Chapter 7
Formwork for Concrete Structures (قوالب المنشآت الكونكريتية)

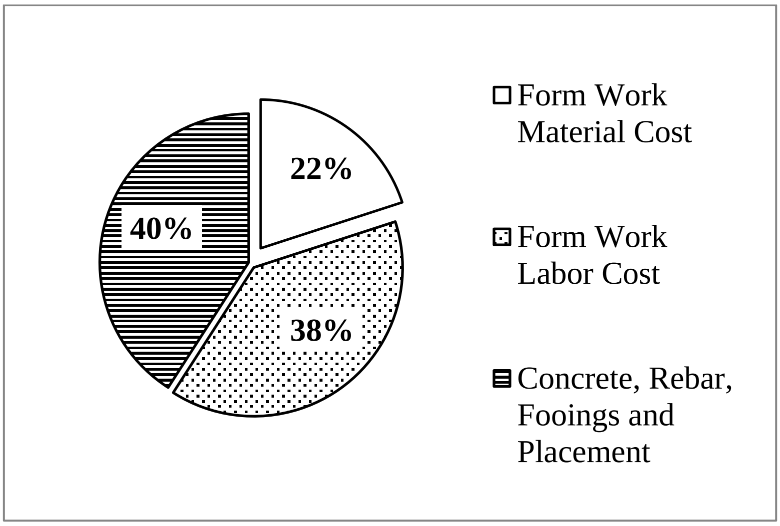
7.1. Introduction:

Formwork development has paralleled the growth of concrete construction throughout the 20th century. Forms mold the concrete to desired size and shape. But formwork is more than a mold; it is a temporary structure that supports its own weight, plus the freshly placed concrete, until it gains sufficient strength to support itself, plus construction live loads (including materials, equipment, and personnel). The basic objectives in form building are:

1. Quality: In terms of strength, rigidity, position, and dimensions of the forms.
2. Safety: for both the workers and the concrete structure
3. Economy: the least cost consistent with quality and safety requirements.

Cooperation and coordination between engineer/architect and the contractor are necessary to achieve these goals.

Economy is a major concern since formwork costs constitute up to 60% of the total cost of concrete work in a project (Figure 7-1).



(Fig. 7-1) - Pie Chart of Cost Components in a Typical Concrete Construction

Therefore any effort to effect economy in concrete structures should be concentrated on reducing the cost of forms.

7.2. Form Requirement:

It is necessary to use forms to confine and support the concrete until it is rigid and self-supporting. So forms for concrete structures should be:

1. Strong enough to resist the pressure or the weight of the fresh concrete plus any superimposed loads.
2. Rigid enough to retain the shape without undue deformation.
3. Economical in terms of the total cost of the forms, concrete and surface finishing, when required.

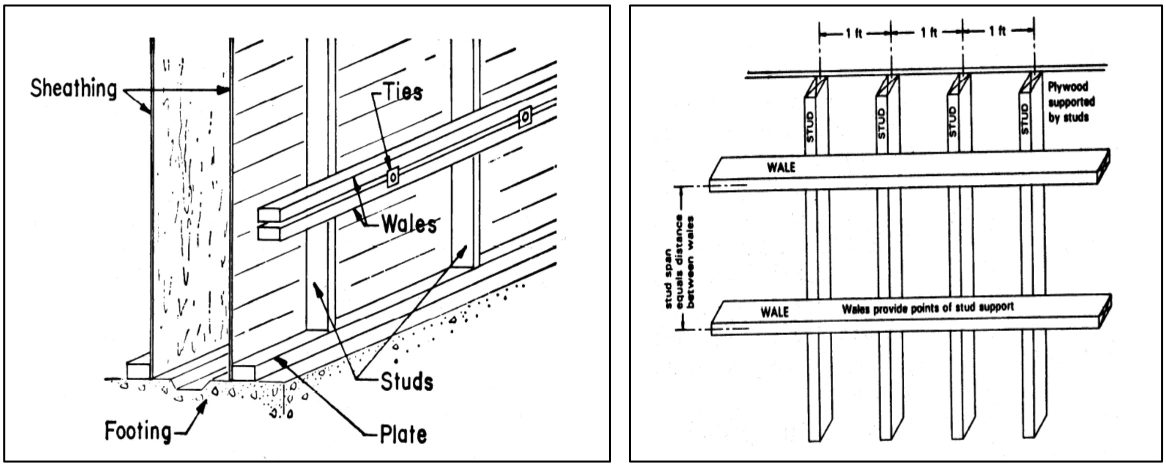
So, forms should be designed by a person who has knowledge of forces and strength of material.

If the concrete surface must be free from marks and smooth, it may be economical to use expensive sheathing materials (such as new plywood) for the exposed surface, while for the back surface any cheap material may be used, but it must be strong enough to resist the pressure of concrete.

7.3. The Cost of Form:

The chief items affecting the cost of form are materials and labor of erecting and removing forms.

Practically all formwork jobs require some lumber. Pine and Douglas fir are widely used in structural concrete forms. They are easily worked and are the strongest in the softwood group. Both hold nails well and are durable. They are used in sheathing, studs, and wales. In addition to lumber, materials include steel, nails, bolts and connectors such as wall ties, etc. (Figure 7-2) shows a typical wall form with its components.



(Fig. 7-2) - A Typical Wall Form with Parts of its Components.

If the materials used to make a form can be used more than once, the cost per use may be relatively low. But, if the materials are for a single use, then the cost will be high.

A concrete wall form may require (3 m^3) of lumber, costing \$0.1per m^3, for each square meter of exposed surface. If lumber can be used only once, the cost will be \$0.3 for each square meter, whereas, if it can be used 10 times the cost will be \$0.03 for each square meter.

The cost of labor includes the cost of making, erecting and removing the forms. If forms can be fabricated into shapes that can be reused several times, by simply reassembling the components parts, the labor cost of fabricating will occur once. For successive uses, the labor cost will involve erection and removal only.

Example 7-1:

Compare the cost of lumber and labor for (100 m^2) of forms to construct concrete columns based on using the form once versus using them 6 times. The forms will be assembled with adjustable clamps, dressed and matched (D and M) sheathing is used; it will require 1.7 m^3 of lumber per square meter of exposed surface, costing (0.1 \$/m^3); make use of the following information:

Carpenter's fees (for making & erecting): 2.5 \$/hr

Carpenter's time (for making): 3hr/100m^2

Carpenter's time (for erecting): 6hr/100m^2

Helpers' fees (for making, erecting & removing):1.25 \$/hr

Helpers' time (for making): 1hr/100m^2

Helpers' time (for erecting & removing): 5hr/100m^2

Solution:

1. For single use, assuming no salvage value for the lumber the cost will be:

Lumber Quantity:	100 m^2 × 1.7 m^3/m^2= 170 m^3
Lumber Cost:	170 m^3 × 0.1\$/ m^3= 17 \$
Carpenter's Making Time:	100m^2 × 3hr/ 100m^2= 3 hr
Carpenter's Making Cost:	3 hr × 2.5 \$/hr = 7.5 \$
Carpenter's Erecting Time:	100m^2 × 6hr/ 100m^2= 6 hr
Carpenter's Erecting Cost:	6 hr × 2.5 \$/hr = 15 \$
Helpers' Making Time:	100m^2 × 1hr/ 100m^2= 1 hr
Helpers' Making Cost:	1 hr × 1.25 \$/hr = 1.25 \$
Helpers' Erecting & Removing Time:	100m^2 × 5hr/ 100m^2= 5 hr
Helpers' Erecting & Removing Cost:	5 hr × 1.25 \$/hr = 6.25
Total Cost = 17+7.5+15+1.25+6.25= 47 \$	
Cost per one square meter = 47/100 = 0.47 \$/m^2	

2. For 6 times use, assuming no salvage value for the lumber the cost will be:

From the previous part for single use:	
Lumber Cost:	= 17 $
Carpenter's Making Cost:	= 7.5 $
Helpers' Making Cost:	= 1.25 $
Cost of erecting & removing for 6 times:	
Carpenter's Erecting Cost:	= 6×15 = 90 $
Helpers' Erecting & Removing Cost:	= 6×6.25 = 37.5 $
Total Cost = 17+7.5+1.25+90+37.5= 153.25 $	
Cost per one square meter = 153.25/600 = 0.26 $/m^2	

Or:

From the previous part for single use:	
Total cost for single use	= 47 $
For five additional uses:	
Carpenter's Erecting Cost:	= 5×15 = 75 $
Helpers' Erecting & Removing Cost:	= 5×6.25 = 31.25 $
Total Cost = 47+75+31.25= 153.25 $	
Cost per one square meter = 153.25/600 = 0.26 $/m^2	

The previous example illustrates the effect which multiple uses of forms have on the cost of forms per use. The reduction frequently is sufficient to justify designing a structure with members having the same size even though loading conditions might permit the use of smaller members for a portion of the structure.

7.4. Designing a Project for Economic Forms :

The designer must have a reasonable knowledge of the cost of forms; the steps which a designer can take to effect economy in concrete forms are the following:

1. Reduce the number of irregular shapes in the structure.
2. Duplicate the sizes and shapes of members in the structure to permit the reuse of forms.
3. Design structural members to permit the use of commercial forms available in the market.

4. Have the preliminary plans to suggest methods of reducing the cost of forms without sacrificing the quality of the structure.
5. Allow the use of construction joints to permit the reuse of forms.
6. Consider the use of tilt-up and slip forms or any other economic cost-saving methods in constructing a project.
7. Permit the constructor to remove and reuse the forms as soon as it is safe to do so.

7.5. Constructing a Project for Economic Forms :

The steps which a constructor can take to effect economy in concrete forms are the following:

1. Design the forms to provide adequate but not excessive strength and rigidity.
2. Fabricate the forms into sizes that permit more reuses without refabricating.
3. Prepare working drawings for all forms prior to fabricating them.
4. Fabricate form sections on the ground using power equipment in order to reduce labor costs and any unnecessary delay on the job. Workers are much more efficient when working on the ground than when working on scaffolds.
5. Use the most economical materials to fabricate forms.
6. Use the minimum amount of nails needed to insure connecting forms in a safe way.
7. Remove forms as soon as it is permissible then clean and oil forms after each use.
8. Install construction joints to reduce the quantity of form material required, and to permit the carpenter to work more continuously.

7.6. Form Materials and Accessories:

- Practically all formwork jobs require some lumber. Yellow pine and Douglas fir are widely used in structural concrete forms. They are easily worked and are the strongest in the softwood group. Both hold nails well and are durable. They are used in sheathing, studs, and wales.
- Steel and aluminum may be used in structural concrete forms separately or in combination with lumber.
- If the material will be used only for a few times, lumber is usually more economic than steel or aluminum, but if the forms are intended to be used repeatedly, steel or aluminum seem better.

- Sometimes steel is used to fabricate forms as a matter of expediency, such as forms for round columns, curved surfaces, tunnels, etc.

Table (7-1) shows the properties of various kinds of lumber used for forms. These properties are based on using lumber of a quality not lower than the specified grade. If a lower-grade lumber is used, the working stresses should be reduced to values which are safe for that particular grade.

The stresses mentioned are higher than those permitted in permanent structures, because they have an adequate factor of safety for forms.

Table (7-1) – Properties of Various Kinds of Lumber Used in Form Construction*

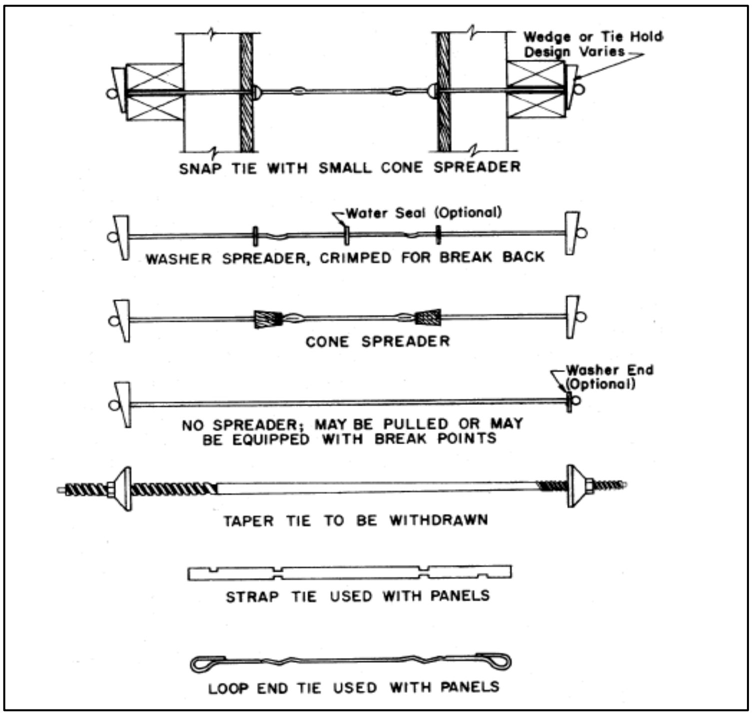
Kind of Lumber	Safe working stresses, (kN/m^2) ×1000				
	Extreme Fiber in Bending (f)	Compression Perpendicular to Grain	Compression Parallel to Grain	Horizontal Shear (v)	Modulus of Elasticity (E)
Douglas Fir, Coast Region** No.1 Grade	12.4	3.4	10.3	1.0	11034.5
Hemlock, West Coast** No.1 Grade	12.4	3.1	9.2	0.9	9655.2
Larch, Common Structural Grade	12.4	3.4	11.4	1.0	10344.8
Pine, Norway Common Structural Grade	9.5	3.1	6.7	0.7	8275.9
Pine, Southern** No.1 Grade	14.7	3.9	12.1	1.3	11034.5
Pine, Southern** (Long Leaf) No.1 Grade	12.4	3.4	10.3	1.04	11034.5
Red Wood, Heart** Structural Grade	11.2	2.6	8.4	0.8	8275.9
Spruce, Eastern** Structural Grade	11.2	2.6	8.4	0.8	8275.9

* American Design Specifications for Stress-Grade Lumber, 1950, Recommended by National Lumber Manufacturers Association.

** Regions Mentioned in Table are in the United States of America.

7.6.1. Ties:

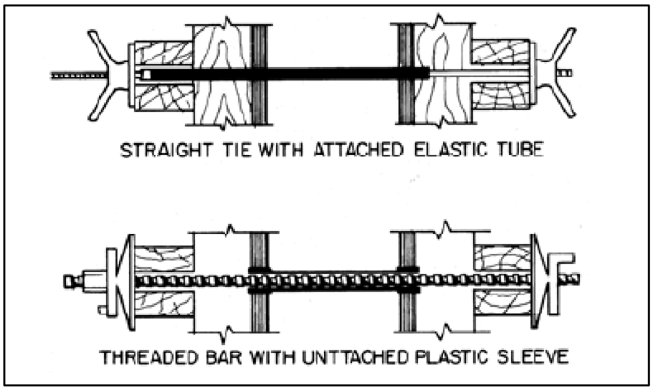
In order to secure concrete forms against the lateral pressure of unhardened concrete, a tensile unit called ***concrete form tie*** is used (they are also referred to as ***form clamps***, ***coil ties***, ***rod clamps***, etc.). They are ready-made units with safe load ratings and have an internal tension unit and an external holding device. (Figure 7-3) shows a typical single member tie.



(Fig. 7-3) – A Typical Single Member Ties

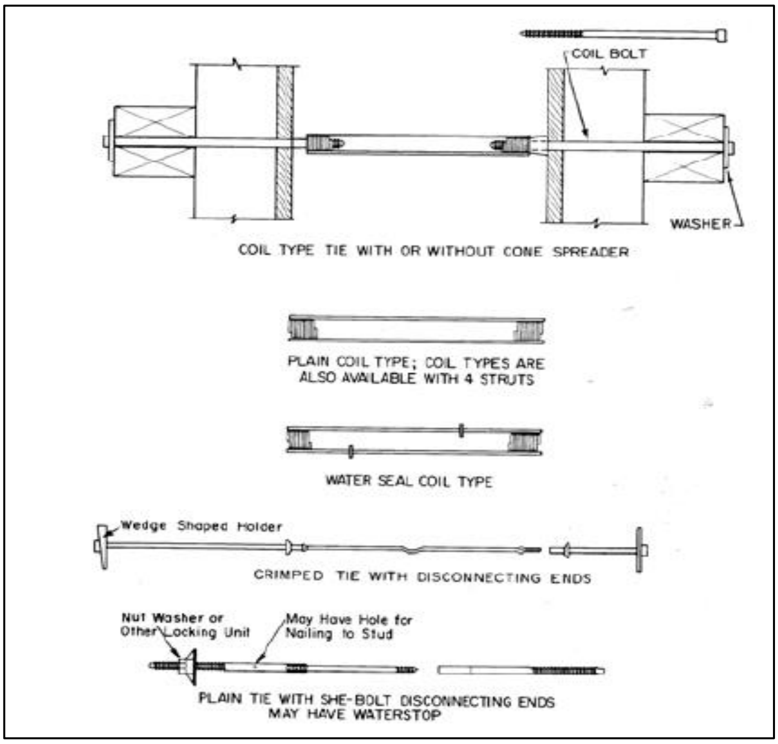
Ties are manufactured in two basic types:

1. ***Continuous single member ties***; in which the tensile unit is a single piece, have a special holding device added for engaging the tensile unit against the exterior of the form (Figure 7-4). It is generally used for lighter loads.



(Fig. 7-4) – A Continuous Single Member Tie

2. ***Internal disconnecting type ties***, in which the tensile unit has an inner part with threaded connections to removable external members generally, remain in the concrete as shown in (Figure 7-5). It is available for light or medium loads, but finds its greatest application under heavier construction loads.



(Fig. 7-5) – An Internal Disconnecting Ties

7.7. Design Loads in Concrete Formwork:

7.7.1. Pressure Produced by Concrete:

When concrete is placed into forms, it produces a pressure perpendicular to the surface of the form. This pressure is proportional to the density and the depth of the concrete in a liquid or semiliquid state. As the concrete sets, it changes from a liquid to a solid state, with a reduction in the pressure exerted on the forms.

The time for the initial set of the concrete varies with the temperature. The pressure is directly proportional with the rate of at which the forms are filled and inversely with the temperature of the concrete.

The American Concrete Institute recommends the following formulas for determining the maximum pressure produced by internally vibrated concrete on forms (P_m):

A. For walls:

1) If the placement rate $\left(R \leq 2.1 \text{ m/hr} \right)$, the pressure is the ***least*** of the following:

$$P_m = 7 + \frac{1414R}{1.8T + 32} \qquad \text{...... (7-1)}$$

$$P_m = \gamma_c \times h \qquad \text{...... (7-2)}$$

2) If the placement rate $\left(2.1 < R < 3 \text{ m/hr} \right)$, the pressure is the least of the following:

$$P = 7 + \frac{2079 + 440R}{1.8T + 32} \qquad \text{...... (7-3)}$$

$$P_m = 96 \ kN/m^2 \qquad \text{...... (7-4)}$$

$$P_m = \gamma_c \times h \qquad \text{...... (7-2)}$$

3) If the placement rate $\left(R \geq 3 \text{ m/hr} \right)$, the pressure is equal to:

$$P_m = \gamma_c \times h \qquad \text{...... (7-2)}$$

B. **<u>For Columns</u>**:

The pressure (measured in kN/m^2) is the least of the following:

1) $$P = 7 + \frac{1414R}{1.8T + 32} \qquad \text{...... (7-1)}$$

2) $$P_m = 144 \ kN/m^2 \qquad \text{...... (7-5)}$$

3) $$P_m = \gamma_c \times h \qquad \text{...... (7-2)}$$

Where:

P_m= maximum Pressure, kN/m^2.
R= Rate of Filling the forms, m/hr.
T= Temperature of Concrete, ^oC.

7.8. Fundamentals of Formwork Design:

The formwork design aims at designing a form that is strong enough to handle the calculated loads safely, and rigid enough to maintain its shape under full load. At the same time the builder or contractor wants to keep costs down by not overbuilding the form.

Sometimes, specifications limit the deflection of forms in order to eliminate objectionable bulges on the concrete surface.

Representable deflection limits might be (3 mm) or (1/270) of the span of the sheathing, studs or wales, $\left(\frac{1}{270} \times l_n \right)$.

* **The size and spacing of studs and wales will be governed by the stresses in bending and shear, while deflection may limit the maximum span for sheathing.**

In developing formulas for designing forms, the following symbols will be used:

w =	Uniform Load kN/m .L
w′ =	Uniform Load, kN/m^2
p =	Pressure, kN/m .L
p′ =	Pressure, kN/m^2
k =	Safe Load on Shore, kN
l =	Span from Center to Center of Supports, mm
L =	Span from Center to Center of Supports, m
b =	Width of Member, m
h =	Depth of Member, m
g =	Unsupported Height of shore, m
f =	Extreme Fiber Stress due to Bending, kN/m^2
v =	Horizontal Shearing Stress, kN/m^2
V =	External Shear in a Member, kN
M =	Bending Moment in a Member, kN.m
M′ =	Resisting Moment of a Member, kN.m
I =	Moment of Inertia of a Member $= \frac{bh^3}{12}$, m^4
S =	Section Modulus of a Member $= \frac{bh^2}{6}$, m^3
E =	Modulus of Elasticity, kN/m^2
D =	Deflection of Member, mm

7.9. Typical Design Formulas:

Typically, the components of formwork are **sheathing**, **studs**, **joists**, **wales**, **stringers**, **shores**, and **tie rods**. **Sheathing** retains the concrete and is supported by ***studs*** in vertical forms and ***joists*** in horizontal forms. Studs are supported by ***wales*** and joists by ***stringers***. The wales are held in place by tension members such as ***tie rods*** and stringers are supported by ***shores*** or ***posts***. Other than tie rods and shores, the other components of the formwork structurally behave like beams, whether being horizontal or vertical. Beam formulas are used to analyze the formwork components. Below the formulas for bending, shear and deflection are introduced. From these formulas the quantities of (L), the safe span is calculated. In formwork design, ***the smallest value of* (*L*)** calculated for each category of bending, shear and deflection is used as ***the safe span that satisfies all conditions***.

7.9.1. Bending Formula:

For most forms, sheathing, studs and wales are continuous over several supports, and the maximum bending moment is given by the formula:

$$M = \frac{wL^2}{10} \qquad \text{...... (7-6)}$$

The resisting moment of a member is given by the formula:

$$M' = f \cdot S = \frac{fbh^2}{6} \qquad \text{...... (7-7)}$$

By equating formulas (7-6) and (7-7) and solving for L we get:

$$M = M' \Rightarrow \frac{wL^2}{10} = \frac{fbh^2}{6} \Rightarrow L^2 = \frac{10\, fbh^2}{6w}$$

$$L = 1.291 \times h \times \sqrt{\frac{fb}{w}} \qquad \text{...... (7-8)}$$

The maximum safe load per linear meter is given by the formula:

$$w = \frac{10\, fbh}{6L^2} \qquad \text{...... (7-9)}$$

7.9.2. Shearing Formula:

Shearing stresses in the member of form may govern the size of the member or the length of the span. This is especially true for short spans and heavy loads. The external shear, which occurs at a support, is given by the formula:

$$V = \frac{wL}{2} \qquad \text{...... (7-10)}$$

The maximum unit shearing stress is:

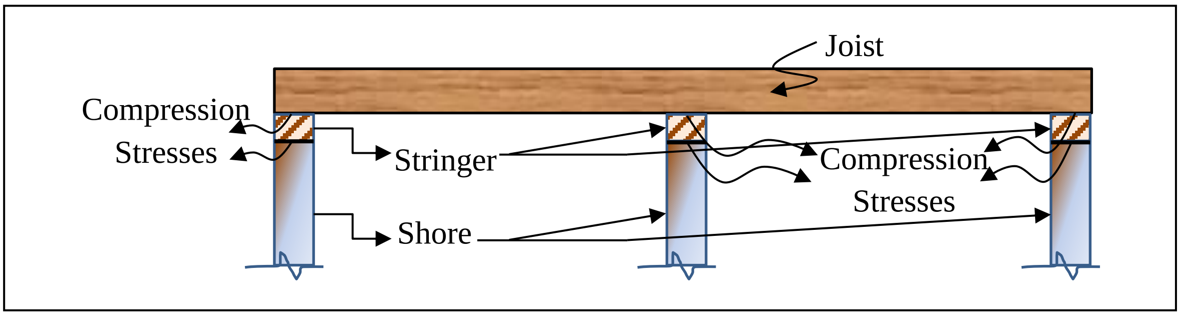
$$v = \frac{1.5V}{bh} \qquad \text{...... (7-11)}$$

or $v = \dfrac{1.5wL}{2bh}$ ***Solving for L,***

$$L = \frac{2vbh}{1.5w} \qquad \text{...... (7-12)}$$

7.9.3. Compression Stresses:

When joints rest on sills or studs bear against wales, the areas of contacts are subjected to ***Compression Stresses*** which acts perpendicular to the wood fibers; these stresses should be checked to see that **the safe values are not exceeded**. Table (7-1) gives the maximum safe values of compression stresses perpendicular to the grain. Compression stresses areas are shown in Figure (7-6)



(Fig. 7-6) – Areas of Compression Stresses

7.9.4. Deflection Formula:

When a member, supported at each end, is subjected to a uniform load along its full length, the maximum deflection is given by the formula:

$$D = \frac{5}{384} \times \frac{wl^4}{EI} \times 1000 \qquad \text{...... (7-13)}$$

Solving for L,

$$L = 0.526 \times \sqrt[4]{\frac{EID}{w}} \qquad \text{...... (7-14)}$$

If the lumber used is No.1 Grade, Douglas fir or Pine, having modulus elasticity of (11034.5×10^3) kN/m^2, and ($I=bh^3/12$), and assuming that ***D*** is limited to (**3mm**), then after substituting these values in Eq. (7-14) the following formula is obtained:

$$L = 21.44 \times \sqrt[4]{\frac{bh^3}{w}} \qquad \text{...... (7-15)}$$

If a member extends continuously over several supports then, the maximum deflection is given by the formula:

$$D = \frac{1}{384} \times \frac{wl^4}{EI} \times 1000 \qquad \text{...... (7-16)}$$

Solving for L,

$$L = 0.787 \times \sqrt[4]{\frac{EID}{w}} \qquad \text{...... (7-17)}$$

If the lumber used is No.1 Grade, Douglas fir or Pine, having modulus elasticity of (11034.5×10^3) kN/m^2, and ($I=bh^3/12$), and assuming that D is limited to (3mm), then after substituting these values in Eq. (7-17) the following formula is obtained:

$$L = 32.08 \times \sqrt[4]{\frac{bh^3}{w}} \qquad \text{...... (7-18)}$$

Since deflection limits the maximum span for sheathing, then for the span of sheathing, the designer should use the value obtained by Eq. (7-14) or Eq. (7-15) instead of Eq. (7-17) or Eq. (7-18), unless he's certain that the sheathing is continuous over several supports (more than three supports).

7.10. Safe Loads on Shores:

The maximum safe load on a shore with a rectangular cross-section is calculated by the formula:

$$K = 7120 \left(1 - \frac{g}{80b} \right) bh \qquad \text{...... (7-19)}$$

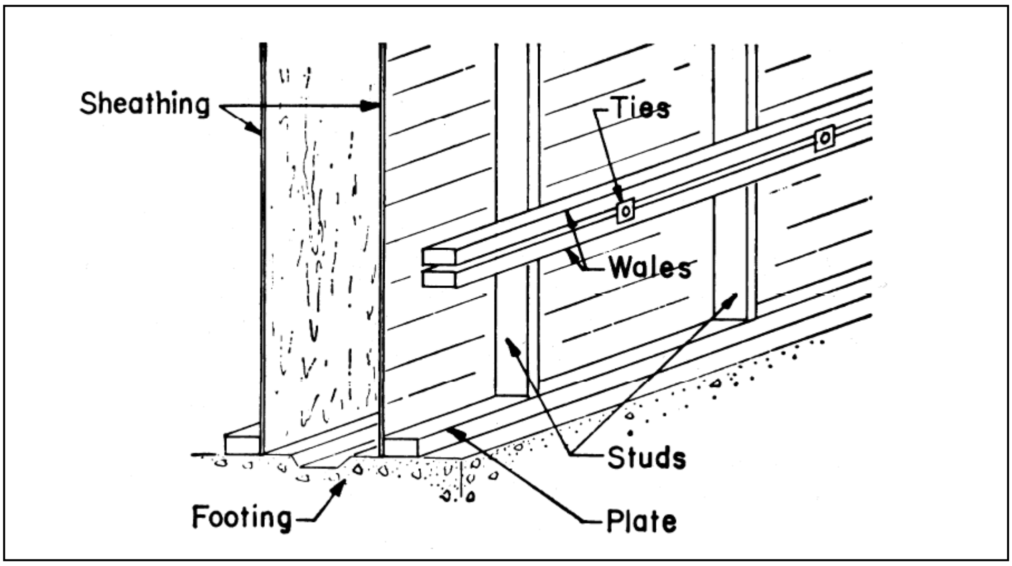
Where: $g =$ Unsupported Height of shore, m

$b =$ Width of rectangular section of shore, m

$h =$ Depth of rectangular section of shore, m

7.11. Wall Forms:

A typical wall form is shown in Figure (7-7) which includes sheathing, studs, wales, ties and braces. Lumber used for sheathing is (25mm, 31mm, 37mm and 50mm); plywood used for sheathing is (15mm or 18mm).

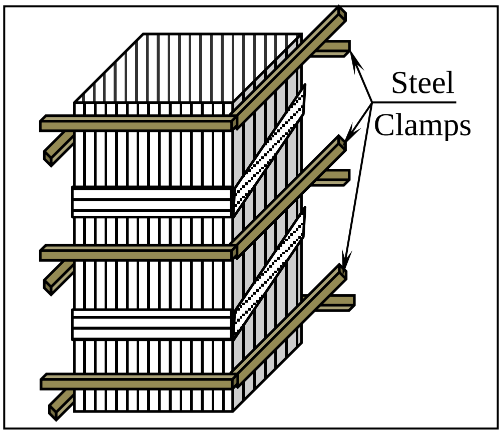


(Fig. 7-7) - Typical Formwork Setup for a Concrete Wall

7.12. Column Forms:

Forms for columns are usually made of vertical planks, with nominal thickness (25mm) or of plywood. Steel clamps are used to resist the pressure from the concrete, as illustrated in figure (7-8).

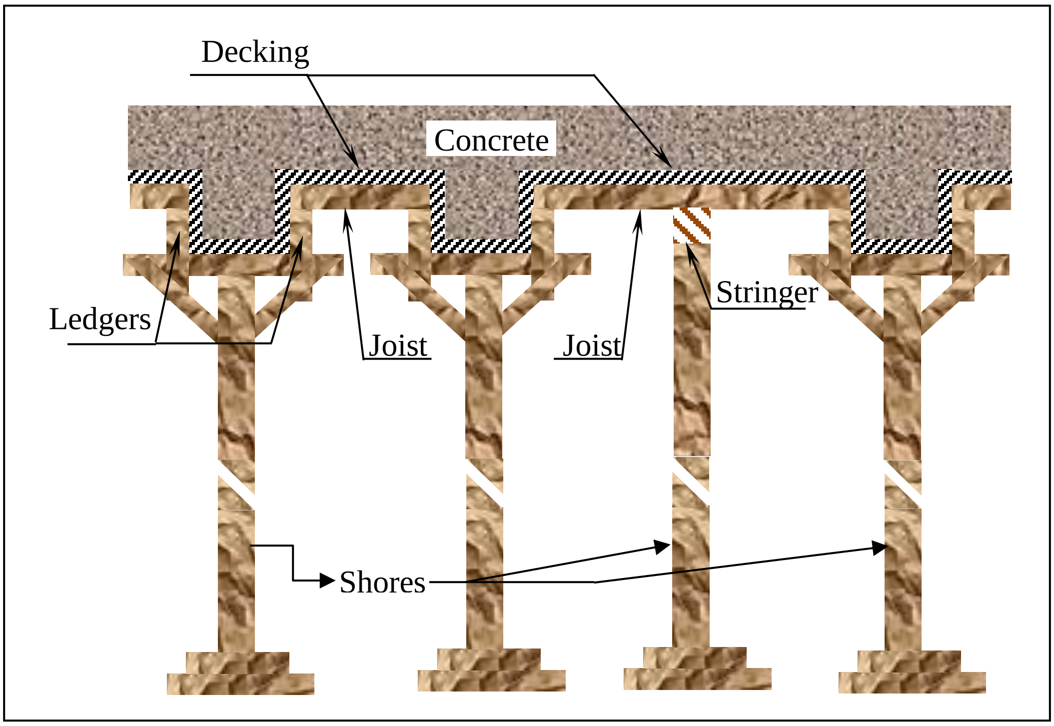
Forms should be designed to resist the high pressure resulting from quick filling. If the forms are filled in 30min or less, the concrete pressure is approximately, ($\gamma \times h$) kN/m^2 where (h) is the height of concrete in the form.



(Fig. 7-8) – Lumber Forms with Steel Clamps for a Concrete Column

7.13. Forms for Beams and Slab Type Floor System:

Figure (7-9) illustrates a method of construction forms for Beam-Slab floor system, using plywood (15mm or 18mm) or using 25mm planks for the decking. Plywood costs higher compared to planks but it is considered common in form industry because it can be installed more rapidly and has a higher salvage values.

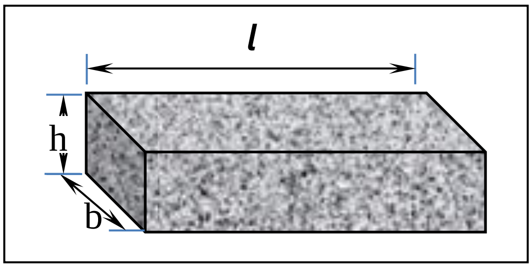


(Fig. 7-9) – Typical Formwork Setup for a Concrete Beam-Slab System

7.14. Steps for Designing Forms:

STEP 1: FIND THE PLACEMENT'S RATE:

$$R = \frac{Out\ Put\ (m^3/hr)}{b \times l}$$



STEP 2: FIND THE LATERAL PRESSURE:

- If the placement rate $(R \le 2.1 \text{ m/hr})$, the pressure is the least of the following:

$$P = 7 + \frac{1414R}{1.8T + 32}$$

$$P_m = \gamma_c \times h$$

- If the placement rate $(2.1 < R < 3 \text{ m/hr})$, the pressure is the least of the following:

$$P = 7 + \frac{2079 + 440R}{1.8T + 32}$$

$$P_m = 96\ kN/m^2$$

$$P_m = \gamma_c \times h$$

- If the placement rate $(R \ge 3 \text{ m/hr})$, the pressure is the least of the following:

$$P_m = \gamma_c \times h$$

STEP 3: SHEATHING DESIGN (Span for Sheathing $L_{Sheathing}$):

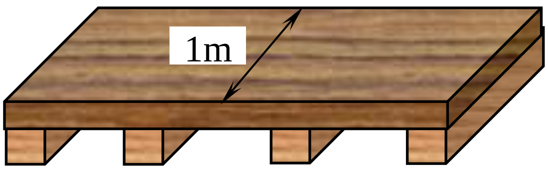
Calculate the spacing between Studs:

Plywood will be used. Use plywood the "strong way" (face grain parallel to plywood span). The maximum allowable span, the required spacing between studs, need to be determined. Design for uniformly spaced supports with studs supporting the plywood sheets at the joints.

Use a strip of 1 meter (b=1m).

Check Bending:

$$L = 1.29h\sqrt{\frac{fb}{w}}$$



Check Shear: $L = \frac{2vbh}{1.5w}$

Check Deflection:

- for three supports: $L = 0.526 \times \sqrt[4]{\frac{EID}{w}}$

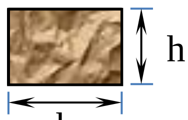
- for more than three supports: $L = 0.787 \times \sqrt[4]{\frac{EID}{w}}$

Use the least number of L calculated rounding the number to the smallest 5cm (ex: 0.78≈0.75, 0.84≈0.80) the latter will be the span for sheathing (spacing between studs).

STEP 4: STUD DESIGN (Span for Studs L_{Stud}):

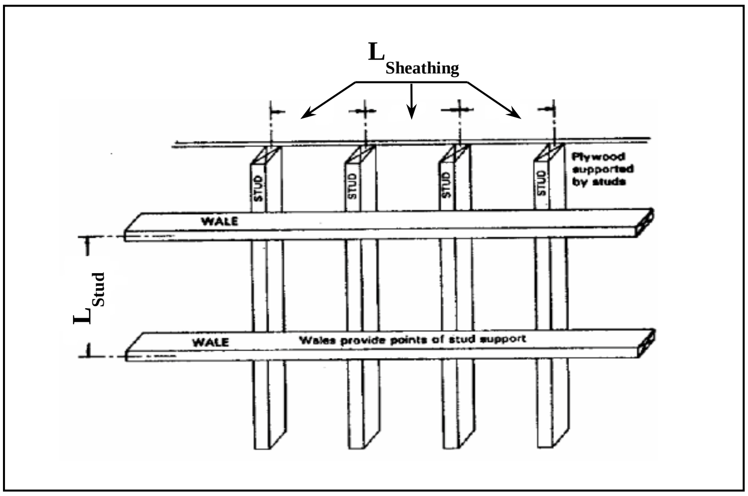
Calculate the spacing between Wales:

$$W_{(Stud)} = P_m \times L_{(Sheathing)}$$



Check Bending: $L = 1.29h\sqrt{\frac{fb}{w}}$

Check Shear: $L = \frac{2vbh}{1.5w}$



Check Deflection:

$$L = 0.526 \times \sqrt[4]{\frac{EID}{w}}$$

$$or\ L = 0.787 \times \sqrt[4]{\frac{EID}{w}}$$

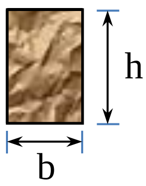
Use the least number of L calculated rounding the number to the smallest 5cm (ex: 0.78≈0.75, 0.84≈0.80) the latter will be the span for Studs (spacing between wales).

STEP 5: WALE DESIGN (Span for Wales L_{Wales}):

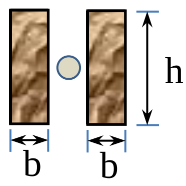
Calculate the spacing between Tie bars:

$$W_{(Wale)} = P_m \times L_{(Stud)}$$

Check Bending: $L = 1.29h\sqrt{\frac{fb}{w}}$



Single Wale



Double Wale

Check Shear: $L = \dfrac{2vbh}{1.5w}$

Check Deflection:

$$L = 0.526 \times \sqrt[4]{\frac{EID}{w}} \quad or \quad L = 0.787 \times \sqrt[4]{\frac{EID}{w}}$$

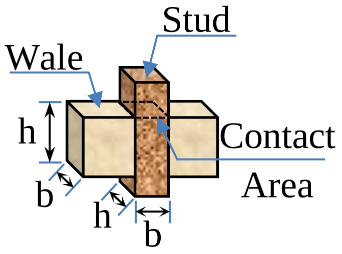
Use the least number of L calculated rounding the number to the smallest 5cm (ex: 0.78≈0.75, 0.84≈0.80) the latter will be the span for wales (spacing between tie bars).

STEP 6: Check Load on tie bar:

$$\textbf{Load on Tie Bar} = P_m \times L_{(Stud)} \times L_{(Wale)}$$

Load calculated should be less than the load available.

STEP 7: CALCULATE THE PRESSURE ON CONTACT AREA:



Bearing of studs on wales:

$$\textit{Contact Area}\,(CA) = b_{(Stud)} \times b_{(Wale)}$$

$$\textit{Load on Contact Area, } P = W_{(Stud)} \times L_{(Stud)}$$

$$\textit{Stress on Contact Area} = \frac{P}{CA} \; kN/m^2$$

The working pressure must be less than the permitted pressure acting perpendicularly to the wood fibers. Table (7-1) gives the values of compression ⊥ to grain, for types of lumber.

Example (7-1):

Design the form for a concrete wall having a length of (20m), a height of (3.5m) and a thickness of (0.5m), using a mixer having a production rate of (12m^3/hr), making use of the following information:

- Sheathing: 10×2.5 cm.
- Studs: 5×10 cm.
- Double wales 5×10 cm.
- Tie bar capacity: 20 kN.
- Type of lumber used: Douglas fir.
- Concrete Temperature: 35^{o}C.
- γ_c=24 kN/m^3

– Safe working Stresses as shown below:

Kind of Lumber	Safe Working Stresses, (kN/m^2) ×1000				
	Extreme Fiber in Bending (f)	Compression Perpendicular to Grain	Compression Parallel to Grain	Horizontal Shear (v)	Modulus of Elasticity (E)
Douglas Fir, No.1 Grade	12.4	3.4	10.3	1.0	11034.5

Solution:

Step 1: Rate of Filling:

$$Rate\ of\ \ filling(R)=\frac{output}{b\times l}=\frac{12}{0.5\times 20}=1.2\ \ m/hr$$

Step 2: Lateral Pressure:

$$1.2\ \ m/hr<2.1\ \ m/hr$$

$$\therefore use\ \ the\ \ least\ \ value\ of\ :$$

$$P_m=7+\frac{1414R}{1.8T+32}=7+\frac{1414(1.2)}{1.8(35)+32}=24.86\ \ kN/m^2$$

$$P_m=\gamma_c\times h=24\times 3.5=84\ \ kN/m^2$$

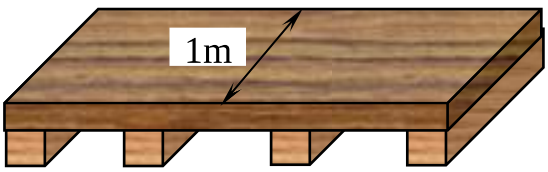
Then use the least value, P_m=24.86 kN/m^2

Step 3: Sheathing Design ($L_{sheathing}$): (spacing between studs)

Use a strip of 1m (b=1m)

$$W_{Sheathing}=P_m\times b_{Sheathing}=24.86\times 1=24.86\ \ kN/mL$$

Check Bending:



$$L=1.29h\sqrt{\frac{fb}{w}}$$

$$L=1.29\times 0.025\sqrt{\frac{12400\times 1}{24.86}}$$

$$L=0.72m$$

Check Shear: $L=\frac{2vbh}{1.5w}=\frac{2\times 1000\times 1\times 0.025}{1.5\times 24.86}=1.34m$

Check Deflection: $L=0.787\times\sqrt[4]{\frac{EID}{w}}$

$$I = \frac{bh^3}{12} = \frac{1 \times (0.025)^3}{12} = 1.302 \times 10^{-6} m^4$$

$$L = 0.787 \times \sqrt[4]{\frac{11034.5 \times 1000 \times 1.302 \times 10^{-6} \times 3}{24.86}}$$

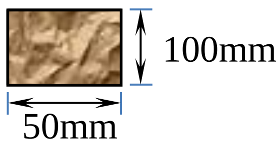
$$L = 0.903m$$

Use the least value, L=0.72 ≈ 0.70m, $\mathbf{L_{Sheathing}=0.7m}$

STEP 4: STUD DESIGN (L_{Stud}): (spacing between wales)

b=50mm, h= 100mm

$$W_{(Stud)} = 24.86 \times 0.7 = 17.4kN / mL$$



Check Bending:

$$L = 1.29h\sqrt{\frac{fb}{w}} = 1.29 \times 0.1\sqrt{\frac{12400 \times 0.05}{17.4}}$$

$$L = 0.77m$$

Check Shear: $L = \frac{2vbh}{1.5w} = \frac{2 \times 1000 \times 0.05 \times 0.1}{1.5 \times 17.4} = 0.38m$

Check Deflection: $L = 0.787 \times \sqrt[4]{\frac{EID}{w}}$

$$I = \frac{bh^3}{12} = \frac{0.05 * (0.1)^3}{12} = 4.166 \times 10^{-6} m^4$$

$$L = 0.787 \times \sqrt[4]{\frac{11034.5 \times 10004.166 \times 10^{-6} \times 3}{17.4}}$$

$$L = 1.32m$$

Use the least value, L= 0.38m ≈ 0.35m

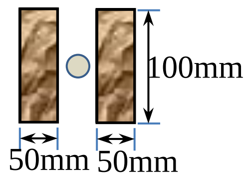
$\mathbf{L_{Stud}=0.35m}$

STEP 5: WALE DESIGN (L_{Wales}): (Spacing between Tie bars)

b=0.05m, h=0.1m

$$W_{(Wale)} = P_m \times L_{(Stud)} = 24.86 \times 0.35$$

$$W_{(Wale)} = 8.7kN / mL$$



Double Wale

Since type of wale is double, then:

$$W_{(Wale)} = \frac{8.7}{2} = 4.35kN / mL$$

Check Bending:

$$L = 1.29h\sqrt{\frac{fb}{w}} = 1.29 \times 0.1\sqrt{\frac{12400 \times 0.05}{4.35}} = 1.54m$$

Check Shear: $L = \dfrac{2vbh}{1.5w} = \dfrac{2 \times 1000 \times 0.05 \times 0.1}{1.5 \times 4.35} = 1.53m$

Check Deflection: $L = 0.787 \times \sqrt[4]{\dfrac{EID}{w}}$

$$I = \frac{bh^3}{12} = \frac{0.05 * (0.1)^3}{12} = 4.166 \times 10^{-6} m^4$$

$$L = 0.787 \times \sqrt[4]{\frac{11034.5 \times 1000 \times 4.166 \times 10^{-6} \times 3}{4.35}}$$

$$L = 1.867m$$

Use the least value, L= 1.53m ≈ 1.50m

L_{Wale}=1.50m

STEP 6: Check Load on tie bar:

Tie bar used capacity=20kN (given)

$$Load\ on\ Tie\ Bar = P_m \times L_{(Stud)} \times L_{(Wale)}$$

$$Load\ on\ Tie\ Bar = 24.86 \times 0.35 \times 1.5 = 13.05kN$$

$$13.05kN < 20kN, \ \therefore OK$$

STEP 7: CALCULATE THE PRESSURE ON CONTACT AREA:

Bearing of studs on wales:

$$Contact\ Area(CA) = b_{(Stud)} \times b_{(Wale)} = 0.05 \times (2 \times 0.05) = 0.005m^2$$

$$Load\ on\ Contact\ Area,\ P = W_{(Stud)} \times L_{(Stud)} = 17.4 \times 0.35 = 6.09kN$$

$$Stress\ on\ Contact\ Area = \frac{P}{CA} = \frac{6.09}{0.005} = 1218\ kN/m^2$$

$$1218\ kN/m^2 < 3400\ kN/m^2$$

$$\therefore OK$$

Example (7-2):

Design the form for a concrete slab having a thickness of (150mm), whose net width between beam faces is (4.7m), use (25mm) lumber for decking, (50×150) mm lumber for joists and (100×100) mm lumber for Stringers; type of lumber used is Douglas fir whose stresses are shown below:

Kind of Lumber	Safe Working Stresses, (kN/m^2) ×1000				
	Extreme Fiber in Bending (f)	Compression Perpendicular to Grain	Compression Parallel to Grain	Horizontal Shear (*v*)	Modulus of Elasticity (E)
Douglas Fir, No.1 Grade	12.4	3.4	10.3	1.0	11034.5

Solution:

The total load on decking will be:

Concrete	3.6 kN/m^2
Live load	1.9 kN/m^2
Total load	5.5 kN/m^2

Design of Decking ($L_{Decking}$): (spacing between joists)

Consider a 1m wide strip of decking, b=1m, h=0.025m

Check Bending: $L = 1.29h\sqrt{\frac{fb}{w}} = 1.29 \times 0.025\sqrt{\frac{12400 \times 1}{5.5}} = 1.53m$

Check Shear: $L = \frac{2vbh}{1.5w} = \frac{2 \times 1000 \times 1 \times 0.025}{1.5 \times 5.5} = 6m$

Check Deflection: $L = 0.787 \times \sqrt[4]{\frac{EID}{w}}$

$$I = \frac{bh^3}{12} = \frac{1 \times (0.025)^3}{12} = 1.302 \times 10^{-6} m^4$$

$$L = 0.787 \times \sqrt[4]{\frac{11034.5 \times 1000 \times 1.302 \times 10^{-6} \times 3}{5.5}}$$

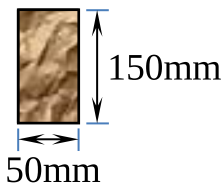
$$L = 1.32m$$

Use the least value, L= 1.32m ≈ 1.30m

$L_{Decking}$ =1.30m

Design of Joists (L_{Joists}): (Spacing Between Stringers)

b=50mm, h=150mm.



$$W_{(Joists)} = P_m \times L_{(Decking)} = 5.5 \times 1.3 = 7.15 \;\; kN/mL$$

Check Bending:

$$L = 1.29h\sqrt{\frac{fb}{w}} = 1.29 \times 0.15\sqrt{\frac{12400 \times 0.05}{7.15}} = 1.8m$$

Check Shear: $L = \frac{2vbh}{1.5w} = \frac{2 \times 1000 \times 0.05 \times 0.15}{1.5 \times 7.15} = 1.4m$

Check Deflection: $L = 0.787 \times \sqrt[4]{\frac{EID}{w}}$

$$I = \frac{bh^3}{12} = \frac{0.05 \times (0.15)^3}{12} = 1.406 \times 10^{-5} m^4$$

$$L = 0.787 \times \sqrt[4]{\frac{11034.5 \times 1000 \times 1.406 \times 10^{-5} \times 3}{7.15}}$$

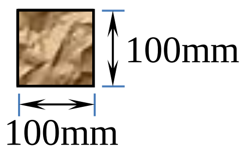
$$L = 2.24m$$

Use the least value, L= 1.4m

L_{Joist} =1.4m

Design of Stringers ($L_{Stringers}$): (Spacing Between Shores)

b=100mm, h=100mm.



$$W_{(Stringer)} = P_m \times L_{(Joist)} = 5.5 \times 1.4 = 7.7 \;\; kN/mL$$

Check Bending:

$$L = 1.29h\sqrt{\frac{fb}{w}} = 1.29 \times 0.1\sqrt{\frac{12400 \times 0.1}{7.7}} = 1.64m$$

Check Shear: $L = \frac{2vbh}{1.5w} = \frac{2 \times 1000 \times 0.1 \times 0.1}{1.5 \times 7.7} = 1.73m$

Check Deflection: $L = 0.787 \times \sqrt[4]{\frac{EID}{w}}$

$$I = \frac{bh^3}{12} = \frac{0.1 \times (0.1)^3}{12} = 8.333 \times 10^{-6} m^4$$

$$L = 0.787 \times \sqrt[4]{\frac{11034.5 \times 1000 \times 8.333 \times 10^{-6} \times 3}{7.7}}$$

$$L = 1.93m$$

Use the least value, L= 1.64m ≈ 1.60m

$L_{Stringer}$ =1.60m

Check Load on Shores with Safe Load on Shores calculated from Eq. (7-19):

$$Load_{(Shores)} = P_m \times L_{(Joist)} \times L_{(Stringer)} = 5.5 \times 1.4 \times 1.6 = 12.32\ kN / mL$$

$$K = 7120\left(1 - \frac{g}{80b}\right) bh$$

$$K = 7120\left(1 - \frac{(3.0 - 0.025 - 0.15 - 0.1}{80 \times 0.1}\right)(0.1)(0.1)$$

$$K = 7120\left(1 - \frac{2.725}{8}\right)(0.01) = 46.95 kN / mL > 12.32 kN / mL$$

$\therefore OK$

* If the shore is supported by inclined or horizontal ledgers, the unsupported length must be used in equation (7-19), to calculate the maximum allowable safe load on a shore.