100	–	110	110	145	120	160	275	340
32	–	–	–	–	–	–	–	–	–	–	–	–	130	170

(a) Deflection limited to 1/360th of the span, 1/270th where shaded.
(b) Plywood continuous across two or more spans.

TABLE 4

RECOMMENDED MAXIMUM PRESSURES ON PLYFORM CLASS I (psf)[(a)]
FACE GRAIN PARALLEL TO SUPPORTS[(b)]

Support Spacing (in.)	Plywood Thickness (in.) 15/32		1/2		19/32		5/8		23/32		3/4		1-1/8	
4	1385	1385	1565	1565	1620	1620	1770	1770	2170	2170	2325	2325	4815	4815
8	390	390	470	470	530	530	635	635	835	835	895	895	1850	1850
12	110	150	145	195	165	225	210	280	375	400	460	490	1145	1145
16	–	–	–	–	–	–	–	120	160	215	200	270	710	725
20	–	–	–	–	–	–	–	–	115	125	145	155	400	400
24	–	–	–	–	–	–	–	–	–	–	–	100	255	255

(a) Deflection limited to 1/360th of the span, 1/270th where shaded.
(b) Plywood continuous across two or more spans.

Recommended Pressures on Plyform

Recommended maximum pressures on the more common thicknesses of Plyform Class I are shown in Tables 3 and 4. Tables 5 and 6 show pressures for Structural I Plyform. Calculations for these pressures were based on deflection limitations of 1/360th or 1/270th of the span, or shear or bending strength: whichever provided the most conservative (lowest load) value. Use unshaded columns for design of architectural concrete forms where appearance is important.

Though not manufactured specifically for concrete forming, grades of plywood other than Plyform have been used for forming when thin panels are needed for curved forms. The recommended pressures shown in the following tables give a good estimate of performance for sanded grades such as APA A-C Exterior and APA B-C Exterior, and unsanded grades such as APA Rated Sheathing Exterior and Exposure 1 (CDX) (marked PS 1), provided face grain is across supports. For Group 1 sanded grades, use the tables for Plyform Class I. For unsanded grades (Span Rated PS 1 panels) use the Plyform Class I tables assuming 15/32" Plyform for 32/16 panels, 19/32" for 40/20 and 23/32" for 48/24.

Textured plywood has recently been used to obtain various patterns for architectural concrete. Many of these panels have some of the face ply removed due to texturing. Consequently, strength and stiffness will be reduced. As textured plywood is available in a variety of patterns and wood species, it is impossible to give exact factors for strength and stiffness reductions. For approximately equivalent strength, specify the desired grade in Group 1 species and determine the thickness assuming Plyform Class I.

TABLE 5

RECOMMENDED MAXIMUM PRESSURES ON STRUCTURAL I PLYFORM (psf)[a]

FACE GRAIN ACROSS SUPPORTS[b]

Support Spacing (in.)	Plywood Thickness (in.)													
	15/32		1/2		19/32		5/8		23/32		3/4		1-1/8	
4	3560	3560	3925	3925	4110	4110	4305	4305	5005	5005	5070	5070	7240	7240
8	890	890	980	980	1225	1225	1310	1310	1590	1590	1680	1680	2785	2785
12	360	395	410	435	545	545	580	580	705	705	745	745	1540	1540
16	155	205	175	235	245	305	270	330	350	400	375	420	835	865
20	–	115	100	135	145	190	160	215	210	275	230	290	545	600
24	–	–	–	–	–	100	–	110	110	150	120	160	310	385
32	–	–	–	–	–	–	–	–	–	–	–	–	145	190

(a) Deflection limited to 1/360th of the span, 1/270th where shaded.

(b) Plywood continuous across two or more spans.

TABLE 6

RECOMMENDED MAXIMUM PRESSURES ON STRUCTURAL I PLYFORM (psf)[a]
FACE GRAIN PARALLEL TO SUPPORTS[b]

Support Spacing (in.)	Plywood Thickness (in.)													
	15/32		1/2		19/32		5/8		23/32		3/4		1-1/8	
4	1970	1970	2230	2230	2300	2300	2515	2515	3095	3095	3315	3315	6860	6860
8	470	530	605	645	640	720	800	865	1190	1190	1275	1275	2640	2640
12	130	175	175	230	195	260	250	330	440	545	545	675	1635	1635
16	–	–	–	–	–	110	105	140	190	255	240	315	850	995
20	–	–	–	–	–	–	–	100	135	170	170	210	555	555
24	–	–	–	–	–	–	–	–	–	–	–	115	340	355

(a) Deflection limited to 1/360th of the span, 1/270th where shaded.

(b) Plywood continuous across two or more spans.

When 3/8" textured plywood is used as a form liner, assume that the plywood backing must carry the entire load.

In some cases, it may be desirable to use two layers of plywood. The recommended pressures shown in Tables 3 through 6 are additive for more than one layer.

Tables 3 through 6 are based on the plywood acting as a continuous beam which spans between joists or studs. No blocking is assumed at the unsupported panel edges. Under conditions of high moisture or sustained load to the panel however, edges may have greater deflection than the center of the panel and may exceed the calculated deflection unless panel edges are supported. For this reason, and to minimize differential deflection between adjacent panels, some form designers specify blocking at the unsupported edge, particularly when face grain is parallel to supports.

Concrete Forming Design Example 1: Step 1 – Selection of Plyform Class I for Wall Forms

Internally vibrated concrete will be placed in wall forms at the rate of 3 feet per hour; concrete temperature is 70°. What is the maximum support spacing for 5/8" Plyform Class I for architectural concrete if the wall is 9 feet high?

The concrete to be used is made with Type I cement, weighs approximately 150 lbs per cubic foot, contains no pozzolans or admixtures, has a 4-inch slump and is internally vibrated to a depth of 4 feet or less.

Find Maximum Concrete Pressure: Table 1 shows 540 psf pressure for 70° and a pour rate of 3 feet per hour. This is less than 150h (150 x 9 ft. = 1350 psf), therefore, use 540 psf maximum pressure.

Select Table Giving Recommended Pressures: Assume the plywood will be placed with its face grain across supports. Therefore, see Table 3.

Determine Maximum Support Spacing: Look down the column for 5/8" Plyform. It shows 575 psf for supports at 12 inches on center. In this case, 12 inches is the maximum support spacing recommended.

Step 2 – Selecting Size of Joists, Studs, and Wales

The loads carried by slab joists, and by wall studs and wales are proportional to their spacings as well as to the maximum concrete pressure. Tables 7 and 8 give design information for lumber framing directly supporting the plywood. Note that tables show spans for two conditions: members over 2 or 3 supports (1 or 2 spans) and over 4 or more supports (3 or more spans). Some forming systems use doubled framing members. Even though Tables 7 and 8 are for single members, these tables can be adapted for use with multiple members. The example following Tables 7 and 8 shows how to account for these factors.

Step 3 – Selection of Framing for Wall Forms

Design the lumber studs and double wales for the Plyform selected in Step 1. Maximum concrete pressure is 540 psf.

Design Studs: Since the plywood must be supported at 12" on center, space studs 12" on center. The load carried by each stud equals the concrete pressure multiplied by the stud spacing in feet:*

$$540 \text{ psf} \times \frac{12}{12} \text{ ft} = 540 \text{ lb per ft}$$

*This method is applicable to most framing systems. It assumes the maximum concrete pressure is constant over the entire form. Actual distribution is more nearly "trapezoidal" or "triangular." Design methods for these distributions are covered in the American Concrete Institute's *Formwork for Concrete*.

Assuming No. 2 Douglas-fir or southern pine 2x6 studs continuous over 3 supports (2 spans), Table 7 shows a 51" span for 400 lb per ft and a 41" span for

TABLE 7

DOUGLAS-FIR LARCH NO. 2 OR SOUTHERN PINE NO. 2

Equivalent Uniform Load (lb/ft)	Continuous Over 2 or 3 Supports (1 or 2 Spans) Nominal Size								Continuous Over 4 or More Supports (3 or More Spans) Nominal Size							
	2x4	2x6	2x8	2x10	2x12	4x4	4x6	4x8	2x4	2x6	2x8	2x10	2x12	4x4	4x6	4x8
200	49	72	91	111	129	68	101	123	53	78	98	120	139	81	118	144
400	35	51	64	79	91	53	78	102	38	55	70	85	98	57	84	111
600	28	41	53	64	74	43	63	84	31	45	57	69	80	47	68	90
800	25	36	45	56	64	38	55	72	27	39	49	60	70	41	59	78
1000	22	32	41	50	58	34	49	65	24	35	44	54	62	36	53	70
1200	20	29	37	45	53	31	45	59	22	32	40	49	57	33	48	64
1400	19	27	34	42	49	28	41	55	20	29	37	45	53	31	45	59
1600	17	25	32	39	46	27	39	51	19	27	35	42	49	29	42	55
1800	16	24	30	37	43	25	37	48	18	26	33	40	46	27	40	52
2000	16	23	29	35	41	24	35	46	17	25	31	38	44	26	37	49
2200	15	22	27	34	39	23	33	44	16	23	30	36	42	24	36	47
2400	14	21	26	32	37	22	32	42	15	22	28	35	40	23	34	45
2600	14	20	25	31	36	21	30	40	15	22	27	33	39	22	33	43
2800	13	19	24	30	34	20	29	39	14	21	26	32	37	22	32	42
3000	13	19	23	29	33	19	28	37	14	20	25	31	36	21	31	40
3200	12	18	23	28	32	19	27	36	13	19	25	30	35	20	30	39
3400	12	17	22	27	31	18	27	35	13	19	24	29	34	20	29	38
3600	12	17	21	26	30	18	26	34	13	18	23	28	33	19	28	37
3800	11	16	21	25	30	17	25	33	12	18	23	28	32	19	27	36
4000	11	16	20	25	39	17	25	32	12	17	22	27	31	18	27	35
4500	10	15	19	23	27	16	23	30	11	16	21	25	29	17	25	33
5000	10	14	18	22	26	15	22	29	11	16	20	24	28	16	24	31

MAXIMUM SPANS FOR LUMBER FRAMING, INCHES

Spans are based on the 1991 NDS allowable stress values.

Spans are based on dry, single-member allowable stresses multiplied by a 1.25 duration-of-load factor for 7-day loads.

Deflection is limited to 1/360th of the span with 1/4" maximum. Spans are measured center-to-center on the supports.

Lumber with no end splits or checks is assumed.

Width of supporting members (e.g. wales) assumed to be 3-1/2" net (double 2x lumber plus 1/2" for tie).

600 lb per ft. Interpolate between these spans for a 540 lb per ft load:

$$\frac{540-400}{600-400} \text{ x } (51-41) = \frac{140 \text{ x } 10}{200} = 7''$$

For 540 lb per ft, span = 51" – 7" = 44"

The 2x6 studs must be supported at 44" on center. Assume this support is provided by double 2x6 wales spaced 44" on center.

Design Double Wales: Load carried by the double wales equals the maximum concrete pressure multiplied by the wale spacing in feet, or

$$540 \text{ psf x } \frac{44}{12} \text{ ft} = 1980 \text{ lb per ft}$$

Since the wales are doubled, each wale carries 990 lb per ft (1980 ÷ 2 = 990). Assuming 2x6 wales continuous over 4 or more supports, Table 7 shows a 35" span for 1000 lb per ft and 39" span for 800 lb per ft.** Interpolation shows that 2x6s can span 35" for 990 lb per ft. Support 2x6s at 35" on center with form ties. (Place bottom wale about 10" from bottom of form).

**Tables 7 and 8 are for uniform loads but the wales actually receive point loads from the studs. This method of approximating the capacity of the wales is adequate when there are three or more studs between the ties. A point load analysis should be performed when there are only one or two studs between the ties.

Load on Ties: The load on each tie equals the load on the double wales times the tie spacing in feet, or

$$1980 \text{ lb per ft x } \frac{35}{12} \text{ ft} = 5775 \text{ lb}$$

If allowable load on the tie is less than 5775 lb, decrease tie spacing accordingly. For instance, a tie with 5000 lb allowable load should be spaced no more than:

$$\frac{5000}{1980} \text{ x } 12 \text{ in.} = 30 \text{ in.}$$

Figure 1 illustrates the final design resulting from the example problem.

TABLE 8

HEM-FIR NO. 2

Equivalent Uniform Load (lb/ft)	Continuous Over 2 or 3 Supports (1 or 2 Spans) Nominal Size								Continuous Over 4 or More Supports (3 or More Spans) Nominal Size							
	2x4	2x6	2x8	2x10	2x12	4x4	4x6	4x8	2x4	2x6	2x8	2x10	2x12	4x4	4x6	4x8
200	48	71	90	110	127	64	96	117	52	77	97	118	137	78	112	137
400	34	50	63	77	90	51	76	99	37	54	69	84	97	56	83	109
600	28	41	52	63	73	43	62	82	30	44	56	68	79	46	67	89
800	24	35	45	55	64	37	54	71	26	38	48	59	69	40	58	77
1000	22	32	40	49	57	33	48	64	23	34	43	53	61	36	52	69
1200	20	29	37	45	52	30	44	58	21	31	40	48	56	33	48	63
1400	18	27	34	41	48	28	41	54	20	29	37	45	52	30	44	58
1600	17	25	32	39	45	26	38	50	18	27	34	42	49	28	41	54
1800	16	24	30	37	42	25	36	48	17	26	32	39	46	27	39	51
2000	15	22	28	35	40	23	34	45	17	24	31	37	43	25	37	49
2200	15	21	27	33	38	22	33	43	16	23	29	36	41	24	35	46
2400	14	20	26	32	37	21	31	41	15	22	28	34	40	23	34	44
2600	13	20	25	30	35	21	30	40	15	21	27	33	38	22	32	42
2800	13	19	24	29	34	20	29	38	14	20	26	32	37	21	31	40
3000	12	18	23	28	33	19	28	37	14	20	25	31	35	21	30	39
3200	12	18	22	27	32	18	27	36	13	19	24	30	34	20	29	38
3400	12	17	22	27	31	18	26	35	13	19	23	29	33	19	28	36
3600	11	17	21	26	30	17	25	34	12	18	23	28	32	19	28	35
3800	11	16	21	25	29	17	25	33	12	18	22	27	31	18	27	35
4000	11	16	20	24	28	17	24	32	12	17	22	26	31	18	26	34
4500	10	15	19	23	27	16	23	30	11	16	20	25	29	17	25	32
5000	10	14	18	22	25	15	22	29	10	15	19	24	27	16	23	31

MAXIMUM SPANS FOR LUMBER FRAMING, INCHES

Spans are based on the 1991 NDS allowable stress values.

Spans are based on dry, single-member allowable stresses multiplied by a 1.25 duration-of-load factor for 7-day loads.

Deflection is limited to 1/360th of the span with 1/4" maximum. Spans are measured center-to-center on the supports.

Lumber with no end splits or checks is assumed.

Width of supporting members (e.g. wales) assumed to be 3-1/2" net (double 2x lumber plus 1/2" for tie).

Other Loads on Forms

Concrete forms must also be braced against lateral loads due to wind and any other construction loads. Design forms for lateral wind loads of at least 10 pounds per square foot – or greater if required by local codes. In all cases, forms over 8 feet high should be designed to carry at least 100 pounds per lineal foot applied at the top.

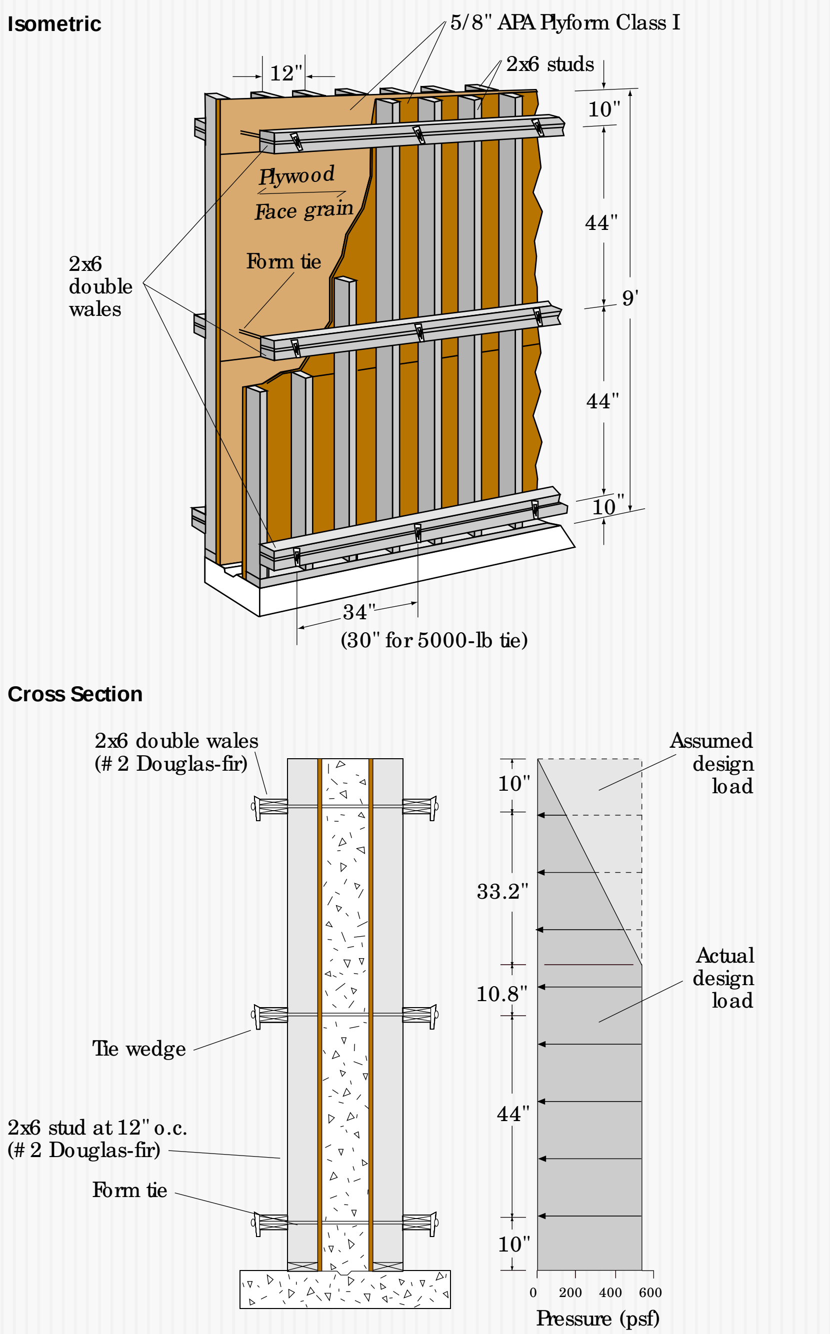
Wall forms should be designed to withstand wind pressures applied from either side. Inclined wood braces can be designed to take both tension and compression, so braces on only one side may be used. Wood bracing must be designed so it will not buckle under axial compression load. Guy-wire bracing, on the other hand, can resist only tensile loads. If used, it is required on both sides of the form.

In general, wind bracing will also resist uplift forces on the forms, provided the forms are vertical. If forms are inclined, uplift forces may be significant. Special tiedowns and anchorages may be required in some cases.

In most forms, it is best to attach the Plyform to the framing with as few nails as possible. For slab forms, each panel must be at least corner nailed. Use 5d nails for 19/32 and 5/8 inch Plyform and 6d nails for 23/32 and 3/4 inch Plyform. In special cases, such as gang forms, additional nailing may be required. Do not butt panels too tightly, especially on the first pour.

FIGURE 1

FINAL SOLUTION TO CONCRETE FORM DESIGN EXAMPLE 1



ENGINEERING DATA

The form designer may encounter loading conditions and spans not covered in the previous tables. This section is included for the engineer or form designer who requires more extensive engineering analysis.

Concrete Pressure

As explained earlier, maximum concrete pressure will depend on several factors. Assuming regular concrete (150 pcf), made with Type I cement, containing no pozzolans or admixtures, with a 4-inch slump, and vibration limited to normal internal vibration to a depth of 4 feet or less, the American Concrete Institute recommends the following formulas to determine design pressure:

a. For ordinary work with normal internal vibration in columns,

$$P = 150 + 9{,}000\,\frac{R}{T}$$

$\left(\begin{array}{l}\text{maximum 3,000 psf or}\\ \text{150h, whichever is least}\end{array}\right)$

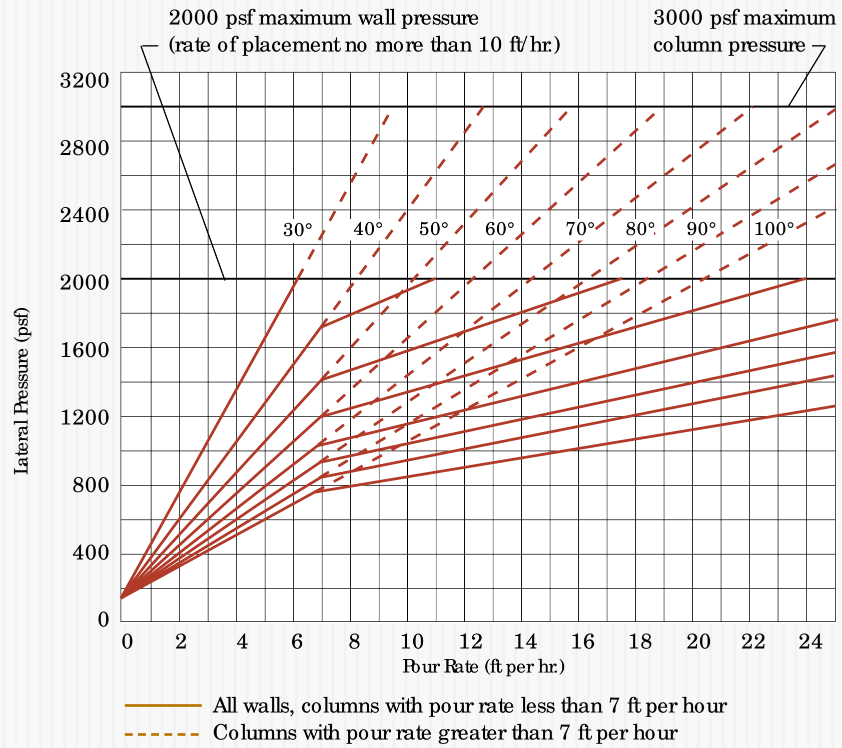
b. For ordinary work with normal internal vibration in walls with rate of placement up to 7 feet per hour:

$$P = 150 + 9{,}000\,\frac{R}{T}$$

$\left(\begin{array}{l}\text{maximum 2,000 psf or}\\ \text{150h, whichever is least}\end{array}\right)$

FIGURE 2

LATERAL CONCRETE PRESSURES FOR VARIOUS TEMPERATURES*



* Based on concrete made with Type I cement, weighing 150 lbs per cubic foot, containing no pozzolans or admixtures, having a slump of 4 inches or less, and placed with normal internal vibration to a depth of 4 feet or less.

c. For ordinary work with normal internal vibration in walls with rate of placement 7 to 10 feet per hour:

$$P = 150 + \frac{43{,}400}{T} + 2{,}800\,\frac{R}{T}$$

$\left(\begin{array}{l}\text{maximum 2,000 psf or}\\ \text{150h, whichever is least}\end{array}\right)$

d. For walls with rate of placement greater than 10 feet per hour:

$$P = 150h$$

Where:

P = lateral pressure, psf

R = rate of pour, feet per hour

T = concrete temperature, degrees Fahrenheit

h = height of fresh concrete above point considered, feet

These formulas are presented graphically in Figure 2 for various combinations of pour rate and temperature.

TABLE 9

SECTION PROPERTIES FOR PLYFORM CLASS I AND CLASS II, AND STRUCTURAL I PLYFORM[(a)]

		Properties for Stress Applied Parallel with Face Grain			Properties for Stress Applied Perpendicular to Face Grain		
Thickness (inches)	Approx. Weight (psf)	Moment of Inertia I ($in.^4$/ft)	Effective Section Modulus KS ($in.^3$/ft)	Rolling Shear Constant Ib/Q ($in.^2$/ft)	Moment of Inertia I ($in.^4$/ft)	Effective Section Modulus KS ($in.^3$/ft)	Rolling Shear Constant Ib/Q ($in.^2$/ft)
CLASS I							
15/32	1.4	0.066	0.244	4.743	0.018	0.107	2.419
1/2	1.5	0.077	0.268	5.153	0.024	0.130	2.739
19/32	1.7	0.115	0.335	5.438	0.029	0.146	2.834
5/8	1.8	0.130	0.358	5.717	0.038	0.175	3.094
23/32	2.1	0.180	0.430	7.009	0.072	0.247	3.798
3/4	2.2	0.199	0.455	7.187	0.092	0.306	4.063
7/8	2.6	0.296	0.584	8.555	0.151	0.422	6.028
1	3.0	0.427	0.737	9.374	0.270	0.634	7.014
1-1/8	3.3	0.554	0.849	10.430	0.398	0.799	8.419
CLASS II							
15/32	1.4	0.063	0.243	4.499	0.015	0.138	2.434
1/2	1.5	0.075	0.267	4.891	0.020	0.167	2.727
19/32	1.7	0.115	0.334	5.326	0.025	0.188	2.812
5/8	1.8	0.130	0.357	5.593	0.032	0.225	3.074
23/32	2.1	0.180	0.430	6.504	0.060	0.317	3.781
3/4	2.2	0.198	0.454	6.631	0.075	0.392	4.049
7/8	2.6	0.300	0.591	7.990	0.123	0.542	5.997
1	3.0	0.421	0.754	8.614	0.220	0.812	6.987
1-1/8	3.3	0.566	0.869	9.571	0.323	1.023	8.388
STRUCTURAL I							
15/32	1.4	0.067	0.246	4.503	0.021	0.147	2.405
1/2	1.5	0.078	0.271	4.908	0.029	0.178	2.725
19/32	1.7	0.116	0.338	5.018	0.034	0.199	2.811
5/8	1.8	0.131	0.361	5.258	0.045	0.238	3.073
23/32	2.1	0.183	0.439	6.109	0.085	0.338	3.780
3/4	2.2	0.202	0.464	6.189	0.108	0.418	4.047
7/8	2.6	0.317	0.626	7.539	0.179	0.579	5.991
1	3.0	0.479	0.827	7.978	0.321	0.870	6.981
1-1/8	3.3	0.623	0.955	8.841	0.474	1.098	8.377

(a) The section properties presented here are specifically for Plyform, with its special layup restrictions. For other grades, section properties are listed in the Plywood Design Specification, page 16.

Plywood Section Properties

The various species of wood used in manufacturing plywood have different stiffness and strength properties. Those species with similar properties are assigned to a species group. In order to simplify plywood design, the effects of using different species groups in a panel, as well as the effects of cross-banded construction, have been accounted for in the section properties given in Table 9. In calculating these section properties, all plies were "transformed" to properties of the face ply. Consequently the designer need not concern himself with the actual panel layup, but only with the allowable stresses for the face ply and the given section properties. Please note that these properties are for Plyform Class I and Class II and Structural I Plyform. For other plywood grades, see the section property tables in the APA publication *Plywood Design Specification* (Form Y510).

Plywood Stresses

The *Plywood Design Specification* gives basic plywood design stresses. As concrete forming is a special application, wet stresses should be used and then adjusted for forming conditions such as duration of load, and an experience factor.

In general, "wet" design stresses are adjusted by multiplying by each of the following factors:

	Duration of Load	Experience Factor
Bending Stress (F_b)	1.25	1.30
Rolling Shear Stress (F_s)	1.25	1.30

	Plyform Class I	Plyform Class II	Structural I Plyform
Modulus of elasticity – E (psi, adjusted, use for bending deflection calculation)	1,650,000	1,430,000	1,650,000
Modulus of elasticity – E_e (psi, unadjusted, use for shear deflection calculation)	1,500,000	1,300,000	1,500,000
Bending stress – F_b (psi)	1,930	1,330	1,930
Rolling shear stress – F_s (psi)	72	72	102

When shear deflection is computed separately from bending deflection, as was done in preparing Tables 3 through 6, the modulus of elasticity used for calculating bending deflection may be increased 10 percent.

These adjustments result in the stresses shown in the table above.

Recommended Concrete Pressure

Recommended concrete pressures are influenced by the number of continuous spans. For face grain across supports, assume 3 continuous spans up to a 32-inch support spacing and 2 spans for greater spacing. For face grain parallel to supports, assume 3 spans up to 16 inches and 2 spans for 20 and 24 inches. These are general rules only. For specific applications, other span-continuity relations may apply.

In computing recommended pressures, use center-to-center distance between supports for pressure based on bending stress. Testing has established that a shorter span, clear span + 1/4 inch, can be used in determining load based on stiffness or deflection for 2-inch nominal framing, with clear span + 5/8 inch for 4-inch nominal framing. Use clear span for calculating shear stress and shear deflection.

In some forming applications, not all of the stress adjustments may be applicable. For instance, with HDO Plyform, stresses for wet locations may not apply if panel edges are properly sealed to maintain a moisture content less than 16 percent.

The allowable pressures for various spans can be found by conventional engineering formulas. The following formulas have been adjusted to compensate for the use of mixed units and were used in preparing Tables 3 through 6.

Pressure Controlled by Bending Stress:

$$w_b = \frac{96\ F_b\ KS}{\ell_1^2} \text{ for 2 spans;}$$

$$= \frac{120\ F_b\ KS}{\ell_1^2} \text{ for 3 spans}$$

w_b = uniform load (psf)
F_b = bending stress (psi)
KS = effective section modulus (in.^{3}/ft)
ℓ_1 = span, center-to-center of supports (in.)

Pressure Controlled by Shear Stress:

$$w_s = \frac{19.2\ F_s\ (Ib/Q)}{\ell_2} \text{ for 2 spans;}$$

$$= \frac{20\ F_s\ (Ib/Q)}{l2} \text{ for 3 spans}$$

w_s = uniform load (psf)
F_s = rolling shear stress (psi)
Ib/Q = rolling shear constant (in.^{2}/ft)
ℓ_2 = clear span (in.)

Bending Deflection:

$$\Delta_b = \frac{w\ell_3^4}{2220\ EI} \text{ for 2 spans;}$$

$$= \frac{w\ell_3^4}{1743\ EI} \text{ for 3 spans}$$

Δ_b = bending deflection (in.)
w = uniform load (psf)
ℓ_3 = clear span + 1/4 inch for 2-inch framing (in.)
clear span + 5/8 inch for 4-inch framing (in.)
E = modulus of elasticity, adjusted (psi)
I = moment of inertia (in./ft)

Shear Deflection:

$$\Delta_s = \frac{Cwt^2\ell_2^2}{1270\ E_eI}$$

Δ_s = shear deflection (in.)
C = constant, equal to 120 for face grain across supports, and 60 for face grain parallel to supports
t = plywood thickness (in.)
E_e = modulus of elasticity, unadjusted (psi)

The following example illustrates the procedure for calculating allowable pressures by the use of engineering formulas. The allowable pressure is the least of the pressures calculated for bending stress, shear stress and deflection.

Example 2:

What is the recommended pressure for 3/4" Plyform Class I with face grain across supports spaced 16 inches on center, if deflection is no more than l/360? Assume 2-inch nominal framing.

Since the span is less than 32 inches, assume 3 spans. From Table 9, section properties of 3/4" Plyform Class I:

I = 0.199 in.^{4}/ft
KS = 0.455 in.^{3}/ft
Ib/Q = 7.187 in.^{2}/ft

Design stresses:

E = 1,650,000 psi
E_e = 1,500,000 psi
F_b = 1930 psi
F_s = 72 psi

Spans for calculation:

ℓ_1 = span, center-to-center of supports = 16"
ℓ_2 = clear span = 16" – 1.5" = 14.5"
ℓ_3 = clear span + 1/4" = 14.5" + 0.25" = 14.75"

Pressure Based on Bending Stress:

$$w_b = \frac{120\ F_b\ KS}{\ell_1^2}$$

$$= \frac{120 \times 1930 \times 0.455}{(16)^2} = 412 \text{ psf}$$

Pressure Based on Shear Stress:

$$w_s = \frac{20F_s(lb/Q)}{\ell_2}$$

$$= \frac{20 \times 72 \times 7.187}{14.5} = 714 \text{ psf}$$

Pressure Based on Deflection:

a) Determine allowable deflection:

$$\Delta_{all.} = \frac{\ell_1}{360} = \frac{16}{360} = 0.0444"$$

b) Find shear deflection due to 1.0 psf load:

$$\Delta_s = \frac{Cwt^2\ell_2^2}{1270\ E_eI}$$

$$= \frac{120 \times 1.0 \times (0.75)^2 \times (14.5)^2}{1270 \times 1{,}500{,}000 \times 0.199}$$

$$= 0.0000374"$$

c) Find bending deflection due to 1.0 psf load:

$$\Delta_b = \frac{w\ell_3^4}{1743\ EI}$$

$$= \frac{1.0 \times (14.75)^4}{1743 \times 1{,}650{,}000 \times 0.199}$$

$$= 0.0000827"$$

d) Allowable pressure:

$$w_\Delta = \frac{\Delta_{all.}}{\Delta_s + \Delta_b}$$

$$= \frac{0.0444}{0.0000374 + 0.0000827}$$

$$= 370 \text{ psf}$$

SUMMARY

w_b = 412 psf
w_s = 714 psf
w_Δ = 370 psf

Therefore, 370 psf is the allowable pressure.*

*Pressures shown in Tables 3 through 6 were determined by computer analysis with values given for design stresses and section properties mathematically rounded. Consequently, pressures determined by hand calculations may not agree exactly with those shown in the tables.

Sophisticated Slipform System Relies on Smooth, Durable Overlaid Plywood Forming Surface.

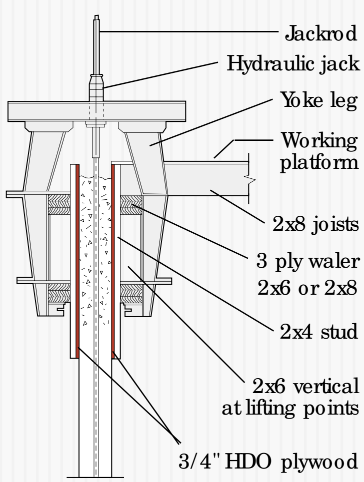
With proper planning, precise scheduling and a well-trained crew, slipforming can save time and labor.

The larger the project, the more imperative the need for precision – and the smaller the margin for error.

The structure pictured here was built with a classic slipform system developed by Heede International of San Francisco, a firm which specializes in slipforming design and equipment. Heede has engineered and supervised slipform operations for structures as large as 30 stories high, with more than a million and a half square feet of interior area.

This building is a 15-story apartment in San Francisco. The 4-foot-deep slipforms were advanced 15 inches per hour during the slipping process to complete a story-height in 8 hours, operating with one shift (two three-man crews for each half-tower).

STANDARD SLIPFORM FOR STRAIGHT WALL



The basic form employed by Heede (see drawing) is relatively simple and foolproof. The preferred forming material is 3/4-inch High Density Overlay plywood. Readily available, these panels deliver a smooth, even surface. Tough and durable, the panels performed throughout the construction process and were still capable of reuse on other projects. The same HDO plywood is frequently used in patented leased form systems where 200 and more reuses are common.

Engineered Wood Formwork and Post-tension Reinforced Concrete Combine for Innovative Solutions in Parking Garage.

When the Port of Seattle decided to add 1.26 million square feet of parking space at Seattle Tacoma International Airport, gang forms and slab forms framed with engineered wood members and HDO and MDO plywood saved money and material.

Wall forming of an eight-story elevator tower was accomplished with gang forms framed with laminated veneer lumber (LVL) studs and walers. The slab forms were framed with wood I-joists.

"The main reason we use the I-joists is that you get longer spans than you can even with aluminum and lower weight than with steel," said Brian Blount, project engineer for Nelson Concrete Company.

The light weight of engineered wood products provided a distinct advantage over steel, according to Blount. Especially since the forms were fabricated in Nelson's Portland, Oregon yard and trucked to the construction site.

The concrete slabs are only six inches thick due to post-tensioned reinforcement. The original parking garage slabs were formed with metal waffle forms. According to Blount, waffle forms for the addition would have been more costly because they require more time and more material.

"The advantage of these types of forms is that you can move forming material faster and with a whole lot less people," said Herb Dunphy, the engineer who designed the forming system for Formwork Engineering. "Speed and labor savings are the primary advantages," said Dunphy.

The exceptional stiffness of LVL and wood I-joists kept form deflection to a minimum and resulted in a nearly architectural finish on the concrete. In addition, the forms averaged 24 pours each before they were re-skinned and put back into service.

Subtle Architectural Expression Achieved with Simple, Practical Forming Approach.

The church pictured at right was designed by Paul Thiry, FAIA, to express the material as directly and simply as possible – the church looks like concrete with the same clear honesty that a stone church from another age looks like stone.

The plywood forming material reads through with a similar directness. Unsanded plywood was used with no attempt to obtain a smoother finish than the pour itself provided. The result is an awareness of the forming material as well as the final surface, without masking and without apology.

Such treatment – or restraint from treatment – helped realize the underlying architectural objective: A structure with elevated purpose produced from humble materials.

The achievement is particularly noteworthy in that the simplest, least complicated structural approach was possible. By emphasizing the character of the basic materials – plywood and concrete – rather than masking them, the architect obtained a practical, economical structure of high aesthetic merit.

Engineered Wood Shapes State History: Structural Wood Panels Used to Form Massive Concrete Arches.

It was clear from the beginning that building the Washington State History Museum in Tacoma, Washington was going to be a challenge. Not only was the museum a high-profile project on a prominent site in downtown Tacoma, but the project featured the construction of a dramatic series of eleven 55-foot-high reinforced concrete arches that were designed to accentuate the building's facade and blend into the neighboring historical Union Station.

Union Station is a huge masonry structure built in 1911 with four vaulted arches forming a central dome. The goal of the Washington State Historical Society was to construct a world class facility while maintaining the historic architecture of the former railroad station. The Historical Society turned to Moore/Andersson Architects, a Texas-based design firm, to design the facility.

Moore/Andersson designed the eleven 55-foot-high reinforced concrete arches to match the same height and scale as those in Union Station. Of the eleven arches, four run east and west and the remainder intersect and run north and south.

The construction team built a 6,800-square-foot gang form composed of APA trademarked high-density overlay (HDO) plywood panels to form a single arch. Over 4,000 sheets of HDO plywood were used to create sections of

gang forms. “The first arch took us four weeks,” recalls Eric Holopainen, senior project manager for Ellis-Don Construction Co., the general contractor. “By the time we finished the second cycle, it took us just 15 days.”

By using HDO plywood, Holopainen was able to reuse the panels seven times while pouring the other arches. A scale model proved essential in determining how the panels would be laid out in the gang forms.

Multiple-Use Panels Help Shape Graceful Freeway Project.

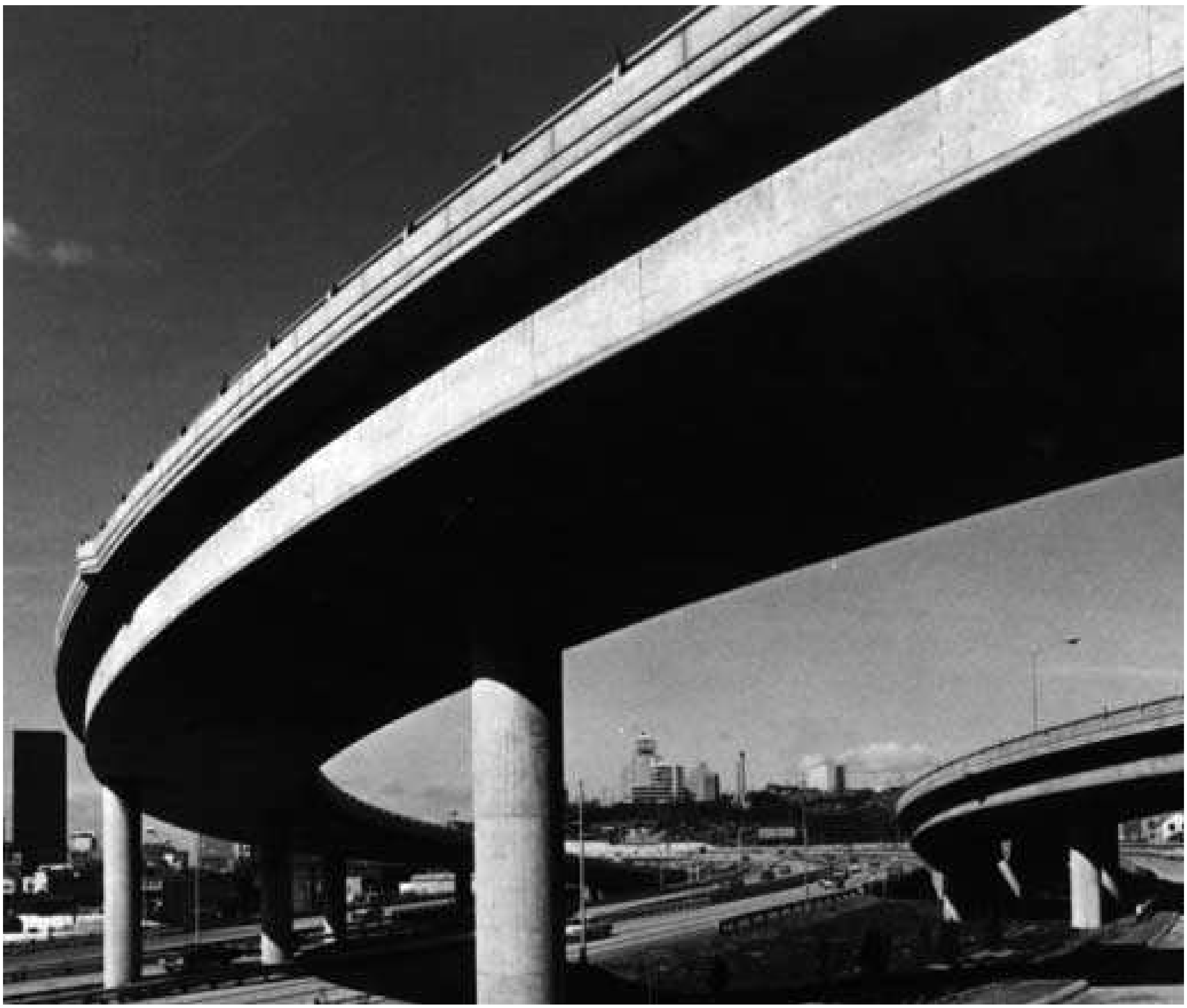
The forming requirements on complex freeway interchanges can range from relatively simple retaining walls to soaring bridges formed atop intricate scaffolding.

All the challenges were present in the Spokane Street interchange on Interstate 5 in Seattle, Washington, a city whose major arterials feed into the city by skirting the surrounding hills and waterways.

The high bridges here were formed against B-B Plyform supported by intricate timber scaffolding. The same panels were reused again and again, frequently being recut to fit new curves and new patterns.

One of the unusual features of the project is the precast retaining walls required for 8,000 feet of the freeway which was carved from a hillside. Casting walls in place would have meant waiting for the weather and the completion of earthmoving operations. The most economical approach proved to be precasting. Decking for the casting beds was smooth 3/4-inch plywood. On top of this, at four-foot intervals, the contractor laid panels of 3/4-inch striated plywood, face up. The resulting wall sections have a pleasant textured surface. Up to 10 pours were made against a form before it was dismantled and the plywood was reused in bridge deck forming.

Most wall panels were cast in 24-foot lengths, some weighing more than 50 tons. Higher sections (maximum 34 feet) were cast in 8- or 12-foot lengths.



Eight Bridges in Final Phase of Dallas Central Expressway Shaped with HDO.

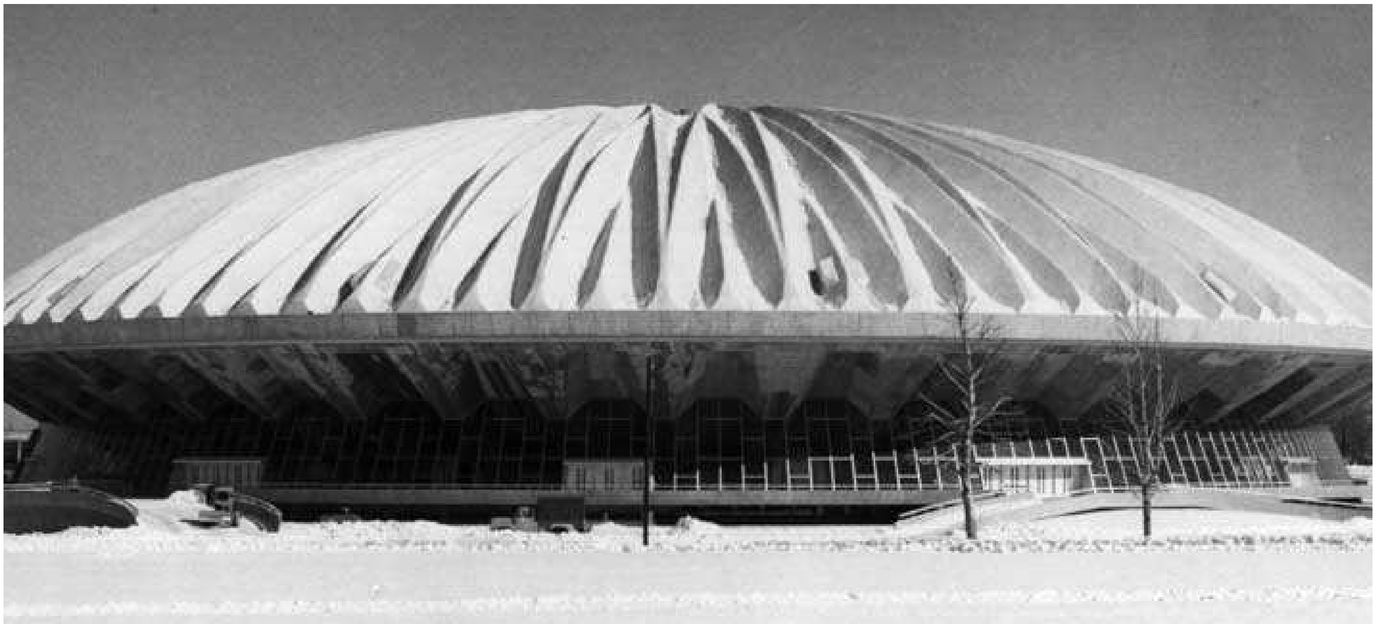
Commuters on their way to work see slow but steady changes in road construction as the final phase of the five-year Dallas Central Expressway project nears completion. Eight bridges are woven into this 2.3 mile stretch of the expressway, creating challenges at every bend. The complexity of the project – differing curves and angles of bridges, 100,000 square feet of concrete retaining walls and 70,000 square feet of cantilever overhang – made versatile engineered-wood concrete forms an ideal choice.

To accommodate the variability in shape and to make the pours more manageable, each bridge was divided into corners – 32 in all. The construction teams of Granite Construction Company, the general contractor, built gang forms for pouring bridge segments, composed of APA trademarked high-density overlay (HDO) plywood panels.

Beyond the need for versatility, the highly visible nature of the surface meant the forms had to have a high reuse capability, while maintaining a top-quality surface for the finished concrete. HDO's hard, smooth surface imparted a nearly polished concrete surface, even after many pours. By using 3/4-inch HDO, Granite was able to save money by using the panels on the overhang forms for over 20 pours before turning the panels over to use the second face. The flexibility and reusability of HDO engineered wood panels also permitted the same gang forms to be used on 6 of the 8 bridges.

Another hurdle in this project was coordinating pours so that numerous home owners and business owners and their patrons still had access to the adjacent restaurants, office buildings and homes. This meant building the complex roadway in small sections and pieces. HDO gangforms made it easier for construction teams to adjust forms for pouring smaller segments.

An additional challenge for project contractors was keeping the waste factor low on a project of this size, a crucial issue in terms of cost and the environment. Approximately 400 sheets of 4 x 8 HDO were used to create the gang forms for the various pours – a low number for a project of this magnitude.



Assembly Hall Shell System Formed with Material First Used in Main Floor and Buttress Pours.

As on many projects, this shell roof structure was constructed over a period spanning several seasons of the year. The forming process, therefore, occurred during a wide range of weather conditions.

Plywood's natural insulating qualities helped level out temperature curves, providing more consistent curing conditions.

The structure is an 18,000-seat spectator arena at the University of Illinois. The 48 buttresses were built with six plywood forms, the same material was reused in the six traveling forms used in the roof system. The shell is composed of 24 folded-plate segments. The plywood system permitted a schedule that resulted in the completion of two roof segment pours per week.

The three concrete rings that make up the support system also were formed with plywood: the continuous ring footing for the buttresses; the compression ring at the top of the dome; and the post-tensioned edge beam at the junction of upper and lower shells, which supports the 6,000-ton roof.

Plywood proved its versatility on this job, functioning as a workhorse material on the massive foundation pours, and also as a precision forming surface when reused in the intricate, shell-shaped roof system.

Plywood's mechanical properties contribute to its versatility, but there are other values so apparent they are often overlooked. Among those values: the material is readily available in a broad selection of thicknesses; it can be worked easily and quickly into countless shapes and patterns using ordinary tools and standard carpentry skills; the nature of the material is such that site improvisation is possible without complicated reworking of a basic system.

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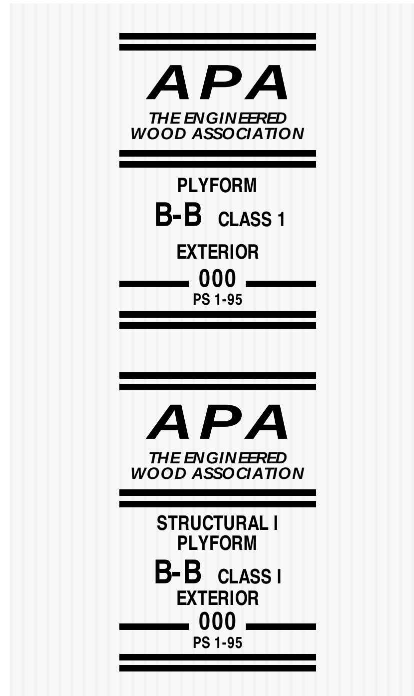
For more information about APA functions and services, write *APA – The Engineered Wood Association,* P.O. Box 11700, Tacoma, Washington 98411-0700.



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