Design of simple beams

Bending Stresses

When a sponge is put across two supports and gently pressed downwards between the supports, the pores at the top will close indicating compression, and the pores at the bottom will open wider indicating tension. Similarly, a beam of any elastic material such as wood or steel will produce a change in shape when external loads are acting on it.

Figure 4.2 Bending effects on beams.

The stresses will vary from maximum compression at the top to maximum tension at the bottom. Where the stress changes from compressive to tensile, there will be one layer which remains unstressed and this is called the neutral layer or the neutral axis (NA).

This is why beams with I-section are so effective. The main part of its material is concentrated in the flanges, away from the neutral axis. Hence, the maximum stresses occur where there is maximum material to resist them.

If the material is assumed to be elastic, then the stress distribution can be represented by two triangular shapes with the line of action of the resultant force of each triangle of stress at its centroid.

The couple produced by the compression and tension triangles of stress is the internal-reaction couple of the beam section.

Internal-reaction couple

The moment caused by the external loads acting on the beam will be resisted by the moment of this internal couple. Therefore:

$M = M_R = C$ (or T) x h where:

M = the external moment

M_R = the internal resisting moment

C = resultant of all compressive forces on the cross sec tion of the beam

T = resultant of all tensile forces on the cross section of the beam

h = lever arm of the reaction couple

Now consider a small element with the area (R) at a distance (a) from the neutral axis (N/A).

Small element with the area (R) at a distance (a) from the neutral axis (N/A)

Note that it is common practice to use the symbol for bending stress rather than the more general symbol . Maximum compressive stress (f_c) is assumed to occur in this case at the top of the beam. Therefore, by similar triangles, the stress in the chosen element is:

$f_a / a = f_c / y_{max}$

$f_a = a \times (f_c / y_{max})$

Since force = stress x area; the force on the element

$= f_a \times R = a \times (f_c / y_{max}) \times R$

The resisting moment due to the small element is: force x distance (a)

$= a \times (f_c / y_{max}) \times R \times a = Ra^2 \times (f_c / y_{max})$

The total resisting moment due to all such small elements in the cross section is:

$M_R = \Sigma\ Ra^2 \times (f_c / y_{max})$

But $\Sigma\ Ra^2 = 1$, the moment of inertia about the neutral axis and therefore

$M_R = I \times (f_c / y_{max})$

Since the section modulus $Z_c = I / y_{max}$

$M_R = f_c \times Z_c = M$;

similarly

$M_R = f_t \times Z_t = M$

The maximum compressive stress (fc) will occur in the cross section area of the beam where the bending moment (M) is greatest. A size and shape of cross section, i.e., is section modulus (Z), must be selected such that the f_c does not exceed an allowable value. Allowable working stress values can be found in building codes or engineering handbooks.

From the diagrams below it can be seen that the concept of a "resisting" couple can be seen in many structural members and systems.

Girders and l-Beams (1/6 of web area can be added to each flange area for moment resistance).

Rectangular Reinforced-Concrete Beams (Note that the steel bars are assumed to carry the whole of the tensile forces).

Reinforced-Concrete T-Beams

In summary the following equation is used to test for safe bending:

f_w f = M_{max} / Z

where:

f_w = allowable bending stress

f = actual bending stress

M_{max} = maximum bending moment

Z = section modulus

Horizontal Shear The horizontal shear force (Q) at a given cross section in a beam induces a shearing stress which acts tangentially to the horizontal cross-sectional plane. The average value of this shear stress is:

$\tau = Q / A$

A where A is the transverse cross sectional area. This average value is used when designing rivets, bolts, welded joints.

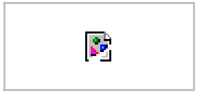
The existence of such a horizontal stress can be illustrated by bending a paper pad. The papers will slide relative to each other, but in a beam this is prevented by the developed shear stress.

Figure 4.3 Shearing effects on beams.

Rectangular Beams

However, the shear stresses are not equal across the cross section. At the top and bottom edge of the beam they must be zero, since no horizontal shear stresses can develop.

If the shear stresses at a certain distance from the neutral axis are considered, their value can be determined according to the following formula:



where:

τ = shear stress

Q = shear force

Δ A = area for the part of the section being sheared off

y = perpendicular distance from the centroid of PA to the neutral axis

I = moment of inertia for the whole cross section

b = width of the section at the place where shear stress is being calculated.

Rectangular Beams

Maximum Horizontal Shear Force in Beams

It can be shown that the maximum shear stress rmaX in a beam will occur at the neutral axis. Thus, the following relations for the maximum shear stress in beams of differ ent shapes can be deduced, assuming the maximum shear force (Q) to be the end reaction at a beam support

(column).

For rectangular sections $\tau_{max} = 3Q / 2bd = 3Q / 2A = 1.5 Q / A$

For square sections $\tau_{max} = 3Q / 2a^2 = 1.5 Q / A$

For circular sections $\tau_{max} = 16Q / 3\pi D^2 = 4Q / 3A$

For l-shaped sections of steel beams, a convenient approximation is to assume that all shearing resistance is afforded by the web plus that part of the flanges that is a continuation of the web.

Thus:

For I - sections $\tau_{max} = Q / (d \times t)$

where:

d = depth of beam

t = thickness of web

If timber and steel beams with spans normally used in buildings are made large enough to resist the tensile and compressive stresses caused by bending, they are usually strong enough also to resist the horizontal shear stresses. However, the size or strength of short, heavily loaded timber beams may be limited by these stresses.

Deflection of Beams

Excessive deflections are unacceptable in building construction, since they can cause cracking of plaster in ceilings and can result in jamming of doors and windows. Most building codes limit the amount of allowable deflection as a proportion of the member's length, i.e. 1/180, 1/240 or 1/360 of the length.

For standard cases of loading the deflection formulae can be expressed as:

$$\delta_{max} = K_c \times (WL^3 / EI)$$

where:

δ_{max} = maximum deflection (mm)

K_c = constant depending on the type of loading and the end support conditions

W = total load (N)

L = effective span (mm)

E = modulus of elasticity (N/mm)

I = moment of inertia (mm4)

It can be seen that deflection is greatly influenced by the span L, and that the best resistance is provided by beams which have the most depth (d), resulting in a large moment of inertia.

Note that the effective span is greater than the clear span. It is convenient to use the centre to centre distance of the supports as an approximation to the effective span.

Some of the standard cases of loading and resulting deflection for beams can be found later in this section.

Design Criteria

The design of beams is dependent upon the following factors:

- 1 Magnitude and type of loading
- 2 Duration of loading
- 3 Clear span
- 4 Material of the beam
- 5 Shape of the beam cross section

Beams are designed by use of the following formulae:

1. Bending Stress

f_w f = M_{max} / z where

f_w = allowable bending stress

f = actual bending stress

M_{max} = maximum bending moment

z = section modulus

This relationship derives from simpled beam theory and

$M_{max} / I_{NA} = f_{max} / y_{max}$

and INA / y_{max} = Z

The maximum bending stress will be found in the section of the beam where the maximum bending moment occurs. The maximum moment can be obtained from the B.M. diagram.

2. Shear Stress

For rectangular cross-sections:

$\tau_{w}\ \tau = (3 \times Q_{max}) / (3 \times A) = 3Q_{max} / 2bd$

For circular cross-sections:

$\tau_w\ \tau = (4 \times Q_{max}) / (3 \times A) = 16Q_{max} / 3\pi\, d^2$

For l-shaped cross-sections of steel beams

$\tau_w\ \tau \cong Q_{max} / A$

τ_w = allowable shear stress

T = actual shear stress

Q_{max} = maximum shear force

A = cross-section area

Allowable shear stress like the allowable bending stress differs for different materials and can be obtained from a building code. Maximum shear force is obtained from the shear force diagram.

3. Deflection

In addition, limitations sometimes are placed on maximum deflection of the beam.

$\delta_{max} = K_c \times (WL^3 / EI)$

Example 15

Consider a floor where beams are spaced at 1200mm and have a span of 4000mm. The beams are seasoned cypress with the following properties:

f_w = 8.0N/mm,

τ_w = 0.7N/mm,

E = 8.400N/mm,

density 500 kg/m

Loading on floor and including floor is 2.5kN/m.

Allowable deflection is L/240

Example 15

Beam loading: w = 1.2m x 2.5kN/m = 3kN/m

Assume a 100 by 250mm cross section for the beams.

Beam mass = 0.1 x 0.25 x 500 x 9.81 = 122.6N/m =0.12kN/m

Total w =3+012=3.12kN/m

2 Calculate reactions and draw shear-force and bending moment diagrams

Calculate reactions and draw shear-force and bending moment diagrams

3 Calculate maximum bending moment (M_{max}) using equation for a simple beam, uniformly loaded. See table 4.4

$M_{max} = wL^2 / 8 = (3.12 \times 4^2) / 8 = 6.24kNm = 6.24 \times 10^6/Nmm$

4 Find the required section modulus (Z)

$Z_{req} = M_{max} / f_w = (6.24 \times 10^6) / 8 = 0.78 \times 10^6 mm$

5. Find a suitable beam depth assuming 100mm breaths:

From table 4.3 the section modulus for a rectangular shape is $Z = 1/6 \times bd^2$

Choose a 100 by 225mm timber. The timber required is a little less than that assumed. No recalculations are required unless it is estimated that a smaller size timber would be adequate if a smaller size had been assumed initially.

6 Check for shear loading:

$\tau = 3Q_{max} / 2A = (3 \times 6.24 \times 10^3) / (2 \times 200 \times 225) = 0.42N/mm$

Since the safe for the timber is 0.7N/mm, the section is adequate in resistance to horizontal shear.

7 Check deflection to ensure less than 1/240 of the span. From table 4.4

$\delta_{max} = -5 / 384 = (WL^3 / EI)$ where

E = 8400N/mm

$I = bd^3 / 12 = (100 \times 225^3) / 12 = 95 \times 10^6 mm^4$

W = 3.12kN/m x 4m = 12.48kN = 12.48 x 103N

$L = 4 \times 10^3 mm$

$\delta_{max} = (-5 / 384) \times [(12.48 \times 10^3 \times 4^3 \times 10^9) / (8400 \times 95 \times 10^6)$

The allowable deflection, 400/240 = 16.7 >13 . beam is satisfactory.

Bending Moments Caused by Askew Loads

If beam is loaded so that the resulting bending moment is not about one of the main axes, the moment has to be resolved into components acting about the main axes. The stresses are then calculated separately relative to each axis and the total stress is found by adding the stresses caused by the components of the moment.

Example 16

Design a timber purlin, which will span rafters 2.4m on center. The angle of the roof slope is 30 and the purlin will support a vertical dead load of 250N/m and a wind load of

200N/m acting normal to the roof. The allowable bending stress (f_w) for the timber used is 8N/mm. The timber density is 600 kg/m.

1 Assume a purlin cross-section size of 50 x 125mm. Find an estimated self-load.

W=0.05 x 0.125 x 600 x 9.81 =37N/m

The total dead load becomes 250 + 37 = 287N/m

2 Find the components of the loads relative to the main axes.

W_x = 200N/m + 287N/m x cos 30 = 448.5N/m

W_y = 287N/m x sin 30 = 143.5N/m

3 Calculate the bending moments about each axis for a uniformly distributed load. The purlin is assumed to be a simple beam.

Calculate the bending moments

M_{max} =WL/8 = $wL^2/8$

$M_{max\ x} = (w_x \times L^2) / 8 = (448.5 \times 2.4^2) / 8 = 323 \times 10^3$Nmm

$M_{max\ y} = (w_y \times L^2) / 8 = (143.5 \times 2.4^2) / 8 = 103 \times 10^3$Nmm

4 The actual stress in the timber must be no greater than the allowable stress.

$f = M_{max\ x} / Z_x + M_{max\ y} / Z_y\ f_w$

5 Try the assumed purlin size of 50 x 150mm.

$Z_x = bd^2 / 6 = (50 \times 125^2) / 6 = 130 \times 10^3$mm

$Z_y = db^2 / 6 = (125 \times 50^2) / 6 = 52 \times 10^3$mm

$f = (320 \times 10^3) / (130 \times 10^3) + (130 \times 10^3) / (52 \times 10^3) = 2.5 + 2 = 4.5$N/mm

This size is safe, but a smaller size may be satisfactory. Try 50 x I00mm.

$Z_x = bd^2 / 6 = (50 \times 100^2) / 6 = 83 \times 10^3$mm

$Z_y = db^2 / 6 = (100 \times 50^2) / 6 = 42 \times 10^3 mm$

$f = (323 \times 10^3) / (83 \times 10^3) + (103 \times 10^3) / (42 \times 10^3) = 3.9 + 2.5 = 6.4 N/mm$

This is much closer to the allowable stress. To save money, also 5O x 75mm should be tried. In this case $f > f_w$ and therefore 50 x 100mm is chosen.

Universal Steel Beams

Steel beams of various cross-sectional shapes are commercially available. Even though the properties of their cross sections can be calculated with the formulae given in the section "Design of members in direct stress" it is easier to obtain them from hand book tables. These tables will also take into consideration the effect of rounded edges, welds, etc.

Sections of steel beams are indicated with a combination of letters and a number, where the letters represent the shape of the section and the number is the dimension, usually height, of the section in millimetres, e.g., IPE 100. In the case of HE sections, the number is followed by a letter indicating the thickness of the web and flanges, e.g., HE 180B.

An example of an alternative method of notation is 305 x 102 UB 25, i.e., 305 by 102mm universal beam weighing 25 kg/m.

The following example demonstrates another method of taking into account the self-weight of the structural member being designed.

Example 17

A steel beam, used as a lintel over a door opening, is required to span 4.0m between centres of simple supports. The beam will be carrying a 220mm thick and 2.2m high brick wall, weighing 20kN/ m. Allowable bending stress is 165N/mm.

Uniformly distributed load caused by brickwork is 0.22 x 2.2 x 4 0 x 20 = 8.7kN.

Assumed self weight for the beam is 1.5kN.

(Note: triangular load distribution for bricks above lintel would result in a slightly lower value of load).

Total uniformly distributed load W = 38.7 + 1.5 = 40.2 kN

M_{max} = WL/8 = (40.2 x 4.0) / 8 = 20.1kNm=20.1 x 10^6Nmm

Z_{req} = (20.1 x 10^6) /165 = 0.122 x 10^6mm = 122cm (as shown in tables)

Suitable sections as found in a handbook would be:

Section	**Z_{x-x}**	**Mass**
INP 160	117 cm	17.9 kg/m
IPE 180	146cm	18.8 kg/m
HE 140A	155 cm	24.7 kg/m
HE 120A	144 cm	26.7 kg/m

Choose INP 160 because it is closest to the required section modulus and has the lowest weight. Then recalculate the required Z using the INP 160 weight: 4.0 x 17.9 x 9.81 = 702N which is less than the assumed self weight of l.5kN. A recheck on Z required reveals a value of 119cm which is close enough.

Continuous Beams

A single continuous beam extending over a number of supports will safely carry a greater load than a series of simple beams extending from support to support. Consider the Shear Force and Bending Movement diagrams for the following two beam loadings:

Beams

[Simple beam]

Although the total value of the load has increased, the maximum shear force remains the same but the maximum bending is reduced when the beam is cantilevered over the supports.

Although continuous beams are statically indeterminate and the calculations are complex, approximate values can be found with simplified equations. Conservative equations for two situations are as follows:

Load concentrated between supports: BM = WL / 6

Load uniformly distributed: BM = WL / 12

It is best to treat the two end sections as simple beams.

Standard Cases of Beam Loading

A number of beam loading cases occur frequently and it is useful to have standard expressions for these available. Several of these will be found in Table 4.4.

Composite beams

In small-scale buildings the spans are relatively small, and with normal loading, solid rectangular or square sections are generally the most economical beams. But where members beyond the available sizes and/or length of solid timber are required, one of the following combinations may be chosen:

Table 4.4 Beam Equation

- **1 Arranging several pieces of timber or steel into a structural frame or truss.**
- **2 Universal steel beams.**
- **3 Built-up timber sections with the beam members either nailed, glued or bolted together into a solid section, or with the beam members spaced apart and only connected at intervals.**
- **4 Strengthening the solid timber section by the addition of steel plates to form a "flitch-beam".**
- **5 Plywood web beams with one or several webs. 6 Reinforced-concrete beams.**

Built-up Timber Beams

When designing large members, there are advantages in building up solid sections from smaller pieces since these are less expensive and easier to obtain. Smaller pieces also season properly without checking. The composite beams may be built up in ways that minimize warping and permit rigid connections between columns and beams. At the same

time the importance of timber defects is decreased, since the load is distributed to several pieces, not all having defects in the same area.

Figure 4.4 Built-up beams and trusses.

Built-up solid beams are normally formed by using vertical pieces nailed or bolted together, nailing being satisfactory for beams up to about 250mm in depth, although these may require the use of bolts at the ends if the shear stresses are high. Simply multiplying the strength of one beam by the number is satisfactory as long as the staggered joints occur over supports.

Built-up sections with the members spaced apart are used mainly where the forces are tensile, such as in the bottom chords of a truss. Where used in beams designed to resist bending buckling of the individual members may have to be considered if those members have a large depth to width ratio. This can, however, be avoided by appropriate spacing of stiffeners which connect the spaced members at intervals.

Where the loading is heavy, the beam will require considerable depth, resulting in a large section modulus to keep the stresses within the allowable value. If sufficient depth cannot be obtained in one member, it may be achieved by combining several members, as, for example, where the members are glued together to form a laminate.

Columns

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The column is essentially a compression member, but the manner in which it tends to fail and the amount of load which causes failure depend on:

- **The material of which the column is made.**
- **The shape of cross section of the column.**
- **The end conditions of the column.**

The first point is obvious - a steel column can carry a greater load than timber column of similar size.

Columns having a large cross-section area compared to the height are likely to fail by crushing. These "short columns" have been dealt with earlier.

Buckling of Slender Columns

If a long, thin, flexible rod is loaded axially in compression, it will deflect a noticeable amount. This phenomenon is called buckling and occurs when the stresses in the rod are still well below those required to cause a compression/ shearing-type failure. Buckling is dangerous in that it is sudden and once started is progressive.

Although the buckling of a column can be compared with the bending of a beam, there is an important difference in that the designer can choose the axis about which a beam bends, but normally the column will take the line of least resistance and buckle in the direction where the column has the least lateral unsupported dimension.

Since the loads on columns are never perfectly axial and the columns are not perfectly straight, there will always be small bending moments induced in the column when it is compressed.

There may be parts of the cross section area where the sum of the compressive stresses caused by the load on the column could reach values larger than the allowable or even the ultimate strength of the material.

Therefore the allowable compressive strength δ_{cw} is reduced by a factor $k\lambda$, which depends on the slenderness ratio and the material used.

$P_{bW} = k\lambda \times \delta_{cw} \times A$ Where:

P_{bw} = allowable load with respect to buckling

$k\lambda$ = reduction factor, which depends on the slenderness ratio

δ_{cw} = allowable compressive stress

A = cross-section area of the column

When the load on a column is not axial but eccentric, a bending stress is induced in the column as well as a direct compressive stress. This bending stress will have to be considered when designing the column with respect to buckling.

Slenderness Ratio

As stated earlier, the relationship between the length of the column, its lateral dimensions and the end fixity conditions will strongly affect the resistance of the column to buckling. An expression called slenderness ratio has been developed to describe this relationship:

$A = KL / r = l / r$ where:

A = slenderness ratio

K = effective length factor, whose value depends on how the ends of the column are fixed

L = length of the column

r = radius of gyration (r = I / A)

I = effective length of the column (K x L)

There are four types of end conditions for a column or strut:

1 Total freedom of rotation and side movement - like the top of a flagpole. This is the weakest end condition.

The consideration of the two end conditions together results in the following theoretical values for the effective length factor. (K_p = factor usually used in practice).

[**Types of end conditions**]

Columns and struts with both ends fixed in position and effectively restrained in direction would theoretically have an effective length of half the actual length. However, in practice this type of end condition is almost never perfect and therefore somewhat higher values

for K are used and can be found in building codes. In fact, in order to avoid unpleasant surprises, the ends are often considered pinned (K_p = 1.0) even if the ends in reality are restrained or partially restrained in direction.

Types of end conditions II

The effective length can be different with respect to the different cross-sectional axes:

1. A timber strut which is restrained at the centre has only half. The effective length when buckling about the y-y axis, as when buckling about the x-x axis. Such a strut can therefore have a thickness less than its width.

2. In the structural framework, the braces will reduce the effective length to 1 when the column A-B is buckling sideways, but since there is no bracing restricting buckling forwards and backwards, the effective length for buckling in these directions is 31. Similarly, the bracing struts have effective lengths of l/2 d and d respectively.

3. The leg of a frame, which is pinned to the foundation has the effective length 1 = 2 L, but if the top is effectively secured for sideways movement, the effective length is reduced to 1 = L.

4. In a system of post and lintel where the bottom of the post is effectively held in

position and secured in direction by being cast in concrete, the effective length / = 2 L.

Axially Loaded Timber Columns

Timber columns are designed with the following formulae:

A =KL / r and $P_{bw} = k\lambda \times \delta_{cw} \times A$

Note that in some building codes a value of slenderness ratio in the case of sawn timber is taken as the ratio between the effective length and the least lateral width of the column l / b

Example 18

Design a timber column which is 3 metres long, supported as shown in the figure and loaded with a compressive load of 15kN. Allowable compressive stress (δ_{cw}) for the timber is 5.2N/mm

Table 4.5 ***Reduction Factor, (k), for Stresses with Respect to the Slenderness Ratio for Wood Columns***

Slend-	l / b	2.9	5.8	8.7	11.5	14.4	17.3	20.2	23.0	26.0	28.8	34.6	40.6	46.2	52.0

erness Ratio															
	l / r	10	20	30	40	50	60	70	80	90	100	120	140	160	180
	$k\lambda$	1.0	1.00	0.91	0.81	0.72	0.63	0.53	0.44	0.35	0.28	0.20	0.14	0.11	0.40

b = least dimension of cross section, r = radius of gyration

1 In this case the end conditions for buckling about the x-x axis are not the same as about the y-y axis. Therefore both directions must be designed for buckling. (Where the end conditions are the same, it is sufficient to check for buckling in the direction which has the least radius of gyration).

Find the effective length for buckling about both axis. Buckling about the x-x axis, both ends pinned:

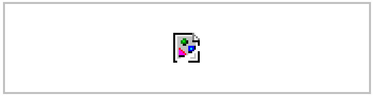
l_x = 1.0 x 3000 = 3000mm

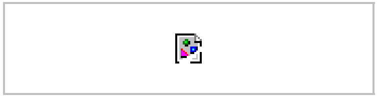
Buckling about the y-y axis, both ends fixed:

l_y = 0.65 x 3000 = 1950mm

2 Choose a trial cross section, which should have its largest lateral dimension resisting the buckling about the axis with the largest effective length. Try 50 x 125mm. The section properties are:

A = b x d = 50 x 125 = 6250mm





3 Find the allowable load with regard to buckling on the column for buckling in both directions.

$\lambda_x = l_x / r_x$ = 3000 / 36.1 = 83 :. $k\lambda_x$ = 0.41 (from table 4.5)

$\lambda_y = l_y / r_y$ = 1950 / 14.4 = 135 :. $k\lambda_x$ = 0.16 (from table 4.5)

$P_W = k\lambda \times \sigma_c \times A$

Pw_x = 0.41 x 5.2 x 6250mm = 13325N

Pw_y = 0.16 x 5.2 x 6250mm = 5200N

4 The allowable load with respect to buckling is smaller than the actual load. Therefore a bigger cross section has to be chosen. Try 75 x 125 mm and repeat steps 2 and 3.

Section properties:

A = 75 x 125 = 9375mm

Find the allowable buckling load for the new cross section:

$\lambda_x = l_x/r_x$ =3000/36.1 = 83 gives $k\lambda_x$ = 0.41

$\lambda_y = l_y/r_y$ =1950 / 21.7 = 90 gives $k\lambda_y$ = 0.35

Pw_x = 0.41 x 5.2 x 9375 = 19988N say 20kN

Pw_y = 0.35 x 5.2 x 9375 = 17063N say 17kN

The allowable load with respect to buckling on the column with cross section 75 x 125mm is therefore 17kN. This is bigger than the actual load, but further iterations to find exactly the section to carry the 15kN are not necessary.

The compressive stress in the chosen cross section will be:

σ_c = F / A = 9375 = 1.6N/mm

This is much less than the allowable compressive stress which made no allowance for slenderness.

Axially Loaded Steel Columns

The allowable loads for steel columns with respect to buckling can be calculated in the same manner as for timber. However, the relation between the slenderness ratio and the reduction factor (k') is slightly different as seen in Table 4.6.

Table 4.6 ***Reduction factor ($k\lambda$) for Stresses with Respect to the Slenderness Ratio for***

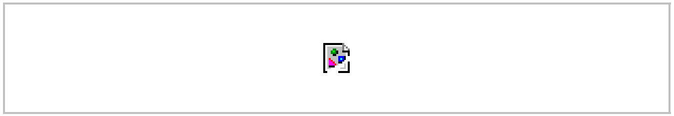
Steel Columns

λ	10	20	30	40	50	60	70	80	90	100	110	120	130	140
$k\lambda$	0.97	0.95	0.92	0.90	0.86	0.81	0.74	0.67	0.59	0.51	0.45	0.39	0.34	0.30
λ	150	160	170	180	190	200	210	220	230	240	250	300	350	
$k\lambda$	0.26	0.23	0.21	0.19	0.17	0.15	0.14	0.13	0.12	0.11	0.10	0.07	0.05	

Example 19

Calculate the safe load on a hollow square steel stanchion, whose external dimensions are 120 x 120mm. The walls of the column are 6mm thick and the allowable compressive stress ace = 150N/mm. The column is 4 metres high and both ends are held effectively in position, but one is also restrained in direction.

The effective length of the column l = 0.85L = 0.85 x 4000 = 3400mm.



λ =l / r =3400 / 46.6 = 73 gives Kλ = 0.72

$P_W = k\lambda \times \sigma_{cw} \times A = 0.72 \times 150 (120^2 - 108^2) = 295$kN.

Axially Loaded Concrete Columns

Most building codes permit the use of plain concrete only in short columns, i.e., columns where the ratio of the effective length to least lateral dimension does not exceed 15, i.e. l/r C 15. If the slenderness ratio is between 10 and 15, the allowable compressive strength must be reduced. The tables of figures relating to l/ b in place of a true slenderness ratio are only approximate, since radii of gyration depend on both b and d values in the cross section, and must be used with caution. In the case of a circular column:

$b = D / 4 \times (12)^{1/2}$ 0.87D, where

D = the diameter of the column.

Table 4.7 ***Permissible Compressive Stress (P_{CC}) in concrete for Columns (N/mm)***

Concrete Mix	Slenderness ratio, 1/b					
	10	11	12	13	14	15

Prescribed						
C10	3.2	3.1	3.0	2.9	2.8	2.7
C15	3.9	3.8	3.7	3.6	3.5	3.4
C20	4.8	4.6	4.5	4.3	4.2	4.1
Nominal						
1:3:5	3.1	30	2.9	2.8	2.7	2.6
1:2:4	3.8	3.7	3.6	3.5	3.4	3.3
1:1.5:3	4.7	4.5	4.4	4.2	4.1	40

Higher values of stress may be permitted, depending on levels of supervision of work.

Example 20

A concrete column, with an effective length of 4 metres has a cross section of 300 x 400mm. Calculate the allowable axial load, if a nominal concrete mix 1:2:4 is to be used.

Slenderness ratio l/b = 400 / 300 = 13.3

Hence table gives P_{CC} = 3.47 N/mm by interpolation.

$P_W = P_{CC}$ x A = 3.47 x 300 x 400 = 416.4 kN.

Eccentrically Loaded Timber and Steel Columns

Where a column is eccentrically loaded, two load effects have to be considered:

The axial compressive stress caused by the load. The bending stresses caused by the eccentricity of the load.

Obviously, by the law of superposition, the added stresses of the two load affects must be below the allowable stress.

Therefore σ /P_{CW} + f / f_W 1 i.e.

(axial comp. stress) / (allowable comp. stress) + (bending stress) / (allowable bending stress) 1

σ_c / (kλ x σ_{cw}) + f / f_W 1 which can be transferred to

P_1 / (Kλ x A) + (σ_{cw} / f_W) x M / Z σ_{cw}

Example 2.1 Determine within 25mm the required diameter of a timber post loaded as

shown in the figure. The bottom of the post is fixed in both position and direction by being cast in a concrete foundation. Allowable stresses for the timber used are σ_{cw} = 9 N/mm and f_W = 10N/mm.

The load of 5kN on the cantilever causes a bending moment of M = F x e = 5kN x 0.5m = 2.5kNm in the post below the cantilever.

The effective length of the post = L x K = 3000 x 2.1 = 6300mm. Try with a post having the diameter 200mm.

The cross sectional properties are:

$A = (\pi D^2) / 4 = (\pi \times 200^2) / 4 = 31400mm$

$A = (\pi D^3) / 32 = (\pi \times 200^3) / 32 = 785400mm$

r = D / 4 = 200 / 4 = 50mm

The slenderness ratio =l / r= 6300 / 50 = 126

interpolation in Table 4.5 gives $k\lambda$ = 0.18

$P / (K\lambda \times A) + (\sigma_{cw} / f_W) \times M / Z \sigma_{cw}$

$30000 / (0.18 \times 31400) + (9 / 10) \times 2.5 \times 10^6 / 167480 = 8.17 N/mm^2$ $9 N/mm^2$

If the post has a diameter of 200mm, it will be able to carry the loads, but the task was to determine the diameter within 25mm. Therefore a diameter of 175mm must also be tried.

λ = 43 75 = 144 kλ = 0.13

$30000 / (0.18 \times 24050) + (9 / 10) \times 2.5 \times 10^6 / 167480 = 23 N/mm^2$ $9 N/mm^2$

This diameter is too small, so a diameter of 200mm should be chosen. It will be appreciated that the choice of effective length based on end fixity has a great effect on the solution.

Plain and Centrally Reinforced Concrete Walls

Basically walls are designed in the same manner as columns, but there are a few differences. A wall is distinguished from a column by having a length which is more than five times the thickness.

Plain concrete walls should have a minimum thickness of 100mm.

Where the load on the wall is eccentric, the wall must have centrally placed reinforcement of at least 0.2% of the cross section area if the eccentricity ratio e/ b exceeds 0.20. This reinforcement may not be included in the load carrying capacity of the wall.

Many agricultural buildings have walls built of blocks or bricks. The same design approach as that shown for plain concrete with axial loading can be used. The maximum allowable compressive stresses must be ascertained, but the reduction ratios can be used as before.

Example 22 Determine the maximum allowable load per metre of a 120mm thick wall, with an effective height of 2.8 metres and made from concrete grade C 15, a) when the load is central, b) when the load is eccentric by 20mm.

Slenderness ratio l / b = 2800 /120 = 23.3

- **a Interpolation gives:**

P_{cw} = 2.8 - 3.3/5 (2.8 - 2.0) = 2.27N/mm = 2.27MN/m

Allowable load P_w = A x P_{cw} = 1.0 x 0.12 x (1.06 x 10^6) / 1000 = 272.4kN/m wall

- **b Ratio of eccentricity e / b = 20 / 120 = 0.167**

A double interpolation gives:

P_{cw} = 1 .06N/mm = 1 .06MN/ m

Allowable load P_W= 1.0 x 0.12 x (1.06 x 10^6) / 1000 = 127.2kN/m wall

Central reinforcement is not required since e / b < 0.20

Table 4.8 ***Allowable Compressive Stress, Pcw for Concrete Used in Walls (N/mm)***

Concrete Grade or Mix	**Slenderness Ratio l/b**	**Ratio of Eccentricity of the load e/ b**					
		Plain Concrete Walls			**Centrally Reinforced Concrete Walls**		
		0.00	0.10	0.20	0.30	0.40	0.50
C20	25	2.4	1.7	0.9	-	-	-
	20	3.3	2.3	1.4	0.8	0.4	0.3
	15	4.1	3.0	2.0	0.8	0.4	0.3
	10	4.8	3.7	2.7	0.8	0.4	0.3

C15	25	2.0	1.3	0.7	-	-	-
	20	2.8	1.9	1.1	0.7	0.35	0.25
	15	3.4	2.4	1.7	0.7	0.35	0.25
	10	3.9	3.0	2.2	0.7	0.35	0.25
C10	20	2.3	1.6	1.0	0.5	0.3	0.2
	15	2.7	2.0	1.4	0.5	0.3	0.2
	10	3.2	2.5	1.8	0.5	0.3	0.2
1:1:3 1:1:2	25	2.3	1.6	0.8	-	-	-
	20	3.2	2.2	1.3	0.8	0.4	0.3
	15	4.1	2.9	1.9	0.8	0.4	0.3
	10	4.7	3.6	2.6	0.8	0.4	0.3
1:2:3	20	3.0	2.1	1.3	0.7	0.35	0.25
	15	3.7	2.7	1.9	0.7	0.35	0.25
	10	4.3	3.4	2.5	0.7	0.35	0.25
1:2:4	20	2.7	1.8	1.0	0.6	0.3	0.2

	15	3.3	2.3	1.6	0.6	0.3	0.2
	10	3.8	2.9	2.1	0.6	0.3	0.2

Higher values of stress may be permitted, depending on levels of supervision work.

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Trusses

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It can be seen from the stress distribution of a loaded beam that the greatest stress occurs at the top and bottom extrem ities of the beam.

This led to the improvement on a rectangular section by introducing the I-section in which the large flanges were situated at a distance from the neutral axis. In effect, the flanges carried the bending in the form of tension stress in one flange and compression stress in the other, while the shear was carried by the web.

For these situations where bending is high but shear is low, for example in roof design, material can be saved by rising a framework design. A truss is a pinpointed framework.

A truss concentrates the maximum amount of materials as far away as possible from the neutral axis. With the resulting greater moment arm (h), much larger moments can be resisted.

Resistance of a truss at a section is provided by:

M = C x h = T x h, where C = T in parallel cords and:

C = compression in the top chord of the truss.

T = tension in bottom chord of a simply supported truss.

h = vertical height of truss section.

If either C, T or h can be increased, then the truss will be capable of resisting heavier loads. The value of h can be increased by making a deeper truss.

Allowable C or T stresses can be increased by choosing a larger cross section for the chords of the truss, or by changing to a stronger material.

A framework or truss can be considered as a beam with the major part of the web removed. This is possible where bending stresses are more significant than shear stresses. The simple beam has a constant section along its length, yet the bending and shear stresses vary. The truss, made up of a number of simple members, can be fabricated to take into account this change in stress along its length.

The pitched-roof truss is the best example of this, although the original shape was probably designed to shed rain water. Roof trusses consist of sloping rafters which meet at the ridge, a main tie connecting the feet of the rafters, and internal bracing members. They are used to support a roof covering in conjunction with purling, which are members laid longitudinally across the rafters, the roof covering being attached to the purling. The arrangement of internal bracing depends on the span. Rafters are normally divided into equal lengths, and ideally, the purlins are supported at the joints, so that the rafters are only subjected to axial forces. This is not always practicable, since purlin spacing is dependent on the type of roof covering. When the purlins are not supported at the panel joints, the rafter members must be designed for bending as well as axial force. See Figure 4.5.

The internal bracing members of a truss should be triangulated and, as far as possible, be arranged so that long members are in tension and compression members are short to avoid buckling problems.

The outlines in Figure 4.6 give typical forms for various spans. The thick lines indicate struts.

Figure 4.5 Truss components.

The lattice girder, also called a truss, is a plane frame of open web construction, usually having parallel chords or booms at top and bottom. There are two main types, the N (or Pratt) girder and the Warren girder. They are very useful in long-span construction, in which their small depth-to-span ratio, generally about 1/10 to 1/14, gives them a distinct advantage over roof trusses.

Steel and timber trusses are usually designed assuming pin-jointed members. In practice, timber trusses are assembled with bolts, nails or special connectors, and steel trusses are bolted, riveted or welded. Although these rigid joints impose secondary stresses, it is seldom necessary to consider them in the design procedure. The following steps should be considered when designing a truss:

1 Select general layout of truss members and truss spacing.

2 Estimate external loads to be applied including self weight of truss, purlins and roof covering, together with wind loads.

3 Determine critical (worst combinations) loading. It is usual to consider dead loads alone, and then dead and imposed loads combined.

4 Analyze framework to find forces in all members.

5 Select material and section to produce in each member a stress value which does not exceed the permissible value. Particular care must be taken with compression members (struts), or members normally in tension but subject to stress reversal due to wind uplift.

Unless there are particular constructional requirements, roof trusses should, as far as possible, be spaced to achieve a minimum of weight and economy of materials used in the total roof structure. As the distance between trusses is increased, the weight of the purlins tends to increase more rapidly than that of the trusses. For spans up to about 20m, the spacing of steel trusses is likely to be about 4m, and in the case of timber, 2m.

The pitch, or slope, of a roof depends on locality, imposed loading and type of covering. Heavy rainfall may require steep slopes for rapid drainage; a slope of 22 is common for corrugated steel and asbestos roofing sheets. Manufacturers of roofing material usually make recommendations regarding suitable slopes and fixings.

Figure 4.6 Types of trusses.

To enable the designer to determine the maximum design load for each member, the member forces can be evaluated either by calculation or graphical means, and the results tabulated as shown:

Member	Dead Load D	Imposed Load I	Dead + Imposed Load D+I	Wind Load W	Design Load

A simplified approach can he used if the intention is to use a common section throughout. Once the layout has been chosen, the member which will carry the maximum load can be established. An understanding of the problems of instability of compression members will lead the designer to concentrate on the top chord or rafter members. A force diagram or method of sections can then be used to determine the load on these members, and the necessary size.

Example 23

A farm building comprised of block walls carries steel roof trusses over a span of 8m. Roofing sheets determine the purlin spacings.

Example 23

Assume a force analysis shows maximum rafter forces of approximately 50kN in compression (D + 1) and 30kN in tension (D + W), outer main tie member 50kN tension (D + 1) and 30kN compression (D + W). A reversal of forces due to the uplift action of wind will cause the outer main tie member to have 50kN of tension and 30kN of compression.

Consulting a structural engineering handbook reveals that a steel angle with a section of 65mm x 50mm x 6mm and an effective length of 1.8m can safely carry 29kN in compression.

***Rafter:* Using two angles back-to-back will be satisfactory, since distance between restraints is only 1.38m. (Note angles must be battened together along the length of the rafter).**

***Main Tie*: The 65mm x 50mm x 6mm section can carry the required tensile force. Although its length is a little greater than 1.8m, the compressive load brought about by the uplift of the wind is safe since the design codes allow a greater slenderness ratio for intermittent loads such as wind.**

***Finished Design:* Note the use of a sole plate to safely distribute the load to the blockwork wall, so that the bearing stress of the blocks is not exceeded. See Figure 4.7.**

Figure 4.7 Finished design of roof truss.

Frames

Apart from the roof truss, there are a number of other structural frames commonly used in farm building construction. They include portal frames, pole barns, and postand-beam frames.

A single-bay portal frame consists of a horizontal beam or pitched rafters joined rigidly to vertical stanchions on either side to form a continuous plane frame. For the purposes of design, portal frames can be classified into three types: fixed base, pinned base (2 pins), pinned base and ridge (3 pins).

The rigid joints and fixed bases have to withstand bending moments and all bases are subjected to horizontal as well as vertical reactions. Hence foundation design requires special attention. The externally applied loads cause bending moments, shear forces and axial forces in the frame.

Portal frames are statically indeterminate structures and the complexity of the analysis precludes coverage here. However, the results of such calculations for a number of standard cases of loading are tabulated in handbooks. Using these and the principle of

superposition, the designer can determine the structural section required for the frame. Determining the maximum values of the bending moment, shear force and axial force acting anywhere in the frame; allows the selection of an adequate section for use throughout the frame. Care must be exercised to ensure that all joints and connections are adequate.

Portal frames may be made of steel, reinforced concrete or timber. With wider spans the structural components become massive if timber or reinforced concrete is used. Hence, steel frames are most common for spans over 20m. At the eaves, where maximum bending moments occur, the section used will need a greater depth than at other points in the frame.

Figure 4.8 Portal or rigid frame.

Pole barns are usually built with a relatively simple foundation, deeper than usual, and backfilled with rammed earth. Pole barns are braced between columns and rafters in each direction. The braces serve to reduce the effective length of compression members and the effective span of rafters and other beam members. This leads to a structure which is simple to analyze and design, and can be a lowcost form of construction.

A shed type building is a simple construction consisting of beams (horizontal or sloping), supported at their ends on walls or posts. There may be one or more intermediate

supports depending on building width. Purlins running longitudinally support the roof covering. As the principle members are simple or continuous beams, (very often timber of rectangular section), the stress analysis aspect of the design is straight forward. When the beam is supported by timber posts, the post design is not difficult since the load is assumed to be axial. Like the poles in the pole barn, the foundation can consist of a simple pad of concrete beneath the post, or the base of the post can be set into concrete.

Example 24

Designing of a building using block walls, timber posts and rafters

It is assumed that the knee braces reduce the effective span of the rafters between the central wall and the timber posts.

Self-weights and service load have been estimated. Continuity over post and brace have been disregarded. This provides a simple but safe member.

Self-weights and service load

Max. shear force 5kN

Max. bending moment 3120kNmm Try 2 rafters 38 x 200 (back to back)

Max. sheer stress = 3Q / 2bd = 3 / 2 x (5000 / 76 x 200) = 0.49N/mm

Max. bending stress = M_i / I = M / Z = (3120 x 10^3 x 6) / 76 x 200^2 = 6.2N/mm

Tables of allowables stresses indicate that most hardwoods, but not all softwoods are adequate.

Load transferred to outer wall by rafters is a little over 3kN. Assuming the strength of the blocks is at least 2.8N/mm, the area required:

3000 / 3.8 = 1072mm, since rafter underside is 76mm the minimum interface across wall is 1072 / 76 = 14mm

Hence, there is no problem of load transfer to wall.

Assume posts 100 x 100mm and 2.5m long, l / b = 25 and table 4.5 gives $K\lambda$ = 0.3

With σ_c = 5.2N/mm allowable for design, 0.38 x 5.2N/mm x 100^2 $\cong$ 20kN The load is safe.

Connections

Timber Structure

The methods used to join members include lapped and butt connectores. Bolt and connector joints, nailed joints and glued joints and sometimes a combination of two are examples of lapped connections. Butt connections require the use of plates or gussets. In all cases the joints should be designed by calculating the shear forces that will occur in the members.

If two members overlap the joint is called a single-lap joint. If one is lapped by two other members, i.e., sandwiched between them, it is called a double-lap joint.

With a single lap the joint is under eccentric loading. For small-span trusses carrying light loads, this is not significant, but when the joints carry large loads eccentricity should be avoided by the use of double-lap joints. Double members are also used to obtain a satisfactory arrangement of members in the truss as a whole.

Sandwich construction enables the necessary sectional area of a member to be obtained by the use of relatively thin timbers, any double members in compression being blocked apart and fixed in position to provide the necessary stiffness.

Butt Joints

The use of gussets permits members to butt against each other in the same plane, avoids eccentric loading on the joints and provides, where necessary, greater joining area than is possible with lapped members. This is often an important factor in nailed and glued joints. Arrangement of members on a single centre line is usually possible with gussets.

When full-length timber is not available for a member, a butt joint with cover plates can be used to join two pieces together. This should be avoided, if possible, for the top members (rafters) of a truss and positioned near mid-span for the bottom member (main tie).

Figure 4.9 Butt Joints.

Bolt and Connector Joints

Simple bolted joints should only be used for lightly loaded joints, since the bearing area at the hole (hole diameter times member thickness) and the relatively low bearing stress allowed for the timber compared with that of the steel bolt, may cause the timber hole to elongate and fail.

Timber connectors are metal rings or toothed plates used to increase the efficiency of bolted joints. They are embedded half into each of the adjacent members and transmit load from one to the other. The type most commonly used for light structures is the

toothed-plate connector, a mild-steel plate cut and stamped to form triangular teeth projecting on each side that embed in the surfaces of the members up on tightening the bolt which passes through the joint. The double-sided toothed connector transmits the load and the bolt is assumed to take no load.

Glued Joints

Glues made from synthetic resins produce the most efficient form of joint, as strong as or even stronger than the timber

joined, and many are immune to attack by dampness and decay. With this type of joint all contact surfaces must be planed smooth, and the necessary pressure provided during setting of the glue. Bolts or nails which act as cramps are often used and left in place.

The members may be glued directly to each other using lapped joints or single-thickness construction may be used by the adoption of gussets. As with nailed joints, lapped members may not provide sufficient gluing area and gussets must then be used to provide the extra area.

Glued joints are more often used when trusses are prefabricated because control over temperature, joint fit and clamping pressure is essential. For home use glue is of the used together with nail joints.

Figure 4.10 Double sided Toothed Plate connector.

Nailed Joints

Joining by nails is the least efficient of the three methods referred to, but is an inexpensive and simple method, and can be improved upon by using glue in combination with the nails.

When trusses are pre-fabricated in factories, nailing plates are often used to connect the member. These fasteners come in two types:

1 A thin-gauge plate called a pierced plate fastener, which has holes punched regularly over its surface to receive nails. The pierced plate can also be used for on-site fabrication.

2 A heavier plate with teeth punched from the plate and bent up 90 degrees, called a toothed-plate fastener, or connector. The type, in which the teeth are an integral part of the plate, must be driven in by a hydraulic press or roller.

Figure 4.11 Truss gussets.

Figure 4.12 Nailing plates for truss construction.

In order to permit the development of the full load at each nail, and to avoid splitting of

the wood, minimum spacings between nails and distances from the edges and ends of the member are necessary.

Nailing patterns for use on timber structures are usually available locally. They are dependent on the quality and type of nails and timber used, and are based on the safe lateral nail load.

The Housing Research and Development Unit of the University of Nairobi investigated timber nailed joints made with spacings in accordance with the continental standard for timber joints, which proved to be satisfactory. The main principles are given in table 4.9 and 4.10.

Table 4.9 Minimum nailing spaces

Connections in Steel Structures

Connections may be bolted, riveted or welded. The principal design considerations are shear, tension and compression, and the calculations are relatively straightforward for the types of design covered.

Nailing area						
x						

	r_o	d_l	d_{11}	r_b	e_0	e_b
0	5d	5d	10d	5d	-	I5d
10	5d	5d	10d	5.5d	8d	15d
20	5d	5d	10d	6d	8d	I5d
30	5d	5d	10d	6.5d	8d	15d
40	5d	5d	10d	7d	8d	15d
50	5d	5d	10d	7.5d	8d	15d
60	5d	5d	10d	8d	8d	15d

d: Diameter of nail mm.

r_0: Distance from extreme row of nails to unloaded edge of member.

d_1: Distance between two nails in nailing area, measured perpendicular to axis of member.

d_{11}: Distance between two nails measured parallel to axis of member.

r_b: Distance from extreme row of nails to loaded edge of member.

e_0: Distance from the nearest row of nails to the unloaded end of member.

e_b: Distance from the nearest row of nails to the loaded end of member.

Figure 4.13 Connections for steel frames.

Stability

Stability problems in a building are due mainly to horizontal loads such as those resulting from wind pressure, storage of granular products against walls, soil pressure against foundations, and sometimes earthquakes.

Overturning of foundation walls and foundation piers and pads is counteracted by the width of the footing and the weight of the structure. Only in special cases will it be necessary to give extra support in the form of buttresses.

Overturning of external walls is counteracted by the support of perpendicular walls and partitions. Note however, that not all types of walls, for example framed walls, are adequately rigid along their length without diagonal bracing. If supporting walls are widely spaced and/ or the horizontal loads are large, extra support can be supplied by the construction of piers, columns or buttresses. See Chapter 5.

Diagonal bracing is used to make framed walls and structures stiff. Long braces should preferably transfer the load with a tensile stress to avoid buckling. Braces are usually supplied in pairs, i.e., on both diagonals, so that one will always be in tension independent of wind direction.

If the framed wall is covered with a sheet material, like plywood, chipboard or metal sheets, the lateral forces on the frame can be counteracted by shear in the sheets. This design requires that the sheets to be securely fixed to the frame, both horizontally and vertically. The sheets must also be strong enough to resist buckling or failure through shear.

Masonry and concrete walls which are stiff and capable of resisting lateral wind loading are called shear walls.

Portal or rigid frame buildings are normally stable laterally, when the wind pressure acts on the long sides. However, when the wind loads occur at the gable ends, the frames may need extra support from longitudinal bracing. Tension rods are frequently used.

Figure 4.14 Bracing for portal frame.

Post-and-beam or shed-frame buildings will, in most cases, require wind bracing, both along and across the building since there are no rigid connections at the top of the wall to

transfer loads across and along the building. The same applies to buildings employing roof trusses. End bracing should be installed.

Walls with long spans between the supporting crosswalls, partitions or buttresses tend to bend inwards due to wind load or outwards if bulk grain or other produce is stored against the wall. At the bottom of the wall this tendency is counteracted by the rigidity of the foundation (designed not to slide) and the support of a floor structure. The top of the wall is given stability by the support of the ceiling or roof structure or a specially designed wall beam which is securely anchored to the wall.

The designer must consider the ability of the building to withstand horizontal loading from any and all directions, without unacceptable deformation.

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Retaining walls

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Wall Failure

Walls are commonly used to retain soil on sloping sites, water in a pond or bulk products within a storage area. There are several limiting conditions which, if exceeded, can lead to the failure of a retaining wall. Each must be addressed in designing a wall.

1 Overturning - This occurs when the turning moment due to lateral forces exceeds that due to the self-weight of the wall. The factor of safety against overturning should be at least two.

2 Sliding - The wall will slide if the lateral thrust exceeds the frictional resistance developed between the base of the wall and the soil. The factor of safety against sliding should be about two.

3 Bearing on Ground - The normal pressure between the base of the wall and the soil beneath can cause a bearing failure of the soil, if the ultimate bearing capacity is exceeded. Usually the allowable bearing pressure will be one-third of the ultimate value. Note that the pressure distribution across the base is not constant.

Bearing pressure

4 Rotational Slip - The wall and a large amount of the retained material rotate about

some point O. if the shear resistance developed along a circular arc is exceeded. The analysis is too complex to include here.

Rotation

5 Wall Material Failure - The structure itself must be capable of withstanding the internal stresses set up, that is, the stresses must not exceed allowable values. Factors of safety used here depend on the material and the level of the designer's knowledge in respect to the loads actually applied. Naturally, both shear and bending must be considered, but the most critical condition is likely to be tension failure of the 'front' facet

Joint failure in block work

Gravity walls and dams are dependent on the effect of gravity, largely from self-weight of the wall itself, for stability. Other types of walls rely on a rigid base, combined with a wall designed against bending to provide an adequate structure.

Tension bending failure

Pressure Exerted by Retained Material

Liquid Pressure

The pressure in a liquid is directly proportional to both the depth and the specific weight of the liquid (w) which is the weight per unit volume. w = pg (N/m) where: p = density of liquid (kg/m) g = gravitational acceleration (9.81m/s2)

Liquid Pressure I

The pressure at a given depth acts equally in all directions, and the resultant force on a dam or wall face is normal to the face. The pressure due to the liquid can be treated as a distributed load with linear variation in a triangular load form, having a centroid twothirds of the way down the wet face.

$p = \rho gH = wH$ (N/m) and:

$P = WH^2 / 2$ acting at a depth of 2/3 H

Liquid Pressure II

It should be noted that a wall retaining a material that is saturated (water-logged) must resist this liquid pressure in addition to the lateral pressure from the retained material.

Example 25

Gravity Wall Retaining Water

Consider a mass concrete dam with the cross section shown which retains water to 3m depth. Assume: Ground safe bearing capacity 300kN/m. Coefficient of sliding friction at base 0.7. Specific weight of concrete 23kN/m.

1 Find water force P:

All calculations per metre length of wall:

$p = wH^2 / 2 = (9.8 \times 10^3 \times 3^2) = 44.1kN$ (acting 1m up face)

2 Find mass of 1m Length of Wall:

W = A x 1 x specific weight

= 3 x (0.6 + 1.8)/2 x 23 = 82.8kN

3 Find line of action of w: Taking moments of area about vertical face:

Hence self-weight of wall acts 0.25m to left of base centre line.

4 Find vertical compressive stress on base:

P_c = W / A = 82.8 / (I x 8) = 46kN/m

5 Find moment about centre line of base

M = (1 x 44.1) - (0.25 x 82.8); (clockwise) (anticlockwise) M = 23.4 kNm

6 Find bending stresses/pressures

$\sigma_b = P_b = MI / Y_{max}$ where;

$I = bd^3 / 12 = (I \times 1.8^3) / 12 = 0.486m^4$

$Y_{max} = 1.8 / 2 = 0.9m$

$\sigma_b = P_b = (23.4 \times 0.486) / 0.9 = 12.6kN/m^2$

7 Find actual stresses/pressures

$\sigma = p = W/A + M_y/I$

$\sigma_E = P_E = 46 + 12.6 = 58.6kN/m$ (comp)

$\sigma_D = P_D = 46 - 12.6 = 33.4kN/m$ (comp)

(Note: Compression only indicates the resultant P and W would intersect the base line within its middle third).

8 Compare maximum pressure with allowable bearing capacity:

$P_{max} = 58.6kN/m$

This is less than the allowable safe bearing capacity of the soil. Hence wall-soil interface is safe in bearing.

9 Compare actual stresses in wall with allowable values:

Max. stress = 58.6 kN/m (Compression) and no tensile stress at any point across wall. Hence wall material is safe.

10 Check overturning:

Overturning moment about D = 44.1 x 1 = 44.1 kNm

Stabilising moment about D = 82.8 x 1.15 = 95.22kNm

Factor of safety overturning = 94.22 / 44.1 = 2.16

Wall safe in overturning.

11 Check sliding

Frictional resistance = μ W

μ W = 0.7 x 82.8 = 58kN

Horizontal thrust = P = 44.1kN

Since required factor against sliding is 2, there is a deficiency of (2 x 44.1) - 58 = 30.2 kN.

Additional anchorage against sliding should be provided.

Example 26

Circular Water Tank

Diameter 5m, depth of water 3m

Water weighs 9.8 x 10^3N/m

Pressure (P) at depth of am

P_3=wH=9.8 x 10^3 x 3=294kN/m

This acts vertically over the whole base, thus design base for u.d.1. of 29.4kN/m.

Pressure P_3 also acts laterally on the side wall at its bottom edge. This pressure decreases linearly to zero at the water surface.

Total force on base = P_3A_B = 29,4 x (π x 5^2) = 577.3 kN

(acting at centre of base)

Total force on side per metre of perimeter wall:

P_3H / 2 = (29.24 x 3) / 2 = 44.1 kN/m run (acting 1m above base)

Pressure Due to Granular Materials

Granular materials such as sandy soils, gravelly soils and grain possess the property of internal friction (friction between adjacent grains), but are assumed not to possess the property of cohesion. If a quantity of such material in a dry condition is tipped on to a flat surface, it will form a conical heap, the shape maintained by this internal friction between grains. The angle of the sloping side is known as the angle of repose.

For a dry material the angle of repose is usually equal to the angle of shearing resistance of the material. This angle of shearing resistance is called the angle of internal friction (a). The angle of friction is the essential property of a granular material on which Rankine's theory is based. This theory enables the lateral pressure to be expressed as a proportion of the vertical pressure, which was shown (above) to depend on specific weight and depth only.

In this case at a depth h, the active lateral pressure is given by:

P=k x w x h where:

k = a constant dependent on the materials involved

There exists some friction between the retained material and the wall face, but usually

this is disregarded giving a relatively simple relationship for k:

where

θ = the angle of friction

where: p_a = total force per m of wallface (N)

(N/m lenght of fall)

P_a = total force per m of wall face (N)

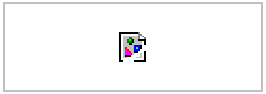
This gives the approximate horizontal resultant force on a vertical wall face, when retaining material that is level with the top of the wall. If the surface of the retained material is sloping up from the wall at an angle equal to its angle of repose, a

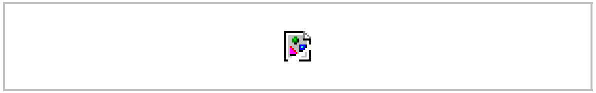
modification is required.

Example 27

Wall retaining soil

Consider the wall shown retaining loose sandy soil to a depth of 2 metres. Tables provide angle of friction 35, specific weight 18.6kN/m. Assuming smooth vertical surface and horizontal soil surface using Rankine's theory gives:





P = 10.1 kN/m length of wall

If steel posts are placed at 2.5m centres, each post can be approximated to a vertical cantilever beam 2.5m long carrying a total distributed load of 10.1 x 2.5 = 25.25kN of linear variation from zero at the top to a maximum at the base. The steel post and foundation concrete must be capable of resisting the applied load, principally in bending

but also in shear.

The timber crossbeams can be analyzed as beams simply supported over a span of 2.5m, each carrying a uniformly distributed load. This load is equal to the product of the face area of the beam and the pressure in the soil at a depth indicated by the centroid of area of the beam face.

Totalu.d.l.onbeam=9.29 x 0.3 x 2.5=6.97 kN

The maximum bending moment at the centre of the span can be determined and the beam section checked.

Example 28

Grain Storage Bin

[Pressure diagrams]

(The theory given does not apply to deep bins). A shallow bin can be defined as one having a sidewall height of less than

S/2 tan (45 + θ / 2) for a square bin of side length S.

Consider a square bin of side length 4m and retaining shelled maize corn to a depth of 2m. Assume θ = 27; specific weight is 7.7kN/m.

Critical height is:

Design as shallow bin since depth of grain is only 2m.

Maximum pressure at base of wall:

or resultant force P = $(5.97 \times 2^2) / 2 = 11.57$kN/m

(acting 2/3m above base of wall)

Note the design of the wall is complex if it consists of a plate of uniform thickness, but if the wall is thought of as consisting of a.number of vertical members cantilevered from the floor, an approach similar to that taken in the wall retaining soil can be used.

Further reading

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Salvadori, M. and R. Heller, *Structure in Architecture,* The Building of Buildings, Englewood Cliffs, New Jersey, Pretice-Hall, 1975.

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Chapter 5 Elements of construction

Elements of Construction

When designing a building, an architect plans for special, environmental and visual requirements. Once these requirements are satisfied, it is necessary to detail the fabric of the building. The choice of materials and the manner in which they are put together to form building elements such as foundation, walls, floor and roof, depend largely upon their properties relative to environmental requirements and their strength properties. The apprehension of building construction thus involve an understanding of the nature and characteristics of a number of materials, of methods to process them and form them into building units and components, of structural principles, of stability and behaviour under load, of building production operations and of building economics.

The limited number of materials available in the rural areas of east and south east Africa result in a limited number of structural forms and methods of construction. Different socioeconomic conditions and cultural beliefs are reflected in varying local building traditions. While knowledge of the indigenous building technology is widespread, a farmer and his family normally can erect a building using traditional materials and methods without the assistance of skilled or specialized craftsmen. However, population growth and external influences are gradually changing people's lives and the agricultural practices some traditional materials are getting scarce. Hence, better understanding of traditional materials and methods is needed to allow them to be used more efficiently and effectively. While complete understanding of the indigenous technology will enable the architect to design and detail good but cheap buildings, new materials with differing

properties may need to be introduced to complement the older and allow for new structural form to develop.

Loads on building components

Loads are usually divided into the following categories:

Dead loads which result from the mass of all the elements of the building including footings, foundation, walls, suspended floors, frame and roof. These loads are permanent, fixed and relatively easy to calculate.

Live loads which result from the mass of animals, people, equipment and stored products. Although the mass of these loads can be readily calculated, the fact that the number or amount of components may vary considerably from time to time makes live loads more difficult to estimate than dead loads.

Also included as live loads are the forces of nature wind, earthquake and snow.

Where wind velocities have been recorded, the following equation can be used to determine the expected pressures on building walls:

$q = 0{,}0127\ V^2 k$ where:

q = basic velocity pressure, P_a

V = wind velocity, m/s

$k = (h/6.1)^{2/7}$

h = design height of building, m (eave height for low and medium roof pitches)

6.1 = height at which wind velocities were often recorded for Table 5.1.

While the use of local wind velocity data allows the most accurate calculation of wind pressures on buildings, in the absence of such data, estimates can be made from the Beaufort Scale of Winds given in Table 5.1.

Table 5.1 ***Beaufort Scale of Winds***

		Velocity in m/s 6.1 m above ground
Strong breeze	Large branches in motion;	11 - 14

	whistling in telephone wires; umbrellas used with difficulty.	
Moderate gale	Whole trees in motion; difficult to walk against wind	up to 17
Fresh gale	Twigs break off trees; very difficult to walk against wind	21
Strong gale	Some structural damage to buildings	24
Whole gale	Trees uprooted: considerable structural damage to buildings	28
Storm	Widespread destruction	33

From U.S. Weather Bureau

Some idea of the worst conditions to be expected can be obtained by talking to long-time residents of the area.

The effect of wind pressure on a building is influenced by the shape of the roof and by whether the building is open or completely closed. Table 5.2 gives coefficients used to determine expected pressures for low-pitch and high-pitch gable roofs and open and

closed buildings. Note that there are several negative coefficients indicating that strong anchors and joint fasteners are just as critical as strong structural members.

Data on earthquake forces is very limited. The best recommendations for areas prone to earthquakes is to use building materials that have better than average tensile characteristics, to design joint fasteners with an extra factor of safety, and to include a ring beam at the top of the building wall.

Table 5.2 ***Wind Pressure Coefficients for Gable Roof Farm Buildings***

H:W Windward Wall Coefficient	**Windward Roof Coefficient Roof Slope**			**Leeward Roof Coefficient**	**Leeward Wall Coefficient**
Completely closed		15	30		
1:6:7	0.70	-0.20	0.19	-0.5	-0.4
1:5	0.70	-0.27	0.19	-0.5	-0.4
1:33	0.70	-0.41	0.16	-0.5	-0.4
1.2	0.70	-0.60	0.00	-0.5	-0.4

Open on both sides < 30 30

Windward slope	+0.6	+0.8
Leeward slope	-0.6	-0.8

H = height to eaves, W = width of building

Table 5.3 ***Mass of Building Materials***

Material	**kg/m**	**kg/m**
Concrete	2400	
Steel	7850	
Dense woods 19mm	900	17.0
Soft woods 19mm	580	11.0
Plywood 12mm		7.3
Galvanized roofing		3.9
Concrete hollow lock wall	100mm	145
	200mm	275

	300mm	390
Brick walls	100mm	180
	200mm	385

Table 5.4 ***Loads on Suspended Floors***

		kN/ m
Cattle	Tie stalls	3.4
	Loose housing	3.9
	Young stock (180 kg)	2.5
Sheep		1.5
Horses		4.9
Pigs	(90 kg) Slatted floor	2.5
	(180 kg) Slatted floor	3.2
Poultry	Deep litter	1.9
	Cages	Variable
Repair shop (allowance)		3.5

Machinery storage (allowance)		8

Snow loads are a factor only in very limited areas of high elevation in East and Southeast Africa. Local information on the mass of snow loads should be used.

Table 5.3 provides information useful in determining dead loads and Tables 5.4 and 5.5 give information relevant to live loads.

Table 5.5 ***Mass of Farm Products***

Product	**Angle of repose**		**Mass kg/m**
	Emptying	**Filling**	
Maize, shelled	27	16	720
Maize, ear	-	-	450
Wheat	27	16	770
Rice (paddy)	36	20	577
Soybeans	29	16	770

Dry beans	-	-	770
Potatoes	-	37	770
Silage	-	-	480-640
Groundnuts, unshelled			218
Hay, loose			65-80
baled			190-240

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Footings and foundations

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A foundation is necessary to support the building and the loads that are within or on the building. The combination of footing and foundation distributes the load on the bearing surface and keeps the building level and plumb and reduces settling to a minimum. When

properly designed, there should be little or no cracking in the foundation and no water leaks. The footing and foundation should be made of a material that will not fail in the presence of ground or surface water. Before the footing for the foundation can be designed, it is necessary to determine the total load to be supported.

If for some reason the load is concentrated in one or more areas, that will need to be taken into consideration. Once the load is determined, the soil bearing characteristics of the site must be studied.

Soil Bearing

The topmost layer of soil is seldom suitable for a footing. The soil is likely to be loose, unstable and contain organic material. Consequently, the topsoil should be removed and the footing trench deepened to provide a level, undisturbed surface for the entire building foundation. If this is not feasible because of a sloping site, the footing will need to be stepped. This procedure is described in later and illustrated in Figure 5.5. The footing should never be placed on a filled area unless there has been sufficient time for consolidation. This usually takes at least one year with a normal amount of rainfall. The bearing capacity of soil is related to the soil type and the expected moisture level. Table 5.6 provides typical allowable soil-bearing values.

Table 5.6 ***Soil Bearing Capacities***

Soil Type	**kN/m**
Soft, wet, pasty or muddy soil	27 - 35
Alluvial soil, loam, sandy loam (clay +40 to 70% sand)	80 - 160
Sandy clay loam (clay +30% sand), moist clay	215 - 270
Compact clay, nearly dry	215 - 270
Solid clay with very fine sand	- 430
Dry compact clay (thick layer)	320 - 540
Loose sand	160 - 270
Compact sand	215 - 320
Red earth	- 320
Murram	- 430
Compact gravel	750 - 970
Rock	- 1700

An extensive investigation of the soil is not usually necessary for small-scale buildings.

Foundation and pier footings can easily be designed to keep within the safe bearing capacity of the soil found on the building site.

Site Drainage

It is desirable to site any building on well-drained land However, other considerations such as access roads, water supply, existing services or a shortage of land may dictate a poorly drained area.

If a building site with poor natural drainage must be used, it may be improved by the use of contour interceptor drains or subsurface drains in order to cut off the flow of surface water or to lower the water-table level. Aparn from protecting the building against damage from moisture, drainage will also improve the stability of the ground and lower the humidity of the site. Figures 5.1 and 5.2 illustrate these methods.

Subsurface drains are usually laid 0.6 to 1.5m deep and the pipe layout arranged to follow the slope of the land. The spacing between drains will vary between 10m for clay soils to 50m for sand. Subsurface drains are usually formed from buttjoined clay pipes laid in narrow trenches. In cases where it is desirable to catch water running on the surface, the trench is back-filled nearly to the top with rubble either continuously along the trench or in pockets. A trench filled with rubble or broken stone will provide passage for water and is effective in dealing with flows on the surface. Pipes and trenches belonging to the main

site drainage system may cause uneven settling if allowed to pass close to or under buildings. Where needed a separate drain, that surround the building and installed not deeper than the footing, is used to drain the foundation trench.

Figure 5.1 Contour interceptor drain.

Figure 5.2 Subsurface site drains.

Foundation Footings

A footing is an enlarged base for a foundation designed to distribute the building load over a larger area of soil and to provide a firm, level surface for constructing the foundation wall.

A foundation wall, regardless of the material used for its construction, should be built on a continuous footing of poured concrete. Although the footing will be covered and lean mixes of concrete are considered satisfactory, a footing that is strong enough to resist cracking also helps to keep the foundation from cracking. A 1 :3:5 ratio of cement - sand - gravel is suggested with 311 of water per 5O kg sack of cement. The amount of water assumes dry aggregates. If the sand is damp, the water should be reduced by 4 to 5l.

The total area of the footing is determined by dividing the total load, including an

estimated mass for the footing itself, by the bearing by dividing the area by the length. In many cases the width required for light farm buildings will be equal to or less than the foundation wall planned. In that case, a footing that is somewhat wider than the foundation is still recommended for at least two reasons. The footings conform-to small variations in the trench and bridge small areas of loose soil making a good surface on which to begin a foundation wall of any kind. The footings are easily made level and this makes it easier to install the forms for a poured concrete wall or to start the first course of a block or brick wall.

Even when loading does not require it, it is common practice to pour a concrete footing that is as deep as the wall is thick and twice as wide. The foundation footings for large heavy buildings require reinforcing. However, this is seldom necessary for light-weight farm buildings. Once a firm footing is in place, a number of different materials are suitable for building a foundation. Figure 5.3 shows footing proportions for walls, piers and columns.

Figure 5.3 Footing proportions.

Although continuous wall footings are frequently loaded very lightly, that is not the case with column and pier footings. It is important therefore, to carefully estimate the proportion of the building load to be carried by each pier or column. Figure 5.4 illustrates the load distribution on a building with a gable roof and a suspended floor.

If wall footings are very lightly loaded, it is advisable to design any pier or column footings required for the building with approximately the same load per unit of area. Then if any settling occurs, it should be uniform throughout. For the same reason, if part of the footing or foundation is built on rock, the balance of the footing should be twice as wide as usual for the soil and loading. Footings must be loaded evenly as eccentric loading may cause tipping and failure.

If a foundation is installed on a sloping site, it may be necessary to dig a stepped trench and install a stepped footing and foundation. It is important that all sections are level and that each horizontal section of the footing is at least twice as long as the vertical drop from the previous section. Reinforcing in the wall as shown in Figure 5.5 is desirable.

Figure 5.4 The division of loads on footings.

Each pier footing must carry t/8 of the floor load. The wall must carry 5/8 of the floor load and all of the roof and wall load.

Figure 5.5 Stepped footing and foundation.

The procedure for finding an appropriate footing may be illustrated using Figure 5.4. Assume a building is 16m long and 8m wide. The roof framing plus the expected wind load totals 130kN. The wall above the foundation is 0.9kN/ m. The floor will be used for

grain storage and will support as much as 7.3kN/m. The floor structure is an additional 0.5kN/m. The foundation wall and piers are each 1 m high above the footing. The wall is 200mm thick and the piers 300mm square. The soil on the site is judged to be a compact clay in a well-drained area. Find the size of the foundation and pier footing that will safely support the loads. Assume that the weight of the mass 1 kg approximately equals 10N. The mass of concrete is 2400 kg/m.

1 The division of the load on each wall is as follows:

a Roof load - 50% on each wall, 130kN	65kN
b Wall load - for each side 16 x 0.9kN	14.4kN
c Floor load - each side carries 7/32 x 998kN	218.4kN
d Foundation load - each side, 16 x 0.2 x 24kN	76.8kN
e Estimated footing 0.4 x 0.2 x 16 x 24kN	30.7kN
f Total on one side	405.3kN
g Force per unit of length 405.3/ 16	25.3kN/ m
h Using for practical reasons,and assumed width of 0.4, 25.3/0.4	63.3kN/m

i Compact clay at 215 - 217kN/m easily carries the load.	
2 The division of the load on each pier is:	
Floor load - 1/8 x 998kN	124.8
Pier 0.3 x 0.3 x 1 x 24kN	2.2
Footing estimate 0.8 x 0.8 x 0 5 x 24kN	7.7
Total	134.7kN
Load/ m	210kN/ m
O.K. but 1 x 1 x 0 7 gives more equality to wall loading	144kN/m

The most logical action to take would be to add one or more additional piers which would allow both smaller footings and smaller floor support members.

Footing Trenches

The trench must be dug deep enough to reach firm, undisturbed soil. For light buildings in warm climates, this may be as little as 30cm. However, for large, heavy buildings footing trenches may need to be up to 1m deep.

Pockets of soft material should be dug out and filled with concrete, stones or gravel. The trenches should be free of standing water when the concrete is poured for the footing.

A level trench of the correct depth can be insured by stretching lines between the setting-out profiles (batter boards) and then using a boning rod to check the depth of the trench as it is dug out.

The footing forms should be carefully leveled so that the foundation forms may be easily installed, or a brick or block wall begun. If the foundation walls are to be made of bricks or concrete blocks, it is important that the footings be a whole number of courses below the top of the finished foundation level.

Alternatively the footing can be cast directly in the trench. While this saves the cost of footing forms, care must be taken so that no soil from the sides is mixed in the concrete. Proper thickness for the footing can be ensured by installing guiding pegs, whose tops are set level and at correct depth, at the center of the foundation trench.

Types of Foundation

Foundations may be divided into several categories which are suitable for specific situations.

Continuous wall foundations may be used either as basement walls or as curtain walls. A continuous wall for a basement of a building must not only support the building but it must be a waterproof barrier capable of resisting the lateral force of the soil on the outside. However, because of the structural problems and the difficulties to exclude water it is recommended to avoid basement constructions in all, but a few special circumstances. Curtain walls are also continuous in nature but being installed in a trench in the soil, they are not usually subjected to appreciable lateral forces and they do not need to be waterproof. Curtain walls may be constructed and then the earth filled back on both sides, or they may be made of concrete poured directly into a narrow trench. Only that portion above ground level requires a form when the concrete is poured. See Figure 5.9. Curtain walls are strong, relatively watertight and give good protection against rodents and other vermin.

Pier foundations are often used to support the timber frames of light buildings with no suspended floors. They require much less excavation and building material. The stone or concrete piers are usually set on footings. However, for very light buildings the pier may take the form of a precast concrete block set on firm soil a few centimeters below ground level. The size of the piers is often given by the weight required to resist wind uplift of the whole building.

Pad and pole foundation consists of small concrete pads poured in the bottom of holes which support pressure treated poles. The poles are long enough to extend and support

the roof structure. This is probably the least expensive type of foundation and is very satisfactory for light buildings with no floor loads and where pressure treated poles are available.

A floating slab or raft foundation consists of a poured concrete floor in which the outer edges are thickened to 20 to 30cm and reinforced. This is a simple system for small buildings that must have a secure joint between the floor and the sidewalls.

A pier and ground level beam foundation is commonly used where extensive filling has been necessary and the foundation would have to be very deep in order to reach undisturbed soil. It consists of a reinforced concrete beam supported on piers. The piers need to be deep enough to reach undisturbed soil and the beam must be embedded in the soil deeply enough to prevent rodents from burrowing under it. For very light buildings such as greenhouses, timber ground level beams may be used.

Piles are long columns that are driven into soft ground where they support their load by friction with the soil rather than by a firm layer at their lower end. They are seldom used for farm buildings.

Foundation Materials

The foundation material should be at least as durable as the balance of the structure.

Foundations are subject to attack by moisture, rodents, termites and to a limited extent, wind. The moisture may come from rain, surface water or ground water, and although a footing drain can reduce the problem, it is important to use a foundation material that will not be damaged by water or the lateral force created by saturated soil on the outside of the wall. In some cases the foundation must be watertight in order to keep water from penetrating into a basement or up through the foundation and into the building walls above. Any foundation should be continued for at least 150mm above ground level to give adequate protection to the base of the well from moisture, surface water, etc.

Stones

Stones are strong, durable and economical to use if they are available near the building site. Stones are suitable for low piers and curtain walls where they may be laid up without mortar if economy is a prime factor, it is difficult to make them water tight, even if laid with mortar. Also, it is difficult to exclude termites from buildings with stone foundations because of the numerous passages between the stones. However, laying the top course or two in good rich mortar and installing termite shields can largely overcome the termite problem.

Earth

The primary advantage of using earth as a foundation material is its low cost and

availability. It is suitable only in very dry climates. Where rainfall and soil moisture are a little high for unprotected earth foundation, they may be faced with stones as shown in Figure 5.6 or shielded from the moisture with polythene sheet. See Figure 5.8.

[Earth foundation faced with stones.]

Poured Concrete

Concrete is one of the best foundation materials because it is hard, durable and strong in compression. It is not damaged by moisture and may be made nearly watertight for basement walls. It is easily cast into the unique shapes required for each foundation.

For example, curtain walls can be cast in a narrow trench with very little formwork required. The principle disadvantage is the relatively high cost of the cement required to make the concrete.

Concrete Blocks

Concrete blocks may be used to construct attractive and durable foundation walls. The forms required for poured concrete walls are unnecessary and because of their large size, concrete blocks will lay up faster than bricks. A block wall is more difficult to make watertight than a concrete wall and does not resist lateral forces as well as a poured

concrete wall.

Bricks

Stabilized earth bricks or blocks or blocks have inherently the same restrictions as monolithic earth foundations. They are suitable only in very dry areas and even there they need protection from moisture. Adobe bricks are to easily damaged by water or ground moisture to be used for foundations. Locally made, burnt bricks can often be obtained at low cost, but only the best quality bricks are satisfactory for use in moist conditions. Factory made bricks are generally too expensive to be used for foundations.

Foundation Construction

Stone Foundation

If the stones available are relatively flat, they may be laid up dry (without mortar) starting on firm soil in the bottom of a trench. This makes a very low cost foundation suitable for a light building. If monolithic earth walls are to be constructed on top of the stone foundation, no binder is necessary for the stones. If masonry units of any type are to be used, it would be prudent to use mortar in the last two courses of stone in order to have a firm level base on which to start the masonry wall. If a timber frame is planned, then mortar for the top courses plus a metal termite shield is necessary both to provide a level

surface and to exclude termites.

If the stones available are round or very irregular in shape, it is best to lay them up with mortar to obtain adequate stability. Figure 5.7 shows earth forms being used to hold stones of irregular shape around which a grout is poured to stabilize them. Stones to be laid in mortar or grout must be clean to bond well.

Figure 5.7a. shows a mortar cap on which a concrete block wall is constructed. A stone shield to protect the base of an earth block wall is shown in b., and in c. the embedding of poles in a stone foundation as well as a splash shield. Proper shielding may reduce the risk of a termite infestation.

Figure 5.7 Stone foundations.

Earth Foundation

Although more moisture resistant materials are generally recommended for foundations, circumstances may dictate the use of earth. Figure 5.6 shows an earth foundation that has been faced with fieldstones. The joints have been filled with a cement-lime mortar and the entire surface coated with bitumen. Figure 5.8 illustrates the use of sheet polythene to exclude moisture from a foundation wall. While either of these methods helps to seal out moisture, the use of earth for foundation walls should be limited to dry-land regions.

Place the polythene sheet on a thin layer of sand or on a concrete footing. Overlap the single sheets by at least 20cm. Construct a foundation wall from stabilized rammed earth or stabilized soil blocks. Once the wall has hardened and dried out, the polythene is unrolled and soil filled back in layers in the foundations trench. Fasten the ends of the sheet to the wall and protect with a drip deflection strip, a skirting or with malting and plaster.

Figure 5.8 An earth foundation protected from moisture with polythene sheet.

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Concrete foundations

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For light buildings a curtain wall may be poured directly into a carefully dug trench 15 to 25cm wide. To have the finished wall extend above the ground, forms built of 50 x 200mm timber can be anchored along the top of the trench.

Figure 5.9 Curtain wall poured in a trench.

A relatively lean mix of concrete, 1:4:8, can be used. The concrete must be placed carefully to keep the walls of the trench from sloughing off and mixing in, thereby causing weak spots. If the soil is not stable enough to allow digging a trench form, a wide excavation and the use of simple forms will be required.

Additional information on ratios, materials, forms, placing and curing concrete will be found in Chapter 3.

Concrete Block Foundation

It is desirable for all dimensions of a block wall to be divisable by 225mm. this will allow full or half blocks to be used at all corners and openings without the need to cut blocks to odd lengths. Blocks must be dry when used or the mortar joints will not develop full strength.

Concrete block foundations should be started in a full bed of mortar on a poured concrete footing. A 1: 1 :5 ratio of cement-lime-sand makes a good mortar. The corner blocks should be carefully located and checked for levelness and plumb. After several blocks have been laid adjacent to the corners, a line stretched between the corners can be used to align the top outside edge of each course of blocks as shown in Figure 5.10.

After the first course, face-shell bedding is used. That is, mortar is placed along the vertical edges of one end and the side edges of the top of the block. This will save up to 50% of the mortar and is about three-quarters as strong as full bedding.

Figure 5.10 Face-shell bonding in blockwall.

Masonry units must be overlapped so that the vertical joints are staggered in order to obtain adequate strength. Where small units such as bricks are used, the bonding must be both along and across the wall. However, blocks are only bonded longitudinally. Cross bonding is required only at points of reinforcement such as pilasters. A halflap bond is normal, but where necessary to permit bonding at returns and intersecting walls, this may be reduced to one-quarter of the block length, though not less than 65mm.

The strength of blocks of either dense or lightweight aggregate is sufficient for normal small-scale work, but where loading is heavy only dense concrete blocks are suitable. Hollow blocks may be used for load-bearing walls, but the courses directly supporting floor and roof structures should be built of solid construction in order to distribute the loading over the length of the wall and thus avoid the concentration of stresses.

The thickness, length and height of the wall determine its structural stability. Table 5.7 indicates suitable relationships for free-standing, single-thickness, unreinforced, concrete block walls not externally supported and not tied or fixed at the top and designed to

resist wind pressure. Longer and higher walls and, for example, walls retaining bulk grain may need the extra strength of being tied to a pier or crosswall.

Figure 5.11 Reinforcing block walls.

Table 5.7 ***Stabilizing Hollow Block Walls***

Thickness of wall	Height of wall	Maximum length of wall panel between piers, cross walls, etc.
100mm	1.8m	3.6m
150mm	3.0m	3.0m
215mm	3.6m	4.0m
215mm	4.5m	3.0m
305mm	4.5m	4.0m

Floating Slab or Raft Foundation

A slab foundation is a large concrete floor covering the entire building area through which all the loads from the building are transmitted to the soil. It is both building floor and

foundation and is well suited to garages, shops, small stores, and homes without basements. The concrete floor and the foundation are cast in one piece. The slab is cast about 100mm thick and lightly reinforced at the top to prevent shrinkage cracks. Steel bars are placed at the bottom under walls or columns to resist tensile stress in these zones. Light surface slabs can also be used to carry lightly loaded structures on soils subject to general earth movement.

As with all foundations the centre of gravity of the loads should coincide with the centre of the slab. This is facilitated when the building has a simple regular plan with load-bearing elements such as walls, columns or chimneys, located symmetrically about the axis of the building.

Pier Foundation

Isolated piers or columns are normally carried on independent concrete footings sometimes called pad foundations with the pier or column bearing on the centre point of the footing. The area of footing is determined by dividing the column load by the safe bearing capacity of the soil. Its shape is usually square and its thickness is governed by the same considerations as for foundation footings. They are made not less than 1 1/2 times the projection of the slab beyond the face of the pier or column or the edge of the baseplate of a steel column. It should in no case be less than 150mm thick. As in the case of strip footings, when a column base is very wide, a reduction in thickness may be

effected by reinforcing the concrete.

When piers are used to support prefabricated building frames of steel or laminated wood, the bolts for anchoring the frame to the piers must be grouted into the concrete and very accurately positioned. this requires skilled labour and supervision.

Figure 5.12 Design of floating slab foundation.

Figure 5.13 Simple rigid frame structure.

Post or Pole Foundation

For lightweight buildings without suspended floors, post or pressure-treated pole frames are suitable and inexpensive. The posts are placed in holes dug into the soil and a footing provided at each post. This is important since otherwise either gravity loads or wind uplift can lead to building failure.

The concrete pad under the pole provides the necessary support for gravity loads. The concrete collar around the base of the pole offers resistance to uplift. The pole is secured to the collar by several spikes driven near the base prior to placing the pole on the pad and pouring the concrete for the collar. While earth backfill should be well tamped to provide the greatest resistance to uplift a concrete collar, that extends to ground level,

offers better protection against ground moisture and termites.

Bracing of the poles to the roof and other building frame members offers adequate lateral stability. Figure 5.14 illustrates the pad and collar design.

Figure 5.14 Pole foundation.

Pier and Ground Level Beam Foundation

As mentioned previously, this design may be chosen for application where safe bearing layers are so deep as to make a curtain wall very expensive. The ground level beam must be designed to safely carry the expected load. Ordinarily the beam is made 150 to 200mm wide and 400 to apart. First the piers are formed and poured on footings of suitable size. The soil is then backfilled to 150mm below the top of the piers. After placing 150mm of gravel in the trench to bring the level even with the top of the piers, forms are constructed and the beam is poured. The reinforcing shown in Figure 5.15 is necessary. The size and spacing must be carefully calculated.

Protective Elements for Foundations

Waterproofing

Figure 5.15 Pier and ground level beam foundation.

Several steps can be taken to prevent ground or surface water from penetrating a foundation wall. If the building is located on sloping land where a footing drain can be terminated at ground level within a reasonable distance, the installation of a continuous drain around the outside of the foundation will reduce both the possibility of leaks and the lateral force of saturated soil bearing against the wall. The recommended drain design consists of 100mm drain tile placed slightly above the level of the bottom of the footing. The tile should be installed with little or no gradient so that the ground water level will remain equal at all points along the footing. Gravel is used to start the backfilling for the first 500mm and then the excavated soil is returned and tamped in layers sloping away from the wall.

The water resistance of poured concrete basement foundation walls may be improved by applying a heavy coat of bituminous paint. Block walls should be given two coats of cement plaster from the footing to above ground level and then covered with a finish coat of bituminous paint.

Moisture creeping up the foundation wall by capillary action can cause considerable damage to the lower parts of a wall made of soil or wood. While a mortar cap on top of the foundation wall usually provides a sufficient barrier, the extra protection of a ship of bituminous felt sometimes is required. To be effective such as damp-proof cause must be

set at least 150mm above the ground and be of the same width as the wall above.

Pitch-roof buildings that are not equipped with eave gutters can be further protected from excessive moisture around the foundation by the installation of a splash apron made of concrete. The apron should extend at least 150mm beyond the drip edge of the eaves and be sloped away from the wall approximately 1:20. A thickness of 50mm of 1:3:6 concrete should be adequate.

Foundations for Arch or Rigid Frames

Additional resistance to lateral forces is needed for foundation walls supporting arch or rigid frame buildings. This can be accomplished with buttresses, pilasters or by tying the wall into the floor. Figure 5.16 shows each of these methods.

Termite Protection

Figure 5.16 Methods of strengthening foundations.

Subterranean termites occur throughout East Africa and cause considerable damage to buildings by eating the cellulose in wood. They must have access to the soil or some other constant source of water. They can severely damage timber in contact with the ground and may extend their attack to the roof timbers of high buildings. Entrance to

unprotected structures is gained through cracks in concrete or masonry walls, through the wood portion of the house or by building shelter tubes over foundation posts and walls.

The main objective in termite control is to break the contact between the termite colony in the ground and the wood in the building. This can be done by blocking the passage of the termites from soil to wood, by constructing a slab floor under the entire building, and/or installing termite shields, treating the soil near the foundation and under concrete slabs with suitable chemicals, or by a combination of these methods.

Creepers, climbers and other vegetation likely to provide means of access for termites should not be permitted to grow on or near a building.

Chemical protection is useful if termite shields are not available, but is also recommended in combination with mechanical protection. Creosote oil, sodium arsenite, pentachlorophenol, pentachlorophenol, pentachlorphenate, copper napthenate, benzene hexachloride and dieldrin are the products predominantly used. The protective duration is 4 to 9 years depending on soil and weather conditions. Timber elements are impregnated before use. The timber surface is protected only if sprayed with insecticide prior to painting. Cracks, joints and cut surfaces must be protected with special care as termite attacks always start in such locations.

Slab on the ground construction: Firstly, the construction site must be carefully cleaned

and all termite colonies be traced down, broken and poisoned with 50 to 2001 chemical emulsion. Secondly, after the top soil has been removed and any excavation is completed, poison should be applied at a rage of 5I/m over the entire area to be covered by the building. The soil used as backfill along the inside and outside of the foundation, around plumbing and in the wall voids is treated at a rate of 61/m run and before casting the floor slab any hardcore fill and blinding sand should also be treated. Existing buildings can be given some protection by digging a 30cm wide and 15 to 30cm deep trench around the outside of the foundation. After having sprayed the trench with poison, the excavated soil is treated and replaced.

It is advisable to do the soil poisoning when the soil is fairly dry and when rain is not pending, otherwise there is risk of the chemical being washed away instead of being absorbed by the soil.

It is also advisable to cover the poisoned band of soil with concrete or with a substantial layer of gravel. This protects the poison barrier and helps to keep the wall clean and free of mud splashes. If the wall is rendered, it is preferable to poison any rendering that is applied within 30cm or so of the ground. To poison concrete or sand:cement mortar, simply use a 0.5 to 1.0% dieldrin emulsion instead of the usual mixing water. There is no effect on the amount of water required or the binding strength of the cement.

All preservatives are toxic and should be handled with care. Some are extremely toxic if

swallowed or allowed to remain in contact with the skin. A recommendation for first-aid from the supplier of the preservative should be insisted upon. When using dieldrin, aldrin or chlorodane, children and animals should be kept away from the area where treatment is to be carried out.

Termite shields: The termite shield should be continuous around the foundation irrespective of changes in level and should be made of 24 gauge galvanized steel. The edge of the shield should extend horizontally outwards for 5cm beyond the top of the foundation wall and should then bend at an angle of 45 downwards for another 5cm. There should be a clearance of at least 20cm between the shield and the ground. All joints in the shield should be double locked and properly sealed by soldering or brazing or with bituminous sealer. Holes through the shield for anchor bolts should be coated with bituminous sealer and a washer fitted over the bolt to ensure a tight fit.

Protection of existing buildings: A building should be regularly inspected inside and out and especially at potential hiding places. The outside should be checked for such things as staining on walls below possibly blocked gutters, accretion of soil, debris or added-on items like steps which might bridge the termite shield. Ground-floor window and door frames and timber cladding should be probed to discover decay or termite damage. All timber, whether structural or not, should be inspected, special attention being paid to places which are infrequently observed such as roof spaces, under-sides of stairs, builtin cupboards and flooring under sinks where there may be plumbing leaks.

Extensively damaged wood should be cut out and replaced with sound timber pre-treated with preservative. In the case of decay the source of moisture must be found and corrected and where subterranean termites are found, their source of entry must be traced and eliminated. Termites within the building must first be destroyed. The treatments to be applied include some measure of soil poisoning, the provision of barriers and the surface treatment of timber and wood-based materials.

In the case of drywood termites fumigation is the only reliable method of extermination and this should be carried out by trained men under proper supervision.

Figure 5.17 Termite protection.

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Walls

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Walls may be divided into two types:

a Load-bearing walls which support loads from floors and roof in addition to their own weight and which resist side pressure from wind and, in some cases, from stored material or objects within the building,

b non-load-bearing walls which carry no floor or roof loads. Each type may be further divided into external or enclosing walls, and internal dividing walls. The term partition is applied to walls, either load-bearing or non-loadbearing, dividing the space within a building into rooms.

Good quality walls provide strength and stability, weather resistance, fire resistance, thermal insulation and sound insulation.

Types of Building Walls

There are various ways to construct a wall and many different materials can be used, but they can be divided into four main groups.

Masonry wall, in which the wall is built of individual blocks of materials such as brick, clay or concrete blocks, or stone, usually in horizontal courses bonded together with some form of mortar. Several of the earth derived products, either air dried or fired, are

reasonable in cost and well suited to the climate.

Monolithic wall, in which the wall is built of a material placed in forms during the construction. The traditional earth wall and the modern concrete wall are examples. The earth walls are inexpensive and durable if placed on a good foundation and protected from rain by a rendering or wide roof overhangs.

Frame wall, in which the wall is constructed as a frame of relatively small members, usually of timber, at close intervals which together with facing or sheething on one or both sides form a load-bearing system. Offcuts are a lowcost material to use for a frame wall covering.

Membrane wall, in which the wall is constructed as a sandwich of two thin skins or sheets of reinforced plastic, metal, asbestos-cement or other suitable material bonded to a core of foamed plastic to produce a thin wall element of high strength and low weight.

Another form of construction adapted for framed or earth buildings consists of relatively light sheeting secured to the face of the wall to form the enclosed element. These are generally termed 'claddings'.

Factors which will determine the type of wall to be used are:

- **a The materials available at a reasonable cost.**
- **b Availability of craftsmen capable of using the materials in the best way.**
- **c Climate**
- **d The use of the building - functional requirements.**

The height of walls should allow people to walk freely and work in a room without knocking their heads on the ceiling, beams etc. In dwelling houses with ceilings is 2.4m a suitable height. Low roofs or ceilings in a house create a depressing atmosphere and tend to make the rooms warmer in hot weather.

Masonry Walls

Apart from certain forms of stone walling, all masonry consists of rectangular units built up in horizontal layers called courses. The units are laid up with mortar in specific patterns called bonding in order to spread the loads and resist overturning and in the case of thicker walls, buckling.

The material in the masonry units can be mud or adobe bricks, burnt clay bricks, soil blocks (stabilized or unstabilized), concrete blocks, stone blocks or rubble. Blocks can be solid or hollow.

Figure 5.18 Examples showing why bonding is necessary.

Figure 5.19 English and Flemish bonding of brick walls.

Bricks

In brickwork, those bricks laid lengthwise in the wall are called stretchers and the course in which they occur, a stretching course. Bricks laid across the wall thickness are called headers and the course in which they occur, a heading course.

Bricks may be arranged in a wide variety of ways to produce a satisfactory bond and each arrangement is identified by the pattern of headers and stretchers on the face of the wall. These patterns vary in appearance resulting in characteristic 'textures' in the wall surfaces, and a particular bond may be used for its surface pattern rather than for its strength properties. In order to maintain bond it is necessary at some points to use bricks cut in various ways, each of which has a technical name according to the way it is cut.

The simplest arrangements, or 'bonds' as they are called, are stretching bond and heading bond. In the former, each course consists entirely of stretchers laid as in Figure 5.20 and is only suitable for half-brick walls such as partitions, facing for block walls and the leaves of cavity walls. Thicker walls built entirely with stretchers are likely to buckle as shown in Figure 5.18. The heading bond is ordinarily used only for curved walls.

The two bonds most commonly used for walls one brick and over in thickness are known

as English bond and Flemish bond. A 'one-brick thickness' is equal to the length of the brick. These bonds incorporate both headers and stretchers in the wall which are arranged with a header placed centrally over each stretcher in the course below in order to achieve a bond and minimize straight joints. In both bonds 120 bricks of standard size are required per m of 23cm wall. This figure allows for 1 5 to 20% breakage and 1cm mortar joints. Figure 5.19 illustrates English and Flemish bonding.

Bricks are sometimes used in the construction of cavity walls since the airspace improves the thermal resistance and the resistance to rain penetration compared to a solid wall of the same thickness. Such a wall is usually built up with an inner and outer leaf in a stretching bond, leaving a space or cavity of 50 to 90mm between the leaves. The two leaves are connected by metal wall ties spaced 900mm horizontally and 450mm vertically as shown in Figure 5.20.

Figure 5.20 Brick cavity wall.

Concrete Blocks

Much of the procedure for the construction of concrete block walls has been discussed under the heading 'Foundations'. However, there are a few additional factors to be considered.

It is best to work with dry, well-cured blocks to reduce shrinking and cracking in the wall to a minimum. Except at quoins (corners), load-bearing concrete block walls should not be bonded at junctions as in brick and stone masonry. At junctions one wall should butt against the face of the other to form a vertical joint which allows for movement in the walls and thus controls cracking. Where lateral support must be provided by an intersecting wall, the two can be tied together by 5mm x 30mm metal ties with split ends, spaced vertically at intervals of about 1 200mm. Expansion joints should be allowed at intervals not exceeding 2 1/2 times the wall height. The two sections of wall must be keyed together or stabilized by overlapping jamb blocks as shown in Figure 5.21. The joints are sealed with flexible mastic to keep water from penetrating the wall.

Figure 5.21 Lateral support for walls at expansion joints.

Many walls in the tropics are required to let in light and air while acting as sun-breakers. To meet this need, perforated walls are popular and are designed in a variety of patterns, some load bearing, others of light construction. Hollow concrete blocks may be used to good effect for this purpose. Horizontal or vertical slabs of reinforced concrete (r.c. slots) can be used to act as sunbreakers. These are usually built at an inclined angle in order to obtain maximum shelter from the sun.

Stones

Quarried stone blocks, either rough or dressed to a smooth surface are laid in the same way as concrete or stabilized soil blocks. Random rubble walls are built using stones of random size and shape as they are found or come from the quarry. Walls using laminated varieties of stone which split easily to reasonably straight faces of random size are called squared rubble walling.

Figure 5.22 Block walls for ventilation.

In these walls, as in all masonry, longitudinal bond is achieved by overlapping stones in adjacent courses, but the amount of overlap varies because the stones vary in size. Since rubble walls are essentially built as two skins with the irregular space between solidly filled with rubble material (small stones), transverse bond or tie is ensured by the use of long header stones known as bonders. These extend not more than three-quarters through the wall thickness to avoid the passage of moisture to the inner face of the wall and at least one is required for each m of wall face. Large stones, reasonably square in shape or roughly squared, are used for corners and the jambs of door and window openings to obtain increased strength and stability at these points.

Random rubble walls may be built as uncoursed walling in which no attempt is made to line the stones into horizontal courses, or it may be brought to courses in which the stones are roughly levelled at 300mm to 450mm intervals to form courses varying in depth with the quoin and jamb stones.

Rough squaring of the stones has the effect of increasing the stability of the wall and improving its weather resistance since the stones bed together more closely, the joints are thinner, and therefore there is less shrinkage in the joint mortar. External load-bearing stone walls should be at least 300mm thick for one-story buildings.

Openings in Masonry Walls

Openings in masonry walls are required for doors and windows. The width of opening, height of the wall above the opening and strength of the wall on either side of the opening are major design factors. They are particularly important where there are many openings that are quite close together in a wall.

The support over an opening may be a lintel of wood, steel or reinforced concrete or it may be an arch constructed of masonry units similar to or the same as used in the adjoining wall. Lintels impose only vertical loads on the adjoining sections of walls and are themselves subjected to bending and shear loads and compression loads at their support points. Concrete lintels may either be cast in place or prefabricated and installed as the wall is constructed.

Figure 5.23 Coursed and uncoursed random rubble walls.

Arches are subjected to the same bending and shear forces, but in addition there are

thrust forces against both the arch and the abutting sections of the wall.

It is not difficult to determine loads and choose a wood or steel lintel to install, or to design the reinforcing for a concrete lintel. However, the design of an arch always involves assumptions and then verification of those assumptions.

Lintels made of wood are suitable for light loads and short spans. Timber pressure treated with a preservative should be used.

Steel angles are suitable for small openings and Table 5.8 presents size, span and load information for several sizes. Larger spans require universal section 1 - beams and a specific design analysis. Steel lintels should be protected from corrosion with two or more coats of paint.

Table 5.8 ***Allowable Uniformly Distributed Loads on Steel Angle Lintels (kg)***

Angle size, mm	**Weight**	**Safe load (kg) at Span length, (m)**				
V x H x Th	kg/m	1	1.5	2	2.5	3
90 x 90 x 8	10.7	1830	1200	900	710	
125 x 90 x 8	13.0	3500	2350	1760	1420	1150

125 x 90 x 13	20.3	5530	3700	2760	2220	1850
125 x 102 x 10	18.3	6100	4060	3050	2440	2032

V = vertical leg. H = horizontal leg, Th = thickness

Reinforced concrete is a very common material used for lintels.

Concrete lintels are made of 1:2:4 concrete mix (with an ultimate strength of 13.8N/mm) and are normally reinforced with one steel bar for each 100mm of width. For reasonably short spans over door and window openings, the 'arching' action of normal well-bonded bricks or blocks due to the overlapping of the units may be taken into account. It may be assumed that the lintel will carry only that part of the wall enclosed by a 45 equilateral triangle with the lintel as its base. For wide spans, an angle of 60 is used. For spans up to 3m the sizes of lintels and the number and sizes of reinforcement bars shown in Table 5.9 may be used. The steel bars should be covered with 40mm of concrete and the bearings on the wall should be preferably 200mm or at least equal to the depth of the lintel. Lintels with a span greater than 3m should be designed for the specific situation.

Long-span concrete lintels may be cast in situ in formwork erected at the head of the opening. However, precasting is usually adopted where suitable lifting tackle or a crane is available to hoist the lintel into position or where it is light enough to be put into position by two men.

Stone is generally used as a facing for a steel or concrete lintel. Unless reinforced with mild steel bars or mesh, brick lintels are only suitable for short spans up to Im, but like stone, bricks are also used as a facing for a steel or concrete lintel.

The arch is a substructure used to span an opening with components smaller in size than the width of the opening. It consists of blocks which mutually support each other over the opening between the abutments on each side. It exerts a downward and outward thrust on the abutments which must be strong enough to ensure stability of the arch.

Jointing and Pointing

Reinforced concrete lintels

Jointing and pointing are terms used for the finishing given to both the vertical and horizontal joints in masonry, irrespective of whether the wall is made of brick, block or stone construction. Jointing is the finish given to the joints as the work proceeds. Painting is the finish given to the joints by raking out the mortar to a depth of approximately 20mm and refilling the face with a hard-setting cement mortar which can have a colour additive. This process can be applied to both new and old buildings. Typical examples of jointing and pointing are given in Figure 5.25.

Figure 5.24 Openings in masonry walls.

Size of Lintel(mm)		Clear Span	Bottom Reinforcement	
H	W	m	Number of bars	Size of bars
150	200	<2.0	2	10mm, round, deformed
200	200	2.0- 2.5	2	10mm, round, deformed
200	200	2.5 - 3.0	2	16mm, round, deformed
Split Lintels with Wall Load Only				
150	200	<2.0	1 each	10mm, round, deformed
200	200	2.0-2.5	1 each	10mm, round, deformed
200	200	2.5 -3.0	1 each	16mm, round, deformed

Safe bearing at each end, 200mm

Figure 5.25 Examples of jointing and pointing.

Monolithic Earth Walls

Earth wall construction is widely used because it is an inexpensive building method and materials are usually abundantly available locally. Because the earth wall is the only type

many people can afford, it is worthwhile to employ methods that will improve its durability. It has been found that susceptibility to rainfall erosion and general loss of stability through high moisture can be eliminated if simple procedures are followed during site selection, building construction and maintenance.

Earth walls are mainly affected by:

- **erosion through rainfall hitting the walls directly or splashing up from the ground**
- **saturation of the lower part of the wall by rising capillary water**
- **earthquake**

For one-story earth walled houses, structural considerations are less important because of the light roofing generally used. A badly designed or constructed earth-walled building may crack or distort, but sudden collapse is unlikely. Durability, not strength, is the main problem and keeping the walls dry after construction is the basic solution. Methods of stabilizing earth can be found in Chapter 3.

Key factors for improving the durability of earth-walled buildings include:

- **Selection of a site with adequate drainage and a free draining and non-swelling soil. Construction of earth buildings on and with swelling soils may lead to foundation and wall distortion during the rainy season.**

- **Construction of a foundation wall either from blocks or stones set in cement or mud mortar. The foundation minimizes the effects of all types of water-caused damage to the base of the wall.**
- **Stabilization of the soil used for construction of walls. Stabilized earth walls are stronger and more resistant to moisture, rain and insects, especially termites. Avoid the use of pure black cotton soil for construction because it shrinks greatly on drying, leading to cracking and distortion. Clay soils should be stabilized with lime, because cement has shown poor results for these soils.**
- **. Impregnating a stabilized earth wall with a waterproof coating.**
- **Plastering to protect the wall from water and insects.**
- **Provision of an adequate cave width (roof overhang) to reduce wall erosion. However, cave width is limited to approximately 0.6m or a little more because of the risk of wind damage. Inclusion of verandahs can be useful for wall protection.**
- **Maintenance of the wall and protective coating.**
- **Provision for free evaporation of capillary moisture by clearing away any low vegetation near the building walls.**

The material soil can be used in many ways for wall construction. Hand - rammed or machine - compacted, stabilized soil blocks and sun-dried mud (adobe) bricks are used in the same mannor as masonry units made of other materials. While masonry constructions have already been described, it should be noted that the somewhat poorer strength

properties and durability of soil blocks and adobe bricks may make them less suitable for some types of construction, e.g. foundation walls. Special care must be taken when designing lintel abutments to ensure that the bearing stresses are kept within the allowable.

Rammed Earth Walls

A method for the construction of a monolithic earth wall is shown in Figure 5.26. The use of soil mixed with a suitable stabilizer at a proper ratio will increase the strength and durability of the wall provided the wall is properly cured. However, the single most important factor when constructing a rammed earth wall (using stabilized or natural soil) is perhaps thorough compaction of each layer of soil as it is filled in the mould. the formwork must be strong enough to resist the lateral forces exerted by the soil during this operation. The distance between lateral supports (cross walls etc.) should not exceed 4m for a 300mm thick rammed earth wall.

Figure 5.26 Construction of a rammed-earth wall

Finish the foundation wall with a sand/cement mortar cap. Supported on horizontal brackets running across the wall - a mould is constructed. The brackets, as well as, draw wires above the mould act as ties and must, together with the rest of the mould be sufficiently strong to resist the pressure of the earth during the ramming operations. Fill

the earth in thin layers and compact thoroughly before the next layer is placed. After the mould has been filled, it is removed and placed on top of the already finished wall. While the mould is only 500 to 700mm deep, it will be moved several times before the finished height of the wall is reached. Notching of the sections will increase the stability of the wall. A work force that is large enough to allow several operations, such as soil preparation, transport, filling and ramming, to go on simultaniously will ensure swift construction.

Gliding Formwork for Rammed-earth Walls

The foundation wall is built to 5Ocm above the ground level with stones and lime mortar. Reinforcement in the walls consists of poles or bamboo which are set in the trench when the stones of the foundation wall are laid. The earth panel in the gliding formwork is tamped layer after layer until the form is full. The form is then moved and a new panel started. Finally the upper ring beam is tied to the reinforcement sticks. After finishing the panels, the joints are filled with earth mortar.

Mud and Pole Walls

The construction of mud and pole walls is dealt with at the end of Section Earth as Building Material along with some other types of mud wall constructions. A pole frame wall can be built with either thick earth construction (25cm or more) or thin earth

cladding (10cm or less). While soil block walls and rammed earth walls usually are superior to mud and pole wall, this should only be used when a supply of durable poles is available and the soil is not suitable for block making. Regardless of the type of wall, the basis of all improvement is to keep the wall dry after construction.

Install a dampproof course on top of the foundation wall, about 50cm above ground level. Pre-fabricate ladders out of green bamboo or wooden poles that are about 5cm diameter. The outside wooden or split bamboo battens are nailed or tied to the ladders as the soil is filled in successive layers. The corners must be braced diagonally. Earthquack resistance is improved by securing the base frame to the foundation with a layer of lime or cement soil mortar.

Figure 5.27 Construction of a rammed-earth wolf with a gliding form.

Figure 5.28 Construction of a mud and pole wall.

Framed Walls

Frame walls consist of vertical timber members called studs framed between horizontal members at the top and bottom. The top member is called a plate and the bottom member a sole or sill. Simple butt joints are used which are end-nailed or toe-nailed. The frame is, therefore, not very rigid and requires bracing in order to provide adequate

stiffness.

Diagonal braces can be used for this purpose, but a common method which is quicker and cheaper, is to use building board or plywood sheething to stiffen the structure. The studs are commonly spaced on 400 or 600mm centres which is related to the standard 1200mm width of many types of building boards used for sheathing. Since the load-bearing members of this type of wall are wood, it is not recommended for termite areas, especially if both faces of the frame are finished or covered, thus making it difficult to detect a termite attack.

Frame construction using timber must be raised out of contact with ground moisture and protected from termites. This is accomplished by erecting it on a base wall or foundation beam rising to a damp-proof course, or on the edge of a concrete slab floor. As a base for the whole structure a sill is set and carefully levelled on the dampproof course and securely anchored to the foundation. To maintain the effectiveness of the dampproof course it must be sealed carefully at all bolt positions. A continuous termite shield should be installed between the damp-proof course and the sill and great care taken to seal around the holes required for the anchor bolts. The sill plate may be 100mm by 50mm when fixed to a concrete base, but should be increased in width to 150mm on a brick base wall.

Instead of timber, bamboo or round wooden poles can be used as studs which are then

clad with bamboo mats, reed mats, grass, palm leaves etc. A further alternative is to fix mats to the studs and then plaster the mats with ;cement plaster or other material. Some structures of this type have a short life due to damage by fungi and termites. They are also difficult to keep clean and the risk of fire is great. Figure 5.30 gives brief information on bamboo wall panels which can be made by skilled craftsmen.

Figure 5.29 Frame wall construction.

Facings and Claddings

Facings and claddings refer to panels or other materials that are applied as external coverings on walls for protection from the elements or for decorative effects. Facings or claddings are particularly useful for protecting and improving the appearance of the walls of earth structures which by themselves may be eroded by rain and become quite unsightly.

Facings generally have little or no structural strength and must be attached to a smooth continuous surface. Plaster or small size tiles are examples.

Cladding differs from facing in that the materials have some structural strength and are able to bridge the gaps between the battens or furring strips on which they are mounted. Various shingles, larger size tiles, both vertical and horizontal timber siding and building

boards such as plywood and asbestos-cement board are suitable for cladding. Corrugated steel roofing is also satisfactory. The cladding materials must be able to transfer wind loads to the building structure and to absorb some abuse from people and animals. The spacing of the furring strips will influence the resistance of the cladding to these forces.

The spacings for shingles and tiles is determined by the length of the units. The spacing for horizontal timber siding should ordinarily be about 400mm, while vertical timber siding can safely bridge 600mm. Plywood of at least 12mm thickness can bridge 1200mm edge to edge if supported at 800mm intervals in the other direction.

Metal roofing used as cladding can be mounted on furring strips spaced 600mm apart. It is common for manufacturers of building materials to provide installation instructions, including the frequency of support members.

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Floors

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Building floors may be as simple as the compacted soil present on the site before the building was constructed or as complex as attractively finished hardwood parquet. A well-chosen, well-built floor offers protection from vermin and rodents, is easy to clean, dry, durable and is a valuable asset to a building. For special circumstances it may be designed to be washable, particularly attractive, thermally insulated, sloped to a drain or perfectly net and level.

For farm buildings, including homes, simple floors offering hard, durable surfaces at ground level grade are probably adequate for the vast majority of situations. Floors may be built at ground level, i.e. on the soil within the building, in which case they are called solid or grade floors, or they may be supported on joists and beams in which case they are called suspended or above-grade floors. The finished level of a solid floor should be at least 150mm above outside ground level as a protection against flooding. The top soil should be removed and replaced with coarse material before the actual floor slab is constructed.

Figure 5.30a Bamboo and wall

Figure 5.30b Plastered bamboo wan mats

Figure 5.30c Woven bamboo panels (Japanese wall panels)

Figure 5.31 Vertical timber siding. Note single nails near center of each board and batten to allow for shrinking and swelling.

Solid or Grade Floors

Tamped soil is often satisfactory for the floors of animal shelters and perhaps the homes of subsistence farm families. They should be designed a little above the ground level outside the building and will be improved by being stabilized with ant-hill clay, cow dung, lime or Portland cement.

A discussion of stabilizing materials to use for different circumstances will be found in Chapter 3.

Concrete makes a more durable, harder and cleaner floor. Properly constructed concrete floors can be made dry enough to be used for grain storage or the farm home. Figure 5.32 shows cross sections of stabilized soil and concrete floors. An earth floor suitable for a well-drained site is shown in figure a, while a concrete floor that needs to be moderately dry is shown in b. The single-size coarse aggregate shown in c, is used to prevent capillary movement of water to the underside of the floor. The polythene sheet prevents moisture from reaching the concrete slab and the layer of sand or mortar protects the sheet from

being punctured.

Floor

- **- 2 layers of tamped stabilized soil (50mm)**
- **- Tamped sand**
- **- Existing subsoil (topsoil removed)**

Figure 5.32a Well drained site

Floor

- **- Concrete slab (min. 75mm)**
- **- Tamped sand (100-150mm)**
- **- Existing subsoil**

Figure 5.32b Well drained site

Floor

- **- Concrete slab (min. 75mm)**
- **- Polythene sheet (750 guage)**
- **- Sand (50 mm) or mortar (25mm)**

- Coarse aggregate (150-200mm)
- Existing subsoil (eu. compacted)

Figure 5.32c Poorly drained site or a very dryfloor is required

Construction of solid floors built at ground level.

The concrete mixture chosen to be used in a solid floor will depend on the severity of use and type of loading. For a deep litter building or a subsistence farm dwelling a mix of 1 :3:6 by weight may be satisfactory for the light service to which it will be subjected. Floors that will be exposed to heavy loads, as in a bag grain store or a farm repair shop, will need to be stronger. A 1 :2:4 should be adequate over a good firm base. The floors in a creamery or slaughterhouse are subjected to acid erosion and require a richer mix of concrete (1 :2:3) to give a durable surface.

Pouring Concrete Floors

Solid concrete floors should be laid on a level and tampered base of hardcore or gravel. On well drained sites also sand or even laterite can be satisfactory. The base layer should be at least 100mm thick. While it is desirable for the finished floor level to be at least 150mm above the surrounding ground, some fill may be required under the base course. However, fill need to be thouroughly compacted to get the required stability and,

generally, it is therefore more satisfactory to increase the thickness of the base course. Any material used for fill or for the base course must be free of organic matter. hence, the excavated top soil must be rejected as fill. If a damp-proof barrier (polythene or a 3mm thick hot bitumen layer) is to be installed, a layer of sand should be spread over the base. Sand can also be used as blinding on a hardcore base to reduce the amount of concrete that 'disappears' in the gaps between the stones. Finally, 75 to 150mm timber screeds are put in place to be used as guides in striking off and leveling the concrete and reinforcement bars, if advocated, are put in position. The thickness of the slab will depend on the expected loads, the quality of concrete used, reinforcement and the bearing characteristics of the ground.

A floor area that is larger than about 10m should be divided into bays for concreting. This will help to prevent the development of shrinkage cracks during the curing process and will allow for each bay to be cast, leveled and finished within a managable time. Square bays are best and 2.5 to 4m sides allow a slab to be cast in one go.

The concrete can then be mixed and placed. Regardless of the mix chooser, the concrete should be kept as stiff as possible and the size of the coarse aggregate should not exceed a quarter of the thickness of the slab. The bays are' concreted alternately as shown in Figure 5.33. When the first set of bays have hardened the timber screeds are carefully removed and the remaining bays can be cast.

Once the concrete is placed it is leveled by moving a straight timber along the screeds, or, in case of the second set of bays, the already hardened concrete in adjoining bays, with a sawing action. The concrete can then be 'floated' slightly to smooth the surface. After the initial light floating, the bay can be left for a few hours before a final floating to give it a smooth surface. If a non-slip floor is desired, the concrete can be broomed soon after it is placed to give a rough surface. It will not be touched again until it sets. Once the concrete is set, it should be kept moist for a week.

Suspended or Above-grade Floors

Timber Floors

Suspended timber ground-level floors are useful on sloping sites where a great deal of filling would be required to level the ground for a solid floor.

Timber ground-level floors must be well protected against moisture, fungus and termites and must therefore be raised above the ground. The space under such a timber floor should be high enough to ensure good ventilation and to allow a person to crawl underneath for inspecting the floor. Termite protection is more likely to be effective if the floor is raised above the ground at least 45cm.

Figure 5.33 Concrete floor construction

The supporting piers are frequently built of timber but are better if made of stone, concrete or steel. Hollow concrete blocks reinforced and filled with concrete make a strong support. Metal termite shields should be fitted to the top of the foundation wall and to steeper walls and piers.

The foundation wall beneath a timber ground-level floor must be fitted with ventilation openings to ensure good air exchange in the crawl space below the floor. The openings should be covered with 10mm mesh screen to keep rodents out.

When the span is more than 5m, joists may be supported by cross walls built with 150mm solid concrete blocks laid about 80mm apart in a honeycomb pattern to allow free passage of air.

Beams of steel, timber or concrete may be used to support upper floors when the span is over 5m.

Figure 5.34 Suspended timber floor construction.

Suspended Concrete Floors

The main advantage of a reinforced-concrete suspended floor is its greater fire resistance and better sound insulation than that of a timber floor, but it is generally too expensive

to find applications in farm buildings.

In its simplest form it consists of a cast-in-situ, one-wayspan slab with the reinforcement acting in one direction only between two supports not more than 5m apart. The reinforcement may be either mild steel main rods and distribution bars wired together at right angles, or reinforcing mesh consisting of main bars and distribution bars electrically welded at the crossings. The reinforcement must be designed by a qualified structural engineer or obtained from a reliable standard design.

Floor Finishes

In rural areas the extra cost of a floor finish is often considered unnecessary, the surface of a slab of concrete or stabilized soil having a durability which is satisfactory for most purposes. However, a floor finish can enhance the appearance of the room, cut down on noise or make the floor easier to clean, depending on the type of finish used.

A cement and sand screed or a granolitich finish (one part cement and three parts hard stone chippings laid about 30mm thick) may be used where an extremely durable finish is needed. Sheet materials and slab tiles are likely to be very expensive, but slab tiles are in exceptional cases installed in farm buildings because of their durability. A typical wood floor over a solid slab is shown in Figure 5.35.

Note that the space between the concrete slab and the wood flooring should be ventilated. a Cured and dried out concrete or stabilized soil slab, preferably with damp-proof course between slab and hardcore. b Joists 50 x 50mm c Bulldog floor clips d Wood flooring or chipboard

Figure 5.35 Wood floor on a solid concrete poor.

Roofs

A roof is an essential part of any building in that it provides the necessary protection from rain, sun, wind, heat and cold. The integrity of the roof is important for the structure of the building itself as well as the occupants and the goods stored within the building.

The roof structure must be designed to withstand the dead load imposed by the roofing and framing as well as the forces of wind and in some areas, snow or drifting dust. The roofing must be leakproof, durable and perhaps satisfy other requirements such as being fire resistant, a good thermal insulator or high in thermal capacity.

There is a wide variety of roof shapes, frames and coverings from which to choose. The choice is related to factors such as the size and use of the building, its anticipated life and appearance, and the availability and cost of materials. Roofs may be classified in three

ways:

- **1 According to the plane of the surface, i.e. whether it is horizontal or pitched.**
- **2 According to the structural principles of the design, i.e. the manner in which the forces set up by external loads are resolved within the structure.**
- **3 According to the span.**

Flat and pitched roofs: A roof is called a flat roof when the outer surface is within 5 of horizontal whereas a pitched roof has a slope of over 5 in one or more directions. Climate and covering material affect the choice between a flat or pitched roof. The affect of climate is less marked architecturally in temperate areas than in those with extremes of climate. In hot, dry areas the flat roof is common because it is not exposed to heavy rainfall and it forms a useful out-of-doors living room. In areas of heavy rainfall a steeply pitched roof drains off rainwater more quickly.

Two-dimensional roof structures have length and depth only and all forces are resolved within a single vertical plane. Rafters, roof joists and trussers fall in this category. They fulfill only a spanning function and volume is obtained by using several two-dimensional members carrying secondary two-dimensional members (purling) in order to cover the required span.

Three-dimensional structures have length, depth and also breadth, and forces are

resolved in three dimensions within the structure. These forms can fulfill a covering and enclosing function as well as that of spanning and are now commonly referred to as 'space structures'. Three dimensional or space structures include cylindrical and parabolic shells and shell domes, multi-curved slabs, folded slabs and prismatic shells, grid structures such as space frames, and suspended or tension roof structures.

Long and short span roofs: Span is a major consideration in the design and choice of a roof structure although functional requirements and economy have an influence as well.

Short spans, up to 8m, can generally be covered with pitched timber rafters or light-weight trusses either pitched or flat. Medium spans of 7 to 15 or 16m require truss frames designed of timber or steel.

Long spans of over 16m should, if possible, be broken into smaller units. Otherwise, these roofs are generally designed by specialists using girder, space deck or vaulting techniques.

In order to reduce the span and thereby reduce the dimensions of the members, the roof structure can be supported by poles or columns within the building or by internal walls. However, in farm buildings a free span roof structure will be advantageous if the farmer eventually wants to alter the internal arrangement of the building. The free space without columns allows greater convenience in maneuvering equipment as well.

Ring beam: In large buildings e.g. village stores, that have block or brick walls, a 150mm square reinforced concrete beam is sometimes installed on top of the external walls instead of a wall plate. The objective of this ring beam, which is continuous around the building, is to carry the roof structure should part of the wall collaps in an earth tremor. It will also provide a good anchorage for the roof to prevent it lifting and reduce the effects of heavy wind pressure on the walls and unequal settlement.

Figure 5.36 Three-dimensional roof structures.Earth dome and vault

Figure 5.36 Three-dimensional roof structures. Grid structure

Types of Roofs

Flat Roof

The flat roof is a simple design for large buildings in which columns are not a disadvantage. Simple beams can be used for spans up to about Sm. but with longer spans it is necessary to use deep beams, web beams or trusses for adequate support. Because farm buildings often need large areas free of columns, flat roofs with built-up roofing are not common. Flat roofs are prone to leak. To prevent pools of water from collecting on the surface they are usually built with a minimum slope of 1:20 to provide drainage.

The roof structure consists of the supporting beams, decking, insulation and a waterproof surface. The decking, which provides a continuous support for the insulation and surface, can be made of timber boards, plywood, chipboard, metal or asbestos-cement decking units or concrete slabs.

The insulation material improves the thermal resistance and is placed either above or below the decking.

The most common design for a waterproof surface is the built-up roof using roofing felt. This material consists of a fibre, asbestos or glass-fibre base which has been impregnated with hot bitumen. The minimum pitch recommended for built-up roofs is 1:20 or 3 which is also near the maximum if creeping of the felt layers is to be prevented.

For net roofs two or three layers of felt are used, the first being laid at right angles to the slope commencing at the eaves. If the decking is timber the first layer is secured with large flat-head felting nails and the subsequent layers are bonded to it with layers of hot bitumen compound. If the decking is of a material other than timber all three layers are bonded with hot bitumen compound. While it is still hot the final coat of bitumen is covered with a layers of stone chippings to protect the underlying felt, provide additional fire resistance and give increased solar reflection. An application of 20 kg/m of 12.5mm chippings of limestone, granite or light-coloured gravel is suitable.

Where three layers of roofing felt are used and properly laid, flat roofs are satisfactory in rainy areas. However, they tend to be more expensive than other types and require maintenance every few years.

Figure 5.37 Built-up roofing felt.

Earth Roof

Soil-covered roofs have good thermal insulation and high capacity for storing heat. The traditional earth roof is subject to erosion during rain, requires steady maintenance to prevent leakage. The roof is laid rather flat with a slope of 1:6 or less.

The supporting structure should be generously designed of preservative - treated or termite-resistant timber of poles, and inspected and maintained periodically, as a sudden collapse of this heavy structure could cause great harm. The durability of the mud cover can be improved by stabilizing the top soil with cement, and it can be waterproofed by placing a plastic sheet under the soil. Figure 5.38 and Figure 5.39 shows two types of earth roofs.

Figure 5.38 Cross-section of an improved earth roof

Figure 5.39 Earth roof with bitumen waterproofing.

However, the introduction of these improvements adds considerably to the cost of the roof. The improved earth roof therefore is a doubtful alternative for low-cost roofing and should be considered only in dry areas where soil-roof construction is known and accepted.

Monopitched Roof

Monopitch roofs slope in only one direction and have no ridge. They are easy to build, are comparatively inexpensive and are recommended for use on many farm buildings. The maximum span with timber members is about 5m, thus wider buildings will require intermediate supports. Also wide buildings with this type of roof will have a high front wall which increases the cost and leaves the bottom of that wall relatively unprotected by the roof overhang. When using corrugated steel or asbestos-cement sheets, the slope should not be less that 1:3(17 to 18). Less slope may cause leakage as strong winds can force water up the slope.

The rafters can be of round or sawn timber or when wider spans are required, of timber or steel trusses which can be supported on a continuous wall or on posts. The inclined rafters of a pitched roof meet the wall plates at an angle and their load tends to make them slide off the plate. To reduce this tendency and to provide a horizontal surface through which the load may be transferred to the wall without excessively high compressive forces, the rafters in pitched roofs are notched over the plates. To avoid

weakening of the rafter, the depth of the notch (seat cut) should not exceed one-third that of the rafter. When double rafters are used a bolted joint is an alternative. The rafters should always be thoroughly fixed to the walls or posts to resist the uplifting forces of the wind.

Figure 5.40 Pole framing for a monopitch building.

Double-pitched (Gable) Roof

A gable roof normally has a centre ridge with a slope to either side of the building. With this design a greater free span (7 to 8m) is possible with timber rafters than with a monopitch roof. Although the monopitch design may be less expensive in building widths up to 10m the inconvenience of many support columns favors the gable roof. The gable roof may be built in a wide range of pitches to suit any of several different roofing materials. Figure 5.41 shows a number of the elements that are associated with a gable roof. The following description is keyed to the figure:

- **The bottom notch in the rafter that rests on the plate is called the seat cut or plate cut.**
- **The top cut that rests against the ridge board is called the ridge cut.**
- **The line running parallel with the edge of the rafter from the outer point of the seat cut to the centre of the ridge is called the work line.**

- **The length of the rafter is the distance along the work line from the intersection with the corner of the seat cut to the intersection with the ridge cut.**
- **If a ridge board is used, half the thickness of the ridge board must be removed from the length of each rafter.**
- **The rise of the rafter is the vertical distance from the top of the plate to the junction of the workline at the ridge.**

Figure 5.41 Gable roof design.

- **The run of the rafter is the horizontal distance from the outside of the plate to the centreline of the ridge.**
- **The portion of the rafter outside the plate is called the rafter tail.**
- **The collar beam or cross tie prevents the load on the rafters from forcing the walls apart which would allow the rafter to drop at the ridge. The lower the collar beam is placed, the more effective it will be. Occasionally small buildings with strong walls are designed without collar beams. The only advantage of this design is the clear space all the way to the rafters. Scissors trusses, as shown in Figure 5.51, at the same time allow some clear space.**
- **The right-hand rafter shows purlins spanning the rafters and supporting a rigid roofing material such as galvanized steel or asbestos-cement roofing.**
- **The left-hand rafter is covered with a tight deck made of timber boards plywood or chipboard. It would be covered with a flexible roofing material such as roll asphalt**

roofing.

- **The left-hand cave is enclosed with a vertical facia board and a horizontal soffit board.**
- **The pitch is shown on the small triangle on the right side.**

The angle of the ridge and seat cuts can be laid out on the rafter using a steel carpenter's square and the appropriate rise and run values both on the outside of the blades or both on the inside of the blades of the square, 30 and 20cm in the example in Figure 5.42. The length may be found with the pythagorean theorem using the rise and run of the rafter. The length is measured along the workline.

When a gable roof must span more than 7 to 8m, trusses are usually chosen to replace plain rafters. For large spans the trusses will save on total material used and provide a stronger roof structure. For solid roof decks the trusses are usually designed to be spaced approximately 600mm on centre, while for rigid roofing mounted on purling, a truss spacing of 1200mm or more is common.

The agricultural extension can provide designs for the spans, spacings and loads that are commonly found on farms. Also, in Chapter 4 the theory of truss design is discussed. Figure 5.43 illustrates a simple truss design.

Figure 5.4.2 Laying out a common rafter.

Figure 5.4.3 A " W" truss design.

Due to large negative windloads, roofs are in danger of being blown off. Therefore it-is important to anchor the roof trusses properly to the wall plates. This can be done with strips of hoop iron, one strip tying the wall plate to the wall at every 90cm and the other tying the trusses to the wall plate. See Figure 5.44. In the coastal areas it is advisable to use galvanized strips. If the walls are plastered the strips can be recessed in the wall by cutting a channel and covering the strip with mortar.

Figure 5.44 Anchoring trusses to the wall

For stores or other buildings where tractors and lorries may be driven inside, considerable free height is necessary. Rigid frame structures are well suited for this purpose. A simple frame can be built of gumpoles or sawn timber connected with bolts as shown in Figure 5.45.

Rigid frames are also manufactured at factories in steel and reinforced concrete.

Hip Roof

A hip roof has a ridge in the centre and four slopes. It is much more complicated in its construction, necessitating the cutting of compound angles on all of the shortened rafters

and the provision for deep hip rafters running from the ridge to the wall plate to carry the top ends of the jack rafters. The tendency of the inclined thrust of the hip rafters to push out the walls at the corners is overcome by tying the two wall plates together with an angle tie. At the hips and valleys the roofing material has to be cut at an angle to make it fit. The valleys are prone to leakage and special care has to be taken in the construction.

Four gutters are needed to collect the rain water from the roof, but that does not mean that there is any increase in the amount of water collected. Because this is an expensive and difficult way to roof a building, it should be recommended only where it is necessary to protect mud walls or unplastered brick walls against heavy driving rain and for wide buildings to reduce the height of the end walls.

Figure 5.45 Timber rigid frame.

Figure 5.46 Hip roof framing.

Conical-shaped Roof

The conical roof is a three dimensional structure that is commonly used in rural areas. It is easy to assemble and can be built with locally available materials, making it inexpensive. It must be constructed with a slope appropriate to the roofing materials used to prevent it from leaking. The conical roof design is limited to rather short spans and to either

circular or small square buildings. It does not allow for any extensions. If modern roofing materials are used there is considerable waste because of the amount of cutting necessary to obtain proper fit.

A conical-shaped roof structure requires rafters and purling, and in circular buildings, a wall plate in the form of a ring beam. This ring beam has three functions:

- **a to distribute the load from the roof evenly to the wall,**
- **b to supply a fixing point for the rafters, and**
- **c to resist the tendency of the inclined rafters to press the walls outward radially by developing tensile stress in the ring beam. If the ring beam is properly designed to resist these forces and secondary ring beams are installed closer to the center, a conical roof can be used on fairly large circular buildings.**

In the case of square buildings, the outward pressure on the walls from the inclined rafters cannot be converted to pure tensile stress in the wall plate. Instead, it resembles the hip roof structure and should be designed with the angle ties across the wall plates at the corners.

Figure 5.47 Conical roof design.

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Roofing for Pitched Roofs

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Desirable characteristics for roof surfacing materials are:

- **1 Resistance to the penetration of rain, snow and dust and resistance to wind effects - both pressure and suction.**
- **2 Durability under the effects of rain, snow, solar radiation and atmospheric pollution in order to minimize maintenance during the life of the roof.**
- **3 Light weight, but with sufficient strength to support imposed loads, so that economically sized supporting members can be used.**
- **4 Acceptable fire resistance.**
- **5 Reasonable standard for thermal and sound insulation.**
- **6 Acceptable appearance.**
- **7 Reasonable cost over the lifetime of the roof.**

The roof shape, type of structure and slope determine the types of roofing material that are suitable. The minimum slope on which a material can be used depends on exposure to the wind, type of joint and overlap, porosity and the size of the unit.

When considering the cost of various roofing materials, it should be noted that those requiring steeper slopes will need to cover a greater area. Table 5.11 provides a guideline for the relative increase in roofing area with an increase in slope. The area for a flat roof has been taken as 100.

The weight of the roof covering material greatly influences the design of the roof structure and the purling. Table 5.12 shows some examples.

Purlins

Table 5.10 ***Minimum Pitch Requirements for Roofing Materials***

Roof Covering	Angle	Slope	Rise in mm/m
Built-up bitumen felt	3	1:20	50
Corrugated metal sheets (min. 150end laps)	12	1:5	200

Corrugated metal sheets (min. 100 end laps)	18	1:3	300
Corrugated asbestos cement sheets with 300mm end lap	10	1:5.7	180
Corrugated asbestos cement streets with 150mm end lap	22.5	1:2.4	410
Single lap tiles	30	1:1.7	580
Plain tiles in burnt clay	40	1:1.2	840
Slates min 300mm wide	25	1:2.1	470
Slates min 225mm wide	35	1:1.4	700
Shingles (wood)	35	1:1.4	700
Thatch of palm leaves (Makuti)	34	1:1.5	670
Thatch of grass	45	1:1	1000
Stabilized soil	9	1:6	170
In-situ mud (dry climates only)	6	1:10	100

Fibre-cement rooPmg sheets	20	1:2.8	360
Concrete tiles, interlocking	17.5	1:3.2	320

The spacing of the purlins which support the roofing depends on the size and rigidity of the roofing material. The dimensions of the purlins depends on the spacing of the rafters and purling, the weight of the roofing material and the loading on the roof from wind, persons constructing and maintaining the roof and in some areas snow. Timber, round or sawn, is the most common material used for purlins since roofing material can be easily attached by nailing. Where the spacing of trusses is in excess of 2,5 to 3,0m, timber purlins are not feasible and steel profiles are used instead. The profile can be an angle iron or a Z-profile made from plain iron sheets;

Small units such as slates, tiles and shingles are affixed to closely spaced battens of rather small section which means that the rafters must be closely spaced.

Table 5.1 1 ***Relative Areas of Roofs of Various Sloped***

Angle	**Slope**	**Relative Area of Roofing**
0	-	100

10	1:5.7	102
15	1:3.7	104
20	1:2.7	106
25	1:2.1	110
30	1:1.7	115
35	1: 1.4	122
40	1:1.2	131
45	1:1.0	141
50	1:0.8	156
55	1:0.7	174
60	1:0.6	200

Table 5. 12 *Weights of Roofing Materials*

Material	**Weight kg/m**
Corrugated aluminium sheet	2.5-5 depending on gauge
Corrugated steel sheets	6-9 depending on gauge

Corrugated steel sheets, laid	8-12 depending on gauge
Asbestos cement sheets	14
Asbestos cement sheets, laid	16
Slates, laid	40
Tiles, laid	65

Thatch

Thatch is a very common roofing material in rural areas. It has good thermal insulating qualities and helps to maintain rather uniform temperatures within the building even when outside temperatures vary considerably. The level of noise from rain splashing on the roof is low but during long, heavy rains some leakage may occur. Although thatch is easy to maintain, it may also harbor insects, pests and snakes.

A number of different plant materials such as grass, reeds, papyrus, palm leaves and banana leaves are suitable and inexpensive when locally available. Although the materials are cheap, thatching is rather labour intensive and requires some skill.

The durability of thatch is relatively low. In the case of grass, a major repair will be required every 2 to 3 years, but when well laid by a specialist and maintained, it can last

for 20 to 30 years or longer. The supporting structure of wooden poles or bamboo, although simple, must be strong enough to carry the weight of wet thatch. The use of thatch is limited to rather narrow buildings since the supporting structure would otherwise be complicated and expensive and the rise of the roof very high due to the necessity of a very steep slope. Palm leaves should have a slope of at least 1 :1.5, but preferably 1:1 and grass thatch a minimum of 1: 1 but preferably 1 :0.6. Increasing the slope will improve the durability and reduce the risk of leakage. The risk of fire is extremely high but may be reduced by treatment with a fire retardant as described later.

Grass Thatch Grass for thatching should be: .

- **Hard, fibrous and tough with a high content of silicates and oils and a low content of easily digestible nutrients like carbohydrates, starches and proteins.**
- **Free of seeds and harvested at the right time.**
- **Straight and have thin leaves and at least 1 metre long.**
- **Proper thatching procedure requires that:**
- **Stems be parallel, densely packed, with the cut side pointing outward.**
- **A steeply sloping roof frame of 45 or more be used.**
- **The eaves are low to offer protection for the walls.**
- **For best results the roof shape be conical, pyramidical or tripped in shape rather than double pitched where the verges present weak points.**

For easy handling the grass is tied into bundles. The thatching is started from the eaves in widths of about 1 m. A number of grass bundles are put next to each other on the roof, with the base of the stems to the bottom. The grass is tied to the purlins with bark fibre or preferably tarred sisal cord. In subsequent layers the bundles are laid to overlap the layer underneath by half to two-thirds of their length, which means there will be two to three layers in the finished thatch.

A long needle is used to push the string through and tie the bundles of grass onto the roof-laths. Then the bundles themselves are untied and with the hands the grass is pushed into the right position giving a smooth surface to the roof. Then the string is pulled and this fixes the grass securely in place. Another method leaves the bundles of grass as they are, which gives the roof a stepped surface. The thickness of the new thatch layers varies between 15 and 20cm but later on this will become somewhat thinner because of settling.

Figure 5.48 Thatching wish grass.

Stitch at bottom of first thatch on lowest batten. The second layer must overlay the stitching of the first row and include the top section of the underneath layer in the actual stitch. it is better to have each layer held by 3 rows of stitching. The stitching of every row must be completely covered by the free ends of the next layer above it.

The grass or straw is bound in bundles to the battens forming thatch boards. These boards are manufactured on the ground and bound to the rafters beginning at the eaves and continuing to the ridge. Each board covers with it's free ends the board underneath.

Palm Leaf Thatch (Makuti)

Palm leaves are often tied into makuti mats which are used for the roof covering. They consist of palm leaves tied to a rib (part of the stem of the palm leaf) using the dried fibre of Doum palm leaves or sisal twine.

The mats are laid on the rafters (round poles) and the stems tied to the rafters with sisal twine. The mats are usually produced to a standard size of 600 x 600mm and laid with a 100mm side lap, thus requiring a rafter spacing of 500mm. For a good quality mat 600mm wide, an average of 75 blades will be required. Spacing up the roof slope, i.e. the distance between the ribs of the makuti mats, is usually 150 to 100mm thus forming a 4 to 6 layer coverage, 5 to 8cm thick.

Papyrus Thatch

First a papyrus mat is placed on top of the purling, then a layer of black polythene and finally another one or two papyrus mats to complete the roof. These materials are fixed to the purlins with nails and iron wire. Nails are fixed to the purlin at 1 5 to 20cm spacing

and the iron wire is then stretched over the top of the papyrus mat and secured to the nails. The papyrus has a life span of about three years but that can be extended by treating the papyrus with a water-repellent paint.

Figure 5.49 Methods of grass thatching.

Figure 5.50 Assembling makuti mats.

Fire Retardant for Bamboo and Thatch

Fire retardant paints are available as oil-bourne or waterbourne finishes. They retard ignition and the spread of flame over surfaces. Some are intumescent, that is, they swell when heated forming a porous insulating coating.

A cheap fire-retardant solution can be prepared from fertilizer-grade diammonium phosphate and ammonium sulphate. The solution is made by mixing 5 kg of diammonium phosphate and 2.5 kg of ammonium sulphate with 50 kg of water. The principal disadvantage is that it is rendered less effective by leaching with rain. Therefore the fire retardant impregnation must be covered with a water repellent paint. The entire roof construction, i.e. bamboo trusses, strings, wooden parts and thatch, should be treated with the fire retardant. The following procedure is recommended:

Impregnation of Thatch

- **1 Dry the thatching materials such as reeds, palmyra, leaves, bamboos, ropes etc. by spreading out in the sun.**
- **2 Prepare the solution of fertilizer grade all-ammonium phosphate, ammonium sulphate and water as recommended.**
- **3 Immerse the material in the chemical solution and let soak 10 to 12 hours. A chemical loading of 10 to 14% by weight of the thatch (dry basis) is adequate.**
- **4 Take out the material, drain excess solution, and again dry in the sun.**
- **5 Prepare thatch roof in the conventional manner using the impregnated material and similarly treated framing material.**

Such roofs do not catch fire easily and fire spreads very slowly.

Figure 5.51 Alternative ridge caps for thatch roofs.

Figure 5.52 Papyrus-polythene roof

Galvanized Corrugated Steel Sheets

Galvanized Corrugated Steel Sheets (GCS) is the cheapest of the modern corrugated sheeting materials and is widely used as roofing material for farm buildings. Unprotected

steel would have a very short life, but a zinc coating (galvanizing) adds substantial protection at a relatively low cost. Alternative coatings for steel sheets are bitumen, polyvinyl chloride (plastic) on zinc, asbestos, felt and polyester. If the coating is damaged the steel will rust. When the first signs of rust appear, the sheet should be coated with a lead-based paint to stop the rusting.

The main advantages of GCS are:

- **1 The relatively light weight makes the sheets easy to transport and flexible so they are not easily damaged during transport.**
- **2 It is easy to install and handle. However, the edges of the sheets are often very sharp and can cause cuts in clothing and skin. The sheets may be cut to any required length and the roofing nails can be driven through the sheets directly without drilling holes.**
- **3 The supporting structure can be relatively simple. Due to the flexibility of the sheets, minor movements of the supporting structure can occur without damage.**
- **4 The sheets are quite durable if maintained and are not attacked by termites or fungus. They are water-tight and non-combustible.**
- **5 They can be dismantled and reused provided that the same nail holes are used.**

The main disadvantages of GCS are its poor thermal properties and the noise caused by heavy rainfall and thermal movements. The thermal and sound properties are improved

by an insulated ceiling.

Most corrugated steel sheets have corrugations with a 76mm pitch and 19mm depth. Thickness varies between 0.3-1.6mm of which 0.375-0.425mm are recommended for farm buildings.

Standard widths normally marketed are 610, 762mm and 1000mm. Lengths range from 2 to 4m. See figure 5.53 and Table 5.13 and 5.14.

Figure 5.53 Corrugated roofing with overlap

Table 5.13 ***Recommendations for Slope, End Lap and Side Lap for Corrugated Steel Roffing***

Type of position	**min slope**	**min end lap**	**min side lap**
Sheltered site	1:5	150mm	1.5 corrugation
	1:3	100mm	1 corrugation
Normal site	1:3	100mm	1.5 corrugation
Exposed site	1:3	150mm	2 corrugation

Figure 5.54 Methods of fastening corrugated roofing to purling.

Table 5.14 ***Covering width for different side lap and type of corrugated iron sheets***

Type	No. of Corr. mm	Overall Width	Covering Width (mm) Number of corrugation side lap		
			1	11/2	2
C.S. Nominal 8/7	6 8	610	533	495	457
C.S. Nominal 10/76	10	762	686	645	610

Laying the Sheets

The spacing of the purlins will depend on the thickness of the sheets used. As a guide, maximum spacing of purlins for 0.475mm sheets is 1500mm. The purlins should be a minimum of 50mm in width in order to be easily nailed.

The laying of the sheets should commence from the eave and away from the prevailing wind. The side laps will then be away from the wind preventing water from being forced

into the lap.

It is very important that the first sheet be laid at right angles to the eave and the ridge for by so doing, all the rest will also be perpendicular with the ridge. The first row of sheets is laid with a 50mm overhang beyond the facie board.

Special roofing nails are used to fix the sheets to timber purling. They are 67mm long and average about 100 nails per kilo. Under average conditions, the nails should be placed at every second corrugation on the purlin at the eave and then at every third corrugation on other purling. A stretched string along the purlin makes it easier to nail the sheets. Extra nails are needed along the verge (gable end overhang). The nails should always be placed at the ridge of the corrugation to prevent risk of leakage. Roofs in exposed positions require closer nailing. All end laps must occur over purling.

Ridging is normally available in pieces of 1800mm length. They should be fitted with a 150mm overlap. Other accessories such as close-fitting ridges, eaves-filler pieces and gutters are available from some suppliers.

The number of sheets to be purchased for a roof can be calculated by using the following formula:

No. of sheets = (Length of roof x width of roof) / (Length of sheets x covering width)

Note that the length of the sheets in the formula is the nominal length minus end lap. When making the bill of quantity for a building, the calculated number of sheets should be increased about 10% due to the waste during transport and installation.

Asbestos-cement Sheets

- **The advantages of asbestos-cement sheets (A-C) as compared to GCS sheets are:**
- **1 Longer life if properly fitted**
- **2 Less noise from heavy rain and thermal movements**
- **3 More attractive**
- **4 Better thermal insulating properties**

The disadvantages are:

- **1 They are heavier - (the weight per square metre is more than twice that of GCS) thus it is more expensive to transport and requires a stronger roof structure.**
- **2 Brittleness causes a high rate of waste due to breakage during transport and installation. A more rigid roof structure is necessary as the sheet does not allow for more than very small movements of the supporting structure without cracking. Walking on the roof may also cause cracking.**
- **3 Labour intensive due to weight and brittleness.**
- **4 The corners of the sheets must be mitred prior to fitting and holes for the fixing**

screws must be drilled.

- 5 Easily discoloured with dust and algae.
- 6 The manufacture and processing of asbestos products presents hazards to health.

Corrugated asbestos-cement sheets are normally marketed in a variety of corrugations and sizes. However, the most common corrugation which is used for farm buildings has a pitch of 177mm and a depth of 57mm. The sheet width is 920mm. It is supplied in lengths ranging from 1.5m to 3m. The effective coverage width is 873mm.

Storage and Handling

At the building site the sheets should be stacked on timber bearers levelled with each other at not more than 1m centres on firm, level ground. The sheets can be stacked to a height of approximately 1.2m without risk of damage. The sheets should be handled by two men - one at each end.

During installation roof ladders or crawl boards must be used to ensure safety and avoid possible damage to the sheets. Under no circumstances should anyone walk on the sheets between two purling.

Laying the Sheets

Corrugated A-C roofing should be installed with a slope of 1:2.5 (22) and an end lap of at least 150mm under normal conditions. Under exposed conditions a 200mm end lap is better. The sheets are designed for a side lap of half a corrugation in all situations.

Purlins must be of sawn timber in order to provide a flat support for the sheets and must be designed with a minimum of deflection. For the type of sheets described here, a maximum purlin spacing of 1.5m is recommended. If used as wall cladding the spacing can be increased to 1.8m.

Sheets should be laid from left to right or right to left depending on the direction of the prevailing wind. Side laps must always be sheltered from the main wind direction.

Figure 5.55 Lapping the roofing against the prevailing wind

Mitring the corner of the sheets at the overlaps is essential to ensure correct positioning and to allow the sheets to lie flat. The smooth surface of the sheet should be laid uppermost. Laying of the sheets should commence at the eaves (or from the lowest course for cladding). The necessary mitring is shown in Figure 5.56.

Mitring

The correct mitre is most important. This should be made from a point along the edge of

the sheet equivalent to the end lap, i.e. either 150mm or 200mm, to a point along the end of the sheet equivalent to the side lap 47mm. The gap between the mitres should be at least 3mm, but not to exceed 6mm. The sheets can be cut with a handsaw or a sheet hacksaw.

Fixing the Sheets

Holes must be drilled 2 to 3mm larger than the diameter of the roofing screws to be used to allow for movement within the framework of the building and the sheets themselves. All holes must be on the crown of the corrugation. It is important to remove all drilling dust before washers are put in position, otherwise water may be allowed to penetrate. Screws should be finger-tight until the correct alignment of the sheets in relation to the purlin has been checked. They should then be tightened until some resistance is felt. Screws should be located in the crown of the second and fifth corrugation of a sheet of seven corrugations. All end laps must occur over the purling.

Sisal-cement Roofing Sheets

These sheets are normally heavier and more brittle than asbestos-cement sheets which means that they will require a stronger roofing structure and even more caution during handling and laying. In all other respects they are similar to and used for construction in the same way as asbestoscement sheets.

Figure 5.56 Mitring asbestos-cement sheets.

Figure 5.57 Mitre dimensions.

Figure 5.58 Screws and cops for asbestos-cement roofing.

Corrugated-aluminium Sheets- CA

CA sheets are lighter and more durable than GCS sheets, but are more expensive. When new, the sheets have a bright reflective surface, but after a year or more oxidation of the surface will reduce the glare. There is never any need to paint aluminium sheets for protection.

The reflective surface will keep the building cooler than with GCS sheets, but since aluminium is softer, the roof is more likely to tear away in a heavy wind storm. Aluminium also has a greater thermal expansion than steel resulting in noisy creaks and more stress on fasteners.

CA sheets are normally supplied with the same corrugation and in the same sizes as GCS. For use in farm buildings, a thickness of 0.425mm is recommended. The sheets are laid and fixed in the same manner as GCS.

Figure 5.59 Examples of single-lap tiles and slate.

Fibreglass-reinforced Plastic Sheets

These sheets are shaped like those of steel, asbestos cement or aluminium and are used to replace some of the sheets in a roof to give overhead light. They are translucent and give good light inside large halls, workshops etc. They are long lasting, simple to install and provide inexpensive light, though the sheets themselves are expensive. They are combustible and must be cleaned occasionally.

Roof Tiles and Slates

Tiles were originally made by hand of burnt clay, but they are now manufactured by machine from clay, concrete and stabilized soil in several sizes and shapes. Plain tiles are usually cambered from head to tail so they do not lie flat on each other. This prevents capillary movement of water between the tiles. The shaped side lap in single-lap tiling takes the place of the double end lap and bond in plain tiles or slates. Many types of single-lap tiles are available, examples of which are shown in Figure 5.59.

Slates were originally made from natural stone, but now are also manufactured from asbestos cement and sisal cement. Since plain tiles and slates have similar properties and are laid and fixed in the same manner, they will be discussed together.

Tiles and slates are durable, require a minimum of maintenance and have good thermal and sound properties. The units themselves are water tight, but leaks may occur between the units if not properly laid. However, handmade tiles tend to absorb water and stabilized-soil tiles may erode in heavy rains. They are fairly easy to lay and fix, but being very heavy, they require a very strong supporting roof structure. The weight is, however, advantageous in overcoming uplifting wind forces. The dead weight of the covering will normally be enough anchorage for the roofing as well as the roof structure.

When rainwater falls on a pitched roof, it will fan out and run over the surface at an angle which is determined by e pitch of the roof. The steeper the pitch, the narrower the angle, while the lower the pitch, the wider the angle. Wider slates will be required for low pitch roofs.

Water running off tile A runs between B and C and spreads between tiles B and D and C and D as shown by the hatched area. It then runs because of the lap, onto the tiles E and F close to their heads. Note that tile is normally laid close together at the sides.

Figure 5.60 Water drainage on tiles.

Table 5.15 ***Slate and Tile Size, Pitch and Lap***

Unit	Min.	Min.	Minimum lap (mm)	

Size	**Pitch**	**Slope**	**Normal sites**	**Exposed sites**
Slates				
305 x 205mm	45	1:1	65	65
330 x 180mm	40	1:1.2	65	65
405 x 205mm	35	1:1.4	70	70
510 x 255mm	30	1:1.7	75	75
610 x 305mm	25	1:2.1	90	100
610 x 355mm	22.5	1:2.4	100	N/A
Plain Tiles*				
Concrete and Machine pressed	35	1:1.4	65	75
Stabilized soil	45	1:1	65	75

*** standard size 265 x 165mm. laid with 32mm side lap**

*** standard size 265 x 165mm. laid with 32mm side lap**

Figure 5.61 Installation of slates.

Plain tiling and slating provides an effective barrier to rain but wind and dust penetrate through the gaps between the units. Therefore boarding or sheeting may be placed under the battens on which the tiles or slates are to be hung. Roofing felt is the material most commonly used for this purpose.

In laying plain tile or slate there must always be at least two thicknesses covering any part of the roof, butt jointed at the side and placed so that no vertical joint is immediately over another vertical joint in the course below. To ensure this, shorter length units are required at the eaves and the ridge and each alternate course is commenced with a tile or slate of one-and-a-half units in width. The ridge is capped with special units bedded in cement mortar.

The hips can be covered with a ridge unit, in which case the plain tiling or slating is laid underneath and mitred at the hip. Valleys can be formed by using special units.

Plain tiles are ordinarily fixed with two galvanized nails in each tile at every fourth or fifth course. However, in very exposed positions every tile should be nailed.

Slates, which do not have nibs securing them to the battens, should be nailed twice in every unit. Plain tiles and small slates are nailed at the head while long slates are sometimes nailed at the centre to overcome vibrations caused by the wind. Centre nailing is mainly used for pitches below 35 and in the courses close to the cave.

Figure 5.62 Plain tile roof

The battens upon which the slates or plain tiles are fixed should not be less than 40mm wide and of sufficient thickness to prevent undue springing back as the slates are being nailed to them. Thus the thickness of the battens will depend upon the spacing of the rafters, and for rafters spaced 400 to 460mm on centres, the battens should be 20mm thick.

The distance from the centre to centre of the battens is known as gauge and is equal to the exposure of the slate or tile.

Figure 5.63 Single-lap tiles.

Wood Shingles

Wood shingles are pleasing in appearance and when made from decay-resistant species, will last 15 to 20 years even without preservative treatment. Cedar and cypress will last 20 years or more. Wood shingles have good thermal properties and are not noisy during heavy rain. The shingles are light and not very sensitive to movements in the supporting structure, which means that a rather simple roof frame made of round timber can be used. The shingles are laid starting at the eaves, touching on the sides and doubled lapped. This means that there are three layers of shingle over each batten. Each shingle is

fastened with one galvanized nail to the batten. No nail should go through two shingles. The shingles can be laid either with the core side of the timber alternating up and down in the successive rows, or with the core side down in all rows, thereby using the cupping effect of timber after drying to produce a roof cover less prone to leakage.

Figure 5.64 Core-side effect on wood shingles.

Bamboo Shingles

The simplest form of bamboo roof covering is made of halved bamboo culms running full length from the eaves to the ridge. Large diameter culms are split into two halves and the cross section at the nodes removed. The first layer of culms is laid side by side with the concave face upwards. The second is placed over the first with the convex face upwards. In this way the bamboo overlaps as in a tile roof and can be made completely watertight. Several types and shapes of bamboo shingle roofing may be used where only smaller sizes of bamboo culms are available.

Rainwater Drainage from Roofs

The simplest method is to let the roof water drop onto a splash apron all around the building. This method also protects the walls from surface ground-water. The water is then collected in a concrete ground channel or allowed to flow onto the ground

surrounding the building to soak into the soil. This latter method can only be recommended for very small buildings since the concentrated flow from a larger building may cause considerable soil erosion and damage to the foundation. The water from ground channels is drained into a soakaway or collected and stored. Blind channels are frequently used. These are simply trenches filled with stones that act as soakaways either for a ground channel or for a splash apron.

Figure 5.65 Roofing with wood shingles.

Figure 5.66 Bamboo shingles.

Pitched roofs are often provided with eave gutters to collect and carry the rainwater to downpipes which deliver the water to ground drains or a tank. Flat roofs are usually constructed with a slight fall to carry rain water directly to a roof outlet.

The sizing of gutters and downpipes to effectively remove rainwater from a roof will depend upon:

- **a The area of the roof to be drained.**
- **b Anticipated intensity of rainfall.**
- **c Material of gutter and downpipe.**
- **d The fall along the gutter, usually in the range of 1 :150 to 1:600.**

- **e Number, size and position of outlets.**
- **f Number of bends each bend will reduce the flow by 10 to 20%.**

Pitched roofs receive more rain than their plan area would indicate due to the wind blowing rain against it. An estimate of the effective area for a pitched roof can be made by multiplying the length by the horizontal width plus half the rise.

In order to find the flow, the area is multiplied by the rainfall rate per hour. The rainfall intensity during a heavy rain will vary between areas and local data should be used where available. As a guide, rainfall values of 75 to 100mm per hour may be used. Gutters should be installed with very little fall, 0.3% being recommended. Falls which are too steep cause difficulties because the water flows too rapidly leaving trash behind. Also gutters with more than a slight fall do not look well.

Table 5.16 ***Flow Capacities in Litres per Second for Level Half-round Gutters***

Gutter size mm	Flow l/s
75	0.43
100	0.84
1 12	1.14

125	1.52
150	2.46

There is always the possibility that unusually heavy rain, or a blockage in a pipe, may cause gutters to overflow. With this in mind, it is always advisable to design a building with a roof overhang so that in case of overflow the water will not flow down the facade or make its way into the wall where damage may result.

Common material for gutters and downpipes are galvanized steel, aluminium and vinyl. The galvanized steel is the least expensive. Aluminium is long lasting but easily damaged. The vinyl is both durable and resistant to impact damage.

Two major types of gutter brackets are normally available. One is for fixing the gutter to a fascia as illustrated in Figure 5.67. The other is used when there is no fascia board and the gutter is fixed to the rafters. The roof cover should extend 50mm beyond the ends of the rafters or the fascia board in order to let the water drop clear.

Figure 5.67 Gutter and downpipe fastenings.

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Doors

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Doors are essential in buildings to provide security and protection from the elements while allowing easy and convenient entry and exit. Farm buildings may be served adequately with unframed board doors, while homes will need more attractive, well-framed designs that close tightly enough to keep out dust and rain and allow only minimal air leakage. Large openings can be better served by rolling doors rather than the side-hinged type.

General Characteristics of Doors

Size: Doors must be of adequate size. For use by people only, a door 70cm wide and 200cm high is adequate. However, if a person will be carrying loads with both hands, e.g. 2 buckets, 100 to 150cm of width will be required. If head loads will be carried, door heights may need to be increased to 250cm. Shop or barn doors need to be considerably larger to give access for tools and machinery.

Strength and stability: Doors must be built of material heavy enough to withstand normal

use and to be secure against intruders. They should be constructed of large panels such as plywood or designed with sturdy, well secured braces to keep the door square, thereby allowing it to swing freely and close tightly. A heavy, well-braced door mounted on heavy hinges fastened with 'blind' screws and fitted with a secure lock will make it inconvenient for someone to break in.

Door swing: Edge hung doors can be hung at the left or at the right and operate inwards or outwards. Careful consideration should be given to which edge of the door is hinged to provide the best control and the least inconvenience. An external door that swings out is easier to secure, wastes no space within the building, and egress is easier in case of emergency. However, unless it is protected by a roof overhang or a verandah, it may be damaged by rain and sun. An inward swinging door is better protected from the weather.

Weather resistance and durability: It is desirable to use materials that are not easily damaged by weathering and to further improve the life of the door by keeping it well painted.

Special considerations: under some circumstances fireproof doors may be desirable or even required. In cooler climates insulated doors and weatherstripping around the doors will help to conserve energy.

Types of Doors

Unframed doors: Very simple doors can be made from a number of vertical boards held secure with horizontal rails and a diagonal brace installed in such a position that it is in compression. These are inexpensive doors and entirely satisfactory for many stores and animal buildings. Because the edge of the door is rather thin, strap or tee hinges are usually installed over the face of the rails.

Figure 5.68 A simple unframed door.

Framed doors: **A more rigid and attractive assembly includes a frame around the outer edge of the door held together at the corners with mortise and tendon joints. The framed door can be further improved by rabbeting the edge of the frame rails and setting the panels into the grooves 10 to 20mm. The door can be hung on strap or tee hinges, but since there is an outer frame the door can also be hung on butt hinges with hidden screws. If the inner panel is made up of several boards braces are needed, but if the one or two panels are made of plywood, no braces will be required. Large barn or garage doors will need the bracing regardless of the construction of the center panels.**

Flush Doors: **Flush panel doors consist of a skeleton frame clad with a sheet facing such as plywood. No bracing is necessary and the plain surface is easy to finish and keep clean. Flush panel doors are easily insulated during construction if that is necessary.**

Double Doors: **Large door openings are often better served by double doors. If hinged**

doors are used, the smaller double doors are not as likely to sag and bend and they are much less likely to be affected by wind. Usually opening one of the double doors will allow a person to pass through. Figure 5.70 shows how the meeting point of the two doors can be covered and sealed with a cover fillet.

When doors are large and heavy and need to be opened only occasionally, it is desirable to place a small door either within or next to the large door. Figure 5.71 shows typical locations for a small door for the passage of people.

Rolling Doors: **An alternative to double-hinged doors for large openings is one or more rolling doors. They often operate more easily, are not as affected by windy conditions nor as subject to sagging and warping as the swinging doors. The rolling doors are usually mounted under the eave overhang and are protected from the weather when either open or closed. It is true that they require space at the side of the doorway when they are open, but there are several designs to suit a variety of situations. For example:**

- **1 One large door rolling one way from the doorway.**
- **2 Two doors rolling in opposite directions from the doorway.**
- **3 Two doors on separate tracks rolling to the same side.**

In all cases it is desirable to have guides at the base to prevent wind interference and to make the building more secure from intruders. For security reasons the door hangers

should be of a design that cannot be unhooked but only roll on or off the end of the track. The most secure place to mount the door hangers is on the stiles (end frame pieces). See Figure 5.72 for details.

Half-Door or Dutch Door: Doors that are divided in half horizontally allow the top section to be opened separately to let in air and light while at the same time restricting the movement of animals and people.

Figure 5.69 Framed door.

Figure 5.70a Unframed door

Figure 5.70b Framed door

Figure 5.70c Flush door

Figure 5.71 Alternative locations of a small door for the passage of people.

Figure 5.72 Rolling door details.

Door Frames

A timber door frame consists of two side posts or jambs, a sill or threshold, and a head or

soffit. For simple buildings not requiring tight-fitting doors, the two jambs as shown in Figure 5.73 may be all that are necessary. However, if a tightly fitting door is desired, then a complete frame is required including strips or stops around the sides and top against which the door closes. In as much as the door jambs are installed against the wall, and the fit may not be precise, dwelling house doors are often hung in an inner frame that can be plumbed and levelled by inserting shims between the inner and outer frames as shown in Figure 5.74.

Figure 5.73 Simple timber door frame installation.

Figure 5.74 Framed timber door in concrete block wall with jamb blocks.

This figure also shows the use of concrete jamb blocks which are often available for concrete masonry walls. They have a corner cut out so that when the wall is laid up there is a recessed area in which to install the jamb rigidly. A door frame may be anchored in an opening where square end blocks are used as shown in Figure 5.75.

The simplest doors do not close tightly because they have no threshold or head. A threshold allows the door to close with a relatively tight fit at the bottom while at the same time allowing the door to swing open with adequate clearance from the floor. The head permits the top of the door to close tightly.

Simple Locks for Barn Doors

Large double doors are normally secured by locking them both at the top and the bottom. Thus four sliding bolt locks are required and should be installed close to where the doors meet. In small double doors top and bottom locks are only required for one of the doors. Figure 5.77a illustrates a simple wooden handle locking with a wedge nailing to the lintel. It can be used at the top of an unframed door. Note that the top rail must be placed down far enough to allow movement of the top of the handle. In, for example barn doors, where movements of the door can be tolerated, often only a lock at the top is provided.

Alternatively the lock shown in Figure 5.77b can be used This lock, which is located at the middle rail, has a bolt running through the door. The bolt is secured to a cross bar on the inside and a handle on the outside. When the handle is pressed down the cross-bar rotates out of the hooks. A padlock can be fitted to secure the handle in locked position.

Windows

Windows provide light and ventilation in a building an allow those within to view the surrounding landscape and observe the activities in the farm yard. In sitting rooms and work rooms where good light and ventilation are important, the window area should be

5 to 10% of the floor area of the room. Windows sometimes need to be shaded to reduce heat radiation or closed to keep out driven rain or dust. In addition screening may be needed for protection from insects. Shutters, either top-or sidehinged, are commonly used to provide the needed protection. Side-hung glazed windows, fly screens and glass or timber louvres are also used.

Figure 5.75 Anchoring a doorframe in a masonry wall without jamb blocks.

Figure 5.76 Types of thresholds.

Figure 5.77 Simple barn door lock.

Shutters: These are basically small doors and are constructed as unframed, framed or flush shutters. Because of the smaller size only two rails are required and the timber can be of smaller dimension. The principles of construction are the same as for doors. However, when the frame for the shutter is recessed in the wall, the sill must be sloped and extend out from the wall to let the water drip clear of the face of the building. The window shutter can be sidehinged or top-hinged. A top-hinged shutter has the advantage of shading the opening when kept open as weld as allowing ventilation while preventing rain from entering.

Glazed windows: Glazed windows are relatively expensive but are most practical in cold

areas. When temperatures are low, the window can be shut while daylight still enters the room. Frames for glazed windows are available in wood and metal, the latter being more expensive. Glazed windows with frames are usually marketed as a unit, but Figure 5.81 illustrates various methods of frame construction and installation.

Figure 5.78 Recessed window or shutter.

Figure 5.79 Window installations.

Stairs and ladders

The angle, as determined by height and the horizontal distance available, will determine the most suitable means of getting from one level to another. For a slope up to 1:8 (7). A ramp is suitable for both walking and pushing a wheelbarrow. For walking alone, a 1:4 (14) slope is satisfactory if it remains permanently dry. For slopes between 1:3 and 1:0.8 (18 to 50), stairways are possible, although 30 to 35 is preferred. Angles steeper than 50 require a ladder or ladder-stairway. Temporary ladders should be set up at 60 to 75, while a fixed ladder may be vertical if necessary.

***Ramps:* Ramps may be made of tramped earth or concrete. An earth ramp should be made of a mixture of fine gravel and clay, the gravel to give texture for a nonslip surface**

and the clay to serve as a binder. The surface of a ramp constructed of concrete should tee 'broomed' across its slope after having been poured and struck off.

***Stairs*: Stairs can be designed as one straight flight, with a landing and a 90 turn or with a landing and a 180 turn. The straight flight is the simplest, the least expensive and the easiest on which to move large objects up or down. However, stairs with a landing are considered safer because a person cannot fall as far.**

Definitions and descriptions of terms relating to stairways: (see Figure 5.80).

***Angle block:* Glued angle block in the junction between tread and riser to reduce movements and creaking.**

***Balusters:* The vertical members between the stringer and the handrail.**

***Going:* The horizontal distance between the nosings or risers of two consecutive steps. This is sometimes called the run or the tread.**

***Handrail:* A safety rail, parallel to the stringers and spanning between newels at either end. This can be attached to the wall above and parallel to a wall stringer. The vertical distance between the stringer and handrail should be 850 to 900mm.**

***Headroom:* The vertical distance between the treads and any obstruction over the stairway, usually the lower edge of a floor. The headroom should be at least 2 metres.**

***Housing*: The treads and risers can be housed in grooves in the stringers or supported on beads that are nailed and glued to the stringers. In both cases they should be secured with wedges and glue.**

***Newel post*: The post supporting the hand-rail at the bottom, turn and top of a staircase.**

***Pitch*: Usually 30-35**

***Rise*: The vertical distance between two consecutive treads.**

***Risers:* The vertical members between consecutive treads. Sometime the riser is omitted (open riser) for simplicity and economy. In that case the treads should overlap by 25 to 35mm.**

***Steps:* The combined treads and risers.**

***Stringers:* The inclined beams supporting the steps. The strength required for the stringers will depend on the load and method of support. They may be supported only at the ends or continuously along the wall.**

***Treads:* The members stepped on as a person climbs the stairs. The treads must be strong enough to carry and transfer the imposed load to the stringers without excessive deflection. They should have a non-slippery surface. The treads can be housed in grooves in the stringers or supported on beads that are nailed and glued to the stringers. In both cases they are secured with wedges nailed and glued to the stringer.**

***Width:* Sufficient width for two persons to pass requires a width of 1.1 metre. A minimum width of 600mm can be used for traffic of persons not carrying anything.**

Figure 5.80 Stairway construction.

The pitch for most stairs should not exceed 42 nor be less than 30, and for stairs in regular use a maximum of 35 is recommended. For most stairs a minimum going of 250mm and a maximum of 300mm should be adopted, although in domestic stairs a minimum of 200mm is acceptable for stairs that are used infrequently. A rise from 150 to 220mm is usually satisfactory. Comfort in the use of stairs depends largely upon the relative dimensions of the rise and going of the steps. Rules for determining the proportion are based on the assumptions that about twice as much effort is required to ascend as to walk horizontally and that the pace of an average person measures about 585mm. Thus, the fact that a 300mm going with a rise of 140mm or 150mm is generally accepted as comfortable, results in the rule that the going plus twice the rise should equal 580 to 600mm.

It is essential to keep the dimensions of the treads and risers constant throughout any flight of steps to reduce the risk of accidents caused by changing the rhythm of movement up or down the stairway.

Stairs are constructed by gluing and wedging the treads and risers into the housing grooves in the stringers to form a rigid unit as shown in Figure 5.80.

Stairs are designed to be either fixed to a wall with one outer stringer, fixed between walls, or freestanding, the majority of stairways having one wall and one outer stringer. The wall stringer is fixed directly to the wall along its entire length or is fixed to timber battens plugged to the wall. The outer stringer is supported at both ends by the posts. The posts also serve as the termination point for handrails which span between them.

The space between the handrail and the tread may be filled with balusters, balustrade or a solid pannel to improve both the safety and appearance of the stairway.

Reinforced concrete is better suited for outdoor stairs than is timber. The number, diametre and spacing of the main and distribution reinforcement must always be calculated for each stairway by an experienced designer.

Figure 5.81 Typical formwork for casting concrete stairs.

Ladder-stairway The recommended pitch for this type of steep, narrow stairway is 60. The width is usually about the minimum of 600mm. The size of the going (tread) is. dependent on the pitch. The values in table 5.17 are recommended:

Table 5.17 ***Measurements of Tread and Rise at different pitch of the stairway***

	Pitch degrees					
	50	55	60	65	70	75
Tread, mm	220	190	160	130	100	70
Rise, mm	262	272	277	278	275	262

Timber ladders are basically of two types:

- **1 Those having round rungs fixed in holes in the stringers, and**
- **2 Those having square or slightly rectangular treads cut and nailed in on the forward side of the stringers.**

Figure 5.82 Ladder-stairway.

Figure 5.83 Two basic types of ladders.

Figure 5.84 Ladder guard.

The width of the ladder should be 350 to 500mm and the rise should be 230 to 400mm, with 300mm as the recommended value.

Ladders which are moved from place to place should have hooks and dowels so that they can be thoroughly stabilized at the bottom and top. Ladders mounted permanently should be firmly secured in their position, and if necessary, provided with handrails. If the total length is more than 5 metres and the pitch steeper than 70, the ladder should be provided with a guard preventing the climber from falling backward. If the ladder is taller than 2.5 metres and starts from a small platform, it too should have a guard.

Electrical installations

Electrical energy can be put to many uses and an increasing number of farms will benefit from electrification as the electrical supply network is expanded in the rural areas or generators are installed at farms. Although few farms, in particular small farms, are connected to an electrical supply at present, everyone concerned with design and construction of farm buildings will need to have an appreciation of the general layout and function of electrical installations.

Figure 5.85 Typical electrical distribution system.

For most types of farm buildings the electrical layout can be drawn on a copy of the plan view by use of the symbols shown in Figure 1.8. The layout should indicate where outlets, lighting points, switches, motors, heaters and other appliances are to be fitted and the accompanying specifications should describe the chooser wiring system, fixing heights and detail each appliance. Detailed wiring plans and installation designs prepared by a specialist will only be necessary for large and complex buildings, such as plants for processing of agricultural produce.

Electrical Supply

Electricity supply to a farm will normally reach it overhead from a local transformer substation where the voltage has been redued to a three-phase, 415/ 240V supply. Four wires are required for a three-phase supply, one for each of the lines and one common return or neutral. The neutral is connected to earth at the substation. The voltage between any phase wire and the neutral is 240V, while it is 415V between any two phase wires. If nearly equal loads are connected to each of the phases, the current in the neutral will be kept to a minimum. To achieve this most appliances that consume large amounts of electricity, notably electrical motors and larger heater and air-conditioning units are designed for connection to a three-phase supply. Lighting circuits, socket outlet circuits and appliances of low power rating are served with single-phase supply, but the various circuits are connected to different phases to balance the overall loading. However, sometimes small farms or domestic houses are served with a single-phase, 240V supply. In this case only two wires are required in the supply cable, one live and one neutral. The balancing of loading is effected at the substation, where the lines from several houses are brought together.

The intake point for the main supply to a farm should be at a convenient place that allow for the possible distribution circuits. The intake point must provide for an easily accessable area that is protected from moisture and dust and where the main fuse, the main switch and the meter can be fitted. Circuit fuses and distribution gear may be fitted at this place or in each buildings at the farmstead that is to be served with electricity.

Electricity tariffs are the charges that are passed on to the consumer. The charges commonly consist of two elements, a fixed cost that often depend on the size of the main fuse, and a running cost that depend on the amount of electric energy consumed. The required amp rating for the main fuse will depend on the maximum sum of power required for appliances that are to be connected at any one time and is also influenced by the type of starter used for electrical motors. Usually the motor having the highest power rating will be the determining factor at a farmstead.

Earthing and Bonding

Should a base live wire touch or otherwise become connected to the metalframe work of an appliance, a person touching this would receive an electric shock. A precaution against this is to connect any exposed metal work to an earth wire, that is lead as an extra conductor in the supply cable and connected to an earthing connector, which consist of a number of copper rods driven well into the ground. An earthing wire will thus be carried as a third conductor in single phase supply cable and as a fourth or fifth conductor in a 3-phase supply cable, depending on whether the cable include a neutral wire. The neutral should not be used for earthing. Some appliances are, instead of being earthed, protected by being enclosed in an insulating cover.

Bonding is a low resistance connection between any two point of an earthed system as to prevent any difference of potential that could produce a current and is an additional protection. If, for example, the metal furnishing in a milking parlour is electrically connected to the reinforcement bars of the concrete floor, the cows will be protected from electrical shocks, should for some reason the furnishing become charged by an earth-leaking current, that is not large enough to blow a fuse, since the floor will get the same electrical potential.

Distribution Circuits

Electricity is distributed within buildings in cables, which consist of one or several conductors made of copper or aluminium each separately surrounded by an insulative

material, such as plastic, and then enclosed in an outer sheet of plastic or rubber. The size of a cable is given by the cross-section area of its conductors. All cables are assigned a rating in amperes, which is the maximum load the cable can carry without becoming overheated. Large conductors are usually divided into strands to make the cable more flexible.

Surface wiring is normally used in farm buildings. This implies sheeted cables laid on the surface of walls, ceilings, etc. and fixed with clips. Care must be taken that cables are not sharply bent, are protected when passing through a wall and are laid well away from water pipes. Conduit wiring, where the cables are drawn in concealed tubing, is to expensive and complex to be employed in farm buildings.

Lighting circuits are normally carried out in 5A fusing and wiring (1.0mm cables). While a suitable arrangement of one-way and two-way switches will allow lamps to be switched on and off individually or in groups, each such circuit can serve for example ten 100W lamps without danger of overloading. If all ten lamps are on together they have a power requirement of 1000W. Following the relation:

W=V x A where:

W = power
V = voltage

A = current

The lamps would produce a 4.2A current in a 240V circuit, i.e. it leaves a suitable factor of safety to overloading the fuse and wiring.

Socket circuits are normally carried out in 2.5mm wiring and arranged as ring circuits that are supplied from the mains at both ends through 10 to l5A fuses. In domestic installations a socket circuit can carry any number of outlets provided it does not serve a floor area greater than 100m. However, when designing socket circuits for farm buildings, such as the workshop, it will be wise to estimate the current produced by all appliances that are expected to be connected at any one time to avoid overloading. Lamp fittings, switches and outlets are available in a range, offering varying degree of protection against dust and moisture penetration. Although more expensive those offering a high level of protection will normally be required in farm buildings as will fittings positioned outdoors.

No socket outlets are permitted in bathrooms and showers and should be avoided in rooms such as clairies and wash rooms, because of the presence of water.

Fixed electrical apparatus that are single phase supplied, such as water heaters, airconditioners and cookers, should have their own circuits with individual fuses.

Three phase electrical motors and apparatus required power supply cables with four or

five conductors, including the earthing wire. Each appliance should have its own power supply and the phase lines must be fused individually. Movable 3-phase motors are supplied from special 3-phase power outlets via a rubber sheeted flexible cord that is fixed to the motor at one end and fitted with a 3-phase plug at the other. All flex cords must be protected from damage by for example wheels and should where possible be hung off the ground. Flex cords must under no circumstances be connected by twisting the conductors together.

Artificial Lighting

In tropical countries with strong natural light even relatively small windows may provide' sufficient indoor lighting. Hence artificial lighting will mainly be required to extend the hours of light.

The two most commonly used artificial light sources, where electrical energy is available, are in candescent bulbs and flourescent tube. Tubes and fittings for tubes are more expensive than bulbs and bulb fittings, but tubes produce three to five times as much light per unit of electric energy, have up to ten times as long life and have a lower heat production. Hence flourescent light normally is the cheapest despite the higher initial cost. However, in small rooms where the light is switched on and off frequently bulb fittings are usually preferred as the installation cost in this case is more important than the energy cost. Merary vapour and sodium lamps are often used for outdoor lighting.

They have higher efficiency in terms of light produced than flourescent tubes, but their light covers only a limited spectrum and this tend to distort colours.

Various types of fittings are normally available for both bulbs and tubes. While a naked bulb or tube may be sufficient in some circumstances, fittings that protect the lamp from physical damage and moisture penetration will often be required in farm buildings. From an optical point of view the fitting should obscure the lamp and present a larger surface area of lower brightness to reduce the glare caused by excessive luminance contrast. This is particularly important if the lamp is positioned where it will be directly viewed. A lighting point must also be positioned so that reflected glare and trouble some shading of a work area is avoided. While light colours on interior surfaces will create a bright room, shades of blue or green produce a feeling of coolness. The dusty conditions in many farm buildings implies the use of fittings that allow for easy cleaning. Accumulated dust can reduce the flow of light by more than 50%.

Most agricultural production operations carried out in buildings can be performed quite satisfactory using natural light, but where artificial light is to be installed the standard of illumination should be related to the activities carried out. While the installation of 2.0 to 3.0W flourescent light per square metre floor area will be sufficient for general illumination, work areas need more light, say 5 to 8 W/ m, and a desk or work bench where concentrated or exacting tasks are performed may need 10 to 15 W/m or more. Where bulbs are to be installed instead of tubes the above values will have to be at least

trippled.

Figure 5.88 Examples of light fittings for farm buildings.

Electrical Motors

Single phase motors in sizes up to about 1kW have a wide range of applications, particularly for use in domestic appliances. The most common type, the single phase series motor or universal motor, produce a good starting torque and can be run on both alternating current (AC) and direct current (DC). While it has the advantage of being able to be connected to an ordinary socket outlet, generally, it can not compete with the performance and efficiency of a 3phase motor.

The 3-phase induction motor is the most common electrical motor at farms, where it is used to power fans, transport devises, mills, etc. Modern electrical motors are manufactured in a wide range of power ratings and types. Their enclosures range from screen protection to totally enclosed. Motors used in farm buildings normally should have an enclosure that is dust-tight and sprinkle-proof, i.e. it should not be damaged by being exposed to sprinkling of water from any direction. However, sometimes even better protection, such as dust-proof and flush-proof, is required and submersible motors must be totally enclosed and completely water proof.

Inherent features of the induction motor are its poor starting torque and heavy starting current - up to six times the full load current. To prevent excessive voltage chop in the supply network and Electricity Company usually allow only small induction motors to be started direct on line. A star/ delta starter is commonly fitted to motor above 2 to 3kW, and will reduce the starting current to about twice the full load current. Unfortunately it also reduces the already poor starting torque even further so that the motor can not start against heavy load. Other types of motors and starters are available for situations where starting against load can not be avoided, however.

The starter for any motor rated above about 0.5kW must incorporate an overloadction that switches off should the current exceed a safe value for longer time than what is required to start the motor. In many installations it would, in addition, be desirable to include a release mechanism that prevent unexpected restarting after a power failure. A wide range of sensors, timers and other devises are available for automatic supervision and control of electric motor operation.

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Chapter 6 Building production

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Building production is the organization and management of the plans, equipment, materials and labour involved in the construction of a building, while at the same time complying with all codes, rules and contractual stipulations. The procedure should be designed to run efficiently, to keep the costs low and to allow returns on the investment to be realized as early as possible.

While many topics included in this chapter, such as standardization, organization of building works carried out by a contractor, tendering, contracting, inspection and control and progress charts may have limited relevance for small scale building projects on African farms, it is felt that an agricultural engineer will need some knowledge of these topics when faced with construction of communal and central facilities for agriculture and medium-to largescale farm buildings.

The costs of farm buildings such as animal housing and stores for produce can be expected to be repaid in terms of increased production, improved animal health, reduced storage losses, increased quality of produce and more efficient work performance. Other buildings such as dwellings are expected to be worth their costs mainly in terms of the

standard of space, environment, convenience, construction and appearance they provide. The term "costs" in this context means costs over the whole life of the building, including operating and maintenance costs as well as an annual portion of the initial cost of construction, which in addition to building materials and construction labour, includes fees paid to consultants, architects and legal advisors as well as capital interest and any loss of production incurred during the construction phase.

Building planning is thus concerned with economic building rather than with cheap building, i.e., with providing the required standard of facilities at the lowest cost.

It should be pointed out that costs include not only cash payments but also the value of materials and work provided by the farmer and his family since these are resources that could have been used for alternative activities at the farm to generate income or produce food. Most methods for construction- costing and economic feasibility studies imply that resources employed for the construction as well as the benefits of the finished structure can be valued in a convenient monetary unit. Subsistence farmers are part of the monetary economy to only a limited extent, thus it is difficult to put a fair price on material and work supplied by these farmers for construction at their farms or to correctly value the benefits of the structure.

There is a national interest in utilizing efficiently the resources invested in buildings. Governments express their minimum demands in the form of building regulations, codes

and laws.

A farmer employing an agricultural engineer to design a building, a contractor to construct it and suppliers to deliver material will expect delivery of work and goods to the standard and price agreed upon. For later reference it is common to specify the agreement in a contract, which makes reference to drawings and specifications for the structure and to general specifications. Inspections and controls are the means used to ensure that the agreement is followed.

The building production process

The building production commences when the farmer starts to seriously consider investing in a structure and does not end until the finished building is in use.

The process is divided into stages which follow in logical sequence. Each stage is terminated by a decision. Table 6.1 is an outline plan of work for the building production process. In small projects where the farmer performs virtually all tasks involved, it may not be necessary to follow the chart in detail. Nevertheless the same procedural basics and logical order should be a goal. During the initial planning stages, the costs are low compared with the importance. The high costs involved in correcting errors once the site operations and construction are under way, can be avoided if time is spent working out a

good, functional design which is technically and economically sound.

Methods of construction

The methods of constructing farm buildings refers to the way in which units and components of the building structure are produced and assembled. The manner of organizing this process differs from region to region and depends on the level of technology and the materials available. The operations involved in the construction of rural buildings of traditional designs are familiar to most rural people in Africa and small buildings on farms are usually constructed by the farmers and their families. However, where new methods of construction, materials or layouts have been adopted, as well as where there is an increase in the size of the project, the assistance of trained artisans will usually be required. Self-help projects for the construction of communal facilities such as village stores must be accompanied by a training programme for the people involved.

Where most of the construction is done by employed building workers, three different contemporary building methods, which are described below, can be distinguished. While in the foreseeable future the traditional method of constructing farm buildings will remain the most common, the fact that an increasing number of industrialized building products are being marketed has lead to the introduction of post-traditional building and, to a limited extent. system building.

Table 6.1 Building Production Process Part 1

Table 6.1 Building Production Process Part 2

Traditional Building

In traditional building, forms of construction are those evolved by the traditional building crafts, particularly those of walling, roofing, plastering, carpentry and joinery. This method is a process of combining many small units. Most of the fabrication and assembly takes place at the site and usually in the position that the unit is to occupy in the completed structure. Within each tribal culture, traditional building results in structures that are similar but differing slightly, depending on the specific requirements and site.

Because of the limited range of materials and forms of construction used, the craftsmen are familiar with the content and order of operations in their own trade and their relation to operations in other trades so well that they carry it out with a minimum of detailed information.

The traditional craft-based building method is flexible and able to meet variations in the demand of the market on the work of the craftsmen more readily and inexpensively than methods based on highly mechanized factory production. This is because production is by craftsmen and there is little investment in equipment, especially mechanical equipment,

and factory buildings.

However, the proportion of skilled labour required at the site is fairly high.

Post-traditional Building

The post-traditional or conventional method of building mixes traditional and new forms of construction, involving both the old crafts and newly developed techniques based on new materials. To some extent traditional building has always been in a state of change, but the introduction of Portland cement and mild steel has made it feasible to construct large and complex buildings and with this arises the need for efficient organization of the construction process.

The amount of on-site fabrication has been reduced by the introduction of prefabricated, factory-produced components, especially in the field of joinery and carpentry (windows, doors, cupboards, roof trusses, etc.). Reinforced concrete and preformed steel lend themselves to off-site fabrication of parts and only their assembly on site.

Post-traditional building varies from the traditional mainly in the scale of the work carried out and in the use of expensive machinery for many operations. The use of prefabricated, standardized components reduces the amount of skilled labour, but at the same time reduces the freedom of the designer in meeting varying design requirements.

The scale of operation makes it necessary to pay greater attention to planning and organization of the work so that material and labour are available in a continuous flow, the mechanical equipment is efficiently used, and the construction can proceed smoothly. It is thus necessary to consider the production operations during the designing stage.

System Building

System building is a method in which most of the building's component parts are factory-produced and siteassembled. The main advantages in system building are the possibilities for efficient factory production of large numbers of similar building elements and the reduced period of time necessary for assembly at the site. A disadvantage with this method is the high level of accuracy required for setting out and foundation work since the nature of the components and the principles of the system are such that mistakes are difficult to correct during the assembly process. The components (e.g., wall, floor, ceiling and roof elements) are usually related to a specific building type, such as houses, schools or warehouses or to a restricted range of types. The design of buildings produced by this method is inflexible and limits the possibility of adjusting to specific requirements at a certain site or to a local building tradition. The building components may, for example, be produced for only a specific width of building and if the wall elements are say 3.6m long, the building length must be a multiple of 3.6m

Components of one system will not ordinarily fit with components of other systems, a

situation referred to as a 'closed system'. On the other hand, en 'open system' allows each component to be interchanged and assembled with components produced by other manufacturers. In order to keep the variety within acceptable limits for mass production, such a system must operate within a framework of standardization of the main controlling dimensions, e.g floor-to-ceiling height of wall elements'

Prefabrication

Prefabrication is the manufacture of building components either on-site (but not in-situ) or off-site in a factory. The use of prefabricated components can reduce the need for skilled labour at the site, simplify construction by reducing the number of separate operations, and facilitate continuity in the remaining operations. However, prefabs are not necessarily timesaving or economical in the overall construction project. For example, the use of prefabricated lintels may save formwork and result in continuity in the bricklaying work, but would be uneconomical if a lifting crane is required at the site to place them, when it is not required for any other purpose on the job.

On-site Prefabrication

On-site prefabrication may be of advantage where a number of identical components such as roof-trusses, doors, windows, gates and partitions are required. Once a jig, mould

or prototype has been made by a skilled craftsman, a number of identical components can be produced by less-skilled labour, e.g. the farmer who could do this job in available time during the off-season. Prefabrication of such items as roof-trusses will also make for more convenient and effective production than construction in-situ.

It is advantageous to prefabricate some concrete components. Components for elevated positions require simpler formwork if cast on the ground or in the ground so that the soil can be used to support the formwork. Prefabrication eliminates the waiting time for concrete components to harden sufficiently for subsequent on- site operations to continue, but the weight and size of concrete parts may make prefabrication impractical.

Local production by farmers of adobe bricks, burnt bricks, soil blocks, etc. is not normally referred to as prefabrication although similar planning and organization are required for the production of these units as for production of prefabricated building components.

Off-site Prefabrication

Factory production of components requires capital investment in machinery and premises, a high degree of organization of work, standardization and a steady demand for the products. Building components, which can be economically produced in a factory, essentially fall into three categories:

- **1 Those which have a high degree of standardization and are in great demand, so that mass production, utilizing the greater efficiency of modern factory production, is feasible, e.g., bricks, blocks, pipes, windows, doors and building hardware.**
- **2 Those which incorporate materials or finishes that are exclusively or more efficiently produced with factory based techniques, e.g., metal components, plastic items, galvanized items and baked-paint finishes.**
- **3 Those which make use of new factory-based techniques and machines, e.g., laminated-wood beams, prestressed concrete beams and insulated-sandwich panels.**

Factory production is relatively inflexible, since large runs of any one component are essential for economical operation. The mere transfer of a simple operation from a site to a factory will not in itself reduce costs; on the contrary, it may increase them. This is particularly true for components for farm buildings, since the demand for them originates from a large number of scattered construction projects resulting in high transportation and distribution costs. Therefore many factory - made components used in farm buildings will have been designed primarily for other purposes.

Dimensional coordination and standardization

In order to limit the variety in size of similar components, to facilitate their assembly at the site, and to make them interchangeable between different manufacturers, building

components are manufactured in standardized dimensions based on an accepted system of dimensional coordination. Such preferred dimensions are given in standards together with specifications for minimum requirements of technical performance. When the experience gained in factory production of components increases, the technique will be applied to components of increasing size and complexity (e.g., wholly finished wall elements) and this will increase the need for dimensional coordination.

One system of dimensional coordination uses the international basic building module of 100mm. The reference system establishes a three-dimensional grid of basic modules, or very often multi-modules of 300mm, into which the components ft.

The modular grid does not give the size of the component but does allow space for it. In order for the component to fit correctly, it will always be slightly smaller than the space allowed for it. The system must allow for some inaccuracy in the manufacturing process and changes in size due to changing temperature and moisture conditions.

This is expressed as a tolerance in size. For example, a window which is allowed a basic size of 1200mm for its width is produced with a working size of 1190mm and a manufacturing tolerance of 5mm, which is expressed as 1190 + 5mm. The actual dimension of a window delivered to the site would be somewhere between 1185mm and 1195mm. The joint would be designed to take these deviations into account.

Modular-size concrete blocks are 290mm long and modular format bricks are 190 x 90 x 40 or 90mm actual size to allow for 10mm mortar joints and plaster. The actual size of openings will then be 1220mm. In this process the designer has a responsibility to specify tolerances that can be achieved with available craftsmen and factories. It will be easier to fit factory produced window and door casements, which are made to standard modular sizes, if these sizes are also used when bricks and blocks are manufactured locally. The common brick size of 215 x 102.5 x 65mm allows for laying four coarses to 300mm vertically and four brick lengths to 900mm horizontally, if 10mm joints are used.

Figure 6.1a Grid of 3M multi-modules between zones of 200mm alowed for load-bearing columns (A). Building components such as partition components (B), external- wall components (C) windows (D) and door sets (E) are manufactured in sizes. which are multiples of the 3M multi-module.

Figure 6.1 Dimensional coordination.

Building legislation

In urban areas, government authorities issue building regulations to provide for the safety, security and welfare of those who use the buildings and to make maximum use of the scarce resources available for building construction. Typically the building regulations

will cover such subjects as building materials, structural integrity, fire precautions, thermal and sound insulation, ventilation, window openings, stairways, drainage and sewage disposal. Building regulations may state minimum functional requirements, such as room height and space, for specific types of rooms. Additional legislation applicable to buildings may be found in the public health act and public road act. The building regulations and other legislation are statutory, i.e., they must be followed as far as they apply. The local authority will ensure that the legislation is complied with through its building-inspector, health inspector, etc. However, the authorities will sometimes, in addition to the regulations, issue guidelines for building. These are mere recommendations and the designer may diverge from them if there are good reasons.

Building regulations do not normally apply to farm buildings outside of urban areas, but there may be instances where other legislation is applicable, for example, where a farmer wants to connect to a main water supply or a main sewer or carry a drain under a public road. There fore it is wise to contact the local authorities about any new building proposal or major alteration to an existing building. If a local authority's approval is necessary, copies of drawings and specifications will have to be submitted for its advice and approval.

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Construction costing

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Throughout the building production process costs will have a major influence when choosing from alternative designs. An excessively high cost may even cause the whole project to be abandoned. In the initial stages, when rough sketches are evaluated, general guideline costs based on building area or volume may be sufficient. In the final design stage, when the farmer has to decide whether or not to proceed with construction, a more detailed cost estimate based on a simplified bill of quantities is usually prepared. A contractor will need the most accurate cost estimate based on a bill of quantities, since his quotation should be low enough to be competitive, but still give him a profit. On large projects, the bill of quantities is also used to determine interim payments for work that has been completed.

Quantity Surveying

The objective of quantity surveying is to provide an accurate bill of quantities, which is a list of the amounts of all materials and labour necessary to complete a construction

project. In the simplified version, supplied by the designer with the final design documents, the labour requirement is not detailed. Enough accuracy for the purpose of this bill will be obtained by including labour as a lump sum, number of hours or day's work or as a percentage cost of the building material cost. A bill of quantities for a standard drawing often excludes such operations as site clearance, excavation and fill, and external works, since such quantities may vary greatly from one site to another and therefore be difficult to assess accurately at the time the drawing is completed. Indeed, the bill for a standard drawing may be a mere list of materials, perhaps with a rough estimate of labour added.

To avoid mistakes or omission of any item, sophisticated methods have been developed for quantity surveying of large-scale projects. Farm buildings are normally smaller and far less complex and therefore a simplified procedure will be adequate. Many rules of thumb or conversions have been developed to take into account such factors as cutting waste, difference between nominal and actual size and breakage.

Taking-off

The objective of taking-off is to produce a detailed list of all materials and work. Assessment of the quantities is made from detailed drawings and specifications of the project and done, as far as possible, in the order that the construction of the building will proceed. First items are site clearing, excavation and foundation and final items are

finishes and external works. The dimensions of each item are obtained from the drawings and then the quantity is calculated in the units in which it is customarily sold or priced. For example, excavation or fill, concrete, mortar and water would be in cubic metres, aggregates in cubic metres or tonnes, cement and lime in number of bags and many things such as bricks and blocks, windows and doors, building boards and roofing sheets in number of units. Sawn timber is listed in the number of pieces of specific sizes or where that is not necessary, total linear or volume quantities. Round timber will be in number of units of specific cross section and length.

A particular item which occurs in several places in a building, can be noted each time it occurs or the number of units can be totaled at one place. One way of obtaining completeness is to tick off each item on the drawing as it is listed.

Assessment of Labour

Detailed labour requirements to complete the type of construction commonly used in farm buildings may be difficult to find in published sources. This is because the contractors, who have the best knowledge of such data, use them as a means to compete for tenders. Also, most construction companies involved in farm building are too small to employ a quantity surveyor, who could collect the data. Data published by Quantity Surveyors' or Building Contractors' Associations tend to emphasize urban types of construction.

The rough estimates of the labour requirement needed by the designer of farm structures must be obtained through experience and by analyzing a number of projects similar to the one at hand. Where the farmer and the farm labourers construct a building, it is to be expected that the labour requirement will be higher than when skilled construction workers are used. However, the farm labour is available without any extra cash payment and may have few alternative uses during the off season.

Bill of Quantities

The items for a bill of quantities are normally grouped together under headings for either the main operations (excavation, foundation, walling, flooring, roof structure, roofing, finishes, external works) or the trades involved (earth work, masonry, concrete work, carpentry and painting). Work normally carried out by sub-contractors (wiring, plumbing, installation of equipment and furnishing) is listed separately.

The total quantity of each material or volume is transferred from the taking-off sheets to the appropriate heading in the bill of quantities, and while doing so, a percentage allowance for waste and breakage, is normally added. The percentage added will depend on the type of material or volume, but is often taken to be 5 to 15%. To keep a record of the items, they should be ticked off on the takingoff sheets as they are transfered to the bill of quantities.

Labour may be listed under each operation or trade, but in the simplified bill, it is given as a lump sum at the end.

Figure 6.2 Main drawing for poultry house.

Example

Make a bill of quantities for the poultry house illustrated in Figure 6.2. Start with taking-off.

Footing and foundation for poles, **concrete 1 :3:6**	
Footing, end walls 2 x 5.4 x 0 4 x 0.2	0.93m
Footing, side walls 2 x 7.6 x 0.3 x 0 15	0.68m
Foundation for poles 4 x 0 3 x 0 3 x 0.6	0.22m
Waste and spill 10%	0.18m
	2.01 m

The amount of ingredients can be calculated using the figures in Table 3.14.

Floor	
Base layer of gravel 8.4 x 5 0 x 0.15	6.30m
Sand for blinding 8.4 x 5 0 x 0.02	0.84m
Concrete (5% waste) 8.4 x 5 0 x 0.08 x 1.05	3.53m

Bricks	
Area of sidewalls,	
(0.6 + 0.2) x (2.4 + 2.8 + 2.4) x 2	12.16m
minus door opening 0.6 x 1.00	0.6m
	11.56m
Number of standard bricks	
(0.215 + 0.010) x (0.065 + 0.010) = 0.017m/brick	
11.56 x 1/0.017 = 680 bricks	
Area of gable walls 0.40 x (2.0 + 0.4) x 4	3.84m
5.0 x (2.25 + 0.4) x 2	26.50m
5.0 x 0.5 x 1.35 x 2	6.70m

	37,04m
Number of standard bricks	
(0.1025 + 0.010) x (0.065 + 0.010) = 0.0084m/brick, 37 04 x 1/0.084 = 4410 bricks	
Number of bricks, 680 + 4410	5090
Waste and breakage 15%	765
Total number of bricks	5855
Mortar, compo mortar 1: 1:6	
Sidewalls 11.56m x 0.025	0.29m
Endwalls 37.04m x 0.051	1.89m
Waste and spill 15%	0.32m
2.50m	
Plaster, cement plaster 1:5	
Plaster thickness 10mm,	
(11.56 + 37 04) x 2 x 0.01	0.97m

Waste and spill 15%	0.15m 1.13m

The amount of cement and sand for the mortar and plaster can be calculated using the values in Table 3.17.

Wooden Posts	
Gumpoles 3.0m, diameter 100mm	4 pieces
Wood preservative	2 litre
Trusses	
Gumpoles 4.0m, diameter 100mm	4 pieces
Bolts 110mm long, diameter 8mm	10 pieces
Bolts 200mm long, diameter 8mm	2 pieces
Purlins	
Gumpoles 3.0m, diameter 50mm	18 pieces

Roofing

Corrugated steel sheets are laid in 2 rows on each side and the covering width is 533mm

per sheet. The length of the roof is 9m.

9000/533=16.9 i.e

17 sheets are required per row or a total of 68.

Roofing Nails

6 nails per m x 68m = 408. Since each kg of nails holds about 97, the requirement will be 4.5 kg.

Netting Wall	
Frame, timber 50 x 50mm, including 10% waste	51.8m
Chicken wire 1800mm wide	16.0m
Door	
Casement, timber 75 x 75mm, including 10% waste 5.5m	
timber 25 x 100mm,	2.0m
Door frame, timber 25 x 100mm,	7.7m

subtotal timber 25 x 100mm	9.7m
10% waste	1.0m
Total timber 25 x 100mm	10.7m
Nails	
Staples for fixing the chicken wire	1 kg
Wire nails 75mm	1 kg
Wire nails 100mm	1 kg
Whitewash	
White-wash is required for 97m	

When all requirements are calculated, the amounts are put in the bill of quantities that follows:

Costing

As mentioned in the introduction to this section there is a need to continuously assess the building costs for a proposed structure throughout the planning stages of the building production process. Three levels of accuracy can be distinguished: general guidance cost,

specific guidance cost and accurate costing.

In addition, costing is carried out during the construction to ascertain how the project is progressing from a financial point of view and to determine any interim payments to the contractor.

In the post-construction stage the actual cost of the project should be calculated so that a record can be developed which will enable future building work to be accurately costed. Unfortunately this is often neglected by designers and builders of farm structures.

General Guidance Cost

In this case, rough estimates, simply giving the scale of costs, are derived by experience and analysis of a number of other similar projects. For example, if the costs of a number of grain stores are assessed and in each case compared with the capacity of each store in tonnes, then a rough cost for grain stores can be estimated in terms of cost per tonne stored. Hence an estimate can be given for a proposed new grain store if the capacity is known. Similarly, a building for dairy animals can be estimated if an average cost per cow is known from a number of different units.

Further, for particular types of construction, it is possible to get average figures in terms of floor area. This type of estimate is based on a number of projects, some of which may

not be directly comparable.

Specific Guidance Costs

By comparing similar projects, it may be possible to get estimates which are reasonably accurate before the time is taken to design the building and work out the bill of quantities. In this case, the costs of other buildings should be assessed in three components:

Established costs, those costs that either have a fixed value or a uniform-unit value regardless of the size of the building. Examples are windows and doors.

Variable costs, those that vary with the size of the building. As the length of a building grows its total cost will grow, but at the same time the unit cost may decrease so that a building that is 50% longer may increase only 40% in cost.

Additional costs, such as fees for consultants, architects, lawyers and accountants. Interest, insurance, fitting costs and losses should also be included.

Therefore, if a number of similar buildings are analyzed, good estimates of each of these types of costs may be obtained and reliable specific guidance costs can be determined.

Table 6.2 Bill of Quantities for Poultry House (see figure 6.2)

Item	Description	Unit	Quant.	Rate	Total
1.	Foundation, 2.01m concrete, mix 1:3:6 (10% waste)				
	Cement	50 kg	9.0		
	River sand (0.88m)	ton	1.3		
	Crushed stone (1.8m)	ton	2.9		
2.	Floor, Gravel (6.3m)	ton	10.1		
	Sand (0.84m)	ton	1.2		
	3.53m Concrete, mix 1:3:6 (5% waste)				
	Cement	50 kg	14.0		
	River sand (1.6m)	ton	2.3		
	Crushed stone (3.2m)	ton	5.0		
3.	Bricks (215 x 102.5 x 65mm)	No	5910		

4.	Mortar, 2.5m. mix 1:1:6 (15% waste)				
	Cement	50 kg	13.0		
	Lime	kg	250.0		
	Building sand (2.8m)	ton	4.0		
5.	Plaster, 1.13m,mix 1:5(15%waste)				
	Cement	50 kg	7.0		
	Building sand (1.3m)	ton	1.8		
6.	Posts, Gumpoles (3.0m x ϕ 100mm)	No	4		
	Wood preservative	Litres	2.0		
7.	Roof Structure, gumpoles (4.0m x ϕ 100mm)	No	4		
	Gumpoles (3.0m x ϕ 50mm)	No	18		
	Bolts (110mm x ϕ 8mm)	No	10		
	Bolts (200mm x ϕ 8mm)	No	2		
8.	Roofing, Corrugated galvanized				

	iron sheets				
	(CS 8/76 x 2.0m, 0.018mm)	No	68		
	Roofing nails	kg	4.5		
9.	Netting wall				
	Sawn timber, grade 3, 50 x 50mm	rm	51.8		
	Chicken wire, width 1800,,	m	16.0		
10	Door, sawn timber grade 2,				
	75 x 75mm	rm	5.5		
	Sawn timber, grade 2,				
	25 ϕ 100mm	rm	10.7		
	Hinges	No.	2		
	Latch	No	I		
11.	Nails, staples	kg	1.0		
	wire nails 75mm	kg	1.0		
	wire nails 100mm	kg	1.0		
12.	Whitewash (97m)				

	Lime	kg	50.0		
	Salt	kg	10.0		
	Cement				
13.	Furnishings, feed troughs	No	4		
	drinkers	No	4		
TOTAl. MATERIAL COST					
14.	Transport cost for material				
15.	Earth works, excavation to level	m			
	remove top soil	m			
	excavation for foundation	m			
16.	Construction	man			
17.	External works	days			
1 8.	Contingencies				
19.	Supervision and contractors' overhead costs				
TOTAL COST					

Accurate Costing

This is done in conjunction with the bill of quantities. By use of the rate column in the final bill of quantities together with the cost rate for each item, the accurate total cost of a job can be derived. This requires each individual item of material, volume or labour to be costed.

However, many building contractors will, for convenience and to facilitate the calculation of a quotation, derive a cost per quantity of common types of construction. For example, a cost per square metre of concrete block wall will include the cost of the blocks, labour to mix mortar, cost of mortar materials and labour required to lay the blocks. It may even incorporate a factor taking into consideration the average requirement of window and door openings and scaffolding.

To be able to do costing with this degree of detail however, considerable information is needed which is gained from experience and data collected and analyzed over a number of building projects. The unit costs will have to be reviewed continuously or be corrected with an index for building costs.

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Economic feasibility

In addition to the actual cost of constructing a building, which must be considered in relation to the financial capacity of the farmer, the total annual cost of the building should be determined. When the annual cost is then compared to the expected increase in income or the saving in storage costs, it forms the basis for deciding whether or not the new building is a worthwhile investment, i.e., the economic feasibility of the building is determined.

To derive the true annual cost of a building, a number of factors must be considered. These include the estimated life of the building, annual repairs and maintenance, interest on the investment, insurance and in some countries real estate taxes. With the possible exception of repairs and maintenance, these are "fixed" costs that occur whether the building is used or not. Consequently it is important to carefully plan the use of the building as well as the construction. The building may be thought of as a production cost and the potential income from the enterprise housed in it must be great enough to justify the cost of building. It must be stressed, however, that there may well be other than economic reasons for constructing a building. For instance, a dwelling cannot be justified in terms of profitability, but the amenity and welfare considerations may outweigh other

factors.

Building Life (Depreciation Period)

Physical Life

All building components have a limited life. After a time materials will deteriorate to a point at which they can no longer fulfill their function. Repair, replacement and maintenance can extend the life, but eventually the overall deterioration becomes excessive.

The life span of a building is influenced by its design and construction. In general, more costly materials such as steel and concrete are likely to last longer than timber and other organic materials. The physical life for agricultural buildings may range from two to five years for the simplest structures and up to fifty years or more for the more substantial ones. An average figure may be between 10 and 20 years.

Economic Life

Although a building may last for many years, it may cease to be economically sound at an earlier time for any of several reasons. It may be that the design has become obsolete and not suitable for new mechanization or perhaps it is too small because the farm has

grown, or a new enterprise requiring a new layout or interior partitions and supports simply cannot be moved to accommodate the new requirements. General purpose buildings will therefore have a longer economic life than those built for a specific enterprise.

Write-off Life

It is impractical to expect any enterprise to pay the full cost of a new building in the first year after construction. Therefore the capital cost of the building is allocated or depreciated over several years. The number of years is determined by the write-off life, that is, the number of years over which it seems feasible to spread the original cost, but never fewer than the duration of a loan. The writeoff life must also be no longer than the estimated physical or economic life to avoid the position of having a useless building for which the original cost has not yet been fully paid.

Economic conditions change rapidly and the risk of a large investment is reduced considerably if the depreciation can be taken over a relatively short write-off period. Ten years is considered short, 1 5 to 20 years medium and 20 to 30 years a long period. This means that a building that is still physically sound and economically practical after the depreciation has been completed can be considered an economic bonus for the farm.

For cost estimating, depreciation is usually taken on a "straight-line" basis, that is, equal

annual amounts over the write-off life. The annual straight-line depreciation cost is the original cost of the building divided by the years of write-off life. There are a number of alternative methods for assessing depreciation, most of which result in greater costs in early years and decreasing costs over the life of the building.

Interest

The cost of the money used to construct a building must be considered whether the financing is by means of a loan or by cash on hand. If money is borrowed, the interest cost is obvious. However, if the farmer invests his own money, he is foregoing interest income from a bank or the possibility of other investments. Consequently, interest is still a real expense and should be included as an annual building cost. The interest rate used is either the rate actually being paid or the prevailing rate for mortgage loans in the area. The interest charge is assessed during the years of depreciation, and during that period the amount invested (principal) is gradually written off from the full cost at the start to zero at the close.

The annual interest charge is therefore usually based on the rate times the average investment (original cost divided by two or the original cost and half the rate). It should be pointed out that either a long term mortgage with equal monthly payments (interest plus principal) or compounded bank interest will result in a larger interest expense.

Repairs and Maintenance

All buildings will require some maintenance, but the cost will vary with the type of building, the climate and environment, the materials used in construction and the use of the building. Although the cost for repairs and maintenance will vary from one year to another and generally increase with the age of the building, it is common practice to assume a uniform annual allowance throughout the life of the building.

One to three percent of the initial construction cost has been typically allowed for repairs and maintenance. While this is true in a monetary economy, it may not apply in a subsistence economy.

Insurance and Taxes

If an owner carries insurance on his buildings to cover the risk of fire and other hazards, then the cost of that insurance is included as an obvious annual cost. On the other hand, if the farmer does not choose to carry insurance, he is in reality carrying the risk himself and he should still include an annual charge for insurance. Insurance will ordinarily range between i/2 to 1% of the original cost.

In countries where an annual real estate tax is assessed, the taxes must also be included as an annual building cost. Taxes will range from zero where there are none, up to 1 to

2% of the original cost of the building.

Annual Cost

The five principal components of the annual cost of a building have been discussed in some detail. A variety of situations produce a rather wide range in the annual cost figures. The greatest variation occurs in the write-off period. This is influenced by the life of a loan, the life of the building, and in some cases, simply the arbitrary decision of the farmer. In the following examples all of the low range values are combined as are all of the highrange values. It should be pointed out, however, that they may fall in any combination. A high depreciation cost and low maintenance or low interest are perfectly possible.

	Low	**Medium**	**High**
Depreciation	3.5(29 yr.)	6.25(16 yr.)	10 (10 yr.)
Interest*	3	5	7
Maintenance and			
repairs	1	2	3
Taxes	0	1	2

Insurance	0.5	0.75	1
Total Annual Cost as % of Original	8%	15%	23%

***Note: The interest rate is halved as interest is ordinarily based on the average value or one half of the original cost.**

Having determined a write-off life and the corresponding depreciation percent, as well as prevailing values for the other costs, the total percent is multiplied by the original cost of the building to obtain the annual cost. Next an estimate is made of the net income from the enterprise to be housed and the result compared with the annual building cost. The income should more than cover the building cost, thus allowing for a reasonable profit.

It should be noted that an existing building already has annual costs and that it is the increased cost of a replacement building which is compared with an increased income. If an entirely new building is planned to house a new enterprise, then it is the total annual building cost that is compared with the total net income from the enterprise.

Cash Flow and Repayments

The annual cost for a building as illustrated in the previous section includes the capital cost in the form of depreciation as well as the carrying cost or interest.

If the farmer is fortunate enough to be able to pay all or most of the original cost of the building, then a comparison of annual building costs with income indicates the length of the period over which the farmer can expect to recapture his investment. However, if the building project must be largely financed by a loan, then cash flow and ability to repay both capital and interest charges must be considered.

Any grantor of a loan will usually demand that repayments start immediately, but due to the problems commonly experienced by farmers in starting up production in a new building, the earnings at this stage may be smaller than expected. In the case of animal housing, the capital needed for the purchase of animals, feed and equipment is often larger than anticipated. The result may be insufficient cash during the first few years after the building has been constructed. Even if a careful analysis has shown the enterprise to be profitable, that is, has shown the expected average annual cost to be lower than the expected average income, the combined interest and principal payments on a long-term loan are likely to be greater than the estimated average annual amounts for the costs.

It is important, therefore, to not only determine whether the cost of a new building can be justified, but whether the necessary cash flow can be generated to cover both interest and capital repayments. While this is more of a business management problem than a farm structures problem, it is no less important to the farmer contemplating a new building.

Organization for small building constructions

In the case of farm structures, the future proprietor - the farmer - is normally much more directly involved in any repair or construction process than would be the case with a building in an urban area. Although the farmer may appoint an advisor to help him with planning and design, employ a contractor or local craftsmen and take out a loan to finance the construction, his and his family's participation at all stages will normally be of great importance and serve to lower the amount of cash necessary for the project.

Depending upon the amount of self-involvement by the farmer, his family and any farm labour, and the way the construction is administered, four forms of organization can be distinguished: personal management, divided contract, general contract and turn-key contract.

Organization Forms

Personal management is a very common form of organization for repair work and construction of small- to mediumsize farm buildings. The work is carried out by the employer (the farmer and his family) with the assistance of farm labourers and temporarily employed craftsmen. The employer may simply administer the work or he may also participate in the construction work himself.

Figure 6.3 Personal management.

A divided contract implies that the employer engages different contractors for the construction work and for installation and fitting work. This form of organization differs from personal management mainly in that the building construction work is carried out on a contract. Self involvement by the farmer can be arranged either by excluding some operations from the contract, such as earth work and external work, or by giving the farmer some form of "employee" status with the contractor. The latter is more easily arranged when current-account payment is used for the contract (see Section Forms of Payment). Building materials may be purchased by either the employer or the contractor. The contractor for the building construction work may be appointed to function as a coordinator for the various contracts.

Figure 6.4 Divided contract.

A general contract implies that the employer engages one contractor to carry out all of the building construction operations. The contractor may in turn engage subcontractors to carry out work, such as fittings and installations, which his firm lacks the skill or capacity to undertake. This form is uncommon for farm building construction, except for the largest projects.

A turn-key contract differs from the general contract in that the planning and design of

the building is also included in the building contract. This form is very uncommon for farm building construction, except perhaps for completely prefabricated buildings in which the manufacturer serves as the contractor for erection.

Figure 6.5 General contract.

Figure 6.6 Turn-key contract.

Forms of Payment

The contract or agreement between an employer and a contractor may state that the payment for the contracted work shall be made either at a fixed price, with or without installments forwork completed, or on a cost-plus basis to a ceiling figure, or with a running account for cost of materials purchased plus an agreement on labour costs.

A fixed price is common for general and turn-key contracts and often practiced with divided contracts. The advantage of a fixed price to the employer is that he will know at an early stage what the construction is going to cost. However, the contractor will require comprehensive documentation in the form of drawings and specifications to be able to give a quotation for a fixed-price contract.

incomplete documentation will cause problems and frequent negotiations to decide on

details and variations usually involving additional expenditure. Therefore the running account is frequently practiced where the documentation is insufficient or where it is difficult to make a satisfactory description of the work beforehand, as in the case of repair and maintenance work. If the running account is given a ceiling, the employer will be guaranteed a maximum cost and will benefit, compared to a fixed price contract, should the work be less costly than the maximum expected.

Tendering

The objective of tendering is to obtain proposals for construction work from different contractors and quotations for building materials from different suppliers. Their competition to present the most favorable offer should result in a less expensive building for the farmer.

The Tender Procedure

When the farmer has decided to proceed with the proposed structure, he and his advisors will prepare the tender documents, which usually consist of a letter of instructions, the necessary drawings and specifications and perhaps a bill of quantities, and send them to various contractors and suppliers.

A contractor, or his estimator, will cost all building materials, volumes and labour and after adding an allowance for supervision, overhead, insurance, contingencies and profit, prepare a tender which is sent to the prospective employer in a sealed envelope. During the preparation of the tender the contractor will visit the proposed building site to consider possible difficulties, in particular: access to the site and the necessity for temporary roads; storage of materials; type of ground; arrangements for siting any temporary office or welfare buildings; availability of labour in the area; arrangements for security of the work from theft and vandalism. He may also request funkier written documentation from the employer and, where subcontractors are to be employed, obtain tenders for their work.

A supplier of building materials or equipment will require less documentation and usually will not have to visit the site in order to prepare a quotation. His offer may or may not include transport to the site.

When the period to reply as stated in the tender instruction has expired, all the sealed envelopes containing the offers from the contractors and suppliers are opened. The contractors/ suppliers may be invited to attend the opening and be given names, prices and other relevant information contained in the offers. After careful evaluation of the offers the most favourable, which may not necessarily be the cheapest, is accepted and a contract is written.

Methods of Tendering

Open tendering. The prospective employer advertises in the press, giving brief details of the work, and issues an open invitation to contractors to apply for the necessary documents. The advertisement should state that the employer is free to select any or no bid that may be tendered. Tenderers are normally required to submit references and to pay a deposit for the documents which is returned on receipt of a serious tender. Open tendering is uncommon for farm construction work.

Selective tendering. Competitive tenders are obtained by drawing up a list of 3 to 5 serious contractors or suppliers in the area and inviting them to submit quotations. Normally the farmer and his advisor will know of a sufficient number of contractors who have the skill and experience to construct farm buildings and are also known to have integrity. Hence the lowest tender can usually be accepted.

Negotiated contracts are obtained by contacting one or two contractors or suppliers, who have been found satisfactory in the past. The price to carry out the work or deliver the material is negotiated until an agreement is reached. Negotiated contracts are also commonly used where the magnitude of the contract may be unknown at first, such as repair work, excavation in unknown ground or where the tender documents are insufficient. In these cases, the negotiation will normally aim at establishing reasonable task rates for a contract with a running account. With a fixed contract, a contractor would

have to safeguard himself against the unexpected and his large allowance for unforeseen expenditures would lead to a high contract price.

Evaluation of Tenders

Quotations submitted to the prospective employer are likely to contain reservations, exceptions, additions and other conditions for the work or delivery of materials. A contractor may also suggest an alternative design or building method. If the letter of instructions for tender has stated that all such divergencies from the tender documents should be priced separately, it will be quite simple to recalculate the tenders so that they are comparable. In other cases they will have to be costed by the employer.

The letter of instruction will normally request the contractor to submit references from similar projects he has constructed in the past. For large projects, a bank reference and a performance bond are advisable. These should be examined to establish the contractor's practical and financial ability to undertake the proposed work.

Contracts

A contract is a legal document signed by both parties before witnesses. The essence of a contract for construction work is the promise of a contractor to erect the building as

shown on the drawings and in accordance with the detailed specifications in return for a specified amount of money known as the contract sum. A variety of standard forms for building construction contracts are available, but it would be desirable to develop a standard contract form specifically applicable to farm-building construction.

If a bill of quantities is included in the documents attached to the contract, the employer will be responsible for any errors of measurement or shortcomings that occur in the bill. However, the selected contractor can be asked to control the bill and accept responsibility for it as being final. In the case of contracts without a bill of quantities, the bill is prepared by the contractor and any errors are then his responsibility.

A standard contract form may include the following information, but each clause in it should be studied prior to signing and any clause that fails to meet the specific requirements of the project should be modified or deleted:

- **1 Names and addresses of employer and contractor.**
- **2 List of all attached documents, i.e., drawings, specifications, and bill of quantities.**
- **3 Amount of the contract sum.**
- **4 Starting date and completion date.**
- **5 Weekly penalty to be paid should the contractor fail to complete the work in time. (Not always included).**
- **6 Directions for the employer to make a fair and reasonable extension of time for**

completion should the work be delayed through any cause beyond the control of the contractor.

- **7 Directions for the contractor to comply with all applicable rules and regulations issued by local authorities.**
- **8 Directions for the contractor to arrange recurrent site meetings between the contractor and the employer and to keep a diary detailing progress of the work. (Not always applicable).**
- **9 Directions for the contractor to obtain the employer's approval before any work is executed involving variations from the drawings or specifications, in particular where the variations involve additional expenditure.**
- **10 Reference to a list of any building materials and equipment that will be supplied by the employer.**
- **11 The extent of the contractor's responsibility for any liability, loss or claim arising in the course of or execution of the contract work, whether for personal injury or loss or damage to property.**
- **12 Insurance requirements for the contractor.**
- **13 Statement requiring the contractor to pay, at his own expense, for any defects or faults arising from materials or workmanship which are not in accordance with the drawings and specifications.**
- **14 Statement requiring contractor to pay at his own expense for any hidden defects or faults which may appear during a specified guarantee period, usually 3 to 12**

months, after the contract work has been completed.

- **15 Payment schedule, describing the percent of contract price to be paid at the completion of each step.**
- **16 Guarantee amount. Normally about 10% of the contract sum is withheld until the guarantee period has expired or all defects are corrected, whichever occurs last.**
- **17 Procedure for resolving disputes between the contractor and employer, e.g., that it shall be referred to an arbitrator for a binding decision.**
- **18 The signatures of the contractor, the employer and witnesses.**

Specifications

The specifications document supplements the drawings. The drawings should describe the geometry, location and relationships of the building elements to each other. The specifications set out quality standards for materials, components and workmanship that cannot be written on the drawings. For example, if the drawing states that concrete Type 1 should be used for a floor, the specifications may set out a mixing ratio, quality standards for aggregate and water, compaction and curing practices and quality standards for joints and finish. Minimum requirements for capacity and reliability of equipment as well as calculations relating to design, insulation, ventilation, etc. may be included as appendices.

In small projects, typical of many farm structures, many of the specifications may be included on the drawings, but in large scale projects the specifications may run to many pages.

General Specification

Since much of the information in the specifications will be similar from one project to another, it can be generalized to apply to most buildings. The building industry or government agencies in many countries have therefore developed a "General Specification for Building Works". This normally covers the majority of materials, types of construction, fittings, furnishings, etc. for the types of buildings and other structures built in urban areas. While some of the information included may also be applicable to farm structures, in general, a list of specifications will need to be developed for the particular structure.

The advantage in the use of a general specification is that all parties are expected to have access to a copy and that they are familiar with the quality standards required in the various sections. Any planner/designer writing specifications for a building may refer to the section numbers in the General Specification without repeating the text of those sections. In addition, particular specifications which supplement, amplify or amend the provisions of the General Specification will be required for each specific project.

To avoid confusion arising from discrepancies between the various building documents, the drawings will normally prevail over the General Specification, particular specifications override both drawings and the General Specification and building code regulations will override all other documentation.

Occasionally when the government is the employer or when buildings are financed with government loans or subsidies, the General Specification is considered statutory, but in all other cases its provisions can be used and amended as and when required.

Progress chart

A progress chart is a schedule, used to coordinate the sequence and timing of the operations in a building production process. It helps to ensure a timely supply of manpower, materials, equipment, machinery and subcontracted services by providing information on what dates and in what quantities they will be required so that they can be ordered in good time. Furthermore it can be used to monitor the progress of the work and ensure that the schedule is being adhered to.

The chart is often divided into three parts:

The first part is produced by the farmer or his advisor and covers all work up to the time

site operations start. It will include the sketching, any applications to authorities, final working drawings, tendering and ordering.

The second part is normally produced by the contractor and includes all site improvements and construction operations. Figure 6.3.

The third part covers the starting up of production in the building and would be developed by the farmer and his advisors.

The preparation of a progress chart starts with listing all operations and their expected duration. and identifying operations which must follow each other in sequence.

In the second step a chart is developed showing the input of labour, machinery and equipment for various operations until the completion date is met. While doing this it will be noticed that there is a sequence of operations called critical operations which must follow each other in a specific order and which together determine the total time required to carry out the work.

In the third step, the requirements of resources, in particular that of labour but also machinery, are adjusted so that a fairly uniform work force can be maintained. This is done by amending the timing and sequence of operations that can take place partly or wholly at the same time as the critical operations.

The fourth step consists of following the work, in particular the critical operations, and revising the progress chart as problems or delays arise, e.g., delayed replies from authorities, contractors or suppliers, delayed delivery of materials and sub-contracted services, delay of the site operations due to prolonged bad weather.

Inspection and control

Whenever a building is constructed, it is likely that faults and defects will occur due to such things as deficiencies in the building materials, negligence by workmen and mistakes in the drawings and specifications. Occasionally a contractor may be tempted to increase his profit by knowingly producing inferior work. To avoid this as far as possible, the employer or a person experienced in building construction appointed by him, will function as an inspector during the site operations.

Control is normally carried out continuously as the construction work proceeds. In addition more formal inspections are required at the completion of a contract and at the end of any guarantee period to determine whether the contracted payment should be paid.

The duties of the inspector include the following:

- **1 To ensure compliance by the contractor with the drawings, specifications and contractual provisions for the project.**
- **2 To ensure that the project progresses according to schedule.**
- **3 To inspect and control all materials delivered to the site and to reject that which fails to meet the contractual quality.**
- **4 To reject work which is not within contractual quality and to stop work when continuation would result in the inclusion of sub-standard work.**
- **5 On behalf of the employer, to interpret drawings? specifications and contractual provisions, and to act on his behalf concerning variations.**

Table 6.3 Progress Chart

Safety at building sites

Accidents may be caused by falling objects, falls resulting from unstable scaffolding or ladders or inadequate guard rails. Unguarded machinery, hazardous materials, carelessly maintained electrical wiring and equipment can also result in injury. Excessive haste may contribute both to accidents and wasteful, poor quality work.

Most accidents can be avoided and safety standards improved considerably with little or no expense if the following basic safety precautions at the building site are observed:

- **1 Well-organised storage of materials and tools with none left scattered around the building site.**
- **2 Well-maintained tools, machinery and equipment, with all guards covering moving parts in place.**
- **3 Maintaining a clean and tidy building site with the removal of all waste, particularly scrap timber with protruding nails.**
- **4 Making sure that all operators have been carefully instructed in the use of machinery and the handling of hazardous materials.**
- **5 Insisting that all workers wear suitable clothing and protective gear, such as hard hats, hard-toe shoes and safety glasses.**
- **6 Using properly designed, supported and braced scaffolds, ladders and platforms.**
- **7 Establishing and enforcing rules as to where people can work while elevated members are being installed.**
- **8 Making sure that all temporary wiring and electrical equipment is kept well maintained and grounded and is properly used.**
- **9 Having a good safety programme. Making workers aware of hazards and how to avoid accidents.**
- **10 Maintaining suitable first aid equipment and supplies and making sure workers know how to use them can minimize the effects of any accidents that do happen.**

Building maintenance

Buildings deteriorate due to age, weathering and use. This necessitates maintenance and repair to allow the building to retain its appearance and serviceable condition.

Cleaning, repainting, reroofing and replacing or repairing broken parts such as window panes, roof tiles, etc. help to maintain the original value of the building.

Maintenance costs can be kept down by using materials suitable for the climatic conditions and with which local builders are accustomed to working. Furthermore, the building should be simple in detail, have easily replaceable parts and be free of unnecessarily complex or sensitive technical installations.

The fabric of a building should be thoroughly inspected once or twice a year to assess the performance of different elements of the building. The inspection will result in a list of repair and maintenance jobs which should be carried out promptly, since insufficient or delayed measures will result in accelerated deterioration. The maintenance work is usually carried out by the farmer himself, but in the case of large repairs it may be done by hired building workers or a contractor. When a contractor is engaged, payment is often made on the basis of time and materials used according to an agreed schedule of prices.

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