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Program : **B.Tech**

Subject Name: **Construction Technology**

Subject Code: **CE-402**

Semester: **4th**

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Unit: -2

Formwork and Temporary structures Design and construction features of different types of temporary structures, stationary and slip form work techniques, special features of in-situ construction, stripping and removal of formworks, formworks for special structures, e. g. shells bridges towers etc.

- **Temporary structures:-**

Temporary structures are critical elements of the overall construction plan. A temporary structure in construction affects the safety of the workers on the job and the general public and there is also the relationship of the temporary structure to the finished structure. Temporary structures are sometimes incorporated into the finished work or are removed at the end of the conclusion of their usefulness. In either case the contractor will have to deal with supervision work, code requirements, contract and legal requirements, and perhaps disputes with others over the work being performed. As far as design, drawings and specifications are concerned, they depend on the temporary structure under consideration. In extremely complex jobs involving such temporary work as cofferdams for bridge piers, the design of the temporary structure will often be done by the designer of the permanent structure. For simpler types of temporary structures, such as temporary ramps used by excavation contractor for building projects, the excavation contractor will do the design. Between these two extremes is the type of temporary structure in which specialty contractors, who make a business of doing a specific type of temporary structure will be employed. The specifications for the temporary structure are usually drawn up by the temporary structure contractor and are required to obtain permits for any work done.

A major emphasis will be placed on concrete formwork construction covering detailed design analysis of both vertical and horizontal timber formwork systems. Any means or methods which provide temporary support, access, enhancement, or otherwise facilitate the construction of permanent structures.

- **Necessity: Temporary structures form the interface between design and construction. Most permanent structures simply could not be built without temporary structures.**

- **Impact on Schedule, Cost, and Quality: Losses in time and money will occur if the temporary structures are not planned and coordinated with the same degree of thoroughness as the permanent structures.**

- **Safety: Failure of temporary structures has been responsible for hundreds of deaths on construction sites. Safety should be the overriding priority of contractors and designers responsible for implementing temporary structures.**

- **Responsibility: The norm in the construction industry is to place the responsibility for temporary structures solely on the general contractor. However, architects and engineers must at least have formulated their own method of construction. Coordinating the design of permanent structure with the temporary structures that will be required can lead to more efficient and cost effective construction.**

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- **Design Considerations**
  - **Safety**

    Designers must place the first priority on safety. OSHA codes, as well as other codes in the industry, provides stringent performance specifications (how the system should work) regarding temporary structures.
  - **Cost**

    Temporary structures can be the most expensive part of some construction projects. Designing cost-effective solutions to temporary structures problems could easily be the competitive advantage a contractor has over others. The designer must have a thorough knowledge of all the options which will sufficiently solve the temporary structures problem.
  - **Unique Design Challenges**

    Temporary structures are subject to unique loading conditions which do not apply to a permanent structure (fluctuating or dynamic loads, impact loads, and loads which change position). Working within spatial constraints and cramped sites requires the most efficient temporary structure so that workers still have room to maneuver safely.

    It is always possible that an unforeseen condition could arise during an excavation due to uncertainty of soil conditions. Designers must include an appropriate factor of safety in their calculations or they may consider contingency plans for changing soil conditions.
  - **The contractor**

    In many cases the contractor is the only member of the construction team with considerable experience and practical knowledge of temporary structures. The contractor must hire his or her own engineer, if the specifications or building codes require one, or self perform the design of temporary structures. The most complex temporary structures are often handled on a design-build basis (design-build approach is a construction technique which allows a single procurement for the design and construction of projects.) The design-build situation is optimal because it guarantees coordination between design and construction. Anyone managing the construction process needs a basic understanding of the engineer's thinking process and the design intentions and the basic understanding of how a structure behaves. Constructor must be able to address a number of technical questions at the project site including structural issues that sometimes are not addressed by the design professionals. Since the safety of construction workers as well as the strength and stability of structures during the construction phase is of paramount importance, construction managers need this knowledge.

- **Structural Design**
  - **Definition: Determination of overall proportions and dimensions of the supporting framework and the selection of individual members.**
  - **Responsibility: The structural engineer is responsible for structural design within the constraints imposed by the architect (number of stories, floor plan, etc.).**

Important factors in design are:

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- Safety (the structure doesn't fall down);
- Serviceability (how well the structure performs in term of appearance and deflection);
- Economy (an efficient use of materials and labor); and
- Several alternative designs should be prepared and their costs compared.

- Types of load that structures support are:

  - Dead loads – permanent; including self-weight, floor covering, suspended ceiling, partitions, etc.
  - live loads – not permanent; the location is not fixed; including furniture, equipment, and occupants of buildings
  - Wind load (exerts a pressure or suction on the exterior of a building);
  - Earthquake loads (the effects of ground motion are simulated by a system of horizontal forces);
  - Snow load (varies with geographical location and drift); other loads (hydrostatic pressure, soil pressure)

If the load is applied suddenly, the effects of IMPACT must be accounted for.

Design specifications provide guidance for the design of structural members and their connections. They have no legal standing on their own, but they can easily be adopted, by reference, as part of a building code i.e. ACI 318-99 Building Code Requirements for Structural Concrete. The Specifications for Design of Wood Members are by National Design Specifications for Wood Construction by American Forest and Paper Association.

- Formwork for Concrete

Formwork development has paralleled the growth of concrete construction throughout the 20th century. The increasing acceptance of concrete as a major construction material presents the form builder a new range of problems in the development of appropriate sheathing materials and maintenance of rigid tolerances. Figure 1 shows a typical concrete wall formwork setup.

Formwork is a classic temporary structure in the sense that it is erected quickly, highly loaded for a few hours during the concrete placement, and within a few days disassembled for future reuse. Also classic in their temporary nature are the connections, braces, tie anchorages, and adjustment devices which form need.

For concrete formworks, the notion of "Temporary Structures" does not quite portray the reality. Forms, its hardware and accessories are used over and over again over their life time. Because of that it is necessary to use materials with high durability and easy to maintain. The form design should be such that it can be erected and disassembled efficiently in order to maximize productivity. The disassembly or stripping of forms depends on factors such as the bond between concrete and the form, rigidity and shrinkage of concrete. Forms should, whenever possible, be left in place for the entire curing period. Since early form removal is desirable for their reuse, a reliable basis for determining the earliest possible stripping time is

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necessary. Some of the early signs to look for during stripping are no excessive deflection or distortion and no evidence of cracking or other damage to the concrete due to the removal of the forms or the form supports. In any event, forms must not be stripped until the concrete has hardened enough to hold its own weight and any other weight it may be carrying. The surface must be hard enough to remain undamaged and unmarked when reasonable care is used in stripping the forms.

Traditionally, formwork was erected in place and wrecked after only one time of usage. In the United States, due to high labor costs, it is more efficient and profitable to prefabricate forms, assemble them in large units using mechanical devices, such as cranes to erect the forms and reuse them as much as possible.

Lumber was once the predominant form material, but developments in the use of plywood, metal, plastics, and other materials, together with the increasing use of specialized accessories, have changed the picture. In 1908 the use of wood versus steel formwork was debated at the American Concrete Institute (ACI) convention, the advantages of modular panel formed with its own connecting hardware and good for extensive reuse were also realized. By 1910 steel forms for paving were being produced commercially and used in the field.

Today modular panel forming is the norm. Figure 3 shows steel forms being used for concrete pavement construction.

Figure 1 - Steel modular forms being used in concrete pavement construction

- **Objectives of Form Building**

Forms mold the concrete to desired size and shape and control its position and alignment. But formwork is more than a mold; it is a temporary structure that supports its own weight, plus the freshly placed concrete, plus construction live loads (including materials, equipment, and personnel).

- **Basic objectives in form building are:**
  - **Quality – In terms of strength, rigidity, position, and dimensions of the forms**

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- Safety – for both the workers and the concrete structure
- Economy – the least cost consistent with quality and safety requirements

- Causes of Formwork Failure

Formwork failures are the cause of many accidents and building failures that occur during concrete construction, usually when fresh concrete is being placed. Generally some unexpected event causes one member to fail, then others become overloaded or misaligned and the entire formwork structure collapses. The main causes of formwork failure are:

- Improper stripping and shore removal
- Inadequate bracing
- Vibration
- Inadequate control of concrete placement
- Lack of attention to formwork details.

- Planning for Formwork
  - The contractor should plan for formwork at the time of making bid considering the following factors:
    - Placing schedule and stripping time requirements;
    - Capacity of equipment available to handle form sections and materials; capacity of mixing and placing equipment;
    - Construction joints;
    - Reuse of forms as affected by stripping time;
    - Relative merits of job-built, shop-built and ready-made forms; and weather (protection requirements and stripping time)
    - Compare alternative methods to determine the most efficient plan.

- Areas of Cost Reduction

- Planning for maximum reuse – A form designed for max reuse is stronger and more expensive, but it can save on the total form cost.

- Economical form construction use shop-built-forms provides greatest efficiency in working conditions and in the purchase and use of materials and tools; create shop area on the site– to form sections too large or transportation cost too high; use job-built– for small jobs, or where forms must be fitted to terrain; buy prefabricated forms(large number of reuses rent prefab forms(better flexibility in regulating volume of work).
- Setting and stripping repeat the same functions to increase the crew efficiency as the job progresses use metal clamp or special wedge pin connections that are secure, yet easy to assemble and dismantle; and add extra features that make handling, erection, and stripping easier such as handles, lifting eyes.
- Cranes and Hoists Size of form sections should be limited to the capacity of the largest crane planned for the job. Stair towers may be completed early in the schedule to be used for

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moving men and materials. Leave one bay open to permit mobile crane and concrete truck movement.

- Bar Setting Form design can permit the rebar to be pre assembled before installation (more favorable condition)
- Concrete Placement High lifts in wall construction make placing and vibration difficult. Placing rate is limited by form design.

- Form Materials and Accessories

Practically all formwork jobs require some lumber. A local supplier will advise what material and sizes are in stock or promptly obtainable, and the designer or builder can proceed accordingly. Southern yellow pine and Douglas fir, sometimes called Oregon pine are widely used in structural concrete forms. They are easily worked and are the strongest in the softwood group. Both hold nails well and are durable. They are used in sheathing, studs, and wales. Figure 5 shows a typical wall form with its components.

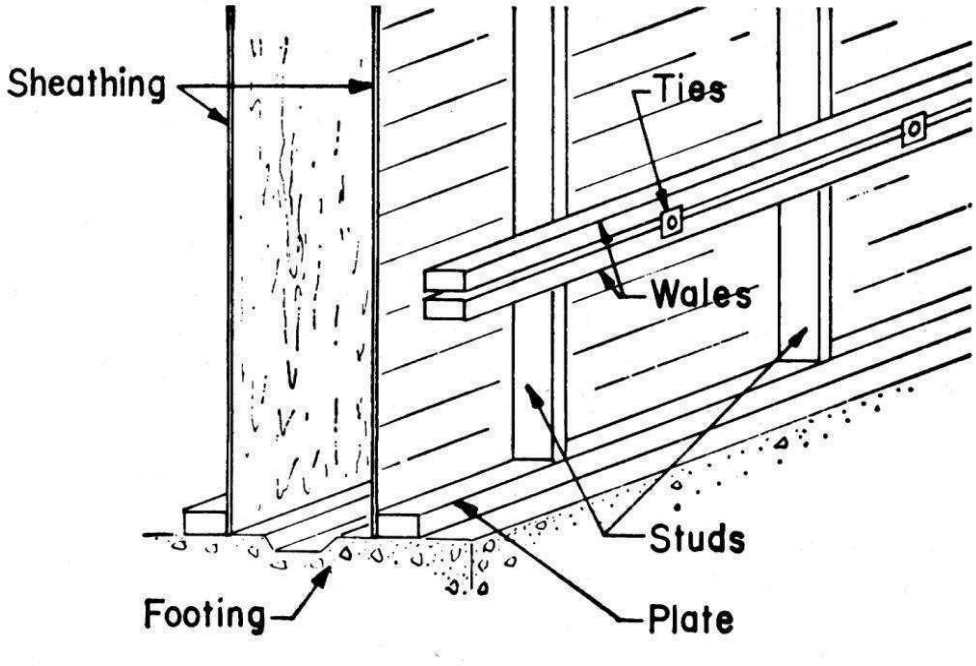

Figure 2 - Typical wall form with components identified.

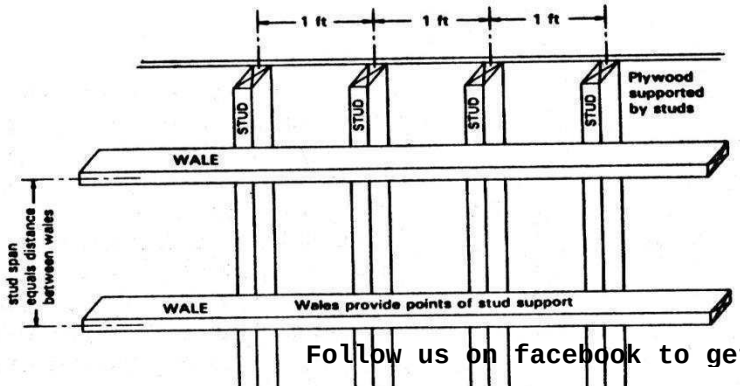

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Figure 3 - Parts of a typical wall form

- **Ties**

In order to secure concrete forms against the lateral pressure of unhardened concrete, a tensile unit called concrete form tie is used (they are also referred to as form clamps, coil ties, rod clamps, snap ties, etc.). They are ready-made units with safe load ratings ranging from 1000 lb to more than 50000 lb and have an internal tension unit and an external holding device. Figure 7 shows a typical single member tie.

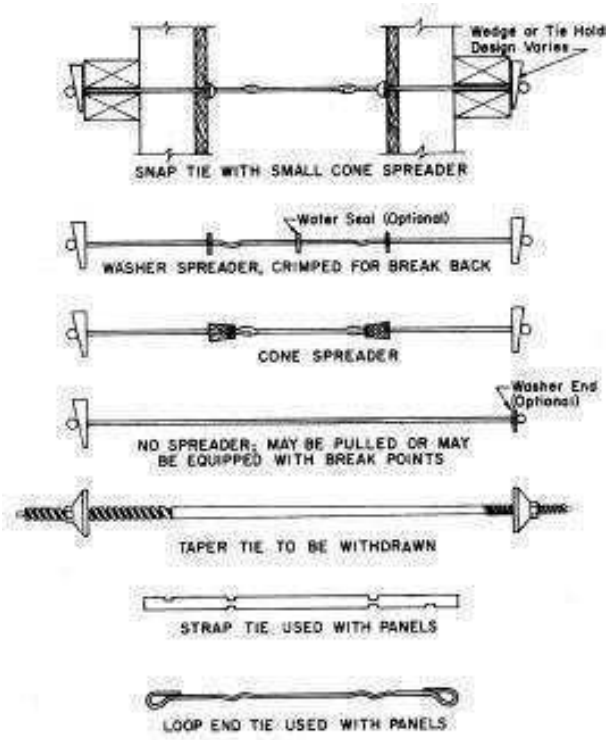

Figure 4 – A typical single member ties

- **Ties are manufactured in two basic types:**

Continuous single member ties; in which the tensile unit is a single piece, have a special holding device added for engaging the tensile unit against the exterior of the form Some single member ties may be pulled as an entire unit from the concrete; others are broken back a predetermined distance. Some are cut flush with the concrete surface. It is generally used for lighter loads, ranging up to about 5,000 lb safe load

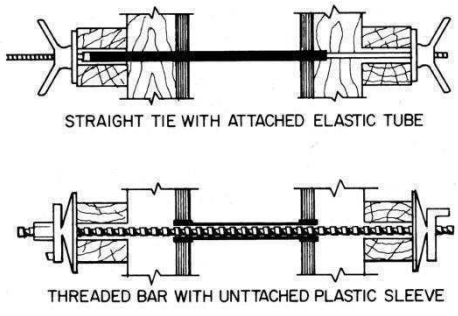

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Figure 5 – A continuous single member tie

Internal disconnecting type ties, in which the tensile unit has an inner part with threaded connections to removable external members generally remain in the concrete (Figure 9). It is available for light or medium loads, but finds its greatest application under heavier construction loads up to about 70,000 lb.

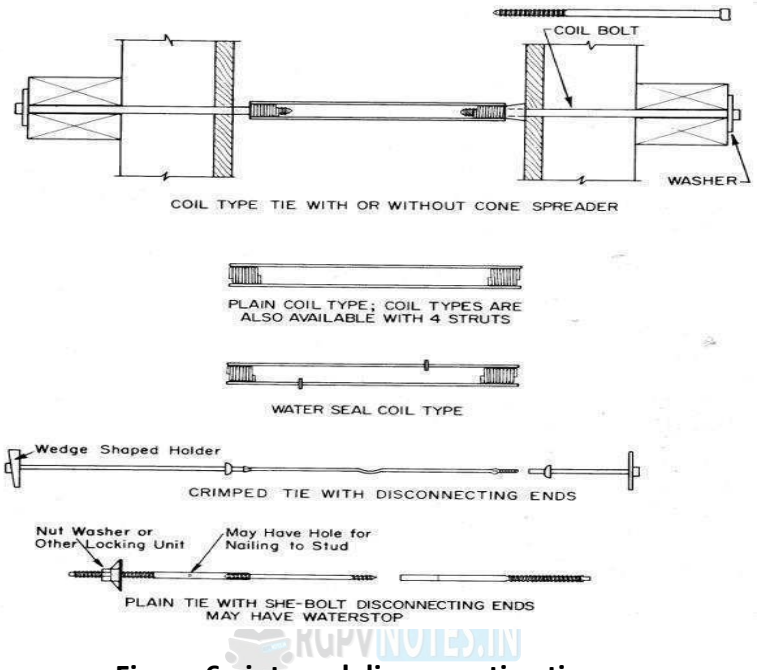

Figure 6 - internal disconnecting ties

- **Different types of temporary structures**
  - **Scaffolding Scaffolding provides a temporary safe working platform for:**
    - **Erection.**
    - **Maintenance**
    - **Construction**
    - **Repair**
    - **Access**
    - **Inspection**

- **There are two main types of scaffolding:**
    - **Freestanding scaffolds, such as independent towers,**
    - **Independent tied scaffolds, such as independent towers tied to an adjacent structure.**

The most common piece of structure used in scaffolding is the scaffold tube. The tube generally comes in two thicknesses, 3.2mm or 4mm. The tubes are galvanized due to their exposure to the elements and axial capacity loads are given either 'as new' or 'used.' Capacities of tubes used in tension are usually limited by the safe slip load capacity of the coupler, which is far lower than the actual tensile resistance of the tube.

Scaffolding is designed support its own self-weight, i.e. the weight of the boards, tubes, guardrails, toe boards etc. and imposed loads such as wind. The imposed load applied to

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the scaffolding depends on its use. The wind load applied to scaffolding will change depending on whether sheeting or debris nets are used.

- **Formwork**

Formwork is the term used for a temporary mould into which concrete is poured and formed.

Traditional formwork is fabricated using timber, but it can also be constructed from steel, glass fiber reinforced plastics and other materials.

Timber formwork is normally constructed on site using timber and plywood. It is easy to produce, although it can be time consuming for larger structures. It is used when the labour costs are lower than the cost of producing re-usable formwork from materials such as steel or plastic.

Re-usable plastic formwork is generally used for quick pours of concrete. The formwork is assembled either from interlocking panels or from a modular system and is used for relatively simple concrete structures. It is not as versatile as timber formwork due to the prefabrication requirements and is best suited for lost-cost, repetitive structures such as mass housing schemes.

Stay-in-place structural formwork is generally assembled on site using prefabricated fiber-reinforced plastic. It is used for concrete columns and piers and stays in place, acting as permanent axial and shear reinforcement for the structural member. It also provides resistance to environmental damage for both the concrete and reinforcing bars.

Proprietary systems are used to support vertical formwork while concrete cures, consisting of a series of tubes and ties.

When selecting formwork, the type of concrete and temperature of the pour are important considerations as they both affect the pressure exerted.

Once the concrete has gained sufficient strength the formwork can be struck (removed). A minimum value of 5 N/mm2 is recommended in all cases when striking vertical formwork as so not to damage the permanent concrete in the process.

High quality workmanship and inspection are necessary to ensure a high standard and appearance of the resulting concrete structure.

- **Trench support**

A trench is defined as an excavation when its length greatly exceeds its depth. Shallow trenches are usually considered to be less than 6 m deep and deep trenches greater than 6m. Depending on the dimensions of a trench, excavation can either be carried out by hand or using a mechanical digger. Trenches are commonly required to allow services, pipelines or foundations to be laid.

Water ingress into the trench is often a major issue and ground water table locations and soil strata should be investigated before any extensive excavation takes place.

Over short periods of time for relatively shallow depths most soil types will stand almost vertically without any problems. However, trenches other than those which are relatively shallow may require a trench support scheme.

- **Timber supports**

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Historically, trenching involved using timber to support horizontal and vertical soil loads and this technique is still used today. Timber trenching is generally used for low risk, narrow trenches, shafts or headings. The timber solutions require good workmanship and are reasonably labour-intensive, however they are versatile and the equipment required is easy to handle and transport.

- Trench boxes

  Trench boxes are suitable for low-risk situations in stable, dry ground and can be placed in pre-excavated trenches or installed using the 'dig and push' technique. The system requires at least two struts at each panel for stability which must be considered when access is required for construction work or piping.

- Trench sheets

  Trench sheets are the most adaptable of the systems available, and are most commonly used to retain poorer soil. They can support deeper trenches with larger surcharges and provide a continuous support. They require multiple levels of strut support and the slenderness of the sheets can often limit the depth of the trench as they are installed by light machinery and could buckle under large vertical loads.

- Slip form work techniques
  - Slip forming or slip form construction is a construction method in which concrete is poured into a continuously moving form.
  - Slip forming is used for tall structures (such as bridges, towers, buildings, and dams), as well as horizontal structures, such as roadways.
  - Concrete needs to be workable enough to be placed into the form and consolidated (via vibration), yet quick-setting enough to emerge from the form with strength.

- Types of Slip forming

  - Vertical Forming
    - In vertical slip forming the concrete form may be surrounded by a platform on which workers stand, placing steel reinforcing rods into the concrete and ensuring a smooth pour.
    - Together, the concrete form and working platform are raised by means of hydraulic jacks.
    - Construction of Silos, Chimneys.

  - Horizontal Slip Forming
    - In horizontal slip forming for pavement and traffic separation walls concrete is laid down, vibrated, worked, and settled in place while the form itself slowly moves ahead.
    - This method was initially devised and utilized in Highway construction.

  - Structural units of Slip Formwork :- Slip formwork includes
    - Steel panels attached to frames,

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- Working platforms,
- Hydraulic jacks,
- Rods,
- Pumps,
- Distribution Centre and other connecting elements.

- **Structure of Slip Formwork**
  - Slip formwork system is a system in which slip forms are continuously raised by hydraulic equipment. By this means the rising from 150 to 300 mm per hour depending on the concrete hardening rate as the cast concrete can become self-supporting very rapidly.
  - The system uses steel panels of special height, which are fixed to working carcass consisting of steel frames (yokes), trusses and fixing devices.
  - Carcass provide stability of the system design and is a reliable base for the wooden flooring used as a working platform for placement of concrete, reinforcement and embedded parts for doors and windows on its surface.
  - A hydraulic jack is placed on the top of each frame. A high tensile steel jacking rod is passed through the jack and is casted into the walls as it rises. The jack consists of a cylinder and a pair of upper and lower clamp mechanisms gripping the rod and working in cycles.
  - The principle is that the jack works against the lower clamp to lift the frame. When the pressure is released upper clamp grips the rod and the lower clamp is released and come up by spring action.
  - Vertical reinforcement is retained in the correct position using guides, which are fixed on the top of the frames. Horizontal reinforcement is laid under the frames and is bounded with the vertical reinforcement.
  - High speed of erection (works' execution speed increases) and as a result, rapid completion of the project - considerable saving of time.
  - Minimal use of a crane, as formwork is lifted by hydraulic jacks.
  - Uniformity of wall sections with the project drawings, smooth wall surfaces are achieved by the use of slip formwork.
  - Reduced labor costs due to the intensity of the working process.

- **Stripping and removal of formworks**

  The removal of concrete formwork also called as strike-off or stripping of formwork should be carried out only after the time when concrete has gained sufficient strength, at least twice the stress to which the concrete may be subjected to when the formworks are removed. It is also necessary to ensure the stability of the remaining formwork during formwork removal.

  - Concrete Formwork Removal Time

  The rate of hardening of concrete or the concrete strength depends on temperature and affects the formwork removal time. For example, time required for removal of concrete in winter will be more than time required during summer.

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Special attention is required for formwork removal of flexural members such as beams and slabs. As these members are subjected to self-load as well as live load even during construction, they may deflect if the strength gained is not sufficient to handle to loads.

To estimate the strength of concrete before formwork removal, the tests on concrete cubes or cylinders should be carried out. The concrete cubes or cylinders should be prepared from the same mix as that of the structural members and cured under same circumstances of temperature and moisture as that of structural member.

When it is ensured that the concrete in the structural members has gained sufficient strength to withstand the design load, only then formworks should be removed. If possible, the formworks should be left for longer time as it helps in curing.

Removal of formwork from concrete section should not make the structural element to:

- Collapse under self load or under design load
- deflect the structural member excessively in short or the long term
- Physically damage the structural member when formwork is removed.
- The following points must be kept in mind during formwork removal whether the structure will be prone to:
- freeze thaw damage
- cracks formation due to thermal contraction of concrete
- After formwork striking. If there is a significant risk of any of the above damages, it is better to delay the removal time of formwork. If formwork has to removed for optimizing the concrete construction activities, then these structures must be insulated well to prevent such damages.

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- Calculation of Safe Formwork Striking Times:

Structural members are constructed based on designed load. But before a structure is complete and subjected to all loads assumed during structural design, the structural members are subjected to its self weight and construction loads during construction process.

So, to proceed with construction activities at a quicker rate, it is essential to calculate the behavior of structure under is self load and construction load. If this can be done and structural member is found to be safe, formwork can be stripped-off.

If these calculations are not possible, then following formula can be used for calculation of safe formwork striking times:

Characteristic strength of cube of equal of maturity to the structure required at time of formwork removal.

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