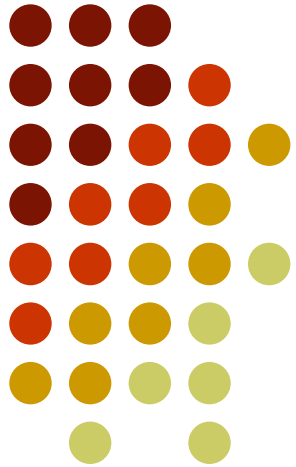
Plain & Reinforced Concrete-1

CE-314

DESIGN OF FORMWORK



INTRODUCTION

- Fresh or green concrete is in the form of a fluid and can be molded into any desired shape.
- Concrete has to be kept within an enclosure till it gains strength.
- The mold used to give concrete a particular shape is called ***form***.
- The load of the fresh concrete is to be safely supported and transferred to the soil underneath.
- This requires the need for a temporary supporting structure called ***falsework*** consisting of shuttering, scaffolding and shoring of forms.
- The form combined with the supporting system for the resulting loads is called ***formwork*** that retains and supports concrete until it has gained strength.
- Forms are also used to produce the desired shapes and desired surface finishes.

- A horizontal platform made of wooden planks, plywood or steel panels to act as formwork for the roof slabs and to provide support to labor, materials and equipment during the construction is called ***shuttering***.
- Most commonly it is resting on the scaffolding.
- ***Scaffolding*** is a temporary structure made up of a skeleton of horizontal and vertical members of wooden rectangular or steel pipe sections.
- It is constructed to support a safe elevated working platform for the formwork, shuttering, workmen and materials during construction.

Following points explain the importance of proper design and construction of formwork:

1. The total cost of the formwork may be up to one-third or even more of the total cost of the reinforced concrete structure.

   Hence, an economical design and efficient construction of formwork is of great importance.

   Proper selection of material for the formwork, reuse of the formwork and proper design of the formwork may significantly reduce the total cost of the project.

2. Sometimes, failures of the structures occur at the time of pouring of concrete or during curing of the concrete.

   The formwork must be designed as a complete but temporary structure using the methods of analysis, knowledge of the strength of materials and precise estimation of the expected loads.

3. The appearance of the finished concrete surface should be decided from an aesthetic point of view and the formwork must accordingly be prepared.

4. The speed with which the formwork may be assembled and striking may be carried out after hardening of the concrete influences the overall economy of the project and total construction time.
5. People having knowledge of the basic principles must design the formwork. Haphazard construction of forms by labor and carpenters using timber of inferior quality is to be avoided.

REQUIREMENTS FOR FORMWORK AND SHUTTERING

1. Forms must be supported on falsework of adequate strength and sufficient rigidity to keep deflections and settlements of the formwork within acceptable limits.

- The maximum deflection of any part of the formwork is usually limited to its span divided by 270.
- Allowance may be made during construction of the formwork by providing upward camber for these deflections so that the resulting hardened concrete surface remains straight and in line.

- The concrete weight until it becomes hardened and sufficiently strong has to be taken by the scaffolding or false structure.
- The lateral pressure is also exerted on sidewalls of the form due to fresh concrete.
- The load may also include weight of men, equipment and materials used in the construction.

- The deflection of newly constructed reinforced concrete members include deflection and settlement of formwork during pouring of concrete and the deflections caused by the dead load just after the removal of supports.
- The engineer may also require an upward camber of the formwork to allow for the elastic deflection of structural member, and that due to creep of the concrete.

- A thumb rule is that the soffit of all beams more than 4.75 m in span shall be laid to a camber (Δ) the amount of which is estimated as follows:

  $\Delta = 139\, L^2/d$ where L is the span of the beam in m and d is the depth of the beam in mm.

- According to another thumb rule, the camber for slabs and beams may be adopted as 1:250 (4mm in a meter length).
- In case of cantilevers, the upward camber must be 1:50 (20 mm in a meter length).

2. The lining of the forms must be strong, rigid and durable to meet dimensional tolerances.

   There should be no bulges, twists, warping, formation of untrue edges and sagging within the sheeting of the forms.

   These requirements may be met by using form lining made up of good quality timber, plywood or steel sheets fixed on wooden or angle iron frames.

   Steel sheets are preferable which also becomes economical if number of uses is greater.

- The sheeting should be thick enough to withstand the pressures of wet concrete.
- Warping can be avoided by using seasoned timber and careful storage when not in use.
- In case of vertical sheeting, resistance to outward push is provided by using adequate bracings and wires which get embedded in the concrete and fastened to the outer side of the formwork to prevent its bulging out.

3. Formwork must be smooth.

   All the impressions that are visible on the formwork will get imprinted on to the concrete.

   If a smooth surface is required for concrete, formwork should be perfectly smooth.

   If a particular texture is required, the formwork surface is accordingly treated.

   For example, sometimes, burnt wood lining is used to get a rough texture of concrete surface.

4. Formwork must not be such that it sticks to or develops bond with the concrete.

   Inner lining of formwork must be greased or oiled before pouring concrete especially in case of steel formwork.

   This makes striking of forms easier and prevents damage to concrete and formwork surfaces.

   These coatings protect the forms from deterioration, weather and shrinkage before concreting.

Form surfaces should be clean.

The oil or coating should be brushed or sprayed evenly over the forms.

The oil or grease must not be permitted to get on construction joint surfaces or reinforcing bars because it will interfere with the required bond between steel reinforcement and concrete.

5. Formwork should strictly be according to the required shape with no change expected by the loading.

   To avoid buckling, the sections of struts, posts, ledgers and shores should be circular or as nearly square as possible.

   Further, the sizes should be designed to carry all the necessary loads with a reasonable margin of safety.

   The sizes of shores may be reduced by bracing them at intervals along their length by horizontal or diagonal bracings.

The side formwork of footing, walls and columns must be perfectly vertical.

For high-rise and important structures, surveying instruments must be used to get verticality and true dimensions.

6. Formwork should be easily and speedily erected and should be designed so that striking can be carried out easily and in the required sequence.

   The formwork elements must be of reasonable size and weight for easy handling.

Bolts and clamps are to be preferred to open parts compared with nails.

No part of formwork should stuck-up in the finished concrete.

Further, removal of all components should not take place simultaneously.

For example, in case of slab formwork, after removing few wedges and cleats, first the lining or sheeting should be removed followed by supporting elements.

7. The design of structure should preferably be carried out using standard sizes of structural components or at least frequent changes in sizes should be avoided.

   This eliminates the need for continued remaking and changing of the forms and prevents the waste of timber.

8. The joints between the various members of the formwork must be tight otherwise the mortar will leak out during vibration and will cause unsightly sand streaks and rock pockets.

   The strength of concrete may also be adversely affected. Joints between elements of the formwork should also be simple.

   Unsightly bulges and offsets at the horizontal construction joints should be avoided by provision of some overlap of the forms with the existing concrete below and by tying and bolting close to the joint to keep the form lining in close contact with the existing surface.

9. Proper arrangement to keep the steel reinforcement at a fixed distance from the face of formwork must be made.

   Spacer pieces, spacer bars, steel chairs and steel ties are used for this purpose.

10. Folding wedges must be used under props or posts to tighten the formwork.

    These are also helpful in removal of formwork. Preferably wedges should be provided at the lowermost end of any strut.

11. The props should be straight, oriented vertically and braced at correct heights.

    These must rest on firm base.

    The complete formwork should be properly braced to prevent vertical displacements and lateral movements.

12. The formwork must be properly designed for important structures.

    This should cover all the details from the forms to the battens, joists, girts, studs, shores, yokes, walings and props, etc.

13. The formwork must be low-cost/economical.

    The material of the formwork should be cheap, easily available and should be suitable for several times re-use.

    In designing formwork, possible number of reuses must always be determined to estimate the true cost per one use.

14. The scheme of the formwork, like spacing of joists, posts, ledgers and yokes, should be efficiently planned and suitably designed to determine the most economical but safe sizes of different components.

    The components should be easily demountable to permit easy reuse.

15. In case higher floor formwork is to be supported on the lower floor already constructed, great care should be exercised in estimating the resulting loads on the constructed floor.

    The concrete age and the gained strength should be carefully estimated. Usually construction loads are greater than the normal live load considered for design of floors.

    Hence, the constructed floor must also be temporarily shored.

16. The form ties that have to pass through the concrete should be small in cross-section as far as possible.

    Further, the holes formed by these ties are to be plugged to stop leaks.

17. Forms should provide ready access for placement, vibration of concrete and inspection.

18. Early removal of forms is generally desirable to permit quick reuse, start curing as soon as possible and allow repairs and surface treatment while the concrete is still green.

    Conditions are favorable at an early age of concrete for bond with the surface treatments like ceramic tiles, etc.

19. Formwork must preserve the water in concrete until external curing may be started. Further, partial release of the formwork should be such that curing may be carried out easily and effectively.
20. Formwork must be capable of release of hydration energy to the atmosphere. Steel forms are much better in this respect.

MINIMUM TIME FOR REMOVAL OF FORMWORK

In moderate conditions of temperature, the formwork should be removed after the following minimum time:

i) For Structures Not Subjected To Superimposed Loads

Sides of beam, walls and columns	2 to 6 days
Bottom sheathings of beams and slabs	7 to 14 days
Props and shores to bottoms of slabs and beams	14 to 28 days

Using rapid hardening cement, the above time may be reduced to 45% of the value with a minimum of 24 hours.

ii) For Structures Subjected To Superimposed Loads

Side forms	7 days
Bottom sheathings and props	28 days

No live load should be allowed on the completed works before 28 days.

USUAL SIZES OF TIMBER FOR FORMWORK

Members	Size (mm)
Sheathings for slab bottoms, column forms and beam sides	25 to 50 thick
Beam bottoms	50 thick
Vertical posts	75×100 to 150×150 or 75 to 150 mm dia.
Joists and ledgers supporting sheathings of slabs	50×100 to 75×200
Studs and walings supporting vertical wall sheeting	50×100 to 150×150
Column yokes	50×100 to 100×100

SHORING

- The temporary support provided to unsafe structure or to a structure undergoing alterations is called a shore.
- The structure may be unsafe due to differential settlement of its foundations, dismantling of the neighboring building or during demolition of part of the building for alterations.
- Shores may consist of rectangular or circular timber or steel jacks.
- The types are given in book but are not discussed here.

SCAFFOLDING

- A temporary structure made up of a skeleton of horizontal and vertical members of wooden rectangular or steel pipe sections.
- It is constructed to support a safe elevated working platform for formwork, shuttering, workmen and material required during the construction.
- Some major types of scaffolding are discussed in the book but will not be repeated here.

PRESSURE OF WET CONCRETE

- The hydrostatic pressure of wet concrete, which causes most of the bulges and collapses of formwork, depends mainly on the rate of filling, the rate of setting and hardening of the cement, temperature, additives and admixtures used, plasticizers, accelerators and retarders and the water/cement ratio.
- In other words, the pressure is dependent on the comparative rates of filling and initial stiffening and setting of the concrete.
- The rate of pouring is therefore important, especially in walls and columns, since the faster the forms are filled, the higher the hydrostatic pressure becomes at the bottom.

- Other factors, including the method of compaction, the size and shape of the formwork, also influence the pressures.
- Closely spaced reinforcement may be expected to have a similar effect.
- Freshly poured concrete exerts pressure in all directions just like a fluid, which is directly proportional to the height of pour (h).
- The pressure is γh; where γ is the unit weight of fresh concrete.
- However, with time, the lateral pressure quickly reduces due to setting of concrete and some restraining effect of reinforcement, etc.
- The forms and false-work should have sufficient strength to support the loads that they are called upon to carry, without undue deflection.

TIMBER FORMWORK

The timber used for formwork should satisfy the following requirements:

- It should be well seasoned.
- It should be light in weight.
- It should be easily workable with nails without splitting.
- It should be free from loose knots.
- It should be cheaper.
- The timber planks for the slab and beam bottoms should be joined by adequate tongue-and-groove joints, as shown in Fig. 15.7, so as to ensure adequate tightness against leaking of cement gout.

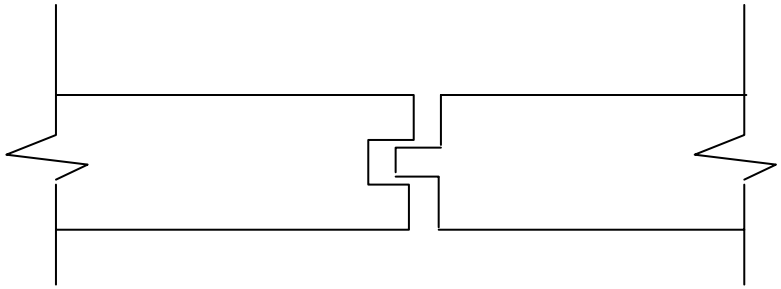


Fig. 15.7. Tongue and Groove Joint of Wooden Planks.

- Timber boards may be used 10 to 12 times.
- The timber surface should be rough or smooth depending upon the concrete surface finish requirements.

PLYWOOD FORMWORK

- The plywood thickness should not be less than 5 mm for light use and smaller number of re-uses but preferably should not be lesser than 15 mm.
- Resin bonded plywood sheets are attached to timber frames to make up panels of required sizes. The panels thus formed can be easily assembled by bolting in the form of shuttering.
- This type of shuttering ensures quality surface finish and is specially recommended for works where large exposed areas of concrete are to be constructed such as floor slabs, faces of retaining walls, etc. Thus due to perfectly smooth surfaces without the joint marks the cost on surface finishing like plastering may be saved.

- Plywood sheets should have a small gap between them to allow for swelling and should be painted before use.
- Number of re-uses of plywood panels is more compared with timber shuttering. The number of re-uses is approximately 20 to 25.
- Larger size panels compared with timber shuttering may be used. This reduces the labor cost of fixing and dismantling of the formwork.
- The initial cost of the plywood panels is higher than timber boards. However, due to greater number of re-uses and good surface finish, it may prove to be economical.

STEEL FORMWORK

- This consists of panels fabricated out of thin steel plates stiffened along the edges by small steel angles.
- The panel units may be held together by two or more clamps or bolts provided along each edge.
- The shuttering can be assembled and kept in alignment by use of horizontal or vertical centering of timber or steel.
- The usual wall or slab panels vary from 600 $\times$ 600 mm to 600 $\times$ 1200 mm.

- This type of shuttering is considered most suitable for circular or curved shaped structures such as tanks, columns, chimneys, etc., and for structures like large bridge decks, tunnels and retaining walls.
- Although steel shuttering has more initial cost but, in view of its various advantages, it may work out to be economical for a medium or large sized work in the long run.

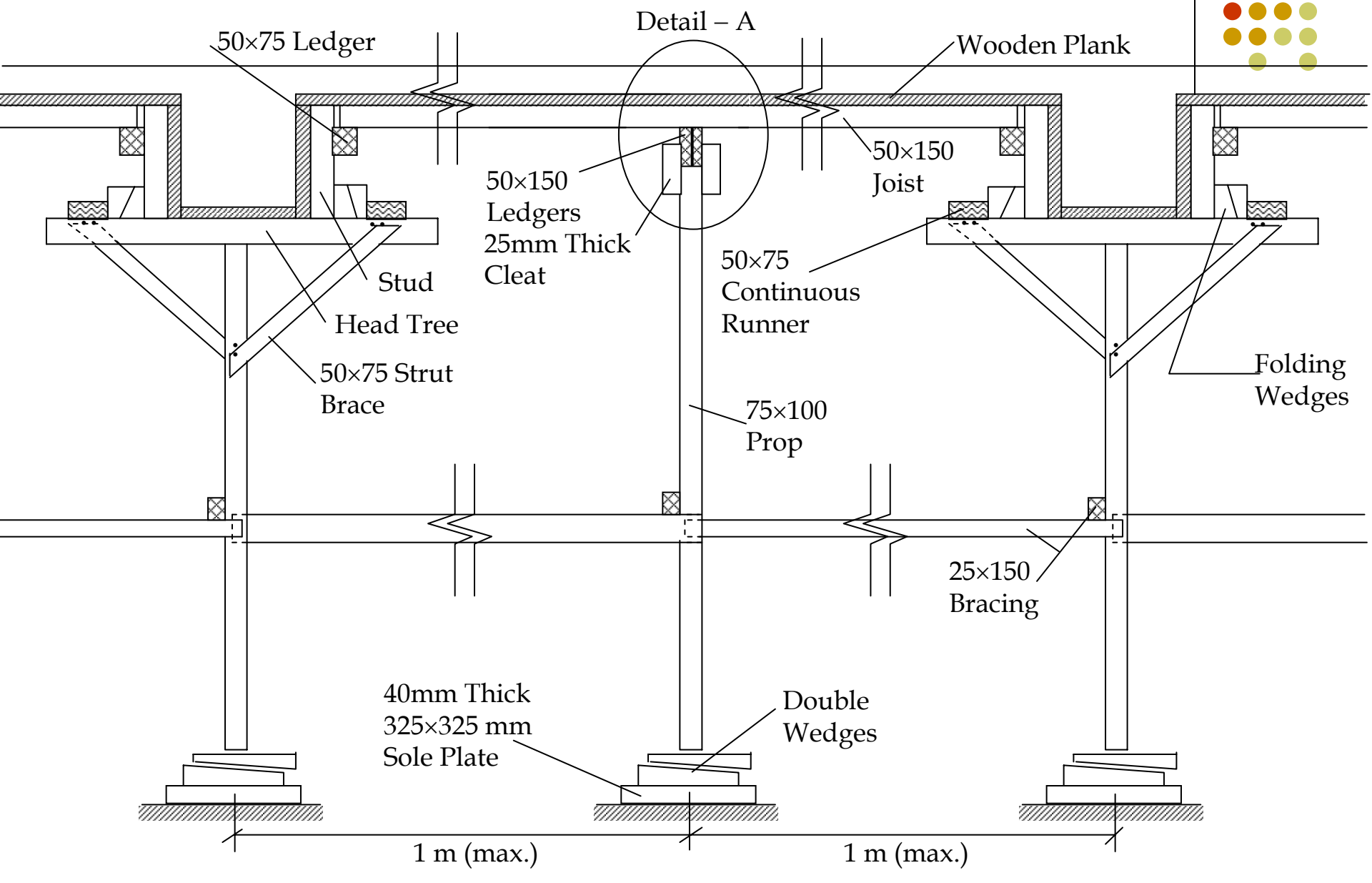
ADVANTAGES OF STEEL FORMWORK OVER TIMBER FORMWORK

- Steel forms are stronger, more durable and have longer life as compared with timber forms.
- They can be used for a sufficiently larger number of re-uses, which may vary between 100 to 120 (ten times that of timber shuttering).
- Steel forms may be assembled and dismantled with greater ease and speed that result in saving in labor cost.

- The quality of exposed concrete surface obtained by use of steel forms is excellent and it needs no further treatment.
- There is no danger of the formwork absorbing water from the concrete. Hence lower water cement ratios and higher concrete workability may be maintained. Chances of honeycombing are also minimized.
- They are not liable to shrink or distort and hence it is possible to achieve better workmanship and higher degree of accuracy by use of steel forms.

Prof. Dr. Zahid Ahmad Siddiqi

BEAM-AND-SLAB WOODEN FORMWORK

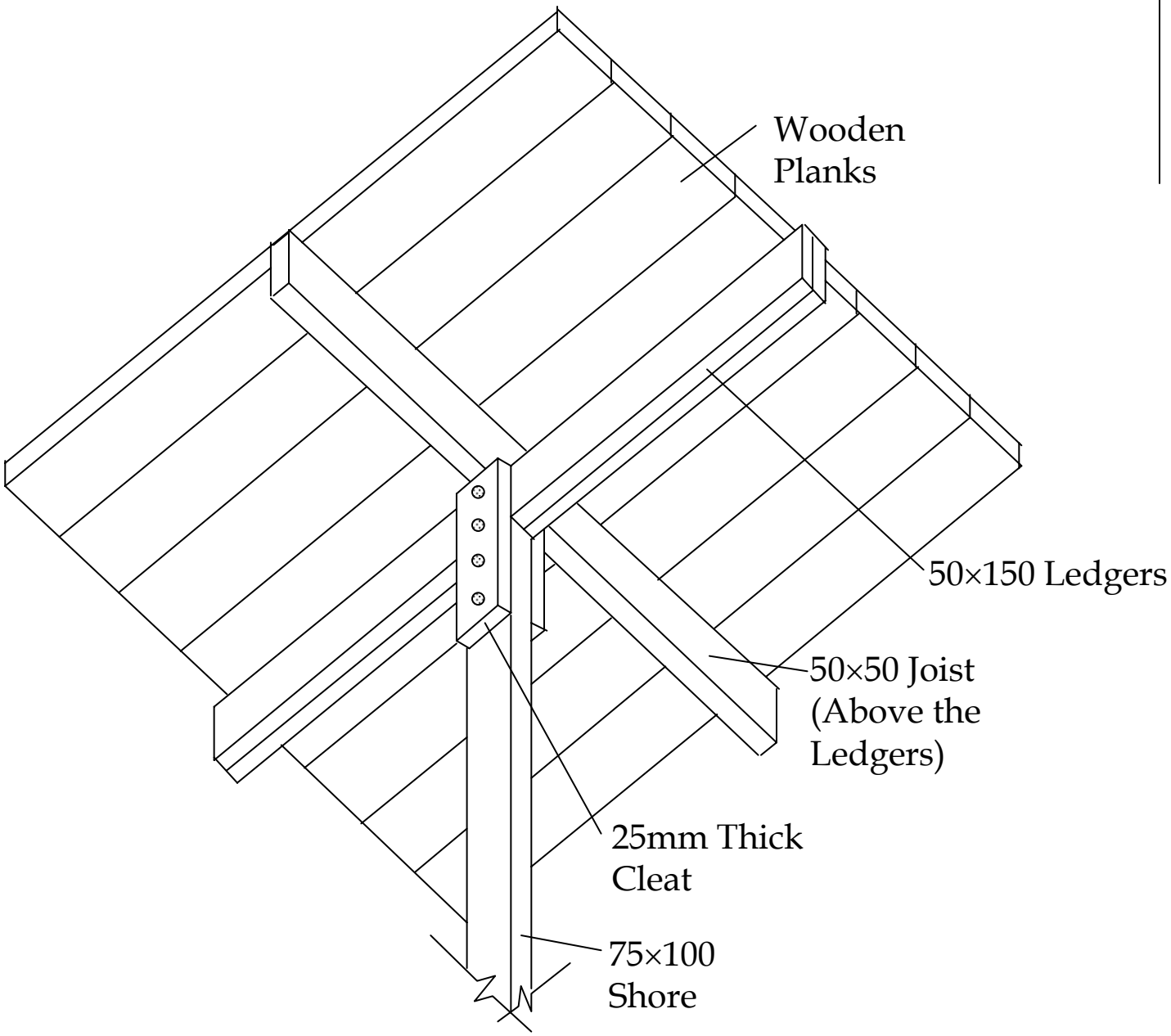


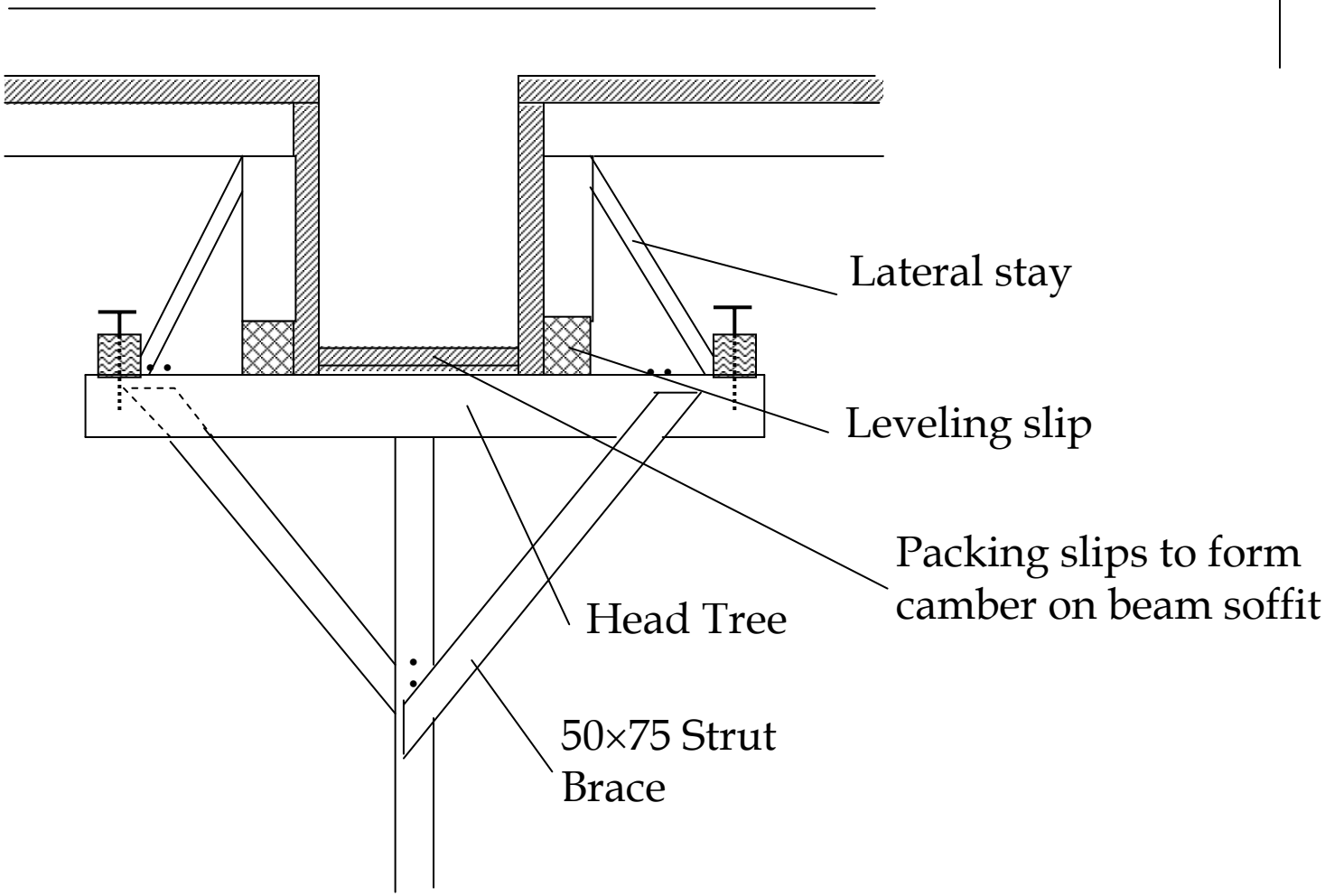
- **Batten** is defined as the smallest beam of wood placed over the vertical joints of sheathing or paneling, used to hold several boards together.
- **Beam bottom** is the soffit or bottom form for a beam.
- **Beam clamp** is tying or fastening units used to hold the sides of beam forms.
- **Beam form or beam box** is a container or mold used to give the necessary shape, support, and finish to a concrete beam.
- **Beam hanger** is a wire, strap, or other similar device used to hang formwork from structural members.
- **Beam pocket** is the opening in the column or girder formwork where an intersecting beam is to be connected.

- Vertical side panels of a beam formwork are called **beam sides**.
- A member used to strengthen another member by reducing its effective length and hence reducing the chances of its buckling is known as **brace**.
- **Cleat** is a small wooden board used to connect formwork members or used to act as a brace.
- **Form tie** is a tensile member attached to the opposite vertical faces of the forms to prevent the forms from bulging outwards due to the fluid pressure of freshly placed concrete.

- A horizontal member fixed on the top of a vertical prop to produce a tree shaped support, usually used to rest the beam formwork is known as **headtree**.
- **Joist** is a horizontal formwork member that supports deck form sheathing, may also support battens.
- An L-shaped horizontal member that supports other permanent or temporary structural members is called **ledger**.
- **L-head** is the top of a shore formed with a braced horizontal member projecting from one side forming an inverted L-shaped assembly.

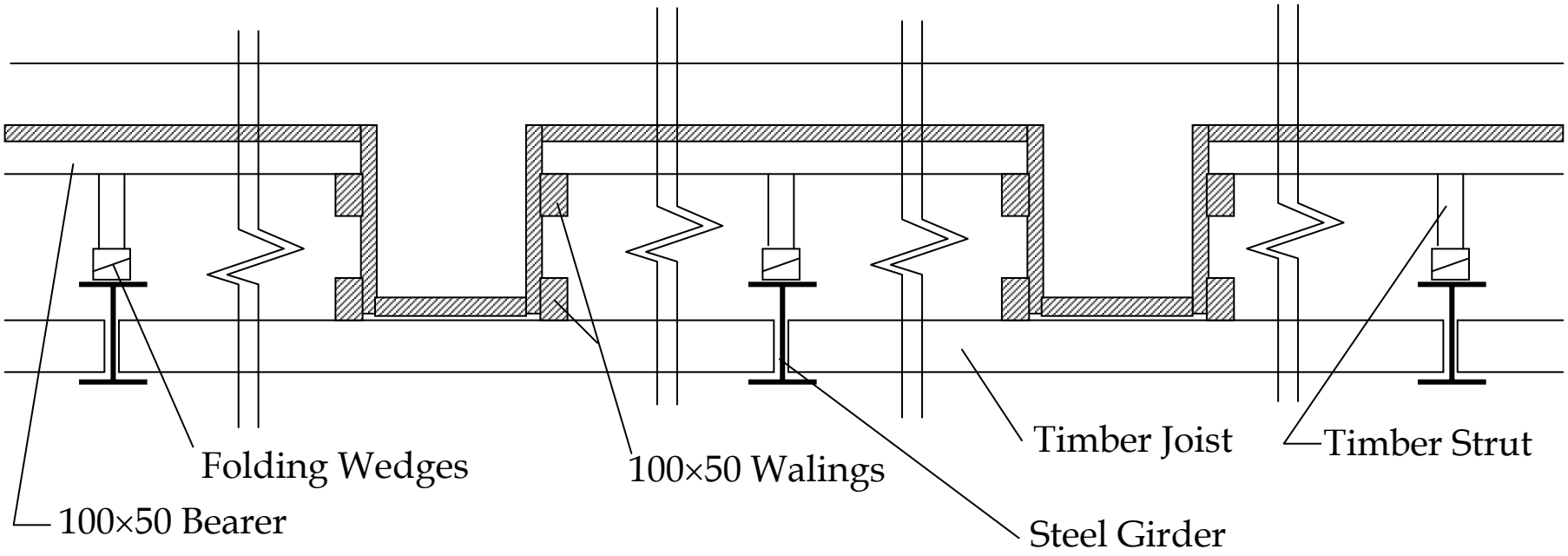
- **Plate, sheeting or sheathing** means a flat, horizontal member at the top or bottom or both of studs or posts.
- **Prop, post, upright, shore, standard, jack or strut** mean vertical support. A strut is a light and lesser length member that is easy to be man-handled.
- When adjustable it is known as an adjustable prop. Adjustable props are commonly of steel tube construction.


Wooden
Planks
50×150 Ledgers
50×50 Joist
(Above the
Ledgers)
25mm Thick
Cleat
75×100
Shore


Lateral stay
Leveling slip
Packing slips to form camber on beam soffit
Head Tree
50×75 Strut Brace

Alternate Arrangement for the Slab-Beam Formwork

- Alternate arrangement for the slab-beam formwork using steel girders is given in Fig. 5.11.
- The steel girders are supported on the props in the usual way.
- In the erection of the first type of formwork, the outside props are first set in plumb and the main beam bottoms are placed on these props all around the building.
- The beam bottoms are properly supported using posts, wedges and sole/sill plates.
- The main beam sides are placed next that are lightly nailed to the bottom.


Folding Wedges
100×50 Walings
Timber Joist
Timber Strut
100×50 Bearer
Steel Girder

- The sides are then made stable by using studs and ledgers / walings.
- The secondary beam bottoms are then lifted in place and are shored from firm stratum.
- Secondary beam sides are now erected and supported.
- To prevent the sides of the beams from spreading, these may be reinforced with spikes / lateral stays attached with the head trees.
- Finally, the slab formwork is placed supported by additional props / posts, if required.

Continued on Part-II