Chapter Three

Analysis & Design

3.1 Introduction

Concrete formwork serves as a mold to produce concrete elements having a desired size and configuration. It is usually erected for this purpose and then removed after the concrete has cured to a satisfactory strength. In some cases, concrete forms may be left in place to become part of the permanent structure. For satisfactory performance, formwork must be adequately strong and stiff to carry the loads produced by the concrete, the workers placing and finishing the concrete, and any equipment or materials supported by the forms.

3.2 The main elements of the formwork

The main elements of the formwork for slab shown in figure (3.1) as listed below

- Sheathing
- Joist
- Stringer
- Shores

The main elements of the formwork for foundation shown in figure (3.2) as listed below

- Formwork sheeting
- Stull
- Waler
- Post
- Thrust-board
- Concrete bottom

- Tie wire

The main elements of the formwork for wall shown in figure (3.3) as listed below

- Ply-wood sheathing
- Studs
- Double wales
- Ties

The main elements of the formwork for column shown in figure (3.5) as listed below

- Sheathing
- Poits
- Weage
- Yokes

3.3 Types of Formwork

There are different types of formwork:

- ***Timber formwork*** this formwork is constructed on the building site and it is made from timber and plywood or moisture-resistant particleboard. It is easy to make but can be time consuming and it should be noted that the plywood or particleboard used has a relatively short lifespan.
- ***Engineered formwork*** this consists of premade modules that have a metal frame and are covered on the concrete side with a material such as timber or aluminum. The metal frame is usually steel or aluminum. The advantage of engineered formwork is that it is modular in nature, so you can simply join it together, making it fast to erect. Because it can be reusable, it is also cost effective.

- ***Reusable plastic formwork*** are made up of lightweight, strong formwork panels that are interlocking and modular in nature, so you can easily construct the formwork for your concrete.
- ***Insulated formwork*** also known as insulated concrete formwork or ICFs, the formwork itself is made out of expanded polystyrene, ad it stays in place once the concrete is set, making it a permanent type of formwork. These formwork systems are very energy efficient.
- ***Permanent formwork*** this type of formwork is designed to stay in place (be permanent). It is put together on the site and it remains even after the concrete is fully set, giving the concrete extra strength and also protecting it.

3.4 Types of form work according to the elements

3.4.1Slab Formwork

formwork for slabs, consist of sheathing, normally made of plywood, which rests on joists, and joists are supported by stringers, and stringers are supported on shores which carry the weight of the entire system. Figure (3.1) shows a typical slab form with its components.

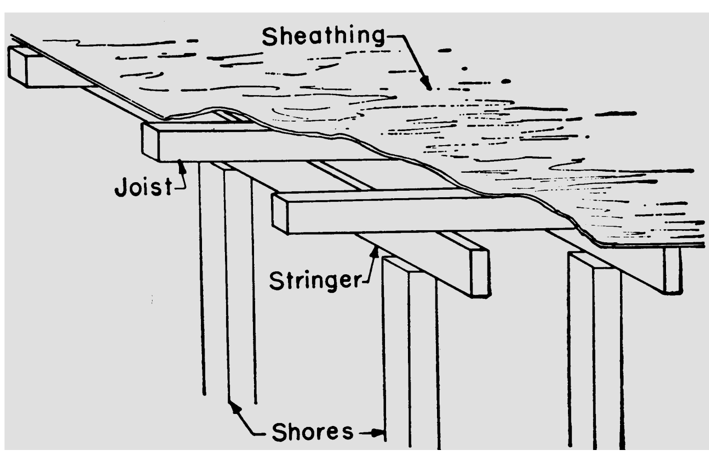


Figure (3.1): Slab Formwork

3.4.2 Foundation Formwork

Foundation formworks can be designed in various ways. Basically there is a difference between formwork for individual foundations, normally designed as socket foundations, and formwork for strip foundations. The type of design is dictated by the size, mainly by the height of the foundation formwork.

The formwork for individual foundations is similar to column formwork and the formwork for strip foundations is similar to the formwork.

Normally sheeting panels with formwork bearers in the form of walers are used for foundation formwork. Individual foundations are also secured by means of walers but of rim type.

Bracing is by squared and round timbers as well as boards diagonally arranged. Tie wires as well as metal screws are used as formwork ties.

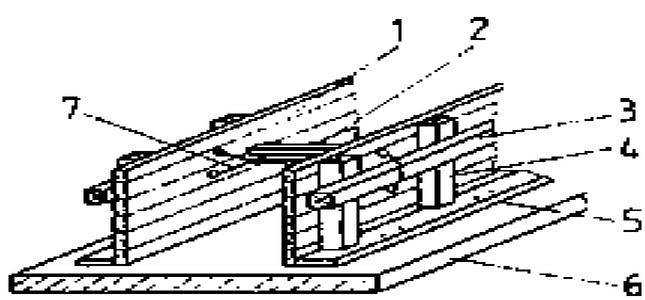


Figure (3.2): Foundation formwork

1 formwork sheeting

2 stull

3 waler

4 post

5 thrust-board

6 concrete bottom

7 tie wire

3.4.3 Wall Formwork

Wall formwork consists of vertically arranged upright timbers (formwork bearers) to which sheeting boards are nailed at the concrete side. The upright timbers are diagonally braced by means of boards at both sides. On cleats situated at every third upright timber, there are horizontally arranged walers.

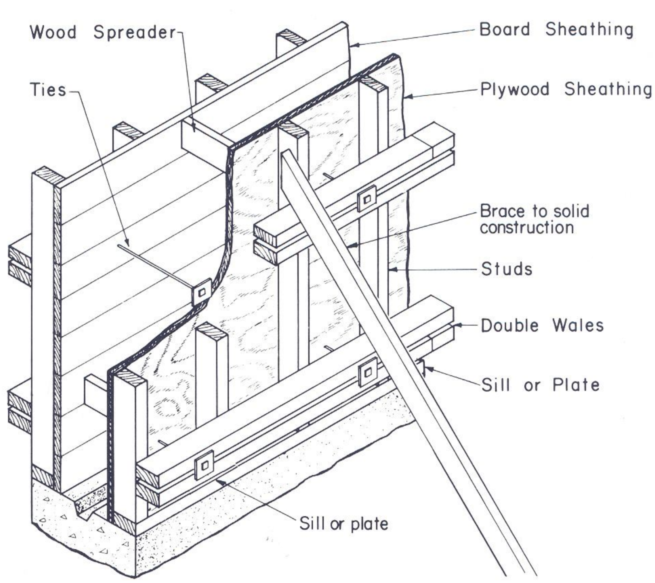


Figure (3.3): Wall formwork (vertical section)

3.4.4 Beam Formwork

Beam formwork has prefabricated formwork sheeting parts (sheeting bottom and side sheeting panels). Such individual parts are manufactured based on the beam dimensions specified in the project. For prefabrication of the formwork sheeting parts, a special preparation table must be manufactured on site.

The sheeting bottom and the side panels consists of sheeting boards nailed together by means of cover straps. Depending on the size of the beam, the width of the sheeting bottom is dimensioned so as to accept, at both sides of the width of the reinforced concrete column, the thickness of the sheeting and cover straps and the width of a thrust-board (approximately 100 mm).

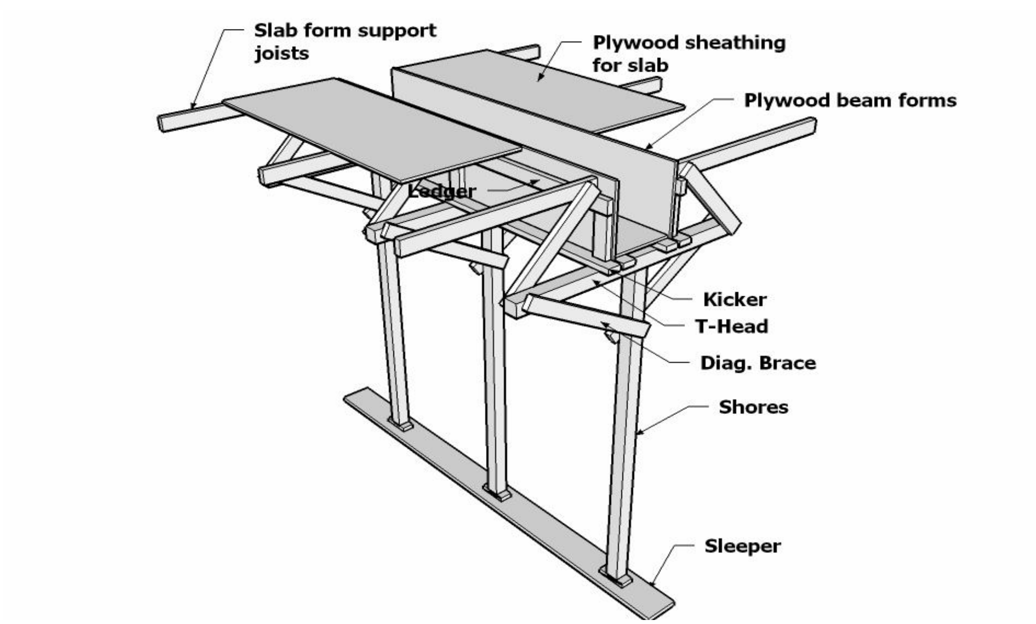


Figure (3.4): Beam formwork

3.4.5 Column Formwork

Similar to beam formworks, the sheeting of column formworks is prefabricated according to the column dimensions from sheeting boards connected by cover straps.

The sheeting panels are placed in a foot rim which is anchored in the soil by steel bolts.

The foot rim consists of double-nailed boards. The foot rim must be exactly measured-in because it is decisive for the exact location of the column. It has the same functions as the thrust-board for foundation or beam formwork.

When the sheeting panels have been inserted in the foot rim, vertical arch timbers are placed to take up the forces from the cover straps of the formwork sheeting.

Around the arch timbers, which have the function of walers, column clamps of flat steel are clamped with wedges or a rim of boards is arranged similar to the foot rim. Additional formwork tieing by tie wires or steel screws is not necessary.

The column in the formwork is laterally tied by diagonal board braces.

A lateral cleaning hole is to be provided at the foot of the formwork for removal of any impurities in the form-work before the concrete is placed.

If a steel reinforcement is to be erected in the column formwork, two sides of the column only are to be provided with formwork first to permit easy erection of the reinforcement. After erection of the reinforcement, the remaining two sides of the column formwork can be mounted.

The two sides mounted first are to be arranged cornerwise to ensure provisional stability.

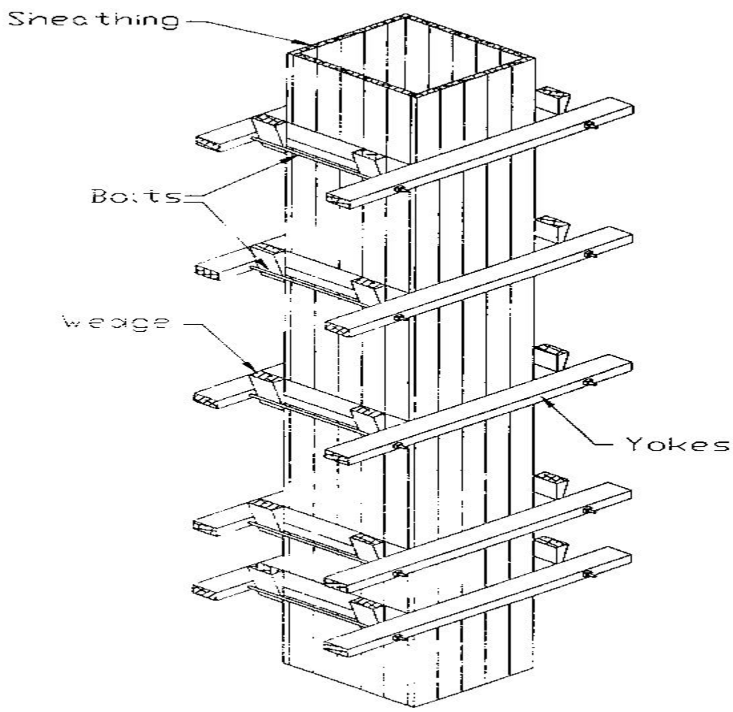


Figure (3.5): Column formwork

3.5 Formwork Materials

Materials used for the construction of concrete formwork range from traditional materials such as wood, steel, aluminum, and plywood to nontraditional materials such as fiberglass. Wood products are the most widely used material for formwork. The objective of this section is to introduce wood as an important material for formwork.

3.5.1 Wood

Wood is widely used for many construction applications including concrete formwork. Wood is harvested from trees and is classified as hardwood and softwood. Hardwood comes from trees that have broad leaves such as oaks, maples, and basswood. Softwood comes from trees that have needle like leaves such as pines, cedars, and firs. Softwoods are most commonly used in construction of formwork. It should be noted that the names ‘‘hardwood’’ and ‘‘softwood’’ give no indication of the hardness or the softness of the wood.

- ***Nominal Size :***

Commercial lumber is sold as boards and planks by dimension sizes. However, the dimensions do not match the actual lumber sizes. For example, a 2*4 in. (50.8*101.6 mm) pine board is cut to the full 2*4 in. (50.8*101.6 mm) at the saw mill. This is called the nominal dimension. The nominal dimensions are reduced because of shrinkage and surfacing in both width and thickness.

For example, the actual dimensions of a nominal 2*4 in. (50.8*101.6 mm) are 1 9/16*3 9/16 in. (39.7*90.5 mm). Lumber that is not surfaced is referred to as rough-sawn. Most lumber for construction is surfaced (dressed) to a standard net size which is less than the nominal (name) size. Surfaced lumber is lumber that has been smoothed or sanded on one side (S1S), two sides (S2S), one edge (S1E), two edges (S2E), or on combinations of sides and edges (S1S1E, S2S1E, S1S2E, or S4S).

❖ *Size Classification*

There are three main size categories for lumber:

1. Boards: Lumber that nominally is less than 2 in. (50.8 mm) thick and 2 in. (50.8 mm) or more wide. Boards' thicknesses refer to the smallest cross-section dimension of lumber and the term width refers to the largest dimension. Boards less than 6 in. (152.4 mm) wide are classified as strips. Boards are used for sheathing, roofing, siding, and paneling.

2. Dimension lumber: Lumber with a nominal thickness of 2–5 in. (50.8–127 mm) and a nominal width of 2 in. (50.8 mm) or more. Dimension lumber ranges in size from 2*2 in. (50.8 * 50.8 mm) to 4 * 16 in. (101.6 *406.4 mm). Dimension lumber is used for general construction where appearance is not a factor, such as studding, blocking, and bracing.

3. Timber: Lumber that is nominally 5 or more inches (127 mm) in the smallest dimension. Timber is used for columns, posts, beams, stringers, struts, caps, sills, and girders.

Lumber is also grouped according to size and intended use into several categories.

1. Light framing: 2*4 in. (50.8*101.6 mm) thick, 2*4 in. (50.8*101.6 mm) wide. Typical grades are Construction Standard, Utility, and Economy and are widely used for general framing purposes. Lumber under this category is of fine appearance but is graded primarily for strength and serviceability. Utility lumber is used where a combination of high strength and economical construction is desired.

An example would be for general framing, blocking, bracing, and rafters.

2. Studs: 2*4 in. (50.8*101.6 mm) thick, 2*6 in (50.8*152.4 mm) wide, 10 ft (3048.0 mm) long and shorter. Primary use is for walls, whether they are load-bearing or non load bearing walls.

3. Structural light framing: 2*4 in. (50.8*101.6 mm) thick and 2*4 in. (50.8*101.6 mm) wide. Typical grades are Select Structural No. 1, No. 2, and No. 3. This is intended primarily for use where high strength, stiffness, and fine appearance are desired. An example of a use would be in trusses.

4. Appearance framing: 2*4 in (50.8*101.6 mm) thick, 2 in. (50.8 mm) and wider. For use in general housing and light construction where knots are permitted but high strength and fine appearance are desired.

5. Structural joists and planks: 2*4 in. (50.8*101.6 mm) thick and 5 in. (127.0 mm) or more wide. Typical grades are Select Structural No. 1, No. 2, and No. 3. Intended primarily for use where high strength, stiffness, and fine appearance are required.

❖ *Mechanical Properties of Lumber*

Basic understanding of mechanical properties of lumber is necessary for concrete formwork design. Wood is different from any other structural material in that allowable stresses of wood are different according to the orientation of the wood. The intent of the following section is to provide a brief introduction to the mechanical properties of lumber.

❖ ***Bending Stresses***

Figure (3.6) shows a simply supported wood beam with a concentrated load applied at the midpoint. This process results in bending. The lumber is stressed internally to resist the external loads. Bending in a member causes tension forces in the extreme fibers along the face farthest from the load and causes compression in the fiber along the side closest to the applied load. The maximum stress induced in the fibers, which occurs at the edges, is referred to as the ‘‘extreme fiber stress in bending.’’ This stress is highly dependent on the parallel-to-grain strength of the wood in both tension and compression. The allowable bending stresses are based on a clear specimen having no defects. Allowable bending stresses are then factored to account for defects.

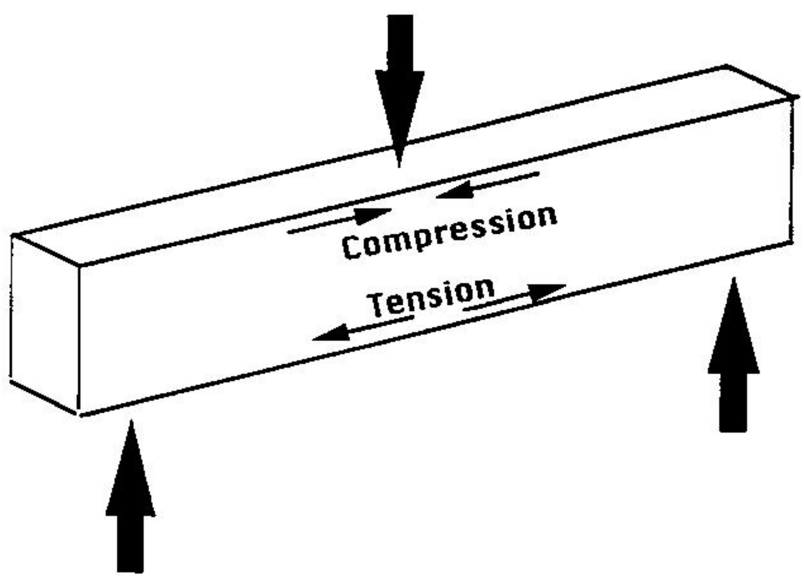


Figure (3.6): Bending stresses.

❖ ***Modulus of Elasticity (MOE)***

Modulus of elasticity is a measure of stiffness. This factor (MOE) is a relationship between the amount of deflection in the member and the value of load applied that causes the deflection. The amount of deflection depends on the size of the member, the span between the supports, the load, and the particular member specie of wood. The parallel-to-grain MOE (i.e., the stiffness when wood is pushed or pulled parallel to the wood grain) is about 30 times greater than the perpendicular-to-grain MOE.

❖ ***Tensile and Compressive Strengths***

Tensile strength is a measure of the ability of wood to resist pulling forces. On the other hand, compressive strength is a measure of the ability of wood to resist pushing forces. For clear wood (wood without defects), the tensile and compressive strengths for parallel-to-grain loads are approximately 10 times greater than for loads applied perpendicular to the wood grain.

3.5.2 Plywood

Plywood is used as sheathing that contacts concrete for job-built forms and prefabricated form panels. Since plywood comes in large sizes, it saves forming time. Plywood is made by gluing together thin layers of wood, called veneer, under intense heat and pressure. Most plywood panels are made of softwood. Many species of trees are used to make plywood, such as Douglas fir and Southern pine. The grain of each ply is laid at a right angle to the adjacent pieces. This process gives plywood extra strength and reduces shrinkage and swelling.

Plywood is commonly sold in large sheets 4*8 ft (1.22 *2.44 m). These large panels reduce erection and stripping costs and produce fewer joints on the finished concrete. Plywood is available in varieties of thicknesses that identify it for sale. For example, plywood called ‘‘1/2 in. (12.7 mm) plywood’’ is 1/2 in. (12.7 mm) thick. In contrast to the situation with lumber, actual and nominal thickness for plywood is the same; 1 in. (25.4 mm) plywood is 1 full inch (25.4 mm) thick.

3.5.3 Ply-form

Ply-form is a plywood product specially made for concrete formwork. Ply-forms are available in class I and class II, where class I is stronger than class II. Other ply-form that is commonly used for formwork includes B-B ply-form, high-density overlaid (HDO), and structural 1 ply-form. Plywood and ply-form have particular orientations that affect their strength. A weak position can be achieved when the grain (face grain) is parallel to the span of support. A stronger orientation is seen when the grain (face grain) is perpendicular to the span of support as illustrated Figure (3.7).

3.5.4 Steel

The major advantages of steel sections in formwork are the ability of steel to form longer spans and its indefinite potential for reuse when handled with reasonable care. Steel sections are used in the fabrication of different formwork components, namely: (1) steel panel forms, (2) horizontal and vertical shores, (3) steel pan and dome components used for joist and waffle slabs, and (4) steel pipes for formwork bracing. Other heavy forms and formwork are also made of steel, such as bridge formwork. Steel is used for formwork when other materials are impossible to use because of their low strength. Steel forms are typically patented, and allowable loads are generally published by the manufacturers.

3.5.5 Aluminum

Aluminum has become an increasingly popular material for many formwork applications such as lightweight panels, joists, horizontal and vertical shoring, and aluminum trusses for flying forms.

The popularity of aluminum stems from its light weight which reduces handling costs and offsets its higher initial material cost. When compared to steel panels, aluminum panels used for ganged forms weigh approximately 50 percent less. The major problem with aluminum forms is corrosion: Pure aluminum is attacked chemically by wet concrete. Aluminum alloys have proven to be very successful in resisting corrosion.

3.5.6 Glass-Reinforced Plastic

In recent years, forms fabricated from glass-reinforced plastic have found increasing use because of their strength, light weight, and high number of reuses. Glass-reinforced plastic also produces high-quality concrete finishes. Glass-reinforced plastic forms are very flexible and can form complex or nonstandard shapes with little capital investment. To fabricate glass-reinforced plastic forms, models of plaster, wood, or steel are prepared to the exact desired dimensions. The model is then waxed, polished, and sprayed with a parting agent to prevent sticking of the resin to the master pattern. Glass mat is then fitted over the model and thoroughly saturated with a brush coat of polyester resin. When the resin has set and the heat dissipated, another layer of glass mat and polyester resin is added, and this process is repeated until the desired thickness of the fiberglass sheet is achieved.

Another method to build glass-reinforced plastic forms is through the use of a spray gun to apply the resin to chopped strands of fiberglass, which are used as the reinforcing material. To increase the number of potential reuses with any of the methods of fabrication mentioned, an extra thickness of resin is molded into the contact surface or additional stiffening and supports are added by means of built-up ribs, wood struts, steel rods, or aluminum tubing.

The two major problems associated with glass-reinforced plastic forms are attack by alkalis in the concrete and form expansion because of exposure to hot sun or heat from hydration of cement.

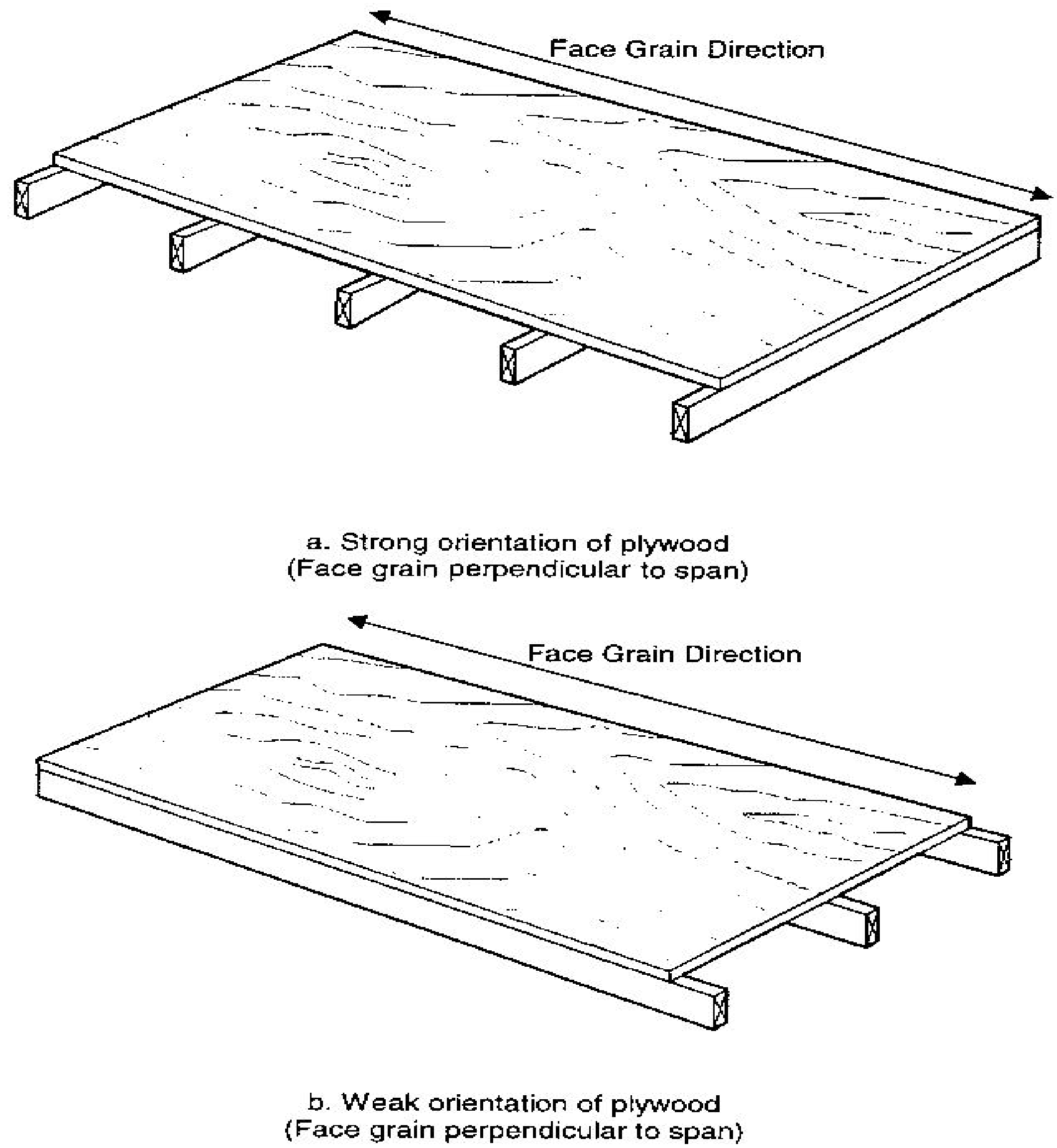


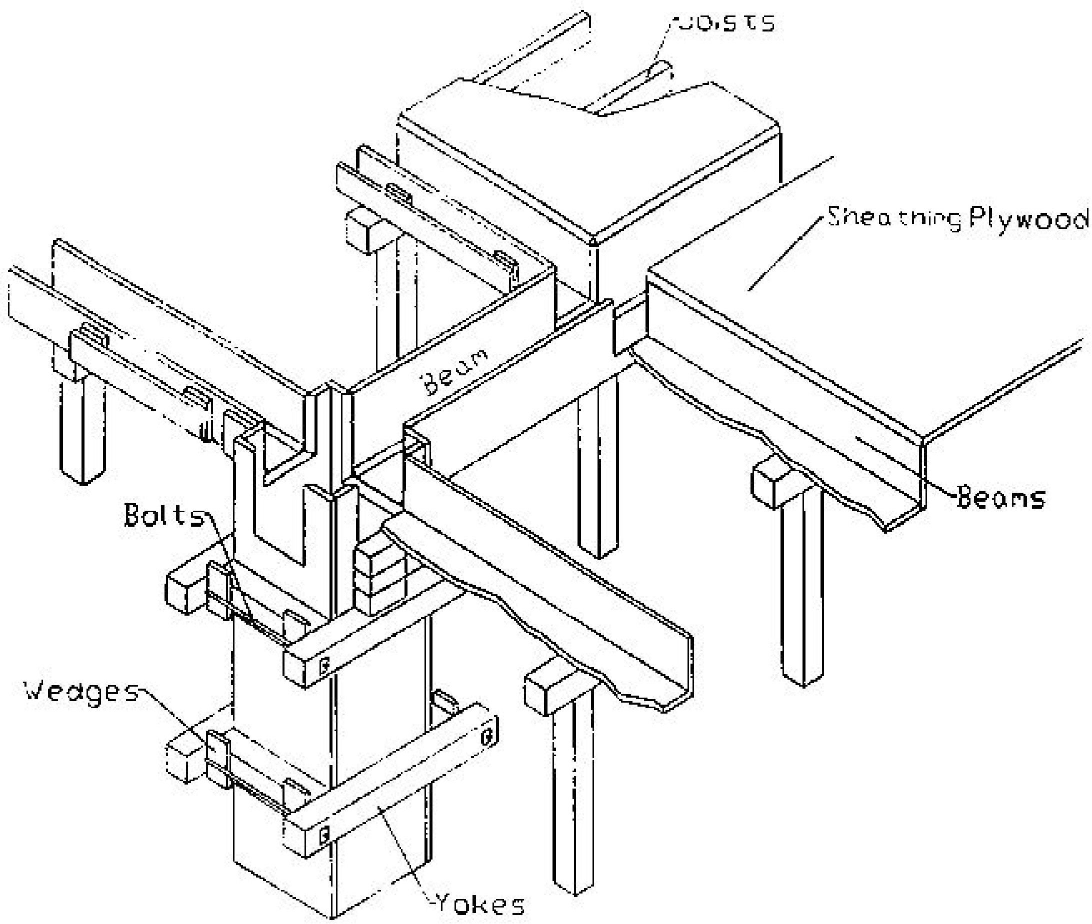
Figure (3.7): *Plywood orientation*

3.6 Formwork for Concrete Slabs

Conventional wood systems for horizontal concrete work are made of plywood or lumber sheathing for decking. the thickness of plywood or lumber is determined by structural analysis and is a function of the applied loads, type of wood or plywood, and the spacing between sheathing supporting elements. Plywood is preferred over lumber sheathing because it provides a smooth concrete surface that requires minimum finishing effort. The use of plywood for decking is also productive because of its large panel size (4*8 in.) (1.22*2.44m).

Sheathing is supported by horizontal members called joists or runners. Joists are made from dimension lumber spaced at constant intervals that are a function of applied loads and the type of lumber. It is a recommended practice to round down the calculated joist spacing to the lower modular value.

Joists are supported by another set of horizontal members perpendicular to the joists, called stringers. The stringers are supported by vertical members called shores. In all-wood conventional formwork systems, shores are made of dimension lumber that have square cross sections [i.e.,4*4 in. (101.6 * 101.6 mm) or 6*6 in. (152.4*152.4 mm)]. Shores are rested on heavy timbers, called mudsills, to transfer the vertical loads to the ground. In the case where a slab-on-grade exists, shores are rested directly on them. Figure(3.8) shows a typical all-wood conventional formwork system for concrete slabs.



Figure(3.8): *All-wood conventional formwork system.*

Vertical timber shores can be replaced by the scaffold type, which has been proven to be more efficient because of its high number of reuses and its height, which means that no splicing is typically required. The scaffold-type shoring system consists of two vertical steel posts with horizontal pipe between them at regular intervals. Adjustable screw jacks are fitted into the steel posts at both ends. The top jacks are fitted into steel caps called tee heads. The bottom jacks are fastened into rectangular steel plates. Adjacent vertical steel posts are braced together by steel X braces.

3.7 Formwork for Concrete Beams

Formwork for beams consists of a bottom and two sides in addition to their supporting elements. The bottom is typically made of plywood or lumber sheathing with thickness of 0.75 in. (19.0 mm) or 1 in. (25.4 mm). The bottom is supported by and fastened to horizontal joists. Beam sides are also made of plywood or lumber sheathing.

Once the bottom of the beam form is constructed and leveled, one side of the beam is erected first with holes drilled into it for installing the tie rods .Tie rods are steel rods that hold the two sides of the beam together. After the first side of the beam form is erected, the reinforcement is placed inside the beam and then the other side of the beam is erected. Tie rods are then inserted into all holes and the walers on both sides of the beam. The tie rods' function is to resist the horizontal pressure resulting from the freshly placed concrete and thus keep the sides of the beams in their proper location. Tie rods are fastened to the sides of the beam and also to vertical walers and clamps. To further support the two sides of the beam and hold them together, additional temporary spreaders are fastened at the top of the beam sides at regular distances. Temporary spreaders may be made from wood or steel.

3.8 Formwork for Foundation

Formwork for continuous or isolated footing is usually made of wood boards (planks) or plywood supported by vertical stakes driven into the ground. The top of the vertical stake is supported by a diagonal brace driven into the ground. Bracing may be replaced by the piling up of dirt to support the sides of the form. The correct distance between the planks is kept by crossing spreaders. On small footings, steel straps are used to replace the spreaders. It is common practice to construct the forms higher than necessary and place the straps in the inner sides of the form at a height equal to the concrete level. Figure (3.9) shows typical formwork for isolated footing.

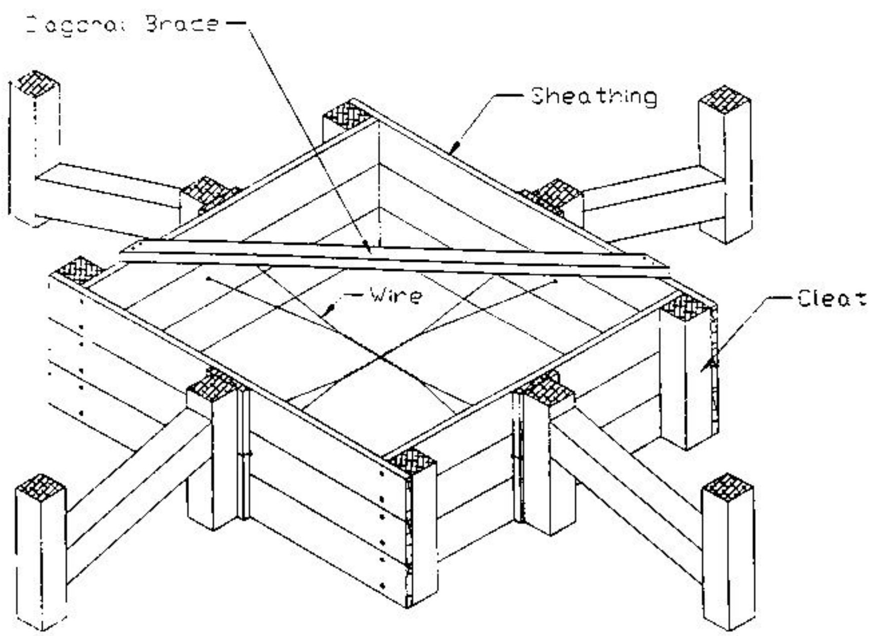


Figure (3.9): Formwork for isolated footing.

Large footings are formed similarly to small and continuous footings except that the sides are supported by studs and wales. Holes are drilled into the sides of the forms, and tie wire is passed through the sides of the forms and fastened to the studs. Lumber planks or steel strap spreaders are used to provide extra support.

3.9 ***Loads on Concrete Formwork***

Concrete forms must be designed and built so that they will safely carry all live and dead loads applied to them. These loads include the weight and pressure of concrete, the weight of reinforcing, the weight of the form materials and any stored construction materials, the construction live loads imposed by workers and machinery applied to the forms, and loads from wind or other natural forces.

3.9.1 Lateral Pressure of Concrete

Fresh concrete still in the plastic state behaves some what like a fluid. The pressure produced by a true fluid is called hydrostatic pressure and depends on the fluid density and on the depth below the surface of the fluid. The hydrostatic pressure formula is:

$$p = wh \qquad (3.1)$$

where: p is the fluid pressure, w is the fluid density, and h is the depth below the free surface of the fluid. This pressure, which is due to the weight of the fluid above it, always pushes against the container in a direction perpendicular to the surface of the container.

If concrete behaved like a true fluid, the pressure it would produce on the forms would have a maximum value of from (ACI Committee 347)

$$p = 150h \qquad (3.2)$$

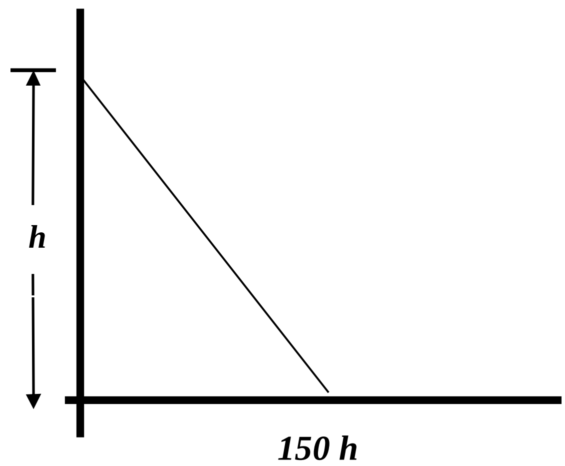


Figure (3.10): A diagram showing the hydrostatic pressure distribution in fresh concrete

for concrete of normal density. Normal-density concrete is usually assumed to weigh 150 pounds for a cubic foot, and ***h*** is the depth of concrete in the form. The pressure of the concrete would vary from the maximum pressure of ***150h*** at the bottom of the form to zero at the surface of the concrete. This pressure distribution is shown in ***Fig (3.10).*** For placing conditions where the form is filled rapidly and the concrete behaves as a fluid, the form should be designed to resist this maximum hydrostatic pressure.

3.9.2 Gravity Loads on Formwork

Gravity loads are from all live and dead loads applied to and supported by the formwork. These include the weight of the concrete and reinforcing steel, the weight of the forms, and any construction loads from workers, equipment, or stored materials. Loads from upper floors may also be transferred to lower level forms in multistory construction. The largest loads are generally due to the weight of the concrete being formed and to the construction live load from workers and equipment. Because the majority of concrete used has a weight of around 140 to 145 pounds per cubic foot (lb/ft3), it is common to use a value for design of 150 lb/ft3, which includes an allowance for the reinforcing steel. Where lightweight or heavyweight concrete is used, the density of that particular mix should be used in calculating formwork loads.

Trying to predict what value should be used for construction loads to account for the weight of workers and equipment is difficult. The weights of the workers and equipment would have to be estimated for each situation and their locations taken into account when trying to determine worst-case loadings. As a guide to the designer in ordinary conditions, ACI Committee 347 recommends using a minimum construction live load of 50 psf of horizontal projection when no motorized buggies are used for placing concrete. When motorized buggies are used, a minimum construction live load of 75 psf should be used.

The dead load of the concrete and forms should be added to the value of the live load.

The dead load of the concrete depends on the thickness of the concrete element. For every inch of thickness of the concrete, 150/12 or 12.5 psf should be used. The dead load of the forms can vary from a value of 4 or 5 psf to as much as 15 to 18 psf. In some cases, the weight of the forms is small when compared to the other loads and can be safely neglected. When the design of the form is complete and form component sizes are known, the form weight should be calculated and compared to the assumed loads.

ACI Committee 347 recommends that a minimum total load for design of 100 psf be used (regardless of concrete thickness) without use of motorized buggies, or 125 psf when motorized buggies are used.

3.9.3 Lateral Loads :

In addition to fluid pressures, formwork must also resist lateral loads caused by wind, guy cable tensions, starting and stopping of buggies, bumping by equipment, and uneven dumping of concrete. Because many formwork collapses can be attributed to inadequate bracing for handling lateral loads, it is important that these loads be properly resisted by an adequate bracing system.

The first step in choosing what bracing is required is to determine the magnitude of the lateral loads created by the effects listed above. When lateral loads cannot be easily or precisely determined, minimum lateral loads recommended by ACI Committee 347 may be used.

3.10 Slab Formwork Design

The objective for the formwork designer is to choose a system that will allow concrete elements that meet the requirements of the job to be cast in a safe and economical way. The designer has to choose the materials for constructing the forms and determine the size of the form components, the spacing of all supporting members, and the best way to properly assemble the forms to produce a stable and usable structure. After the materials for constructing the form have been selected and the loads that the form must withstand are determined, the designer must determine how to make the form strong enough to carry the stresses from these loads. The forms must also be proportioned so that deformations are less than those allowable under the specifications and conditions of the job. Many times, the form designer can rely on past experience with other jobs with similar requirements and simply use the same forming system as used before. However, the current job requirements, the materials to be used, or the loading conditions are sometimes different enough to make it necessary for the forms to be designed for the new situation. Form design can be approached in two ways: by relying on tables that give allowable loads for various materials such as lumber and plywood or by following a rational design procedure similar to those used in designing permanent structures. In the rational design procedure, known elastic properties of the materials are used to determine the required member sizes, spacing, and other details of the form system, and established engineering principles are followed.

3.11 Simplifying Assumptions for Design

Because of the many assumptions that can be made about loads, job conditions, workmanship, and quality of materials for formwork, too much refinement in design calculations may be unwarranted. The designer’s effort to attain a high degree of precision in calculations is usually negated by the accuracy of the field construction and by uncertainties about loads and materials. A simplified approach for the rational design of formwork members is usually justified. The need to make the forms convenient to construct makes choosing modular spacing desirable, even when other dimensions are indicated by calculations. For example, the strength of the plywood sheathing for a wall form may be sufficient to allow a stud spacing of 14 in. For ease of construction and to ensure that the panel edges are supported, a spacing of 12 in. for the studs would probably be chosen, even though it is conservative and requires more supports.

For concrete formwork that supports unusually heavy loads, requires a high degree of control of critical dimensions, or presents unusual danger to life or property, a complete and precise structural design may be essential. In this situation, a qualified structural engineer experienced in this kind of design should be engaged. The following simplifying assumptions are commonly used to allow more straightforward design calculations:

• Assume that all loads are uniformly distributed. Loads on sheathing and other members directly supporting the sheathing are, in fact, distributed, though not necessarily uniformly distributed. Loads on other form members may be point loads but can usually be approximated by equivalent distributed loads. In cases where the spacing of the point loads is large compared to the member span, bending stresses and deflections should be checked for actual load conditions.

• Beams continuous over three or more spans have values for moment, shear, and deflection approximated by the formulas.

3.11.1Mechanical Properties of Lumber

The mechanical properties that will be used in the design of formwork are compression parallel to grain (F_c), compression perpendicular to grain ($F_{c\perp}$), tension parallel to grain (F_t), and tension perpendicular to grain ($F_{t\perp}$) .

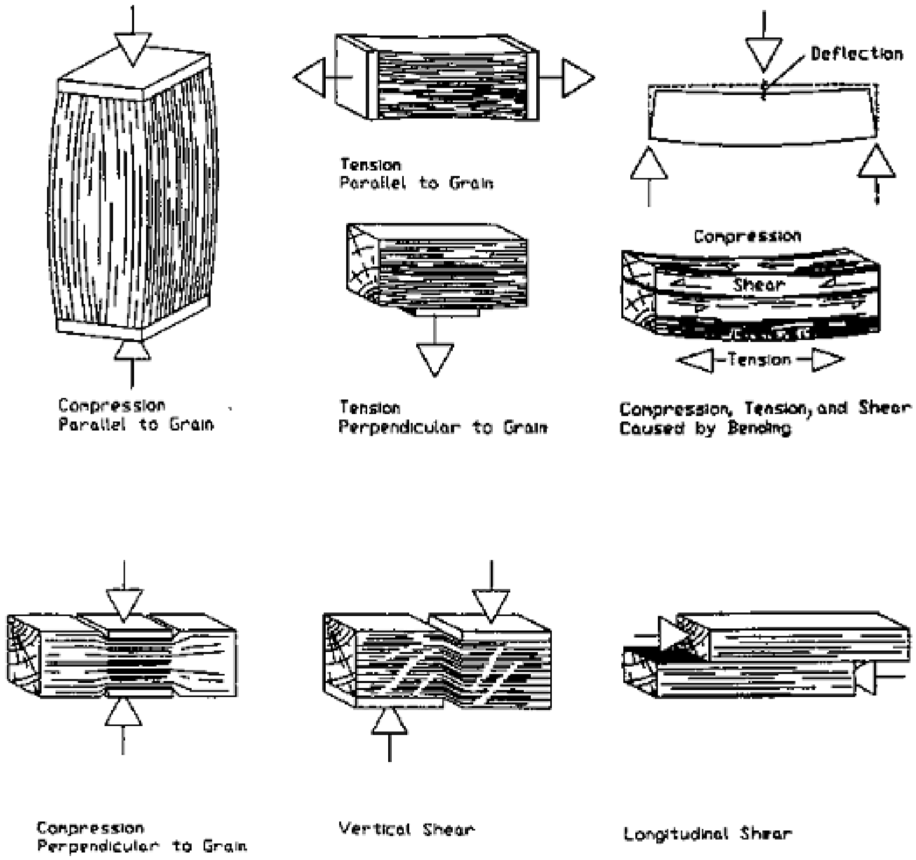


Figure (3.11): Force and direction of grains

3.11.2Design Values of Mechanical Properties

Design values for the different types of stresses are dependent on the type of lumber. The design values given in these tables are to be adjusted to fit the conditions under which the structure will be used. Tables (3.3) through (3.6) (Appendix (B)) give the design values along with its adjustment factors that are specified by NDS (National Design Specification for wood construction 1991) for dimension lumber, southern pine dimension lumber timber (5*5 in. and larger) and decking. Table (3.3a) through (3.3d) (Appendix (B)) gives the design values along with its adjustment factors for all species except Southern Pine. Design values for Southern Pine are shown in Tables (3.4a) through (3.4d) and Table (3.5)(Appendix (B)).

3.11.3 Size Factor

Stresses parallel to grain for visually graded dimension lumber should be multiplied by the size factors provided in Tables 3.3a and (3.4a) (Appendix (B)) . When the depth d of the beam, stringer, post, or timber exceeds 12 in., the tabulated design value F_b shall be multiplied by the following size factor :

$$C_f = \left[\frac{12.0}{d}\right]^{1/9} \tag{3.3}$$

3.11.4 Effect of Moisture

Dry service conditions are those in which the moisture content during the use of the member will not be more than 19 percent, regardless of the moisture content of the member at the time of its manufacture. The design values (allowable design stresses) for lumber are applicable to members that are used under dry service conditions, such as in most covered structures. For lumber used under conditions where the moisture content of the wood will exceed 19 percent for an extended period of time, the design values of the member shall be multiplied by the wet service condition factor C_m, as is specified by the National Design Specification for Wood Construction (NDS). The wet service factor (<1.0) is used to decrease the allowable stresses to account for the weakening of the member due to the increase in its moisture content. An example of the wet service factor is given in Table (3.3c) (Appendix B) .

Also, moisture content adds additional weight to the lumber . NDS specifies that the following formula shall be used to determine the density (in lb./ft3) of wood.

$$Density = 62.4\left[\frac{G}{1+G(0.009)(m.c.)}\right]\left[1+\frac{m.c.}{100}\right] \tag{3.4}$$

Where :

G = specific gravity of wood based on weight and volume when oven-dry

$m.c$ = moisture content of wood, %

3.11.5 Load Duration Factor

Wood has the property of carrying a substantially greater maximum load for short duration than it can for long duration of loading. The tabulated design values given by NDS apply to normal load duration. Normal load duration is defined as the application of the full design load that fully stresses a member to its allowable design value for a cumulative period of approximately 10 years. Values for load duration factors are given in Table (3.1).

Table (3.1): Load Duration Factor

Load duration	C_d	**Typical design load**
Permanent	0.9	Dead load
10 years	1.0	Occupancy live load
2 months	1.15	Snow load
7 days	1.25	Construction load
10 minutes	1.6	Wind/earthquake load
Impact	2.0	Impact load

From National Design Specification for Wood Construction 1991

3.11.6 Temperature Factor

Wood increases in strength when cooled below normal temperatures and decreases in strength when heated. Prolonged heating to a temperature above 150°F may result in permanent loss of strength. Tabulated design values shall be multiplied by temperature factors C_t for a member that will experience sustained exposure to elevated temperature up to 150°F. These values are shown in Table (3.2) .

Table (3.2): Temperature factor (C_t)

Design values	**In service moisture content**	C_t		
		$T \le 100^\circ F$	$100^\circ F \prec T \le 125^\circ F$	$125^\circ F \prec T \le 150^\circ F$
F_t , E	Wet or dry	1.0	0.9	0.9
F_b, F_v, F_c **&** $F_{c\perp}$	Dry Wet	1.0 1.0	0.8 0.7	0.7 0.5

3.11.7 Bearing Area Factor

Tabulated compression design values perpendicular to grain $F_{c\perp}$ apply to bearings of any length at the ends of the member, and to all bearings 6 in. or more in length at any other location. For bearings less than 6 in. and not nearer than 3 in. to the end of a member, the tabulated design values perpendicular to grain $F_{c\perp}$ shall be permitted to be multiplied by the bearing area factor c_b. Values of c_b are given in Table (3.3).

Table: (3.3) Bearing Area Factor $(C_b)^*$

$l_b(in)$	0.5	1.0	1.5	2.0	3.0	4.0	6 or more
C_b	1.75	1.38	1.25	1.19	1.13	1.10	1.00

** For round bearing area such as washers, the bearing length l_b will be equal to the diameter.*

From National Design Specification for Wood Construction 1991

3.12 Design Methodology and Design Equations:

In selecting the sizes of plywood, joists, and stringers for given spans and loads, the following requirements must be considered.

1. The allowable working stresses for bending and for shear must not be exceeded.

2. The allowable limits for deflection must not be exceeded.

3. The sizes of the joists and stringers should be easily obtained in the local markets.

❖ ***Design for bending:***

a. For single span [See Appendix (B) – Table (3.16)]:

$$w_b = \frac{96F_b(KS)}{l^2{}_1} \tag{3.5}$$

b. For two spans :

$$w_b = \frac{96F_b(KS)}{l^2{}_1} \tag{3.6}$$

c. For three or more spans :

$$w_b = \frac{120F_b(KS)}{l^2{}_1} \qquad (3.7)$$

Where:

w_b = uniform load for bending , Ib/ft

F_b = adjusted allowable bending stress , psi

KS = effective section modulus , in^3 / ft

l_1 = span center to center of supports , in.

Design for shear:

a. For a single span :

$$w_s = \frac{24F_s(Ib/Q)}{l_2} \qquad (3.8)$$

b. For two spans:

$$w_s = \frac{19.2F_s(Ib/Q)}{l_2} \qquad (3.9)$$

c. For three or more spans :

$$w_s = \frac{20F_s(Ib/Q)}{l_2} \qquad (3.10)$$

Where:

w_b = uniform load for shear , Ib/ft

Fs = adjusted allowable rolling shear stress, psi

Ib/Q = rolling shear constant , in^2 / ft

l_2 = clear span, in. (center to center span minus support width)

❖ ***Design to satisfy deflection requirements:***

a. Bending deflection:

i. For a single span :

$$\Delta_b = \frac{wl_3^{\ 4}}{921.6EI} \tag{3.11}$$

ii. For two spans:

$$\Delta_b = \frac{wl_3^{\ 4}}{2220EI} \tag{3.12}$$

iii. For three and more spans :

$$\Delta_b = \frac{wl_3^{\ 4}}{1743EI} \tag{3.13}$$

Where:

Δ_b = bending deflection, in.

w = uniform load for bending, psf

E = modules of elasticity, psi

I = effective moment of inertia, in^4 / ft

l_3 = clear span + SW (support width factor)

SW = 0.25 in. for 2-in. nominal framing, and

= 0.625 in for 4-in. nominal framing

b. Shear deflection :

The shear deflection may be closely approximated for all span condition by the following formula :

$$\Delta_s = \frac{wCt^2 l_2^{\ 2}}{1270EI} \qquad (3.14)$$

Where:

Δ_s = Shear deflection, in.

w = uniform load, psf

C = constant, equal to 120 for panels with face Grain parallel to supports and 60 for panels With face grain perpendicular to supports

t = nominal panel thickness, in.

E = modulus of elasticity, psi

I = effective moment of inertia, in^4 / ft

For cases when shear deflection is computed separately and added to bending deflection to obtain the total deflection, E for these bending-deflection equations should be increased by 10 percent. In this case the total deflection will be $\Delta = \Delta_b + \Delta_s$.

3.13 Design Loads

Formwork should be designed to adequately sustain all the applied loads without failure or excessive deflection. ACI Committee 347-94 is considered the industry guide for estimating minimum and maximum loads applied on formwork. The following is a summary of the different load types and values.

3.13.1 Vertical Loads

Vertical load consists of dead load and live load. The weight of the formwork plus the weight of the freshly placed concrete is dead load. The live load includes the weight of workers, equipment, material, storage, impact, etc.

1. Form’s self-weight. The self-weight of the form is usually assumed to be 5 lb/ft2. Self weight cannot be determined until the form is actually designed. After carrying out the design, the assumption of 5 lb/ft2 needs to be checked. If the assumed value is far from the correct value, design should be repeated. This process is continued until one arrives at a reasonable difference between the two values. In most small and moderate spans, the 5 lb/ft2 assumption holds well.

2. Weight of concrete. The weight of ordinary concrete is assumed to be 150 lb/ft3. Thus the load from the concrete slab on a square foot of decking will be

$$P = \frac{150 * t}{12} = 12.5t \tag{3.15}$$

Where: t is the thickness of slab in inches.

3. Live load. The American Concrete Institute (ACI_347) specifies that different elements used to support vertical loads should be designed for a minimum live load of 50 psf on the horizontal projection. When motorized cars are present, the minimum live load should be 75psf The minimum design load for combined dead and live load should be 100 psf, or 125 psf if motorized cars are present.

3.13.2 Horizontal Load

Braces and shores should be designed to resist all foreseeable horizontal loads such as seismic, wind, inclined support, starting and stopping of equipment, and other such loads.

3.14 Design Steps

The steps in the design of forms to support concrete slabs include the following:

1. Determine the total unit load on the floor decking, including the effect of impact, if any.

2. Select the type of floor decking, along with its net thickness.

3. Determine the safe spacing of floor joists, based on the strength or permissible deflection of the decking.

4. Select the floor joists, considering the load, type, size, and length of joists.

5. Select the type, size, and lengths of stringers, if required to support the joist.

6. Select the type, size, length, and safe spacing of shores, considering the load, the strength of the stringers, and the safe capacity of the shores.

Usually the most economical design of forms results when the joists are spaced for the maximum safe span of the decking.

Likewise, reasonably large joists, which permit long spans, thus requiring fewer stringers, will be economical in the cost of materials and in the cost of labor for erecting and removing the forms . The use of reasonably large stringers will permit the shores to be spaced greater distances apart, subject to the safe capacities of the shores, thus requiring fewer shores and reducing the labor cost of erecting and removing them.

3.15 Size, Length, and Spacing of Joists

The selection of the size, length, and spacing of the joists will involve one of the following:

1. Given the total load on the decking, the spacing of the joists, and the size and grade of the joists, determine the maximum span for the joists.

2. Given the total load of the decking, the size and grade of the joists, determine the maximum spacing of the joists.

3. Given the total load on the decking, and the size and the span of the decking, determine the minimum size joists required.

For practical purposes, the selected span is rounded down to the next lower integer or modular value.

3.16 Stringers and Shores

The joist span selected will be based on the spacing of the stringers. We can follow the same procedure that is used for analyzing joists. Again, an integer or modular value is selected for stringer spacing.

After calculating the stringer spacing, the span of the stringer is checked against the capacity of the shore. The load on each shore is equal to the shore spacing multiplied by the load per unit foot of the stringer. The maximum shore spacing will be the lower of these two values (based on joists loading or shore spacing).

In calculating the design load of stringers, we do not consider the effect of joists on stringers. Instead, as a good approximation, we calculate load transmitted directly from sheathing to stringers. Hence, it is necessary to check for crushing at the point where the joists rest on stringers. Finally, shores are designed as columns (compression member).

In checking the capacity of the different elements of the form, we use the same equations that will be used in the analysis of the wall form design. These equations are shown in Table (3.4) (3.5) (See Appendix B).

Table (3.4): Design Equations for Different Support Conditions

Type	**One span**	**Two spans**	**Three spans**
Bending moment (in – Ib)	$M = \frac{wl^2}{96}$	$M = \frac{wl^2}{96}$	$M = \frac{wl^2}{120}$
Shear (Ib)	$V = \frac{wl}{24}$	$V = \frac{5wl}{96}$	$V = \frac{wl}{20}$
Deflection(in)	$\Delta = \frac{5wl^4}{4608EI}$	$\Delta = \frac{wl^4}{2220EI}$	$\Delta = \frac{wl^4}{1740EI}$

From National Design Specification for Wood Construction 1991

Notation:

L = length of span (in.)

W = uniform load per foot of span (lb/ft)

E = modules of elasticity (psi)

I = moment of inertia (in.4)

Table (3.5): Bending Moment, Shear, and Deflection Equations*:

Design Condition	Support Conditions		
	One span	Two spans	Three or more span
Bending			
Wood	$L = 4.0d\left(\frac{F_b b}{w}\right)^{1/2}$	$L = 4.0d\left(\frac{F_b b}{w}\right)^{1/2}$	$L = 4.46d\left(\frac{F_b b}{w}\right)^{1/2}$
	$L = 9.8\left(\frac{F_b s}{w}\right)^{1/2}$	$L = 9.8\left(\frac{F_b s}{w}\right)^{1/2}$	$L = 10.95\left(\frac{F_b S}{w}\right)^{1/2}$
Plywood	$L = 9.8\left(\frac{F_b KS}{w}\right)^{1/2}$	$L = 9.8\left(\frac{F_b KS}{w}\right)^{1/2}$	$L = 10.95\left(\frac{F_b KS}{w}\right)^{1/2}$
Shear			
Wood	$L = 16\frac{F_v A}{w} + 2d$	$L = 12.8\frac{F_v A}{w} + 2d$	$L = 13.3\frac{F_v A}{w} + 2d$
Plywood	$L = 24\frac{F_s\, Ib/Q}{w} + 2d$	$L = 19.2\frac{F_s\, Ib/Q}{w} + 2d$	$L = 20\frac{F_s\, Ib/Q}{w} + 2d$
Deflection	$L = 5.51\left(\frac{EI\Delta}{w}\right)^{1/4}$	$L = 6.86\left(\frac{EI\Delta}{w}\right)^{1/4}$	$L = 6.46\left(\frac{EI\Delta}{w}\right)^{1/4}$
If $\Delta = \frac{L}{180}$	$L = 1.72\left(\frac{EI}{w}\right)^{1/3}$	$L = 2.31\left(\frac{EI}{w}\right)^{1/3}$	$L = 2.31\left(\frac{EI}{w}\right)^{1/3}$
If $\Delta = \frac{L}{240}$	$L = 1.57\left(\frac{EI}{w}\right)^{1/3}$	$L = 2.10\left(\frac{EI}{w}\right)^{1/3}$	$L = 1.94\left(\frac{EI}{w}\right)^{1/3}$
If $\Delta = \frac{L}{360}$	$L = 1.37\left(\frac{EI}{w}\right)^{1/3}$	$L = 1.83\left(\frac{EI}{w}\right)^{1/3}$	$L = 1.69\left(\frac{EI}{w}\right)^{1/3}$

From National Design Specification for Wood Construction 1991

Notation:

L = length of span, center to center of supports (in.)

F_b = allowable unit stress in bending (psi)

$F_b KS$ = plywood section capacity in bending (lb _ in./ft)

F_c = allowable unit stress in compression parallel to grain (psi)

$F_{c\perp}$ = allowable unit stress in compression perpendicular to grain (psi)

$F_s \, Ib/Q$ = plywood section capacity in rolling shear (lb/ft)

F_v = allowable unit stress in horizontal shear (psi)

f_c = actual unit stress in compression parallel to grain (psi)

$f_{c\perp}$ = actual unit stress in compression perpendicular to grain (psi)

f_t = actual unit stress in tension (psi)

A = area of section (in.2)*

E = modulus of elasticity (psi)

I = moment of inertia (in.4)*

P = applied force (compression to tension) (lb)

S = section modulus (in.3)*

Δ = deflection (in.)

b = width of member (in.)

d = depth of member (in.)

w = uniform load per foot of span (lb/ft)

*For a rectangular member: $A = bd$, $S = bd^2/6$, $I = bd^3/12$.

3.17 Wall Formwork Design

This chapter presents a design method for all-wood concrete wall forms. This procedure was formulated to provide for a safe wall form design for all components. The design methodology is based on loads recommended by ACI-347-1994 and stresses values recommended by NDS-1991 and APA 1997.

3.17.1 Wall Form Components

A wall form is usually made up of sheathing, studs, wales, ties, and bracing as shown in Figure (3.3)(Section 3.4.3) . The fresh concrete places a lateral pressure on the sheathing, which is supported by studs. Studs behave structurally as a continuous beam with many spans supported on walls. Wales, in turn, are assumed to act as a continuous beam that rests on ties. Ties finally transmit concrete lateral pressure to the ground.

3.17.2 Design loads:

The pressures exerted on wall forms during construction need to be carefully evaluated in the design of a formwork system. Loads imposed by fluid concrete in walls and columns are different from gravity loads produced on slab forms. Fresh concrete exhibits temporary fluid properties until the concrete stiffens sufficiently to support itself.

- ***Lateral Pressure of Concrete Forms for Wall***

Formwork should be designed to resist the lateral pressure loads exerted by the newly placed concrete in the forms. If concrete is placed rapidly in wall or column forms, the pressure can be equivalent to the full liquid head pressure. This requires that rate of placement exceed the initial set time of the concrete mix. Excessive deep vibration can liquefy the initial set of concrete within the effective coverage of the vibrations. Retarded additives or cool weather can also delay the initial set and result in higher than anticipated lateral pressure. The formula for wall pressure established by the American Concrete Institute (ACI-347) considers the mix temperature and the rate of placement of concrete. The rate of placement is expressed in terms of feet per hour of concrete rise in the forms. Table (3.6) shows pressure values for concrete walls of different temperature and rate of filling.

Table (3.6): Pressure Values for Concrete Walls: Relation among the Rate of Filling Wall Forms, Maximum Pressure, and Temperature (ACI)

Rate of filling form , ft/h	Maximum concrete pressure , Ib/ft2						
	Temperature , F°						
	40	50	60	70	80	90	100
1	375	330	300	279	262	250	240
2	600	510	450	409	375	350	330
3	825	690	600	536	487	450	420
4	1050	870	750	664	600	550	510
5	1275	1050	900	793	712	650	600
6	1500	1230	1050	921	825	750	690
7	1725	1410	1200	1050	933	850	780
8	1793	1466	1246	1090	972	877	808
9	1865	1522	1293	1130	1007	912	836
10	1935	1578	1340	1170	1042	943	864
15	2185#	1858	1573	1370	1217	1099	1004
20	2635#	2138#	1806	1570	1392	1254	1144

 # These values are limited to 2000Ib/ft3

1. For columns and walls with rate of placement less than 7 ft/h (2.1m/h)

$$p = 150 + \frac{9000R}{T} \qquad (3.16)$$

With a maximum of 3000 psf (1.47 Kgf/cm2) for columns, 2000 psf (0.98 Kgf/cm2) for walls, a minimum of 600 psf (0.29 Kgf/cm2), but no greater than $150h$ $(0.24h_{st})$.

Where :

p = Lateral pressure (Ib/ft2)

R = rate of placement, ft/h

T = temperature of concrete in the form F°

h = height of the form, or the distance between construction joints, ft

Or

$$p_M = 0.073 + \frac{8.0R_{st}}{T_c + 17.8} \quad \text{(metric equivalents)} \qquad (3.17)$$

Where :

p_M = lateral pressure, Kgf/ cm2

R_{st} = rate of placement, m/h

T_c = temperature of concrete in the forms, C°

h_{st} = height of fresh concrete above point considered, m

2. For walls with rate of placement of 7 to 10 ft/h (2 to 3 m/h):

$$p = 150 + \frac{43{,}400}{T} + \frac{2800R}{T} \qquad (3.18)$$

0r

$$p_M = 0.073 + \frac{11.78}{T_c + 17.8} + \frac{2.49R_{st}}{T_c + 17.8} \quad \text{(metric equivalents)} \qquad (3.19)$$

With a maximum of 2000 psf {0.98 Kgf/cm2}, a minimum of 600 psf {0.29 Kgf/cm2}, but no grater than $150h$ ($0.24h_{st}$).

3. For rate of placement > 10 ft/h :

$$p = 150h \qquad (3.20)$$

Or

$$p_M = 0.24h_{st} \quad \text{(metric equivalents)} \qquad (3.21)$$

The above three formulas can only be applied if concrete satisfies the following condition:

- Weight 150 pcf (2403 Kg/m3).
- Contains no admixtures.
- Has a slump of 4in. (100 mm) or less.
- Uses normal internal vibrator to a depth of 4ft (1.22 m) or less.

If concrete is pumped from the base of the form, the form should be designed to resist the lateral hydrostatic pressure of fresh concrete plus minimum allowance of 25 percent to account for pump surge. Caution must be taken when using external vibration or concrete made with shrinkage-compensating or expansive cements as pressure higher than the hydrostatic pressure is expected to occur. It is a good practice to reduce the allowable stresses to half its original value when using external vibrators.

❖ ***Horizontal Loads:***

Braces should be designed to resist all foreseeable horizontal loads, such as seismic forces, wind, cable tension, inclined supports, dumping of concrete, etc.

Wall form bracing must be designed to meet the minimum wind load requirements of ANSI A58.1 or the local design building code, whichever is more stringent. For exposed wall, the minimum wind design load should not be less than 15 psf. Bracing for wall forms should be designed for a horizontal load of at least 100lb per lineal foot of the wall, applied at the top.

3.18 Method of Analysis

Step 1: The procedure for applying equations of Tables 3.15 and 3.16 (Appendix B) to the design of sheathing is to consider a strip of 1 ft depth (consider the lower 1 ft of sheathing where concrete lateral pressure is maximum). Determine the maximum allowable span based on the allowable values of bending stress, shear stress, and deflection. The lowest value will determine the maximum spacing of studs.

Step 2: Based on the selected stud spacing, the stud itself is analyzed to determine its maximum allowable spacing. The studs are subject to uniform pressure resulting from the fresh concrete. This pressure is resisted first by the sheathing which in turn transfer the loads to studs. The selected stud span will be the spacing of the wales.

Step 3: Based on the selected stud spacing, the maximum wale spacing (distance between horizontal supports or ties) can be determined using the same procedure. For simplicity and economy of design, this maximum span value is usually rounded down to the next lower integer or modular value when selecting the spacing.

3.19 Stresses Calculations

After appropriate design loads are calculated, the sheathing, studs, and wales are analyzed in turn, considering each member to be a uniformly loaded beam supported in one of the three conditions (single span, two spans, or three or more spans) to determine the stresses developed in each member. Vertical supports and lateral bracing must be checked for compression and tension stresses. Except for sheathing, bearing stresses must be checked at supports to ensure safety against buckling. Using the methods of engineering mechanics, the maximum values of bending moment, shear, and deflection developed in a uniformly loaded beam of uniform cross section is shown in Tables 3.15 to 3.17(Appendix B).

The maximum fiber stresses in bending, shear, and compression resulting from a specified load may be determined from the following equations:

Bending : $$f_b = \frac{M}{S} \tag{3.22}$$

Shear : $$f_v = \frac{1.5V}{A}$$ for rectangular wood members

$$= \frac{V}{Ib/Q} \tag{3.23}$$

Compression : $$f_c \text{ or } f_{c\perp} = \frac{P}{A} \tag{3.24}$$

Tension : $$f_t = \frac{P}{A} \tag{3.25}$$

Where : $f_b, f_v, f_{c\perp}, f_c\, f_t$ are as defined before in the NDS tables

And

A = section area, in^2

M = maximum moment, in.-lb

P = concentrated load, lb

S = section modules, in^3

U = maximum shearing force, lb

Ib/Q = rolling shear constant, in^2/ft

3.20 Determination of Maximum Allowable Span

Maximum span corresponding to bending, shear, and deflection can be directly obtained using equations given in Table (3.6) . As previously mentioned, the maximum allowable design value for the span will be the smallest one rounded it to the next lower integer or modular value.

3.21 Design of Lateral Bracing

For wall forms, lateral bracing is usually provided by inclined rigid braces. Bracing is usually required to resist wind loads and other horizontal loads. Since wind load may be applied in either direction, braces must be arranged on both sides of the forms. When rigid braces are used, they may be placed on one side of the form if designed to resist both tension and compression. Figure (3.12) gives a visual example of form bracing.

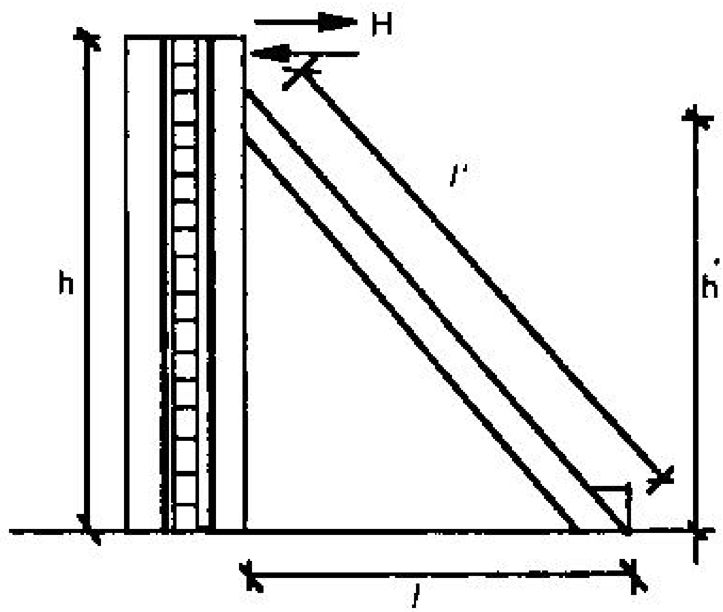


Figure (3.12): Bracing of formwork

- ***Design Load***

Design load for bracing can be calculated using the following equations:

$$p^{\backslash} = \frac{Hhl}{h^{\backslash} l^{\backslash}} \tag{3.26}$$

$$L = \left[h^{\backslash 2} + l^{\backslash 2}\right]^{1/2} \tag{3.27}$$

Where :

p\ = strut load per foot of the form, Ib/ ft

H = Lateral load at the top of the form , Ib/ ft

h = Height of the form , ft

h\ = Height of the top of strut , ft

L = Length of strut , ft

L\ = Horizontal distance from bottom of strut to form (ft)

❖ *Design Procedure*

1\ Start design by selecting a certain strut size such that it satisfies

$$\frac{l}{d} \leq 50$$

Where :

d = the least dimension of the cross section of the selected strut.

2\ Calculate Euler's critical buckling stress for column F_{cE} as follows:

$$F_{cE} = \frac{K_{cE} E^{\backslash}}{\left(L_e / d \right)^2} \qquad (3.28)$$

where :

$K_{cE} = 0.3$ for visually graded lumber (also used in form design)

3\ Calculate the limiting compressive stress in column at zero slenderness ratio F_c^* from the equation:

$$F_c^* = F_c (C_D)(C_M)(C_t)(C_F) \qquad (3.29)$$

Where :

C_D, C_M, C_t, C_F are defined tables (see Tables 3.4a,b, 3.7, and 3.8)(Appendix B)

4\ Calculate the column stability factor C_p from the formula:

$$C_p = \frac{1 + \frac{F_{CE}}{F_{CE}^{*}}}{2 * 0.8} - \sqrt{\left(\frac{1 + \frac{F_{CE}}{F_{CE}^{*}}}{2 * 0.8} \right)^2 - \frac{\frac{F_{CE}}{F_{CE}^{*}}}{0.8}} \qquad (3.28)$$

5\ The allowable compressive stress $F_c^{/}$ in the strut is given by :

$$F_c^{/} = F_c^{*}\left(C_p\right) \qquad (3.29)$$

6\ If $F_c^{/} \prec F_{cE}$, this means that the selected cross section is not enough to resist buckling. So increase the size of the cross section and go iteratively through steps 1 to 6 until you get $F_{cE} \prec F_c^{/}$.

7\ The maximum load that can be carried by the strut is the product of $F_c^{/}$ and the actual (not the nominal) cross sectional area of the selected strut.

8\ The maximum spacing of struts in feet that can be carried by one strut is obtained by dividing the maximum load by strut load per foot.

It should be noted that the strut usually carries compression or tension force depending on the direction of the horizontal load applied to the form. Those two forces are equal in magnitude but differ in their sign. Designing struts as compression members usually ensures that they are safe also in tension because we are considering an additional precaution against buckling associated with compression.

3.22 Columns Formwork Design

Concrete columns are usually one of five shapes: square, rectangular, L-shaped, octagonal, or round. Forms for the first four shapes are generally made of Ply-form sheathing backed with either $2*4$ or $2*6$ vertical wood battens. Column clamps surround the column forms to resist the concrete pressure acting on the sheathing. Forms for round columns are usually patented forms fabricated of fiber tubes, plastic, or steel. However, all shapes of columns can be made of fiberglass forms.

An analysis of the cost of providing forms, including materials, labor for erecting and removing, and number of reuses, should be made prior to selecting the materials to be used.

3.22.1 Pressure on Column Forms

Determining the lateral pressure of the freshly placed concrete against the column forms is the first step in the design of column forms. Because forms for columns are usually filled rapidly, frequently in less than 60 minutes, the pressure on the sheathing will be high, especially for tall columns.

The American Concrete Institute recommends that formwork be designed for its full hydrostatic lateral pressure as given by the following equation:

$$P_m = wh \qquad (3.30)$$

Where : P_m = is the lateral pressure in pounds per square foot

w = is the unit weight of newly placed concrete in pounds per cubic foot

h = is the depth of the plastic concrete in feet

For concrete that is placed rapidly, such as in columns, h should be taken as the full height of the form. There are no maximum and minimum values given for the pressure calculated from Eq. (3.30).

For the limited placement condition of concrete with a slump 7 in. or less and normal internal vibration to a depth of 4 ft or less, formwork for columns may be designed for the following lateral pressure:

$$P_m = C_w C_c \left[150 + 9000R/T\right] \tag{3.31}$$

Where :

P_m = calculated lateral pressure, lb per sq ft

C_w = unit weight coefficient

C_c = chemistry coefficient

R = rate of fill of concrete in form, ft per hr

T = temperature of concrete in form, degrees Fahrenheit

Minimum value of P_m is $600C_w$, but in no case greater than wh

Applies to concrete with a slump of 7 in or less

Applies to normal internal vibration to a depth of 4 ft or less

Values for the unit weight coefficient C_w in Eq. (3.31) are shown in Table 3-1 (Appendix B) and the values for the chemistry coefficient C_c are shown in Table 3-2(Appendix B). The minimum pressure in Eq. (3.31) is 600 C_w lb per sq ft, but in no case greater than wh.

3.22.2 Designing Forms for Square or Rectangular Columns:

Figure (3.13) illustrates a form for a representative square column, using sheathing and patented column clamps. If the thickness of the sheathing is selected, the design consists of determining the maximum safe spacing of the column clamps, considering the pressure from the concrete and the strength of the sheathing. The strength of the sheathing must be adequate to resist bending and shear stresses, and it must be sufficiently rigid so that the deflection will be within an acceptable amount, usually less than l/360 or 1⁄16 in.

As illustrated in Figure 3.14b, it is assumed that the magnitude of the pressure on a given area of sheathing will vary directly with the depth of the area below the surface of the concrete. For concrete weighing 150 lb per cu ft, the maximum pressure is given by Eq. (3.30).

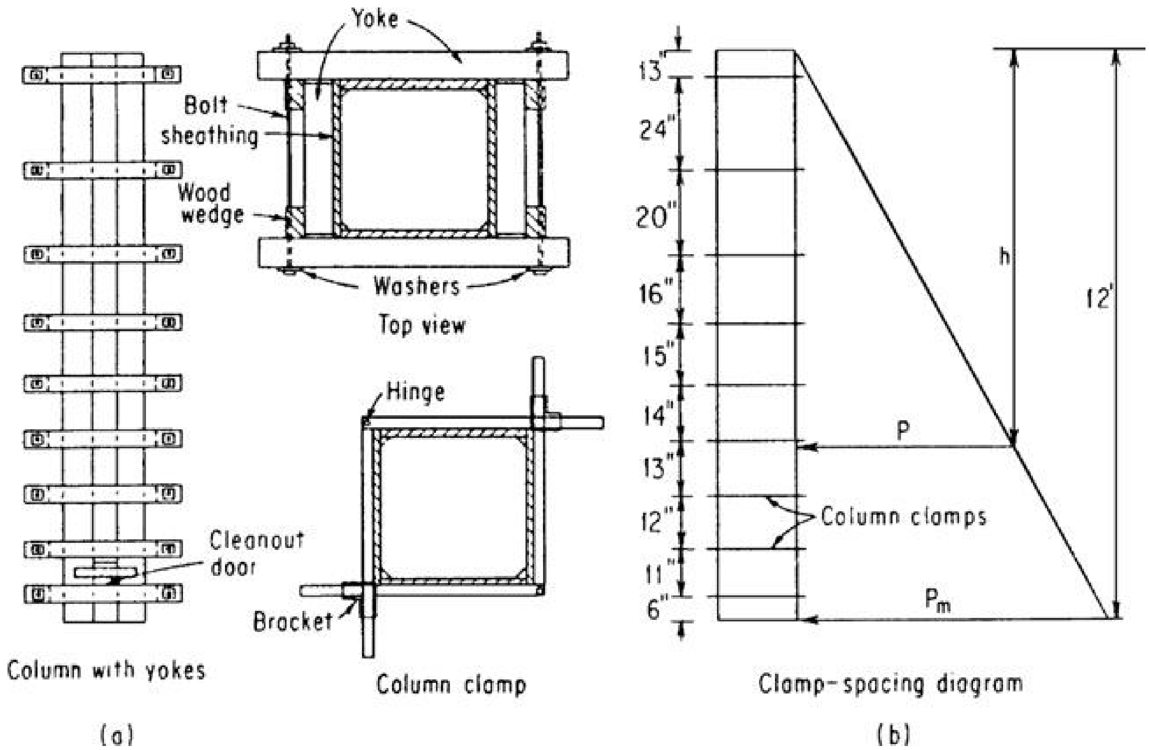


Figure (3.13): Forms for Square Column

For lumber, the allowable span lengths with multiple supports are as follows:

For Bending:

$$l_b = \left[120 F_b \, S / w\right]^{1/2} \tag{3.32}$$

For Shear:

$$l_v = 192 F_v \, bd / 15w + 2d \tag{3.33}$$

For Deflection :

$$l_\Delta = \left[1{,}743\, EI \big/ 360w\right]^{1/3} \qquad \text{for } \Delta = l/360 \qquad (3.34)$$

For Deflection :

$$l_\Delta = \left[1{,}743\, EI \big/ 16w\right]^{1/4} \qquad \text{for } \Delta = 1/16 \text{ in} \qquad (3.35)$$

For Plyform , the allowable span lengths with multiple supports are as follows:

For Bending:

$$l_b = \left[120 F_b\, S_b \big/ w_b\right]^{1/2} \qquad (3.36)$$

For Shear:

$$l_s = \frac{20 F_s \left(Ib/Q\right)}{w_s} \qquad (3.37)$$

For Deflection:

$$l_d = \left[1{,}743\, EI \big/ 360 w_d\right]^{1/3} \qquad \text{for } \Delta = l/360 \qquad (3.38)$$

For Deflection:

$$l_d = \left[1{,}743\, EI \big/ 16 w_d\right]^{1/4} \qquad \text{for } \Delta = 1/16 \text{ in} \qquad (3.39)$$

Equations (3.32) to (3.39) may be used to calculate the maximum spacing of column clamps and yokes, based on the strength and deflection criteria of the sheathing.

3.22.3 Sheathing for Column Forms

Sheathing for job-built square or rectangular columns may be constructed with S4S dimension lumber or plywood. Using only S4S lumber as sheathing is not a common practice today, but it has been in the past. When plywood is used as column sheathing, it is backed with vertical wood battens, laid flat on the outside of the plywood, to permit a larger spacing between column clamps than could be provided by plywood spanning only.

For round columns, the common types of forms are fiber tubes, fiberglass, or steel forms. Fiber tubes are lightweight and easily handled, but may only be used once. Fiberglass column forms may be reused, but may occasionally require some repair or Maintenance. Steel column forms are heavier than fiber tubes or fiberglass forms, but may be reused many times without requiring repairs.

3.22.4 Tables for Determining the Maximum Span Length of Ply-form Sheathing:

Table (3.7) (Appendix C) gives the maximum span lengths using Eqs. (3.36) to (3.39) for Class I Ply-form with short-duration load, less than 7 days. The values are shown for single span, two spans, and multiple spans applications. The maximum span lengths for the Ply-form sheathing shown in Table(3.7) (Appendix C) applies to conditions where the panels are installed in the vertical direction; therefore, the panels are placed in the weak direction for transferring the concrete pressure horizontally between vertical wood battens.

The span length is the maximum permissible horizontal distance between the vertical battens that are used to support the panels.

Table(3.8) (Appendix C) gives the maximum span lengths using Eqs. (3.36) to (3.39) for Class I Plyform with short-duration load, less than 7 days. The values are shown for single span, two spans, and multiple spans applications. The maximum span lengths for the Plyform sheathing shown in Table (3.8) (Appendix C) applies to conditions where the panels are installed in the horizontal direction; therefore, the panels are placed in the strong direction for transferring the concrete pressure horizontally between vertical wood battens. The span length is the maximum permissible horizontal distance between the vertical battens that are used to support the panels.

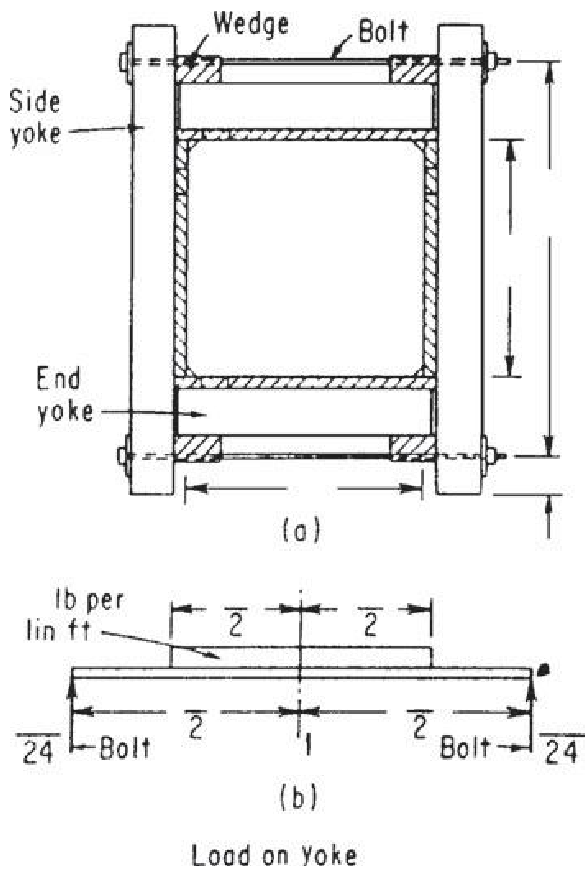
3.22.5 Column Clamps for Column Forms:

Column clamps that provide support for the sheathing of column forms may be constructed of wood yokes or steel clamps. Wood yokes are not as commonly used today as they have been in the past.

Several types of attachments and locking devices are available from numerous manufacturers, which may be used to secure the composite plywood and stud forming system. These formwork accessories include patented steel clamps, which are attached with wedge bolts, and cam-locks, which attach horizontal walers on the outside of the vertical studs.

3.22.6 Design of Wood Yokes for Columns:

Wood yokes may be made from 2 × 4, 3 × 4, or 4 × 4, or larger pieces of lumber, assembled around a column, as illustrated in Figure (3.14).Two steel bolts are installed through holes to hold the yoke members in position. The members are designed as side yokes (A) and end yokes (B). The members must be strong enough to resist the forces transmitted to them from the concrete through the sheathing.



Figure(3.14): Column forms with wood yokes

End yoke B is held against the sheathing by two hardwood wedges, which act as end supports for a simple beam subjected to a uniform load. Consider the two wedges to be x in. apart, producing a span equal to x. Let the spacing of the yokes be equal to l in. Let p equal the pressure on the sheathing in pounds per square foot. The uniform load on the yoke will then be:

$$w = {pl}/{12} \text{ lb per lin ft} \qquad (3.40)$$

The bending moment at the center of the yoke will be:

$$M = {wx^2}/{96} \text{ in.-lb} \qquad (3.41)$$

$$= \left({pl}/{12}\right)\left(x^2\right)/96$$

$$= {plx^2}/{1152} \qquad (a)$$

The resisting moment will be:

$$M = F_b S \qquad (b)$$

Equating (a) and (b) gives :

$$F_b S = {Plx^2}/{1152}$$

$$S = {Plx^2}/{1152F_b} \qquad (3.42)$$

Where: S is the required section modulus of end yoke B, in.3

Side yoke A, illustrated in Figure (3.14b), is a simple beam, subjected to a uniform load equal to w lb per lin ft over a distance equal to x in the midsection of the beam. The two bolts, spaced y in.

apart, are the end supports, each subjected to a load equal to $wx/24$ lb. Summing moments about Point 1,

$$M = \left(wx/24\right)\left(y/2\right) - \left(wx/24\right)\left(x/4\right) \tag{3.43}$$

Substituting $Pl/12$ for w in the above equation, the applied moment is:

$$M = \left(Plx/12(24)\right)\left(y/2\right) - \left(Plx/(12)(24)\right)\left(x/4\right)$$

$$= Plxy/576 - Plx^2/1152$$

$$M = Plx(2y-x)/1152 \tag{c}$$

The resisting moment will be :

$$M = F_b S \tag{d}$$

Equating (c) and (d) gives :

$$F_b S = Plx(2y-x)/1152$$

Solving for S, we get :

$$S = Plx(2y-x)/1152F_b \tag{3.44}$$

Where S is the required section modulus for side yoke A, in^3

3.22.7 Steel Column Clamps with Wedges

Figure (3.15) illustrates a steel column clamp for forming square or rectangular columns. One set of clamps consists of two hinged units, which permits fast assembly with positive locking attachments by steel wedges. This clamp is available in a 36-in. and a 48-in. overall side bar length and can be adjusted to any fraction of an inch. The

36-in. size clamp with flat 2 × 4 s can form up to a 24-in.-square column. The 48-in. size with the same lumber will form a 36-in.-square column. Both clamps will form rectangular columns, ranging from 8 to 24 in. for the smaller size clamps and from 12 to 36 in. for the larger size clamps.

Steel wedges are used to attach and secure the column clamps. The clamps automatically square the column as the wedge is tightened. To prevent twisting of the column forms, the clamps should be alternated 90° as shown in Figure (3.15) .

Column forms are often made with .-in.-thick Plyform and either 2 × 4 s or 2 × 6 s placed flat against the outside of the Plyform. The spacing of column clamps is governed by deflection of both the lumber and the clamps. Table(3.9) provides clamp spacing s for this steel column clamp. Column clamp deflection is limited to $^{l}\!/_{270}$ and

a concrete temperature of 70°F. The spacing shown are for the column clamps only. Additional checks of the sheathing must be performed to determine the limiting clamp spacing based on the strength and deflection and of the sheathing.

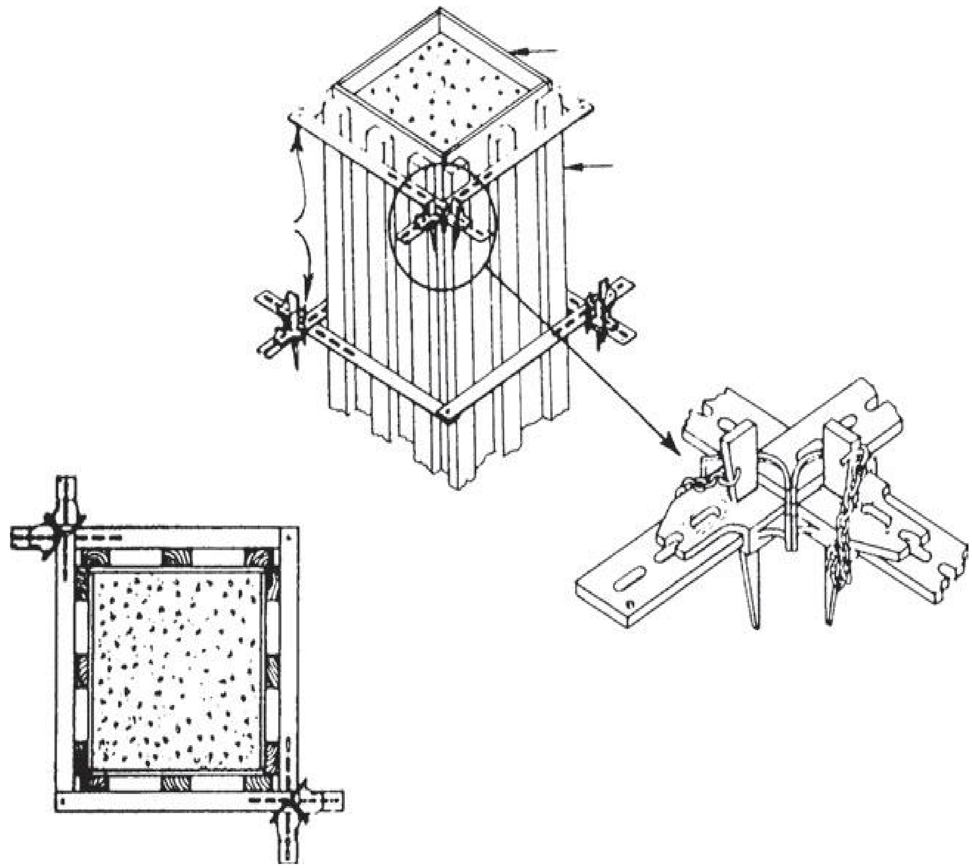


Figure (3.15): Column form with steel clamps and steel wedges