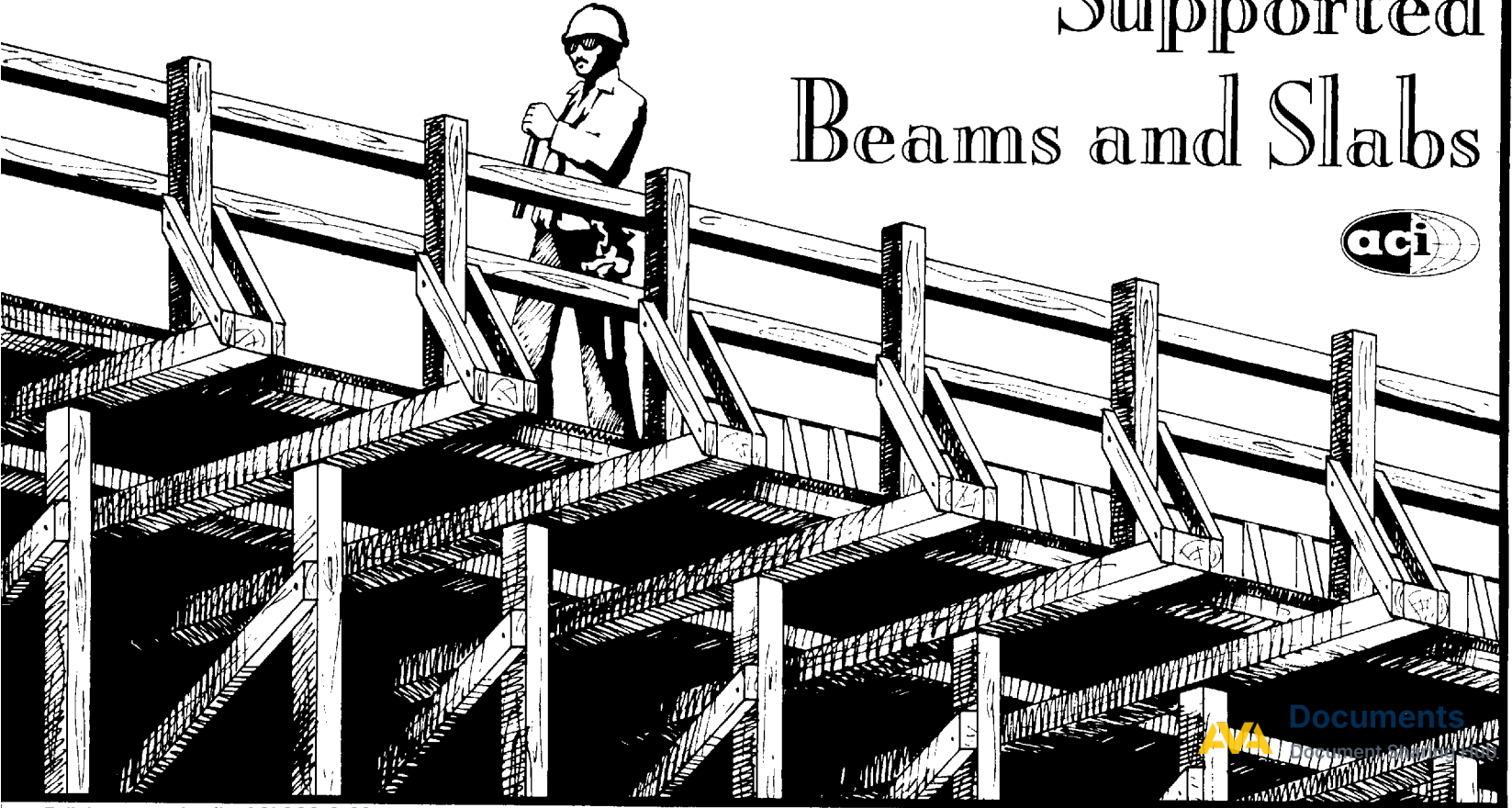


Concrete Craftsman Series.3

Supported Beams and Slabs



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CONCRETE CRAFTSMAN SERIES—SUPPORTED BEAMS AND SLABS



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PREFACE

This is the third booklet in the Concrete Craftsman Series published by the American Concrete Institute. The first booklet, *Slabs on Grade* covers placing, curing and finishing. The second booklet, *Cast-in-Place Walls* covers formwork, reinforcement, placing of concrete, curing, and wall finishes.

This third booklet is intended to provide construction knowledge for the apprentice, journeyman, and foreman involved with cast-in-place elevated slabs and beams. For the apprentice craftsman, it provides a source of information to help supplement his practical experience. For the foreman, it provides technical background on such topics as shoring, reshoring, form removal, reinforcement placement, and concrete placing, finishing, and curing. This booklet is not intended as a design aid, but rather a guide to good practice.

The design of supported slabs and beams is the responsibility of a professional engineer. Designs are usually reviewed and approved by local building authorities and governed by codes such as the Uniform Building Code, Standard Building Code, BOCA (Building Officials and Code Administrators) Code and others which reference "Building Code Requirements for Reinforced Concrete" (ACI 318).

The selection and design of formwork is the responsibility of the contractor. The system selected must consider economics, schedule, quality, and safety. If the craftsman is involved with the selection, he must not assume responsibility beyond his level of experience. Poor selection may cost more money, and more important, may cause injury or death to fellow workers.

While the craftsman is not responsible for the structural design of the slabs and beams, he is responsible for good quality workmanship and a final product that meets the requirements of the job plans and specifications.

Information in this booklet should be used as a guide to good practice. Plans and specifications for a project and local building requirements must be followed, even if they differ from the information in this booklet.

CHAPTER 1

GENERAL

The American Concrete Institute defines slabs and beams as follows:

Slab: A flat, horizontal or nearly so, molded layer of plain or reinforced concrete, usually of uniform but sometimes of variable thickness, either on the ground or supported by beams, columns, walls, or other framework.

Beam: A structural member subjected primarily to flexure (bending).

Elevated slabs and beams require shoring to properly support the formwork during the casting and curing sequences.

Appendixes A, B, C, D, and E contain valuable information regarding concrete in general, materials and mix proportioning, and a detailed listing of definitions of words used throughout this booklet. In addition to the slab and beam definitions above, it is important that the following terms also be defined at this point:

Form: The mold or sheathing and its reinforcing members which contact the concrete and give the concrete final shape.

Formwork: The total system of support for freshly placed concrete, including the mold or sheathing which contacts

the concrete as well as supporting members, hardware, and necessary bracing.

Falsework: Any temporary structure erected to support work in the process of construction.

Shoring: A System of vertical or inclined supports for forms; may be wood or metal posts, scaffold type frames, or various patented members.

Reshoring: The placing of shores snugly under a stripped concrete slab or structural member after the original formwork and shores have been removed from a large area, thus requiring the new slab or member to deflect and support its own weight and existing construction loads prior to the installation of reshores.

Backshoring: The placing of shores snugly under a stripped concrete slab or structural member after the original formwork and shores have been removed from a small area without allowing the slab to deflect or support its own weight or existing construction loads from above.

Stay-in-place forms: Forms left in place that may or may not become an integral part of the structural frame. These forms may be the rigid type such as metal deck, precast concrete, wood, plastics, and fiberboard, or the flexible type such as reinforced, water-repellent corrugated paper or wire mesh with water-proof paper backing.

Craftsmen who seek further in-depth information should read American Concrete Institute's publication SP-4, *Formwork for Concrete*, by M. K. Hurd. This extensive volume contains detailed discussions on formwork planning, materials, loads and pressures, design, design tables, construction, architectural concrete, shells, domes, folded plates, tunnels, and shafts.

Other ACI documents may be of interest to the craftsman. A publication list may be requested from the American Concrete Institute. Appendix F contains a bibliography of appropriate ACI and CRSI documents. CRSI has several valuable documents on reinforcement placement and a publication list may also be requested from them.

CHAPTER 2

FORMWORK—GENERAL

Formwork materials

Material requirements for elevated slabs fall into two categories:

- forms for the slab, including horizontal members
- vertical support for slab forms

Formwork for flat slabs or slab and beam construction generally consists of plywood and dimensional lumber such as 2×4 's, 4×4 's, or 4×6 's. Fig. 2.1, 2.2 and 2.3 show various slab designs and notations that will be used throughout this booklet.

If the slab design is for a two-way joist (waffle), Fig. 2.3(e), or for one-way joist (pan-joist), Fig. 2.3(c) or 2.3(d), the formwork will generally be steel. These materials are readily available from suppliers and may be rented for each project. Table 2.1 shows available sizes.

Many building designs have a structural steel frame with a corrugated metal decking attached to the steel beams. Reinforcing is set and concrete placed directly onto the corrugated stay-in-place decking. Depending on span and slab thickness, it may be necessary to provide vertical supports under the metal decking while the concrete is placed and cured.

Some bridge designs use a metal stay-in-place

deck for structural steel bridges or a precast stay-in-place concrete plank for bridges with precast-prestressed concrete beams. This eliminates the

need for formwork for the interior spans. Formwork will be required to be built for the exterior overhang of the bridge.

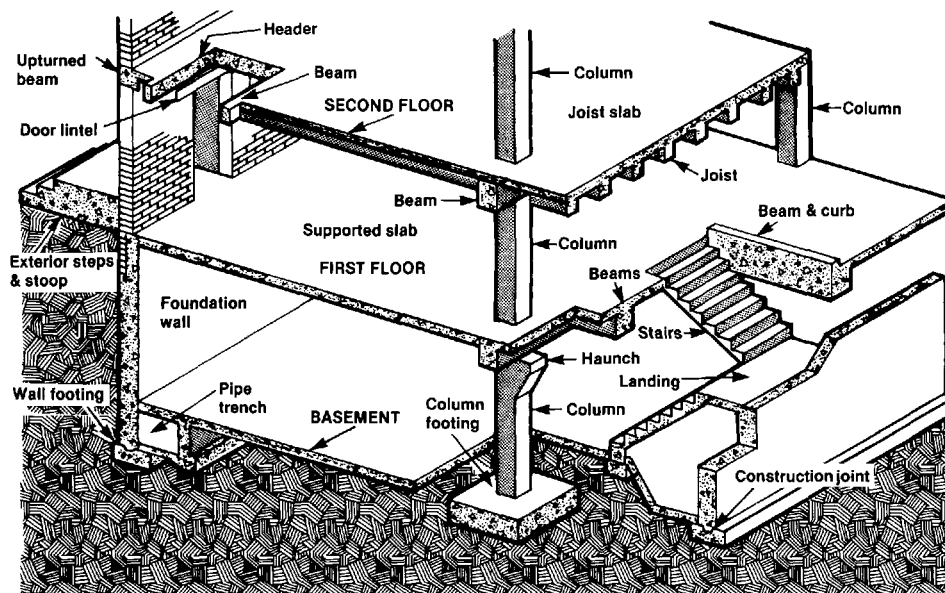


Fig. 2.1—Reinforced Concrete building elements

For multistory buildings with a structural steel or precast concrete frame and a flat slab, formwork can be supported by using prefabricated hangers that rest on the structural beams. This eliminates the need for shoring. Such hangers are available from accessory suppliers.

Supports for the elevated formwork are usually:

- Wood shores (4×4 's, 4×6 's, etc.)
- Prefabricated tubular welded frame shoring (ladder frames) either of steel or aluminum.
- Prefabricated individual post shores either steel or aluminum.
- Flying forms. These are complete prefabricated formwork systems usually supported on trusses with rollers that can be moved by a crane ("flown") to its next position.

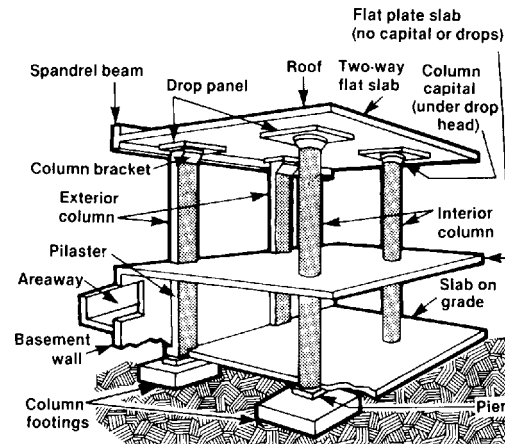


Fig. 2.2—Reinforced concrete building elements

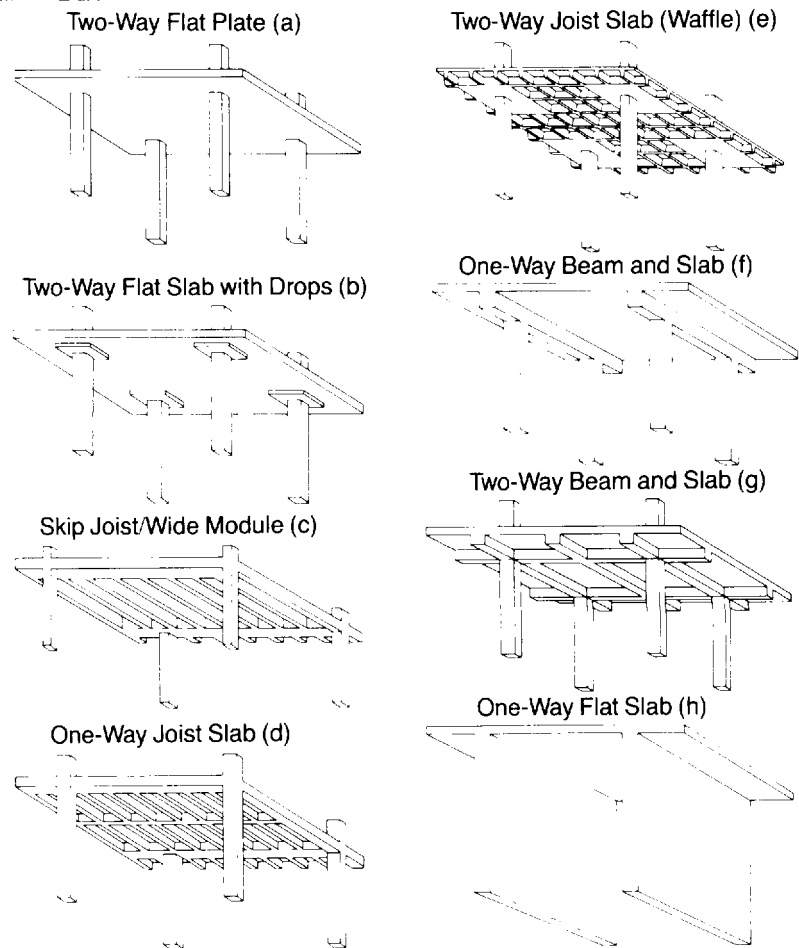
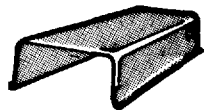
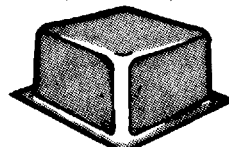


Fig. 2.3—Typical elevated slab systems (Courtesy of Ceco Corp.)

Table 2.1—Standard dimensions for one- and two-way joist forms

TYPICAL ONE-WAY JOIST FORM

TYPICAL TWO-WAY JOIST FORM
(waffle flat slab)ONE-WAY JOIST CONSTRUCTION¹

Module	Standard Forms		Special Filler Forms ⁴	
	Width ²	Depth ³	Width ²	Depth ³
2'-0"	20	8, 10, 12	10, 15	8, 10, 12
3'-0" ⁵	30	8, 10, 12, 14, 16, 20	10, 15, 20	8, 10, 12, 14, 16, 20
4'-0" ⁶	40	12, 14, 16, 18, 20, 22, 24	20, 30	12, 14, 16, 18, 20, 22, 24
5'-0"	53	16, 20	—	—
6'-0"	66	14, 16, 20	—	—

TWO-WAY JOIST CONSTRUCTION¹

System	Standard Forms		Special Filler Forms ⁴	
	Width ²	Depth ³	Width ²	Depth ³
2'-0" Module 19" x 19" Square with 2½" Flanges	19 x 19	8, 10, 12, 14, 16	—	—
2'-6" Module 24" x 24" Square with 3" Flanges	24 x 24	8, 10, 12, 14, 16, 20	—	—
3'-0" Module 30" x 30" Square with 3" Flanges	30 x 30	8, 10, 12, 14, 16, 20	20 x 20 20 x 30	8, 10, 12, 14, 16, 20 8, 10, 12, 14, 16, 20
4'-0" Module 41" x 41" Square with 3½" Flanges	41 x 41	12, 14, 16, 20, 24	—	—
5'-0" Module 52" x 52" Square with 4" Flanges	52 x 52	14, 16, 20, 24	40 x 40	14, 16, 20, 24

NOTES

1. All dimensions are in inches, except the module designations.
2. Width is the horizontal clear distance, between two consecutive joists, measured at the bottom of the joists.
3. Depth is the vertical distance, measured between two consecutive joists from the underside of the concrete slab to the bottom of the joists.
4. Special filler forms may be available only in limited quantities. Availability should be investigated before specifying these forms.

5. Tapered endforms are available for the one-way 3'-0" module. These forms are 30 inches wide at one end and 25 inches wide at the other end, and they are 36 inches long. Standard depths of these forms are 8, 10, 12, 14, 16, and 20 inches.
6. Tapered endforms are available for the one-way 4'-0" module. These forms are 40 inches wide at one end and 34 inches wide at the other end, and they are 36 inches long. Standard depths of these forms are 12, 14, 16, 18, 20, 22, and 24 inches. These forms are generally available only on the West Coast.

- e. Horizontal shores. These are adjustable span members used to support forms over relatively long spans, thereby reducing the number of vertical supports.

The size of the project and number of reuses of the formwork will determine which support system will be used. For smaller projects the contractor may own wood shores, post shores, or ladder frames and elect to build the necessary formwork in place. On large multistory projects, such as hotels and condominiums, flying forms may be used, since the number of reuses warrants the investment in a form system that can be recycled quickly and does not require dismantling and reassembling for each use.

Tunnel forms are a variation of the flying form. In such cases, the walls and slab are cast at the same time. After the specified concrete strength is reached, the tunnel form sides can be moved inward, and the entire form lowered and removed from the "tunnel" and "flown" to the next position.

The following chapters contain more specific information and illustrations for each of the slab designs discussed above.

Tolerances

Unless the contract documents specify a more rigid tolerance, formwork should be constructed to produce slabs to the following tolerances:

Variation of slab soffit from level or slope indicated on drawings should not exceed $\pm 1/4$ in. in 10 ft, $\pm 3/8$ in. in any bay or 20 ft of length, or $\pm 3/4$ in. for the entire length. Variations in soffit level are to be measured

before removal of supporting shores. The contractor is not responsible for variations due to deflection, except when the deflections are caused by poor concrete quality or curing or misplacement of reinforcement.

Variations in the sizes and locations of openings should be no more than $-1/4$ in. or $+1/2$ in. Variations in slab thickness may be $-1/4$ in. or $+1/2$ in. maximum.

Camber/tolerances

It may be necessary to set formwork elevations before concreting to compensate for the following:

- Deflection or settlement of the formwork and supports.
- Deflection of the completed structure under load from the time it begins to carry its own weight.
- Optical sag (the illusion of sagging in long members even though they are perfectly horizontal).
- Camber is an intentional upward deflection which compensates for normal downward deflection. It must be measured from the bottom of the slab after concreting and before stripping.

Formwork deflection or settlement will be caused by loads on the formwork, closure of form joints, crushing of lumber, settlement of mudsills, shrinkage of lumber, and the like. A frequently used rule of thumb has been to camber $1/4$ in. per 10 ft of span to take care of these deflections and movements.

When wood members are used, the number of horizontal joints where end grain bears on horizontal grain should be kept to a minimum to minimize crushing. Soil under mudsills should be stable so that little or no settlement occurs. Mudsills should not be placed on frozen ground, new backfill with inadequate compaction, or where water will be flowing. See Fig. 2.4 for typical mudsill applications.

Available Information

Manufacturers or local suppliers of shoring or formwork materials will provide catalogs describing their materials and the appropriate safe working loads. Many of these bulletins will have tables showing the permissible span of the product for various slab thicknesses and distances between supports. Reviewing this material and maintaining a personal library of these catalogs should be a continuing part of career growth.

Loads

Formwork for concrete must support all vertical and lateral (horizontal) loads that may be applied until these loads can be carried by the concrete structure itself. Loads on the forms include the weight of the reinforcing bars and fresh concrete, the weight of the forms themselves, and various live loads that will occur during construction. Dumping of concrete, movement of construction equipment, and action of the wind may produce lateral forces which must be resisted by the formwork.

Dead load is the weight of the reinforced concrete and the weight of the forms. Live load is the weight of material storage, workmen, and equipment, including dumping and movement of construction equipment.

Though structural concrete can vary in weight from 60 to 300 pounds per cubic foot (lb/ft^3), most structural slabs will use concrete weighing about

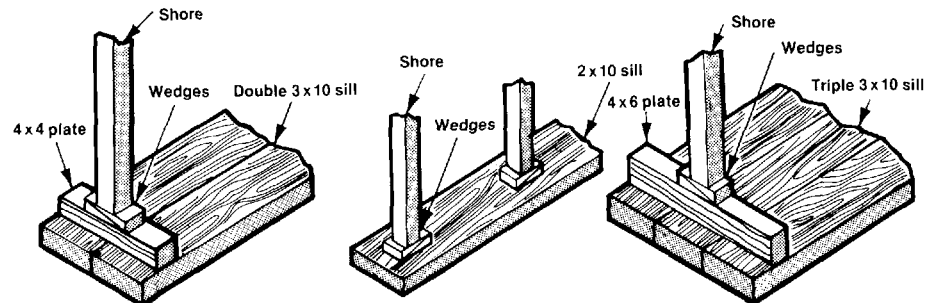


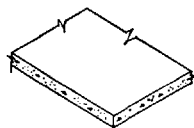
Fig. 2.4—Examples of wood mudsills

150 lb/ft³. This includes the weight of the reinforcing bars. Formwork weights can vary from 4 to 15 pounds per square foot (lb/ft²).

Concrete weighing 150 lb/ft³ will result in a dead load on the forms of 12.5 lb/ft² for each inch of slab thickness. A 6-in. slab exerts a dead load of $12.5 \times 6 = 75 \text{ lb/ft}^2$ not including the weight of the forms. ACI Committee 347 recommends that all members of a shoring system be designed for a minimum live load of 50 lb/ft² for the weight of workers, runways, screeds, material storage, and other equipment. When motorized carts are used, the minimum should be 75 lb/ft². Regardless of the slab thickness, the *minimum* design value for combined dead and live loads should be 100 lb/ft², or 125 lb/ft², if motorized carts are used.

Table 2.2 shows the vertical load on forms for various kinds of slabs of varying thickness and includes the 50 lb/ft² minimum live load. The weight of the formwork is not included and should be added by the designer.

Table 2.2—Vertical load for design of slab forms, lb/ft² (includes weight of concrete and reinforcing steel plus construction live load of 50 lb/ft²; weight of formwork not included)

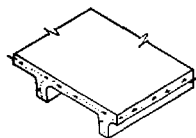


SOLID SLAB CONSTRUCTION

Slab thickness, in.	3	4	5	6	7	8	9	10	11	12
100 lb concrete	100	100	100	100	108	117	125	133	142	150
125 lb concrete	100	100	102	113	123	134	144	154	165	175
150 lb concrete	100	100	113	125	138	150	163	175	188	200

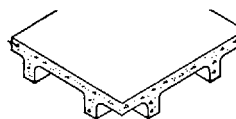
TYPICAL JOIST SLAB CONSTRUCTION

Depth of form, in.	Joist width, in.	20 in. wide forms		30 in. wide forms	
		3 in. slab	4½ in. slab	3 in. slab	4½ in. slab
8	5	110	129	104	122
	6	113	132	106	125
10	5	117	135	108	127
	6	120	139	111	130
12	5	124	142	113	132
	6	128	147	117	135
14	5	131	149	118	137
	6	136	154	122	141
16	6	144	163	128	147
	7	149	168	133	151
20	6	161	180	141	159
	7	168	186	146	165



TYPICAL "WAFFLE" TYPE TWO-WAY JOIST SYSTEMS

Depth	Size of "pan" form, in.		Slab thickness above form, in.	
	Outside plan	Inside plan	3	4½
6	24x24	19x19	122	140
8	24x24	19x19	135	153
	36x36	30x30	123	142
10	24x24	19x19	141	161
	36x36	30x30	133	152
12	24x24	19x19	157	176
	36x36	30x30	145	164
14	36x36	30x30	156	170
16			164	183
20			185	204



CHAPTER 3

SHORING, RESHORING, BACKSHORING, AND FORM REMOVAL

In Chapter 2 we described briefly the types of shoring that can be used to support the vertical loads. Fig. 3.1 shows some typical single post shores that are in use today.

Fabricated single-post shores

Several types of adjustable fabricated shores are available. Fig. 3.1(a) shows a clamping device that permits overlapping of two 4×4 members. This shore is used most when load capacity is about 3000 lb. Capacity varies with condition and quality of the lumber and mainly on the unbraced length.

Fig. 3.1(b) shows a timber shore fabricated of two wooden vertical members and attached metal adjustable hardware. Shores of this style were popular some years ago and many are in use today. Users are cautioned to check the lumber for quality before using.

Fig. 3.1(c) shows an all metal individual adjustable shore which is available from several manufacturers in heights from 6 to 16 ft. Safe load ratings range from 2500 to 9000 lb, depending on the shore and its extended length. Metal brackets with holes for nailing wood bracing are provided and heads of different shapes are available.

Fig. 3.1(d) shows a metal shore fitting that will fit over the end of a 4×4 or 6×6 wood shore, making it into an adjustable shore. This device will

develop the full strength of the lumber and is capable of varying the shore height as much as 12 in.

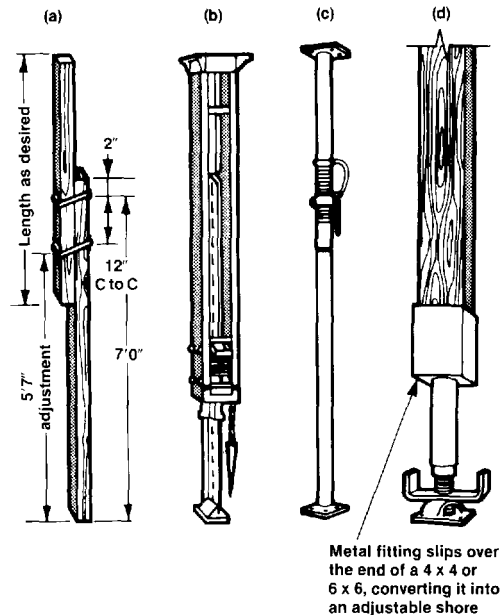


Fig. 3.1—Single-post shoring

All individual shores must have solid base support to provide stability. For safety a "U" shaped shore head must hold the horizontal timber in the center of the width of the head to avoid uneven loading (see Fig. 3.2). Wedges should be used to center the timber in oversize heads.

Fig. 3.3 shows a typical wood supporting system. Note the left shore is a fixed height. Cutting all shores to the exact height required is impossible to do. Hardwood wedges provide the necessary adjustment. This can be a time consuming procedure, especially if the project is fairly large. Adjustable shore bases and "U" heads are commercially available and can be used with a fixed length shore. The shore on the right utilizes two pieces of shore connected with shore clamps that provide more vertical adjustment. The stringer should be secured to the shore by means of a clip or plywood cleat. Do not rely on the stringer to rest on top of the shore without a means of securing it to the shore. Horizontal and uplift forces can shift the stringer and may cause a failure (see Fig. 3.4 and 3.5). On the left shore, wedges provide for final adjustment.

Safety considerations to be followed when using a timber shoring system (See Fig. 3.1, 3.2 and 3.3) are:

1. Such shores shall have the safety factor and allowable working load for each grade and species as recommended in tables for wood columns in the "Wood Structural Design Data Book," prepared by the National Forest Products Association, Washington, D.C., or by the clamp manufacturer.
2. Design of the shoring layout should be based on the working loads obtained from item 1 above, or the clamp manufacturer.
3. All timber and adjusting devices to be used should be inspected before each use by the contractor who erects the equipment.
4. Timber should not be used if it is split, cut, has sections removed, is rotted, or is otherwise structurally damaged.
5. Adjusting devices should not be used if excessively rusted, bent, dented, rewelded beyond the original factory weld locations, or have broken welds.
6. When using wedges to obtain final adjustment, they should have firm contact with footing sills and form materials.
7. All nails (double head) used to secure bracing/lacing on adjustable timber single-post shores should be driven home or bent over, if necessary, to prevent injury.

Bracing and lacing

The total formwork system must transfer all horizontal loads to the ground or previously completed construction in a manner that insures safety at all times. Diagonal bracing will be required to resist horizontal loads and must be provided by the formwork designer. Horizontal lacing will reduce the unsupported height of the shore and thereby

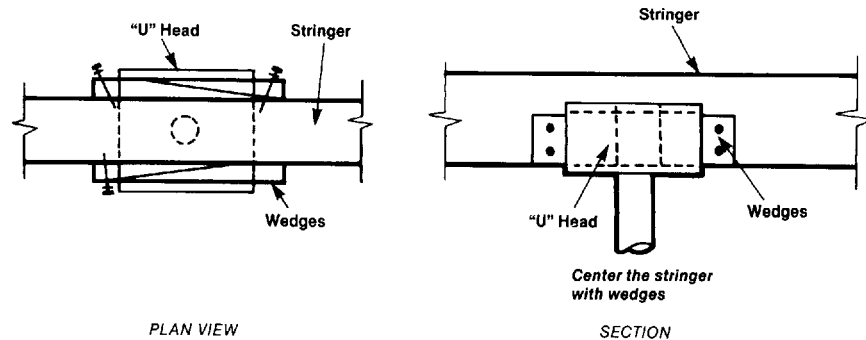


Fig. 3.2—Oversized U head centered with wedges

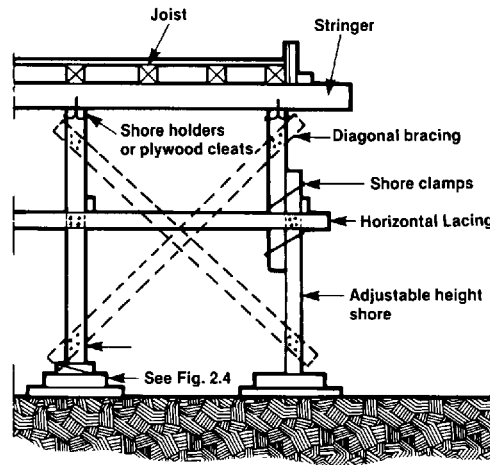


Fig. 3.3—Typical wood supporting system

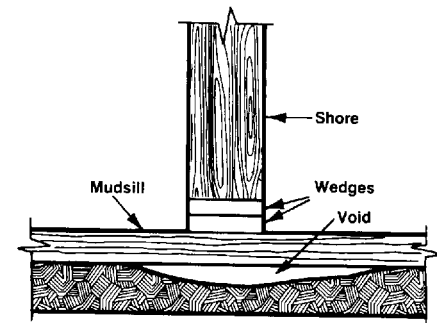


Fig. 3.4—Inadequate bearing for mudsill

increase its vertical capacity. Lacing increases the vertical load carrying capacity of each individual vertical member, and bracing insures horizontal stability of the total system. See Fig. 3.3 for identification of these members. If in doubt, add more bracing where it appears to be needed or check with the formwork designer.

Metal adjustable single-post shores

Prior to each use, all accessory parts should be inspected for the following:

1. All clamps, screws, pins, and other components should be in the closed or engaged position.
2. For stability, single-post shores should have adequate lacing provided in both the longitudinal and transverse directions. Adequate diagonal bracing must be provided.
3. All base plates and shore heads should be in firm contact with the footing sill and form material.
4. Loads on shore heads must be centered. (See Fig. 3.2)
5. Special blocking and bracing must be provided when the formwork is sloping, or when the base slab or ground is sloping.
6. Adjustment of shores to raise formwork must not be made after concrete is in place.
7. The shoring layout should be based on the safe working load of the equipment selected and have at least a 3.1 safety factor.
8. All fabricated single-post shores should be inspected before each use by the contractor who erects the equipment.

9. Fabricated single-post shores should not be used if excessively rusted, bent, dented, rewelded beyond the original factory weld locations, or have broken welds. If they contain timber, they shall not be used if timber is split, cut, has sections removed, is rotted, or is otherwise structurally damaged.
10. All clamps, screws, pins, threads and all other components should be in a condition similar to that of original manufacture. Substitute pins, such as reinforcing bars, should never be used.
11. Shoring should be set plumb and spaced according to design drawings.

Tubular welded frame shoring

A typical shoring frame assembly consists of end frames of various designs and dimensions, diagonal bracing locking clamps, adjustable jacks, and adjustable "U" heads or other shapes for attaching to the forms. Fig. 3.6 shows a tubular welded frame shoring system. Tubular frames generally range from 2 to 5 ft wide and frame heights from 2 to 6 1/2 ft. Safe working loads range from 4,000 to 25,000 lb per leg, depending on construction of the frame and hardware. Rated loads are based on a safety factor of 2.5 to 1 as recommended by the Scaffolding, Shoring, and Forming Institute. Because of their light weight, handling labor is reduced. The majority of slab work is constructed using this type of equipment.

The following is a listing of some safety requirements that should be observed when using ladder type frames:

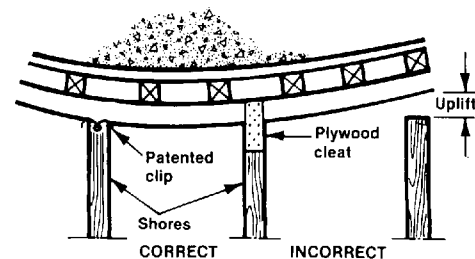


Fig. 3.5—Shores must be secured to stringer to prevent uplift.

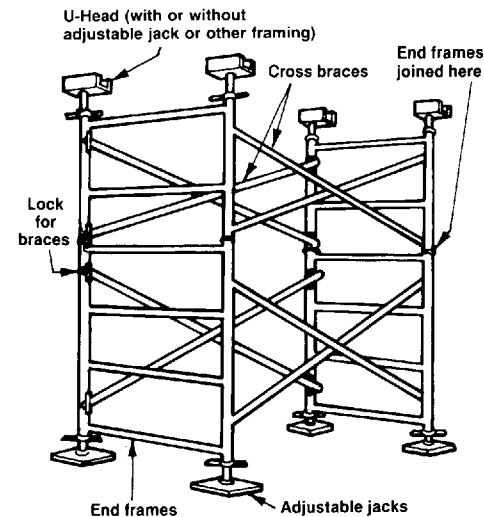


Fig. 3.6—Tubular welded frame shoring

1. Metal tubular frames used for shoring shall have allowable loads based on tests conducted according to a standard test procedure for the compression testing of scaffolds and shores as established by the Scaffolding, Shoring, and Forming Institute or its equivalent. Information may be obtained from equipment vendor.
2. Design of shoring layouts using tubular welded frames shall be based on allowable loads which were obtained using these test procedures, and at least a 2.5 to 1 safety factor.
3. All metal frame shoring equipment shall be inspected before each use by the contractor who erects the equipment.
4. Metal frame shoring equipment and accessories shall not be used if excessively rusted, bent, dented, rewelded beyond the original factory weld locations, have broken welds, or have other defects.
5. All components shall be in good working order and in a condition similar to that of original manufacture.
6. When checking the erected shoring frames with the shoring layout, the spacing between towers and cross brace spacing shall not exceed that shown on the layout, and all locking devices shall be in the closed position.
7. Devices to which the bracing is attached shall be securely fastened to the legs of the shoring frames.
8. Use base plates, shore heads, extension devices, or adjustment screws in top and bottom of each leg of every shoring tower.

9. All base plates, shore heads, extension devices, or adjustment screws shall be in firm contact with the footing sill, or the form material, and shall be snug against the legs of the frame.
10. Leave no gaps between the lower end of upper frames and the upper end of the lower frames.
11. Remove and replace any component which cannot be brought into proper alignment or contact with the component into or onto which it is intended to fit.
12. Cross brace two or more tiers of frames. Towers shall have bracing in accordance with manufacturer's recommendations and as shown on the shoring layout.
13. Avoid eccentric loads on shore heads and similar members.
14. Special precautions shall be taken when formwork is at angles or sloping, or when the surface shored from is sloping.
15. Adjustment screws shall not be adjusted to raise formwork after the concrete is in place.
16. Base plate adjustable jacks shall only be used to plumb tower. Use shore head adjustable jacks for formwork leveling or camber set.
17. When high leg loads bear on slabs below, including slab on grade, adequate load distribution with sills is critical.

Horizontal shoring

Adjustable horizontal beams which support formwork over a long span and eliminate intermediate vertical shores are called horizontal shores (See Fig. 3.7a). These shores support formwork for

spans of 6 ft to 30 ft, and have either a built-in or an adjustable camber. The reduction in the number of shores which leaves large open spaces clear for other work is a major advantage of horizontal shoring.

Horizontal shores may carry allowable loads up to 600 pounds per lineal foot, resulting in much heavier loads on the post shores or hangers that are required. Consequently, great care must be taken in lacing and bracing the vertical shores that are used. See Fig. 3.7b.

Manufacturer's recommendations for adjusting the length of shoring members should be followed. These members have a built-in camber of the correct amount to produce a level slab, as cast, when the horizontal shores are loaded to the amount recommended by the manufacturer. If for some reason the full loading will not be carried, then adjustments to the camber must be made according to the manufacturer's instructions. Otherwise, the finished slab will have an upward camber.

Here is a checklist of safety requirements to be followed when using horizontal shoring:

1. Horizontal shoring beams shall have allowable loads based on tests conducted according to a standard test procedure for testing of horizontal shoring beams established by the Scaffolding, Shoring, and Forming Institute, or its equivalent.
2. The design of horizontal shoring components in shoring layouts shall be based on allowable loads which were obtained using the test procedures of the Scaffolding, Shoring, and Forming Institute, and at least a 2 to 1 safety factor.

3. All horizontal shoring beams shall be inspected before each use by the contractor who erects the equipment.
4. Erected horizontal shoring beams shall be inspected to be certain that the span, spacing, types of shoring beams, and the type, size, height, and spacing of vertical shoring supports are in accordance with the shoring layout.

5. Adequate support shall be provided and maintained to properly distribute shoring loads. When supporting horizontal beams:
 - 5.1 Masonry walls shall have adequate strength. Brace walls as necessary.
 - 5.2 Ledgers supported by walls using bolts or other means shall be properly designed and installed per recommendation of supplier or architect/engineer.

Actual anchor detail and design is the responsibility of the engineer or architect.

- 5.3 The formwork designer has the responsibility to design the formwork to carry the additional loads imposed by the shoring beams.
- 5.4 The ability of the structural steel framework to support this construction loading shall be checked and approved by the responsible architect/engineer.
- 5.5 Steel hangers shall have their bearing pads fully engaged on the support. The hangers shall be designed to conform to the bearing end, and to safely support loads imposed. Hanger manufacturer's recommendations shall be followed.
6. When installing horizontal shoring beams or designing a shoring system using horizontal shoring beams, the following precautions should be taken:
 - 6.1 Sloping metal stringers shall not be used to support metal horizontal shoring beams when there is direct metal to metal contact, unless a positive connection method is provided to adequately resist potential slippage or relative movement of the stringers and horizontal shoring beams.
 - 6.2 Ledger (stringer) height to width ratio shall not exceed 2.5 to 1. Under no circumstances shall horizontal shoring beams bear on a single "two by" ledger (stringer).
 - 6.3 Eccentric loading conditions should be avoided.



Fig. 3.7a—Plywood laid directly on typical telescoping lattice-type horizontal shoring to support concrete slab

6.4 Ledgers (stringer) consisting of multiple members (i.e., double 2×6 , 2×8 , etc.).

6.5 Varying elevation of horizontal shoring beam prong to match prefabricated joist (any additional blocking must be considered in the base to height ratio).

6.6 Should not be used as part of lacing system.

6.7 Support must be sufficiently stable to prevent fallout of horizontal shores. Construction activity needs to be controlled under shores to prevent movement of supports.

7. Bearing ends of horizontal shoring beams shall be properly supported and locking devices, if any, properly engaged before placing any load on beams.

8. Horizontal shoring beams shall not be supported other than at the bearing prongs unless recommended by supplier.

9. Do not nail adjustable horizontal beam bearing prongs to ledger.

10. Adjustable horizontal shoring beams shall not be used as part of a reshoring system.

11. Adjustable horizontal shoring beams shall not be used as a stringer (ledger) for other horizontal shoring beams, unless recommended and approved by the supplier/manufacturer.

12. Horizontal shores at an angle to a beam side must have full support under the bearing prong. The male bearing prong should be used at the beamside to facilitate full bearing.



Fig. 3.7b—Horizontal shoring supported on braced wood bents. Filler pieces laid on top of bents allow stripping of decking and horizontal shores, while leaving wood bents in position as support for the partially cured slab.

Flying deck forms

Flying forms are large crane handled sections of formwork which can be made up by unitizing a truss-supported system, a beam system supported on columns or walls, or a metal shoring frame system. Fig. 3.8 shows a truss-supported system in the process of being positioned. Fig. 3.9 shows a typical bracket arrangement for a beam-supported flying form system.

Flying forms are best suited for tall multistory structures where many reuses can be expected. In the early usage of flying forms repetitious buildings

such as hotels, apartments, condominiums, and hospitals were ideal structures. Today, innovative form designers are utilizing flying forms on more complicated slabs, including slabs with joist pans, waffles, and spandrel beams. Regardless of the shape of the building in plan, if the number of floors are sufficient to justify the initial cost of a flying form, clever formwork designers will adapt one of the three styles mentioned above.

Some of the cautions to be noted when using flying forms are:

1. Flying deck forms shall have allowable loads as determined by detailed structural analysis. The results of the structural analysis shall be verified by tests conducted under, or equal to, field conditions, witnessed by an independent authority. This is necessary only when using a newly developed system, not for assembly and use of standard components.
2. Design of shoring layouts using flying deck form systems shall be based on the above results and using factors of safety as follows: trusses and vertical supporting members—2.5 to 1.
3. All flying deck components shall be inspected by the designer prior to use to insure that the erected form conforms to the shoring layout, that correct components are being used, and that no damaged components are being used.
4. Follow manufacturer's instructions, load ratings, and layout drawings for placement on each project.
5. All components are to be in good working

order and in a condition similar to that of original manufacture, and no components shall be used if they are heavily rusted, bent, dented, torn, or otherwise defective.

6. All screw jacks and connections shall be checked to insure a snug fit and free movement.

7. Special precautions shall be taken by the user when the flying deck form is angling or sloping.
8. Adjustments of flying deck forms to raise formwork shall not be made after concrete is in place.
9. A method of positive control must be pro-

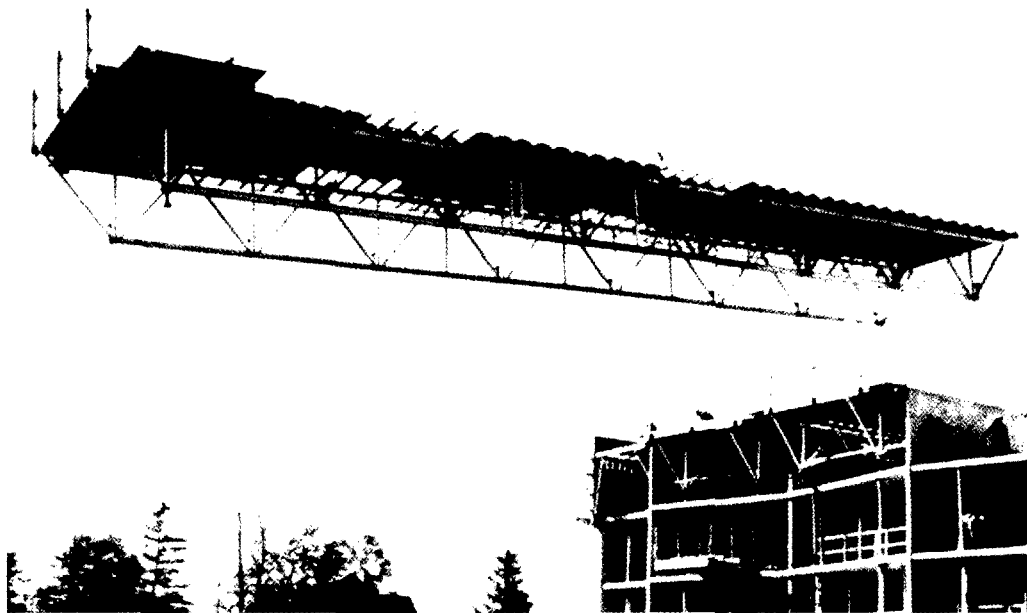


Fig. 3.8—Aluminum truss provides support for 80 × 18 ft flying form

vided for the rolling-out operation by tie-back, braking system, or other devices. The form must never be allowed to have uncontrolled horizontal movement.

10. Positive connection between the components of the form and the crane must be

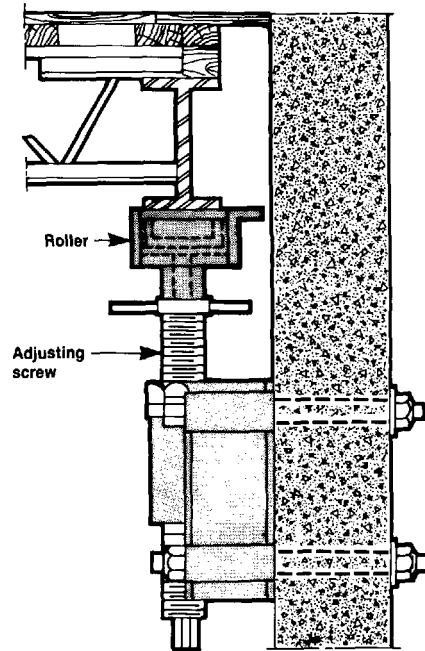


Fig. 3.9—Bracket attached to column or wall supports slab form assembly without vertical shores. This one has roller head to facilitate movement of flying forms.

provided by slings, eyes, or other devices recommended by the appropriate manufacturer.

11. A tag line must be attached to the flying deck form to prevent rotation while flying and for helping to position the form when landing.
12. Flying of deck forms during high winds is hazardous and not recommended.

Caution: Truss forms generally have very large concentrated loads posted to floor below. A competent engineer should make the determination to reshore and location of reshores.

13. Crane pick points shall not be changed without consulting with the form manufacturer or designer.

Formwork safety—failures

The form builder should have as his main objectives quality, safety, and economy. All three in combination will produce a concrete structure that will be long lasting, pleasing to the eye, and with no injuries, fatalities, or formwork failures during the construction process.

With backshoring, so long as the first level of shores remains in place in contact with grade, each tier of shores must carry the weight of all concrete and construction loads above it. This may be the weight of several floors. While reshoring remains in place at grade level, accumulated shore loads are less because each slab has been permitted to carry its own weight before the reshores were installed.

When using reshores, stripping of the formwork is more economical, since all formwork material can be removed at the same time. Reshoring requires fewer levels, thus freeing more area for

other trades. When using backshoring, stripping of the formwork can be done at an earlier age because large areas of concrete are not required to carry their own weight.

In North America a majority of supported slabs use reshores as compared to backshores. When placing shoring on the previously cast slab, ideally the shores should be located directly above the shores or reshores below. This will prevent a reversal of stresses in the slab. When misalignment does occur, it is not necessarily dangerous, unless the slab is thin or the location of reinforcement is inadequate to handle the reversal stresses and punching shear. Fig. 3.10 shows what can happen in such cases. Such conditions must be avoided by preplanning.

Example

A simple three-story flat slab building to demonstrate how the loads develop in the slab, shores, and reshores. The weight of the slab is called “D” and does not include the weight of the formwork or the construction live load. This example shows loads that are transferred to the structure. We must also know if the structure has sufficient strength to resist those loads. A structural engineer must determine if the structure can safely support the loads, based on the construction sequence that is selected. If the structure does not have this capacity or if the formwork is not properly designed, then a failure will occur.

To properly design a shoring system, ACI Committee 347 recommends consideration of the following factors. Caution: Some governing agencies require design of shoring be done by a Registered Engineer.

Table 3.1—Comparison of Backshoring and Reshoring

Backshoring	Reshoring
Strip small areas	Strip several entire bays
Do not let slab deflect	Allow slab to deflect
Install backshores before any further stripping occurs	Install reshores without removing deflection
Slab does not carry its own weight	Slab carries its own weight
Backshores have an initial load	Reshores have no initial load

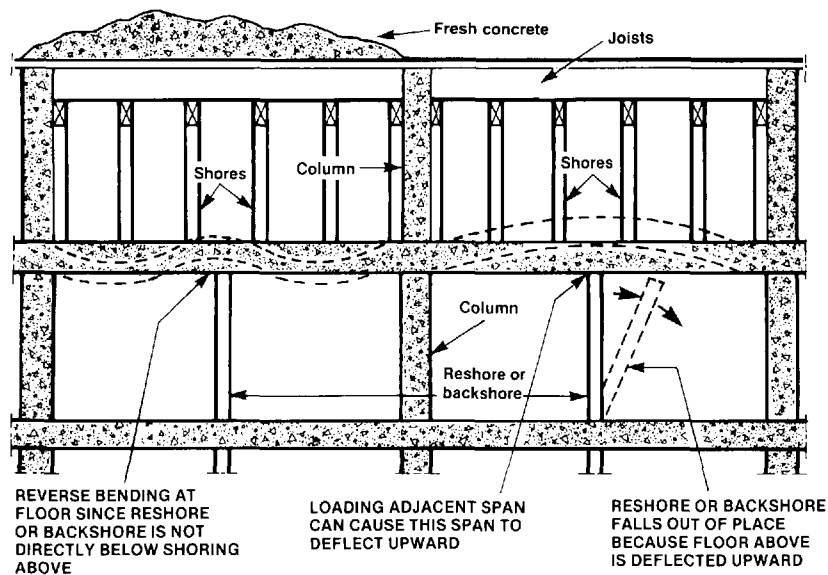


Fig. 3.10—Improper positioning of shores from floor to floor may create bending stresses for which the slab was not designed. If reshores on backshores do not match shores above, stresses would need to be recalculated by the form designer. Reshores and backshores must be prevented from falling.

For purposes of analyzing this three-story example, the following assumptions are made:

1. Shores and reshores are infinitely stiff relative to the slabs.
2. Slabs interconnected by shores therefore all deflect equally when a new load is added, and carry a share of the added load in proportion to their relative stiffnesses.
3. Slabs have equal stiffness and added loads are shared equally by the interconnected slabs. Whether one assumes the slabs are all equally stiff or that stiffnesses are proportional to the various levels of strength attained by slabs of different ages, the results differ by relatively small amounts. Therefore it seems both satisfactory and convenient to follow the simpler assumption.
4. Ground level floor or other base support is rigid.

Obviously these assumptions are not precisely true, but field measurements reported thus far show that the effect of the errors is small enough to make a useful analysis on this basis.

1. Set up a story of shores and forms and place the fresh concrete.
2. Remove the reshores at lowest interconnected level. Remove forms and shores from next story above.
3. Place reshores *snugly* under the slab just stripped, but *without reshores carrying any load when they are first placed*.

The first two slabs are placed without removing any shores, and the load is transmitted directly to the ground; the slabs carry no load until the first level of shores is removed, and each then bears its own

weight. As the cycles proceed, when each fresh slab is placed (Operation 1) we assume the load is distributed equally among interconnected slabs in the system. Whenever a level of reshores or shores is removed (Operation 2 and 3), the shore force is distributed equally among the slabs in the system.

The load in shores at the end of each step is calculated on the basis of a summation of vertical forces. Total weight of slabs and construction loads above the shore level being considered, less the loads carried by slabs above, gives the load transmitted by the shores. For example, look at Step 10 in Table 3.2. Consider the shores between Levels 2 and 3;

$$\begin{aligned} \text{Total weight of slabs above} &= 2D \\ (\text{Slabs 3 and 4}) \end{aligned}$$

$$\begin{aligned} \text{Total load carried by slabs} \\ \text{above } (0.11 D \text{ for Slab 4} + \\ 0.94 D \text{ for Slab 3}) \end{aligned} = 1.05D$$

The difference between these two is $0.95 D$, which is the load transmitted by the shores to Slab 2.

Depending on sequence of formwork cycling for taller structures, it can be shown that shores at ground level may have to be designed for $3D$ and that slabs can be asked to carry $2 \frac{1}{2}$ times their own dead weight.

This design work should be done by a qualified engineer familiar with the preparation of formwork drawings. At the jobsite it is the craftsmen's responsibility to install all formwork members in accordance with the engineer's design drawings to assure a safe workplace for fellow workers and a quality concrete structure.

If at any time you have doubts concerning the load capacity of the formwork or the structure, immediately seek answers from your supervisor. In certain instances, it may be necessary to seek help from the design engineer of the structure, or even to have the opinion of an outside consulting engineer. It is better to search for an answer in this manner than to search for a fellow worker in the rubble.

Watching formwork

During and after concrete placement competent persons should continuously watch the formwork from below or alongside the forms. They should be in a protected area and have a means of communicating with the placement crew in case of an emergency.

Telltale devices such as string or wire lines will enable form watchers to constantly check elevations, camber and plumbness. Whenever necessary, they should tighten wedges and promptly make appropriate adjustments of elevation by jacking or wedging. All such adjustments must be made before the concrete takes its initial set. Adjustments after or during placing of concrete may be impossible. There is also a possibility of failure. Do not count on being able to adjust forms (especially spandrel beam bottoms).

If any serious weakness occurs during concreting that would endanger workers or cause excessive settlement, work should be halted while the formwork is strengthened. After concreting has been completed, form watchers should continue observing the telltales until deflection has ceased. A potential form failure often gives warning by gradually increasing deflection. Shores on ground can keep settling and cause cracks in newly placed

slabs. Such slow settlements can go unnoticed unless periodic measurements are made and compared with before-concreting elevations.

Form and shore removal times

While the contractor has the general responsibility for the design, construction, and safety of the formwork, standards for removal of forms and shores should be given by the engineer/architect. Since early form removal is desirable so that forms can be reused, a reliable basis for determining if it is safe to do so must be available.

Concrete strength is one fairly reliable method; some agencies specify a certain strength such as 2500 pounds per square inch (psi) or two-thirds the design strength. The engineer/architect who designed the structure and understands its behavior under load is in the best position to decide what strength level is required before stripping, considering the reshoring or backshoring plan.

Testing of cylinders prepared at the jobsite is one method that requires a specific curing condition. Nondestructive testing of hardened concrete can be done by the following methods:

1. Pulse velocity (ASTM C 597)
2. Rebound hammer (ASTM C 805)
3. Penetration resistance (ASTM C 803)
4. Pull-out cones (ASTM C 900) and (ASTM STP-626)
5. Maturity measurement (ACI 306)

Any of these methods can be used to supplement test cylinders.

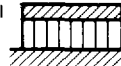
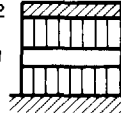
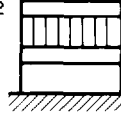
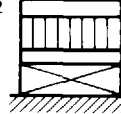
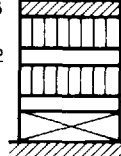
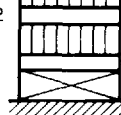
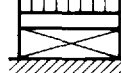
Table 3.2—Simplified analysis of loads on shores and slabs of multistory structure; two levels of shoring, one of reshoring (construction live load and weight of formwork not included; D = weight of slab)

RIGID SUPPORT AT
STARTING LEVEL 

FRESHLY PLACED SLAB 
HARDENED SLAB 

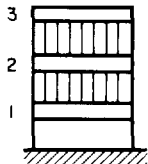
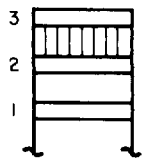
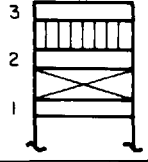
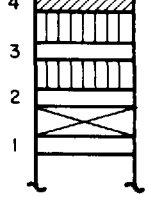
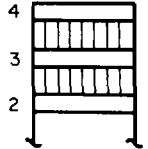
STORY OF SHORES 

STORY OF RESHORES 

STEP NUMBER	OPERATION AND REMARKS	STATUS OF STRUCTURE	LOAD CARRIED BY SLAB, IN MULTIPLES OF D .			SHORE LOAD AT END OF OPERATION*
			AT BEGINNING OF OPERATION	CHANGE DURING OPERATION	TOTAL AT END OF OPERATION	
1.	Place Level 1 concrete; full load transmitted by shores to ground.	1 	0	0	0	$1D$
2.	Place Level 2 concrete; all load goes thru shores to ground since Slab 1 can't deflect and pick up load.	2  1 	0 0	0 0	0 0	$1D$ $2D$
3.	Remove first level shores; shore load of $2D$ is divided equally between two slabs. In this case, each one takes its own weight.	2  1 	0 0	$+1D$ $+1D$	$1D$ $1D$	0
4.	Place reshores snug but not loaded. This causes no change in other slab or shore loadings.	2  1 	$1D$ $1D$	0 0	$1D$ $1D$	0 0
5.	Place Level 3 concrete; all new load is carried to ground by shores and reshores. Slabs can't deflect further and therefore don't pick up any of the new load yet. Slabs 1 and 2 continue to carry their own weight.	3  2  1 	0 $1D$ $1D$	0 0 0	0 $1D$ $1D$	$1D$ $1D$ $1D$

* Shore load at end of operation is obtained by adding total applied loads above the shores and taking away the total load carried by slabs above the shores being considered.

Table 3.2—Continued

6.	Remove first floor reshores. The three slabs will deflect together. Reshore load is then divided equally among the three interconnected slabs. Remaining shores carry that portion of the load above them not carried by the slabs.		0 1D 1D	+0.33D +0.34D +0.33D	0.33D 1.34D 1.33D	0.67D 0.33D
7.	Remove shores under Slab 2. Load formerly carried by those shores is divided equally between two remaining interconnected slabs.		0.33D 1.34D 1.33D	+0.17D +0.16D -0.33D	0.50D 1.50D 1D	0.50D
8.	Reshore beneath Slab 2. Reshores act as struts. Slab loads remain unchanged.		0.50D 1.50D 1D	0 0 0	0.50D 1.50D 1D	0.50D 0
9.	Place Level 4 concrete. Its load is distributed equally among three interconnected slabs below.		0 0.50D 1.50D 1D	0 +0.33D +0.33D +0.34D	0 0.83D 1.83D 1.34D	1D 1.17D 0.34D
10.	Pull reshores beneath Level 2. The 0.34 D load in reshores is divided equally among three remaining interconnected slabs.		0 0.83D 1.83D	+0.11D +0.11D +0.12D	0.11D 0.94D 1.95D	0.89D 0.95D

Where no specific provision is made by the engineer/architect, ACI Committee 347 suggests that the minimum times forms and supports should remain in place under ordinary conditions are:

Walls*	12 hr
Columns*	12 hr
Side of beams and girders*	12 hr
Pan joist forms†	
30 in. wide or less	3 days
Over 30 in. wide	4 days

where design live load is:	less than dead load	greater than dead load
Arch centers	14 days	7 days

Joist, beam or girder soffits		
Under 10 ft clear span between structural supports	7 days‡	4 days
10 to 20 ft clear span between structural supports	14 days‡	7 days
Over 20 ft clear span between structural supports	21 days‡	14 days

One-way floor slabs		
Under 10 ft clear span between structural supports	4 days‡	3 days
10 to 20 ft clear span between structural supports	7 days‡	4 days
Over 20 ft clear span between structural supports	10 days‡	7 days

*Where such forms also support formwork for slab or beam soffits, the removal times of the latter should govern.

†Of the type which can be removed without disturbing forming or shoring.

‡Where forms may be removed without disturbing shores, use half of values shown but not less than 3 days.

Two-way slab systems . . . Removal times are contingent on reshores where required being placed as soon as practicable after stripping operations are complete but not later than the end of the working day in which stripping occurs. Where reshores are required to implement early stripping while minimizing sag or creep (rather than for distribution of superimposed construction loads), capacity and spacing of such reshores should be specified by the engineer/architect.

These periods represent cumulative number of days, or fractions of a day, not necessarily consecutive, during which the air temperature at the concrete is above 50 degrees Fahrenheit, or if retarding agents are used, then the engineer/architect may increase these periods.

CHAPTER 4

FORMS FOR FLAT SLABS

Let's put into practice some of the materials that have been discussed in the first three chapters. We'll use the valve pit example from "Cast-in-Place Walls," Concrete Craftsman Series 2. The valve pit plan looks like Fig. 4.1.

A cross section through the valve pit is shown in Fig. 4.2.

The walls are 10 ft-3 in. high and it has a 6 in. thick roof slab with a steel framed opening and hinged cover to permit access to the valve pit. Our job is to design the shoring system that will safely support the 6 ft slab.

We must first decide on the size and quality of plywood to use as well as the direction of the face grain plies (outer plies), so that we utilize the plywood in its strong direction. Fig. 4.3 shows plywood when it is used in the strong and weak directions.

There are several types and grades of plywood. Types are exterior and interior, while grades within each type range from A to D (interior) and A to C (exterior), depending on the number of surface defects. Grade B-B is commonly used for formwork with both faces of B grade veneer containing some repaired plugs and knots. Since this slab is not exposed to public view, it is acceptable to use the Grade B-B. We will also select either a 5/8 in.

or 3/4 in. thickness, since they are the most common. There may be instances where the 5/8 in. thickness would be more suitable and we can evaluate that alternative when we examine the plywood safe span tables. We will run the face grain plies in the 6 ft-0 in. direction. This means the plywood must be cut from the 4 ft-0 in. $\times$ 8 ft-0 in. sheets and the plan will look like Fig 4.4. The 24 in. widths are used so the plywood can be stripped and removed through a 30 in. $\times$ 30 in. hatch opening.

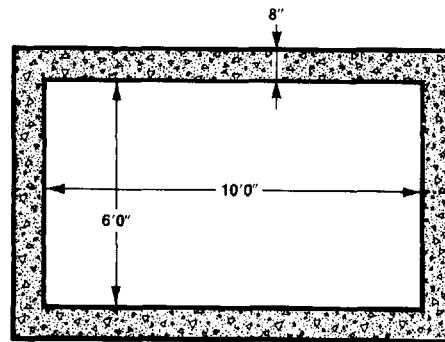


Fig. 4.1—Valve pit plan

It may be that the walls are not perfectly square and a small, but acceptable, variation of the inside dimensions will exist. It is best to measure this accurately before cutting the plywood. Once the measuring is accomplished, cut the plywood 1/8 in. less than the measured length. We will use a 1/8 in. urethane tape on the edge of the plywood to make up this difference. This will assist in removal of the plywood during the stripping process. The same must be done for the overall width with the last sheet cut 1/4 in. less than the filler width.

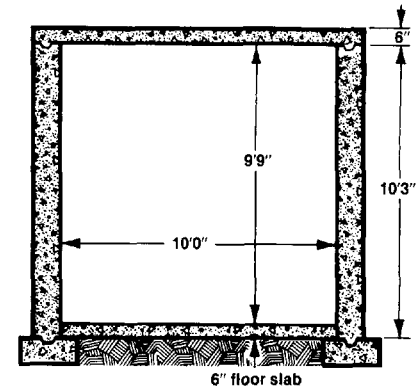


Fig. 4.2—Cross section of valve pit

1. Design load and joist spacing—Selecting the face grain plies to be in the 6 ft-0 in. direction means that we must place the joists in the 10 ft-0 in. direction. Table 4.1 shows the safe spacing of the joists for various thicknesses of plywood and various loading conditions.

To use Table 4.1 we must establish the load of concrete in terms of pounds per square foot (lb/ft²). We know that reinforced concrete weighs approximately 150 lb/ft³ (a square foot, one foot high) and a square foot of concrete 1 in. thick weighs 12.5 lb. Our 6 in. slab therefore has a dead load weight of

75 lb/ft². But we must take into account that we will have a labor force on the deck forms during construction and perhaps some equipment. ACI 347 recommends that a minimum of 50 lb/ft² be added to the dead load to obtain the total design load. This is called “live load” or sometimes

Table 4.1—Safe spacing in inches of supports for plywood sheathing, continuous over four or more supports (Maximum deflection 1/360 of span, but not more than 1/16 in.)

Pressure or load of concrete, pounds per square foot	Stresses and spans for short duration loads, for all sanded grades of Group 1 plywood. <i>E</i> modified for deflection calculations.								Stresses and spans for long term loading, for all sanded grades of Group 1 plywood. <i>E</i> modified for deflection calculations.							
	<i>f</i> = 1930 psi; rolling shear = 72 psi; <i>E</i> = 1,500,000 psi								<i>f</i> = 1545 psi; rolling shear = 57 psi; <i>E</i> = 1,500,000 psi							
	sanded thickness, face grain parallel to span				sanded thickness, face grain perpendicular to span				sanded thickness, face grain parallel to span				sanded thickness, face grain perpendicular to span			
	½ in.	⅝ in.	¾ in.	1 in.	½ in.	⅝ in.	¾ in.	1 in.	½ in.	⅝ in.	¾ in.	1 in.	½ in.	⅝ in.	¾ in.	1 in.
75	20	23	26	31	10	14	18	25	20	23	26	31	10	14	18	25
100	18	21	24	29	9	13	17	23	18	21	24	29	9	13	17	23
125	16	20	23	27	8	12	15	22	16	20	23	27	8	12	15	22
150	15	18	21	26	8	11	14	21	15	18	21	26	8	11	14	21
175	15	17	20	25	7	10	14	20	15	17	20	25	7	10	14	20
200	14	17	19	24	7	10	13	19	14	17	19	24	7	10	13	19
300	12	15	17	22	6	9	11	16	12	14	16	20	6	9	11	16
400	11	13	15	20	5	8	10	15	10	12	14	18	5	8	10	15
500	10	12	14	18	5	7	10	14	9	11	12	16	5	7	10	14
600	10	11	13	16	5	7	9	13	9	10	11	14	5	7	9	13

“construction load.” Our total design load then is:

$$\begin{aligned} 6 \text{ in. Slab—Dead load} &= 75 \\ \text{Live load allowance} &= 50 \\ \text{Total design load} &= 125 \text{ lb/ft}^2 \end{aligned}$$

Referring to Table 4.1, find 125 in the left-hand column and proceed horizontally under $f = 1930$ psi (pounds per square inch) and in the column

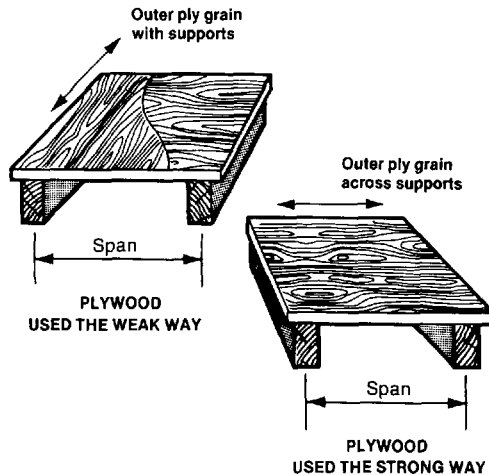


Fig. 4.3—Plywood on the right-outer ply (face) grain parallel to span is used the strong way. The specimen on the left-outer face grain perpendicular to span is used the weak way. Most plywood used structurally for formwork has five layers rather than the three shown in this simplified drawing.

headed face grain parallel to span, note that the safe spacing of the joists can be 20 in. for 5/8 in. plywood and 22 in. for 3/4 in. plywood. For comparison, note how the safe spacings are reduced when the face grains are used the weak way, perpendicular to the span. The right side of the long-term loading spacings is not applicable in this example.

Let's space our joists for the 72 in. valve pit width, being sure not to exceed the maximum 22 in. spacing. As shown in Fig. 4.5, even spacing would be 72 divided by 4 = 18 in., and we could therefore use 5/8 in. plywood, since the allowable spacing is 20 in.

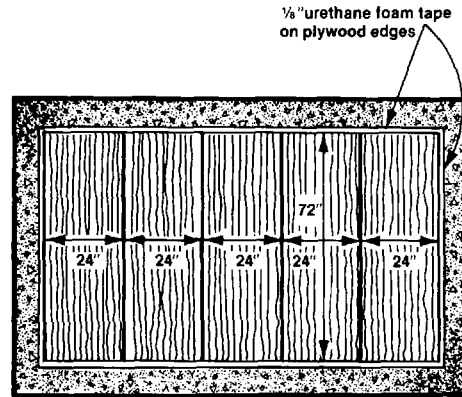


Fig. 4.4—Plan-Plywood sheet layout

2. Selecting joist size and ledger spacing—We must now support the joists with a ledger as well as select the joist size, based on the quality of lumber we will be using. Table 4.2 shows various species and grades of lumber along with the properties of bending, compression, horizontal shear, and modulus of elasticity. The choices are many and the experienced formwork designer will specify the exact grade and species on which the design is based. For this example we will use a Douglas Fir, No. 2 Grade with a property of 1200 psi in the extreme fiber in bending. Purchasing lumber with a higher allowable stress would be too costly.

Note at the bottom of the table that a 25 percent increase in the allowable stresses can be made because the load duration will be 7 days or less. We will take advantage of this unusual feature of lumber, as shown in Table 4.3. Note that this table is based on a fiber stress (f) of 1500 psi. This is 25 percent higher than the 1200 psi we have specified.

We must calculate the load per lineal foot acting on the joist. Simply, this is design load times the

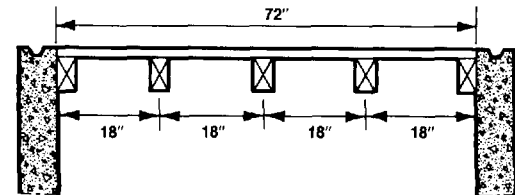


Fig. 4.5—Joist spacing

Table 4.2—Representative working stress values (psi) for lumber at 19 percent moisture content, continuing or prolonged reuse (Derived from National Design Specification for Wood Construction and from recommendations of American Plywood Association)

PROPERTIES SPECIES AND GRADE	Extreme fiber bending †	Com- pression ⊥ to grain	Com- pression ‖ to grain	Horizon- tal shear ‡	Modulus of elasticity
EASTERN SPRUCE Range, all grades No. 2, 4x4 and smaller Constr., 4x4 and smaller	200-1785 1050 775	255 255 255	425-1200 700 800	105	1,100,000-1,400,000 1,200,000 1,100,000
SOUTHERN PINE Range, all grades No. 2, 4x4 and smaller Constr., 4x4 and smaller	275-2600 1250 1050	405-475 405 405	575-2000 975 1100	135	1,400,000-1,800,000 1,600,000 1,400,000
DOUGLAS FIR-LARCH Range, all grades No. 2, 4x4 and smaller Constr., 4x4 and smaller	275-2450 1450 1050	385-455 385 385	600-1850 1000 1150	140	1,500,000-1,900,000 1,700,000 1,500,000
CALIFORNIA REDWOOD Range, all grades No. 2, 4x4 and smaller Constr., 4x4 and smaller	225-2300 1400 825	270-425 425 270	500-2150 1100 925	120	900,000-1,400,000 1,250,000 900,000
HEM-FIR Range, all grades No. 2, 4x4 and smaller Constr., 4x4 and smaller	225-1650 1150 825	245 245 245	500-1300 825 925	110	1,200,000-1,500,000 1,400,000 1,200,000
ADJUSTMENT FOR MOISTURE CONTENT GREATER THAN 19 PERCENT: Use percentage shown (also applies to wood used wet)	86 **	67	70	97 §	97 **
INCREASE FOR LOAD DURATION OF 7 DAYS OR LESS, permitted for lumber and plywood	25%	25%	25%	25%	0
PLYWOOD SHEATHING USED WET, Plyform B-B, Class I (Grade stress level 8-2)	1545*	(Bearing on face) 210	— —	57ff *	1,500,000§§

*Under appropriate conditions, as described in the text, repetitive-member stress 15 percent higher may be used for normal duration of load.

‡Based on Sec. 3.4.4.2 of The 1977 Specification of The National Forest Products Association.

§For redwood use 94 percent; for southern pine use 90 percent.

**For redwood and southern pine, use 80 percent of bending stress, 93 percent of E.

††Value for rolling shear in plane of the plies: check for rolling shear should be made according to formula on p. 6-7 in *Formwork for Concrete*, SP-4.

‡Includes the experience factor of 1.3 recommended by the American Plywood Association.

§§May be increased 10 percent if shear deflection is computed separately.

spacing of the joists in feet and is called a uniform load. Uniform load acting on joists = (125) (1.5) = 188 pounds per lineal foot (lb/lin ft).

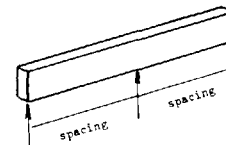
Enter the left-hand column of Table 4.3 at 200 and move horizontally, selecting a size of member that would be appropriate for this work, such as 2×4 or 4×4 . Note that a 2×4 may be supported at 47 in. centers, while the stronger 4×4 may be supported at 72 in. centers. Such spacings could be increased slightly, since the 200 lb/lin ft load is larger than our 188 lb/lin ft design load. Selecting a uniform spacing for the 120 in. span would be 60 in. spacing for two spans, or 40 in. spacing for three spans. It is best to choose the 4×4 as a joist, since it satisfies the 60 in. span and will not "roll" as would a 2×4 . Using a 2×4 would require 40 in. spacing of the ledgers and toe nailing of the joists to the stringers to prevent them from "rolling." Fig. 4.6 shows the 4×4 joists cut about 1/2 in. shorter than the overall span to permit stripping and removal through the hatch opening (30 in. $\times$ 30 in.).

3. Selecting stringer size and shore spacing—

From Fig. 4.6 we can see that the stringer at the center of the slab carries more load than the stringers against each wall. The load per lineal foot acting on the stringer (half the spans to the left and right) is calculated thus:

$$\text{Load on stringer lb/lin ft} = (2 \text{ ft-6 in.} \\ + 2 \text{ ft-6 in.}) (1) (125) = 625 \text{ lb/lin ft}$$

Table 4.3—Safe spacing in inches of supports for joists, studs (or other beam components of formwork), continuous over two spans


 Δ_{max} is $\frac{1}{360}$ of spacing, but not more than $\frac{1}{4}$ in.

Uniform load, lb per lineal ft (equals uni- form load on forms times spacing be- tween joists or studs, ft)	$f = 1500$ psi										$E = 1,700,000$ psi										$H = 140$ psi									
	Nominal size of S4S lumber																													
	2x4	2x6	2x8	2x10	2x12	3x4	3x6	3x8	3x10	4x2	4x4	4x6	4x8	6x2	6x4	6x6	6x8	8x2	8x8	10x2										
100	66	104	138	175	202	86	134	165	199	43	101	146	180	54	117	164	207	60	223	65										
200	47	74	97	124	151	61	95	126	160	31	72	113	149	38	90	138	174	44	188	50										
300	38	60	79	101	123	49	78	103	131	25	59	92	121	31	73	115	157	36	170	41										
400	30	48	63	81	98	43	67	89	113	22	51	80	105	27	64	100	137	31	158	35										
500	26	41	53	68	83	38	60	79	101	19	45	71	94	24	57	89	121	28	143	32										
600	23	36	47	60	73	33	52	69	88	18	41	65	86	22	52	82	111	25	130	29										
700	20	32	42	54	66	29	46	61	78	16	38	60	79	21	48	75	103	24	120	27										
800	19	29	39	50	60	27	42	55	70	15	34	54	71	19	45	71	97	22	113	25										
900	17	27	36	46	56	24	38	51	64	13	31	49	65	18	42	67	91	21	106	24										
1000	16	26	34	43	53	23	36	47	60	12	29	45	60	17	40	63	86	20	101	22										
1100	16	24	32	41	50	21	33	44	56	12	27	42	56	16	38	60	82	19	96	21										
1200	15	23	31	39	48	20	31	42	53	11	25	40	52	15	36	56	77	18	92	20										
1300	14	22	29	38	46	19	30	39	50	10	24	37	49	14	33	53	72	17	88	20										
1400	14	22	28	36	44	18	29	38	48	10	23	36	47	14	32	50	68	17	85	19										
1500	13	21	27	35	43	17	27	36	46	9	22	34	45	13	30	47	64	16	82	18										

Since the stringer length will be approximately 72 in., we can select a shore spacing of either 72 in. or 36 in. Using Table 4.3, enter the left column at 600 lb/lin ft and move horizontally, looking preferably for a 4 × 4 member that satisfies either the 36 in. or 72 in. spacing. We find that a 4 × 4 stringer can safely span 41 in. and a 4 × 8 will

span 86 in. For the small slab area of this job, we will select a 4 × 4 stringer with shore spacing of 36 in.

4. Selecting shore size—We must select the shore that covers the most slab area and therefore carries the highest load. At this point it is best to

draw a simple plan and place the shores in the relative positions. Fig. 4.7 shows such a plan and we note that the shore at location B-2 “covers” the largest area of 3 ft × 5 ft. The respective load on the shore is:

$$3 \times 5 \times 125 = 1875 \text{ lb}$$

At this point it is best to consider the weight of the formwork as well as the weight of the concrete and construction loads. One may make an exact calculation of the weights of the members supported by the shore, however, formwork using members of this size weigh approximately 10 lb/ft². So, we should add that amount to the shore load, which now becomes:

$$\text{Shore load} = 1875 + (3 \times 5 \times 10) = 2020 \text{ lb}$$

The capacity of a lumber shore to carry vertical loads is a function of the quality, size, and least dimension of cross section, such as a 4 × 6, and the shore height. Fortunately, this information has

been tabulated and we need only concern ourselves with the quality of the lumber and the L/d ratio, where L is the shore height and d is the least dimension. For normal shoring conditions the ratio of L/d should be 50 or less. These are safety guides for the design of columns that guard against buckling and are beyond the scope of this Craftsman Book. However, we must use the L/d ratio when using the tables. For example, for a 4 × 6 shore with a height of 12 ft, the L/d ratio would be: 12 ft × 12 in./ft divided by 3.5 in. = 41.14 and we would be able to use the figures as shown in Table 4.4.

We must first refer to Table 4.2 and determine the allowable compression parallel to the grain stresses for the Douglas Fir, No. 2 lumber we are using. Note that this value is 1000 psi, which may also be increased 25 percent to 1250 psi because of

short-term loading. Note also that the allowable stresses for compression perpendicular to the grain are much less. Fig. 4.8 shows both types of loads. Designers must be alert to potential crushing when loads are perpendicular to the grain, as this can cause a lowering of the slab formwork by 1/8 in., 1/4 in., or larger.

From Figure 4.2 we can determine that the shore's unsupported length will be:

$$\begin{array}{r} 9 \text{ ft}-9 \text{ in. minus the} \\ \text{formwork: } 5/8 \text{ in. Plywood} \\ - 9 \text{ } 5/8 \text{ in. } 3 \text{ } 1/2 \text{ in. Joist (4 } \times \text{ 4)} \\ \text{Say } 9 \text{ ft}-0 \text{ in. } 3 \text{ } 1/2 \text{ in. Ledger (4 } \times \text{ 4)} \\ \quad \quad \quad 2 \text{ in. Wedges} \\ \hline 9 \text{ } 5/8 \text{ in.} \end{array}$$

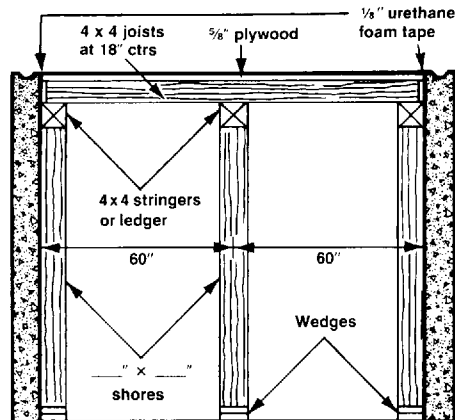


Fig. 4.6—Shoring design

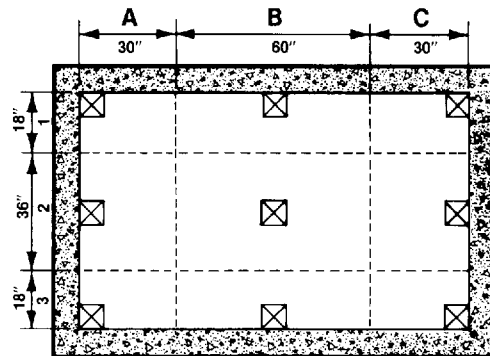


Fig. 4.7—Shore load areas

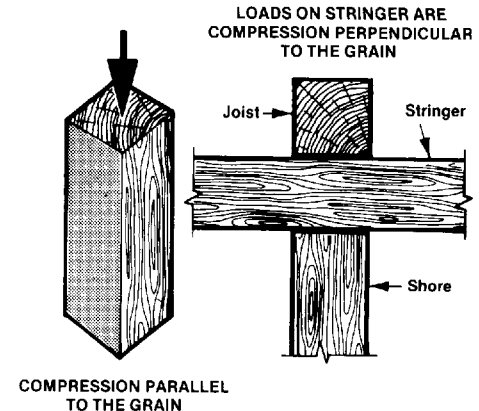


Fig. 4.8—Compression parallel and perpendicular to grain

Locating 9 ft in the left column and moving horizontally to any shore with a 4 in. dimension and S4S, we find that:

a 3 × 4 can safely carry 2000 lb

a 4 × 4 can safely carry 5400 lb

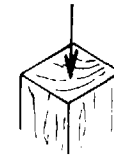
S4S means that the lumber is finished on all four

sides and R means rough sawn lumber. While the 3 × 4 would probably satisfy the 2025 lb load, to be safe and conservative, we will select the more readily available 4 × 4 shore.

Wood wedges placed under the shore will provide final adjustment of the plywood deck to an

exact elevation. See Fig. 4.9. Once the proper elevation is obtained, the shore must be toenailed to the wedges to prevent slippage. If adjustable timber shores are used, or shores with patented clamps, then the manufacturer's load tables must be used to determine the safe capacity of such shores.

Table 4.4—Allowable axial load (pounds) on simple wood shores* of the indicated strength, based on unsupported length



c to grain = 1100 psi			E = 1,400,000 psi				l/d _{max} = 50							
Nominal lumber size, in.	2x4 R ** S4S **		3x4 R S4S		4x4 R S4S		4x2 R S4S		4x3 R S4S		4x6 R S4S		6x6 R S4S	
Unsupported length, ft							BRACING NEEDED							
4	2800	2200	9300	8300	14000	13000	6300	5600	10100	9300	21700	20400	34800	33300
5	1800	1400	7600	6400	13300	12300	6000	5300	9700	8800	20700	19300	34800	33300
6	1300	1000	5300	4400	12100	11000	5400	4700	8800	7900	18800	17300	33800	32300
7			3900	3300	10300	8900	4600	3800	7400	6400	15900	14000	33100	31400
8			3000	2500	7900	6800	3500	2900	5700	4900	12200	10700	31800	30100
9			2400	2000	6200	5400	2800	2300	4500	3900	9700	8500	30000	28300
10			1900	1600	5000	4400	2300	1900	3600	3100	7800	6900	27500	25600
11			-	-	4200	3600	1900	1500	3000	2600	6500	5700	24100	22100
12					3500	3000	1600	1300	2500	2200	5400	4800	20300	18500
13					3000	2600	1300	1100	2200	1800	4600	4100	17300	15800
14					2600	2200	1200	1000	1900	1600	4000	3500	14900	13600
15					2200	-	1000	-	1600	-	3500	-	13000	11900
16					-		-		-				11400	10400
17													10100	9200
18													9000	8200
19													8100	7100
20													7300	6700

* Calculated to nearest 100 lb. ** R indicates rough lumber; S4S indicates lumber finished on all four sides.

5. Stability of the shoring system—While we have selected members of the shoring system that will safely support the loads, we must be sure that all members are properly connected to each other.

In the erection process the shores are cut to length (8 ft-11 1/4 in.) and must be positioned and braced to the adjacent shores. A 1 × 4 piece of Douglas Fir will satisfy this requirement and two duplex nails at each intersection will secure the bracing to the shore. At the same time, place the wood wedges under each 4 × 4 shore. Cross-bracing (X-bracing) in both directions will assure stability of the entire system of shores.

Each row of shores, in both the 10 ft and 6 ft direction, should have 1 × 4 bracing as shown in Fig. 4.10. The 4 × 4 ledgers can now be positioned on top of the shores and secured with a

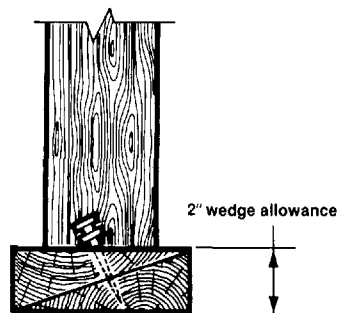


Fig. 4.9—Wood wedges for adjusting deck elevation

patented shore clip or plywood cleat. Nailing will assure that the ledger will not slip off the shore.

Now the 4 × 4 joists may be positioned and lightly toenailed to the ledgers to prevent any movement during erection. Final adjustment of the formwork can now be made using the wood wedges to raise or lower the system before the plywood is secured. If large movements are required, it may be necessary to undo some of the nailing of the braces. Remember to renail after the final elevation is obtained.

Finally, the plywood sheets may be positioned and nailed to the joists. If any joints of the plywood are unevenly matched, you may install a 2 × 4

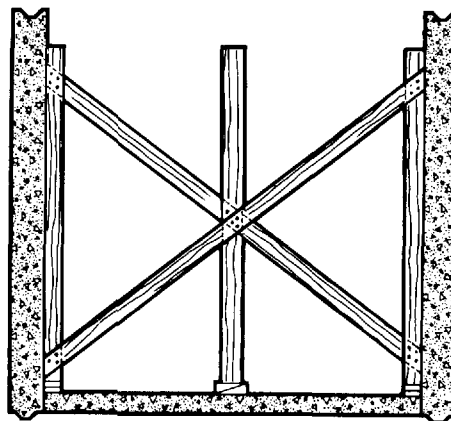


Fig. 4.10—Bracing of shores

bridging between joists and nail the plywood to the bridging as shown in Fig. 4.11.

6. Safety considerations—We must consider worker safety at all times. For this example we have not yet addressed the exterior form for the slab edge. The forms for the vertical walls may have been left in place and sufficiently high to act as the formwork as shown in Fig. 4.12. But, assume that was not the case and we will be required to place formwork for the slab edge. Backfill may or may not be in place. If it is, it will be a safer working condition when laborers and finishers are casting concrete for the slab. If backfill has not yet been placed, then we must be concerned about the potential danger if workers were to fall off the deck formwork. While this 10 ft × 6 ft valve pit job seems simple, there are many considerations workers must take into account—BE ALERT!

If the wall formwork has been removed, we must attach exterior forms for the slab edge. One method is to attach forms to the form ties left in place after

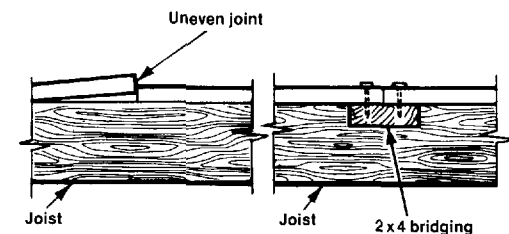


Fig. 4.11—Use of 2 × 4 bridging