

Chapter Two

Literature Review

2.1 Introduction

Formwork is a significant aspect of concrete construction as it usually represents a greater cost than the concrete itself ¹. There have been some interesting trends and developments in the concrete construction industry concerning formwork over the last few decades. It has progressed from highly labor intensive traditional timber formwork, that allows high output rates to be achieved. This has been achieved through developments in the technical knowledge and machinery that makes, large quantities of concrete readily for lifting and handling the rapid placement of concrete was developed. This further led to developments in new forming materials such as aluminum, steel plywood, plastics, glass fiber and proprietary systems. This has taken the design of formwork further away from the foreman and carpenter on site, and brought in the temporary works designer and an improved engineering approach to design².

The recent developments in equipment have been equally matched by developments in formwork design. There have been several innovations in formwork design since the introduction of the draft BS code of practice for false work in 1975³. The joint efforts of the Concrete Society and the Institution of Structural Engineers to produce guidelines to the practice and design of formwork resulted in the publication of the Concrete Society Technical Report No. 13 in 1977⁴. Later in 1982 the British Standard Institution (BSI) published the Code of Practice for False work, BS5975⁵. The code only covered the support of soffit formwork and there was a need for an all embracing text on formwork. Consequently in 1986, the Concrete society and the Institution of

Structural Engineers produced a joint textbook entitled *Formwork: A Guide to Good Practice*². It gives guidelines and recommendations to the design and use of formwork with separate sections on materials, loadings and design. It was written as a complementary document to BS5975 and superseded Concrete Society Technical Report No. 13. Another major development was the publication of the Concrete Pressure on Formwork CIRIA Report 108⁶ by CIRIA in 1985, which superseded CIRIA Report 1 of 1965⁷. These documents have helped to quantify the design of formwork so that safe and economic formwork can be designed more accurately.

The formwork structure should be strong enough to hold the concrete in the desired size and shape until the concrete hardens and becomes self supporting. The design in the preliminary stages generally involves some guesswork backed by engineering judgment and experience. It is based on known strength of materials and the estimated loads that may be carried. Formwork is made from a number of simple components or a system of component which may be arranged in many different ways. Plywood sheets, timber or metal soldiers and wailings, tie and tie plates are examples of these components. In atypical design process, a component is chosen and its arrangement within the formwork assembly is assumed. A structural analysis is then performed on the arrangement to verify that the resulting forces and deflections are within the allowable limits of the material. If not, an alternative component material is chosen either based on the type or size of component. This process is repeated until the component satisfies the structural requirements as well as the safety and economic requirements. The design formwork is therefore a highly repetitive process which can become very tedious. The design also involves the use of information from various sources and the abstraction of data from codes of practice.

2.2 Definitions:

The following terms will be used in this guide. All these terms may also be found in American Concrete Institute (ACI 347)

Backshores: shores placed snugly under a concrete slab or structural member after the original formwork and shores have been removed from a small area at a time, without allowing the slab or member to deflect; thus, the slab or other member does not yet support its own weight or existing construction loads from above.

Centering: specialized temporary support used in the construction of arches, shells, and space structures where the entire temporary support is lowered (struck or de-centered) as a unit to avoid introduction of injurious stresses in any part of the structure.

Engineer/architect: the engineer, architect, engineering firm, architectural firm, or other agency issuing project plans and specifications for the permanent structure, administering the work under contract documents.

Formwork: total system of support for freshly placed concrete, including the mold or sheathing that contacts the concrete as well as all supporting members, hardware, and necessary bracing.

Formwork engineer/contractor: engineer of the formwork system, contractor, or competent person in-charge of designated aspects of formwork design and formwork operations.

Pre-shores: added shores placed snugly under selected panels of a deck forming system before any primary (original) shores are removed. Pre-shores and the panels they support remain in place until the remainder of the complete bay has been stripped and back-shored, a small area at a time.

Re-shores: shores placed snugly under a stripped concrete slab or other structural member after the original forms and shores have been removed from a large area, requiring the new slab or structural member to deflect and support its own weight and existing construction loads applied before the installation of the re-shores. If prefabricated drop-head shores for slab formwork systems are used, the shores can become the re-shores if a large area of shoring is unloaded, permitting the structural members to deflect and support their own weight. If they are not, then they become backshores.

Shores: vertical or inclined support members designed to carry the weight of the formwork, concrete, and construction loads above.

2.3 Formwork System

A formwork system is defined as “the total system of support for freshly placed concrete including the mold or sheathing which contacts the concrete as well as supporting members, hardware ,and necessary bracing.” Formwork system development has paralleled the growth of concrete construction throughout the twentieth century. As concrete has come of age and been assigned increasingly significant structural tasks, formwork builders have had to keep pace. Form designers and builders are becoming increasingly aware of the need to keep abreast of technological advancements in other materials fields in order to develop creative innovations that are required to maintain quality and economy in the face of new formwork challenges. Formwork was once built in place, used once, and subsequently wrecked. The trend today, however, is toward increasing

Prefabrication, assembly in large units, erection by mechanical means, and continuing reuse of forms. These developments are in keeping with the

increasing mechanization of production in construction sites and other fields.

2.4 Formwork Economy and Significance

Formwork is the largest cost component for a typical multistory reinforced concrete building. Formwork cost accounts for 40 to 60 percent of the cost of the concrete frame and for approximately 10 percent of the total building cost. Figure 2.1a, b presents a breakdown of different cost categories for conventional concrete slab and wall formwork. A large proportion of the cost of conventional formwork is related to formwork labor costs.

Significant cost saving could be achieved by reducing labor costs. Formwork costs are not the only significant component of the formwork life cycle. Other important aspects of the formwork operation include speed, safety, and quality.

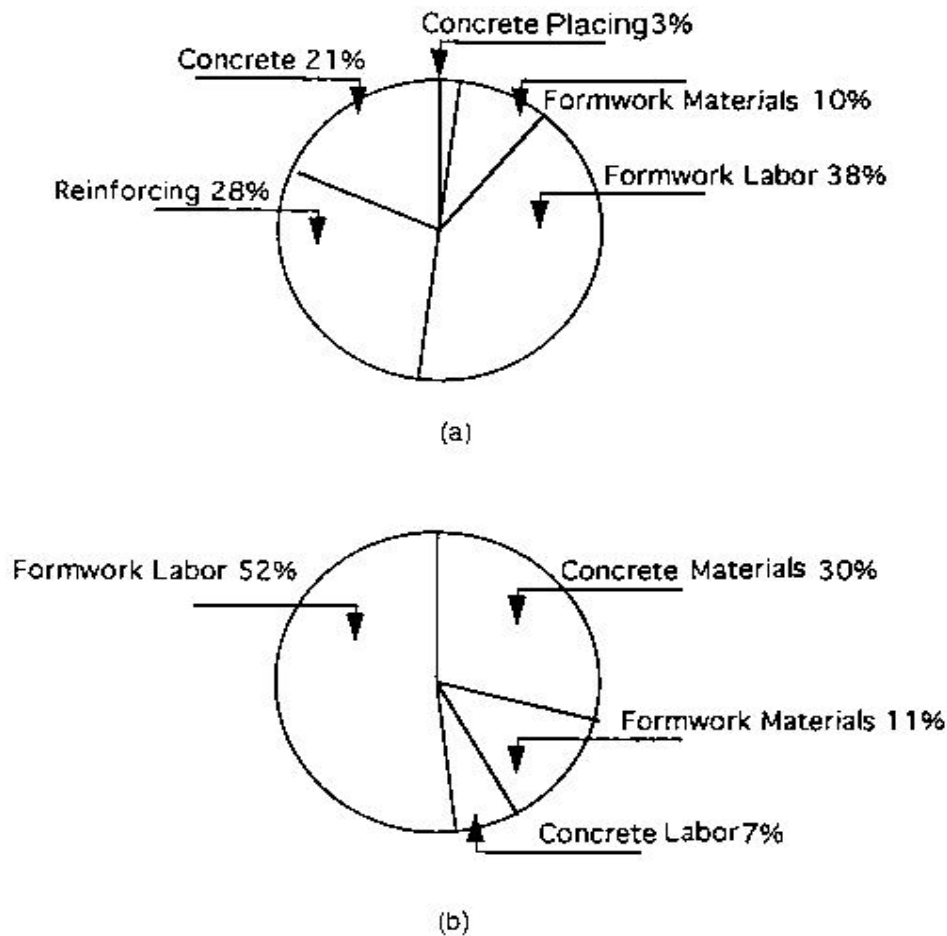


Figure (2.1): Distribution of costs for cast-in-place concrete slab and wall:
(a) slab; (b) wall.

2.4.1 Speed of Construction:

Speed of construction is defined as the rate in which concrete building is raised and can be expressed in terms of number of floors erected per week or months. Speed of construction can be also measured in terms of inches or millimeters of concrete poured per hour. Formwork operations can control the pace of construction projects. Formwork is typically supported

by several levels of shores and re-shores that carry the loads until the concrete gains enough strength to support its own weight and all other externally applied loads. Shores are vertical members made of wood that support recently built concrete that have not developed full design strength. On the other hand, re-shoring occurs when the original shoring is removed and replaced in such a manner as to avoid deflection of the cured concrete. As a result, several floors may be blocked, preventing the progress of any other construction activities. Faster formwork cycle from erection to stripping would allow for faster removal of shoring and re-shoring and faster overall project progress.

2.4.2 Safety

Formwork operations are risky, and workers are typically exposed to unsafe working conditions. Partial or total failure of concrete formwork is a major contributor to deaths, injuries, and property damages within the construction industry. Another common hazard occurs during stripping of formwork in which loose formwork elements fall on workers under the concrete slab being stripped. Structural collapses and failures involving concrete structures account for 25 percent of all construction failures. More than 50 percent of concrete structure failure during construction is attributed to formwork failure. Formwork failures result from faulty formwork structural design, inadequate shoring and re-shoring, improper construction practices during construction, inadequate bracing, unstable support or mudsills, and insufficient concrete strength to sustain the applied load after construction. Contractors are generally responsible for stability and safety of concrete formwork. Contractors are guided by several federal, state, and local codes and regulations that regulate formwork safety. Most of these documents provide general guidelines for safety but provide no guarantee against failure. Contractors typically are

trying to achieve fast removal of formwork elements without compromising the safety and integrity of structures.

2.4.3 Quality

The quality of the resulting concrete is dictated by the quality of formwork materials and workmanship. Many concrete-related problems such as discoloration, stains, and dusting are attributed to concrete formwork. Also, some deformed concrete surfaces are due to deformed formwork systems caused by repetitive reuse and inadequate support of formwork.

2.5 An Integrated Concrete/Formwork Life Cycle

The purpose of this section is to introduce formwork operation as an integrated part of the whole building process and to explain some of the terminology used in concrete and concrete formwork.

The process of providing formwork and concrete is highly integrated. The left circle in Figure 2.2 represents the formwork life cycle, while the right circle represents the concrete construction life cycle. The two intersecting points represent the beginning and the end of the concrete construction life cycle. The life cycle of formwork starts with the “choose formwork” activity. The physical activities in the formwork life cycle are represented by these steps: (1) fabricate formwork; (2) erect formwork; and (3) remove formwork. The concrete construction life cycle starts after the “fabricate formwork” activity and ends before the “remove formwork” activity. The function of the formwork life cycle is to provide the structure with the specified shape and size, while the function of the concrete construction life cycle is to provide the structure with concrete of specified strength, durability, and surface texture. A brief description of each stage of both the concrete and formwork life cycles is given below.

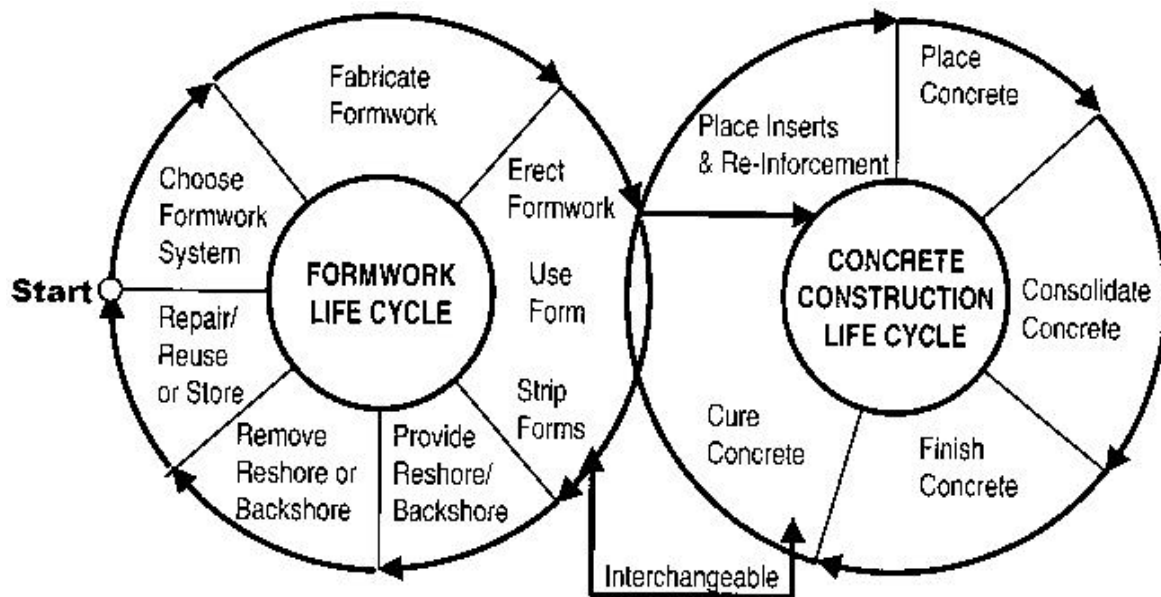


Figure 2.2 Integrated concrete formwork life cycle.

2.5.1 Choose a Formwork System :

The choose formwork system activity includes the process of selecting formwork systems for different structural elements. It also includes the process of selecting accessories, bracing, and a release agent for the selected formwork system. There are several forming systems used in the construction of reinforced concrete structures. For example, formwork systems for concrete slabs can be classified as hand-set or conventional systems and crane-set systems. Conventional systems are still the most common and popular formwork systems. Their popularity stems from their ability to form different shapes and elements. However, conventional formwork usually results in high labor and material cost. Non conventional or crane-set systems have gained increasing popularity because of low labor costs and their ability to achieve faster construction Cycle.

2.5.2 Fabricate Formwork

The second step in the formwork life cycle is fabricating formwork. This activity includes receiving formwork materials, cutting and stockpiling the materials by sizes and types, assembling the pieces into the desired shapes and sizes, and storing the forms near the lifting devices. The contractor may also choose between building forms on the job site by setting up a special fabrication area, or building many forms in a central yard facility and transporting them to the site. The contractor may also choose between building the forms themselves and buying or renting them. Many contractors find that flexibility in controlling the volume of work they are able to perform.

2.5.3 Erect Formwork, Place Inserts, and Reinforcement

The method and sequence of erecting formwork may vary depending on the availability of lifting equipment and whether reinforcing cages are available. Forms are usually handled manually, by small derrick, or by crane. The erect formwork activity includes the process of lifting, positioning, and aligning the different formwork elements. This activity also includes the process of applying the form release agent or coating that prevents bonding of concrete to forms. The concrete life cycle starts after the erect formwork activity is finished with placing inserts and reinforcement activity. The logical sequencing of erecting formwork and its relation to placing inserts and reinforcement is :

1. Set lines—a template is generally set in place on the floor slab or footing to accurately locate the column floor.
2. Erect scaffolding
3. Install column reinforcement
4. Provide forms for column

5. Erect outside forms for walls
6. Install wall reinforcement
7. Erect inside forms for walls
8. Install ties
9. Provide bracing for walls
10. Erect forms for beams
11. Install beam reinforcement
12. Erect forms for slabs
13. Place inserts for mechanical and electrical connections, openings for ducts and conduits, and supporting bars for reinforcement
14. Place secondary and main reinforcement

A form coating or release agent is often applied to the inside surface of formwork to prevent the concrete from bonding to the formwork elements. Coating can be applied by spraying, brushing, or by a roller. Form coating facilitates the operation of removing the formwork after the concrete has gained enough strength to support itself. Another function of the formwork coating is sealing the surface of the wooden elements which prevent the water in freshly placed concrete from being absorbed by wood. Form release agent should not affect or react with the finished concrete in any way.

2.5.4 The Placing of Concrete:

This activity includes mixing, transporting, pumping, and placing of the concrete. The concrete used in most projects is truck-mixed. Concrete is usually transported by belt conveyers for horizontal applications, by buckets for delivery via cranes, by chutes for delivery via gravity to lower levels, and by pumping for horizontal and vertical delivery of concrete.

2.5.5 Consolidation of Concrete:

Consolidation is the process of compacting or striking the concrete to mold it within the forms, around embedded inserts and reinforcement. It is also done to remove the humps and hollows. Consolidation of concrete is usually performed with hand tools or mechanical vibrators to guarantee a dense structure.

2.5.6 Concrete Finishing:

This activity includes the process of treating the exposed concrete surfaces to produce the desired appearance, texture, or wearing qualities. Finishing of concrete is usually performed by moving a straight edge back and forth in a saw like motion across the top of the concrete.

2.5.7 Curing of Concrete

The hardening of concrete is a chemical process that requires warmth and moisture. This activity involves curing concrete with water, steam, or any other method to prevent shrinkage and allow the concrete to gain sufficient early strength. Steam curing is used where early strength gain of concrete is important. After the concrete is cured, the rest of the formwork life cycle continues with the strip forms activity. The cure concrete and strip forms activities are interchangeable depending on the type of structural element. For example, columns and walls are cured after stripping of the forms, while slabs and beams are cured before and after the forms are stripped.

2.5.8 Strip Forms

As soon as concrete gains enough strength to eliminate immediate distress or deflection under loads resulting from its own weight and some additional loads, formwork should be stripped to allow other construction activities to start. The operation of removing the forms is called stripping

or wrecking the forms. Formwork can either be partially stripped by removing small areas to prevent the slab from deflecting or completely stripped to allow the slab to deflect. As a general rule, formwork supporting members should not be removed before the strength of concrete has reached at least 70 percent of its design value.

2.5.9 Providing of Re-shores/Backshores

Re-shoring and back shoring are the processes of providing temporary vertical support shores for the stripped structural elements which have not yet developed full design strength. They also provide temporary vertical support for the completed structure after the original shoring support has been removed. Re-shoring and back shoring are the two methods used to provide the concrete with support until it reaches its full design strength. Re-shores are shores placed snugly under a stripped concrete slab or structural member after the original forms and shores have been removed from a large area. In re-shoring, the concrete slab is allowed to deflect and, thus, formwork can be removed from a large area. This can help reduce stripping costs, which is the main advantage of re-shores. Backshores are shores placed snugly under a stripped concrete slab or structural member after the original forms and shores have been removed from a small area. In back-shoring, formwork is removed from a small area of slab and then backshores are provided. Concrete slabs or other structural elements are not allowed to deflect, and as a result, stripping can be accomplished at an earlier concrete curing age.

2.5.10 Removing of Re-shores or Backshores

Re-shores and backshores can be removed after the supported slab or member has attained sufficient strength to support all loads transferred to

it. Removal of re-shores or backshores must be carried out with care to avoid subjecting the structure to impact loads.

2-5-11 Repairing and/or Reusing Formwork

Reuse of concrete formwork is a key for economic formwork construction. After only five reuses, formwork materials costs drop to 40 percent of the initial cost. Formwork elements must be handled with care and should not be dropped. After repairing, cleaning, and oiling, the used formwork elements should either be stockpiled for future use or reused in other areas. Before reusing formwork elements, they should be inspected for damage. Defects on the inside face must be repaired or removed; otherwise they will reflect on the finished surface of the concrete to show the same defect.

2.6 Considerations for Multistory Construction

Formwork loads in multistory construction are sometimes transferred by shores and re-shores to the floors below. The shores directly support the slab forms and carry the loads to the level below. When the shores are removed from the slab and the slab forms are stripped, new shores are placed under that slab. These new shores are called re-shores. The re-shores transfer additional loads applied to the floor slab directly to the level below. The loads in the shores and re-shores from the slab may be carried all the way to the ground when the building is only a few stories high or when work on a taller building is still only a few levels above the ground. Otherwise, the loads have to be supported by the lower floors of the building. Depending on the speed of the construction, the loads may be imposed on floors that have not yet reached their full design strength. This under strength, due to lack of curing time combined with the possibility that loads from several floors above may be applied to the

floor, can create dangerous overloads or even failures. Most of the failures of concrete buildings occur during the construction phase (Chen and Mosallam, 1991). To avoid a disastrous accident during the construction of a multistory building, careful analysis should be made of the loads in the forms, the shores, the re-shores, and the concrete floor systems for each step in the building process. According to ACI Committee 347, the structure's capacity

to carry these construction loads should be reviewed or approved by the structural engineer. The plan for the forms and shoring remain the responsibility of the contractor.

The basic method for ensuring that loads applied to any floor level in the building do not exceed that floor's capacity is to use as many levels of shores and re-shores as necessary to distribute the loads. With this system, the loads can either be carried through all levels to the ground below, or when the building has too many levels to make that arrangement practical, the latest-applied loads can be distributed through the shores and re-shores to several floors simultaneously, so that no one level has a load that exceeds its capacity. The ability of any floor to support construction loads depends on the service capacity the floor was designed to carry as well as the age of the concrete when the construction loads are applied. Because the service capacity is based on the specified minimum 28-day strength, the floor capacity prior to the concrete reaching that strength will be less than this service capacity.

When preparing a forming system for multistory buildings, the sizes and specifications for the forming elements must be selected and the schedule for when the forms will be erected and stripped must be carefully prepared. In planning this kind of system and its schedule of use, consider the following:

- The dead load of the concrete and reinforcing, and the dead load of the forms when significant
- The construction live loads (workers, equipment, storage of materials) .
- Design strength of concrete specified.
- Cycle time for placing of floors of building.
- Structural design load for the floor element supporting construction loads (slab, beam, girder, etc.) — include all loads the engineer designed the slab to carry.
- The rate at which the concrete will gain strength under job conditions — use to find the strength of the concrete when loads are applied to it .
- The way the loads applied at the different levels are distributed to the floors at the different levels by the elements of the form system .

Because of the complex ways the elements of forms for multistory buildings interact with the building elements, and because these interactions may change from one building to another (due to cycle times, concrete properties, weather, different ratios of dead-to-live loads, and many other variables), no single method or procedure for forming and shoring will be satisfactory for all projects.

2.7 Loading of vertical formwork

Vertical formwork is used for strip foundations, concrete walls and columns. Immediately after placement in the formwork until achievement of its inherent stability, the concrete mix, under the effect of its own load and of compaction by vibration, exerts lateral pressure on the formwork which is called lateral pressure of the concrete mix.

The lateral pressure of the concrete mix depends on the following factors:

- ❖ Composition and properties of the concrete mix (density, type of cement, quality of Concrete),
- ❖ Concrete placing technology (concreting speed, compaction, vibration depth, total height of the concrete mix)
- ❖ Ambient conditions (temperature, air humidity).
- ❖ Tie wires (tie rods) are used to take up the lateral pressure of the concrete mix. They are to be included in the formwork project.
- ❖ The maximum lateral load with external vibration occurs at the foot of the formwork and with internal vibration above the foot.
- ❖ In addition to the lateral pressure of the concrete mix, the concrete mix also produces buoyant forces which may cause lifting of the formwork. This can be the case particularly with foundation formwork. To avoid this, the formwork is to be anchored in the subsoil.

2.8 Loading of horizontal formwork

Horizontal formwork is used for ceilings and beams. Horizontal formwork is subjects to vertical loads which are to be carried off to solid sub soils through formwork bearers and main bearers as well as columns.

Vertical loads are produced by:

- ❖ The concrete mix weight in the specified height,
- ❖ Reinforcements,
- ❖ Concrete cones on the concrete pouring spot,
- ❖ Concrete pouring impact on the formwork,
- ❖ Persons and working tools,
- ❖ Dead load of the formwork.

In addition to vertical loads, there are also horizontal loads which are produced by:

- ❖ Wind effects
- ❖ Inclined position of columns,
- ❖ Backing up, etc.

The horizontal forces are taken up by auxiliary structures, such as braces and struts, or rigid connection to existing structural components, such as walls and columns.

2.9 Construction Process

A typical construction cycle for a shoring scheme using both shores and re-shores as described by Gross and Lew (1984) is performed in four repeated basic operations:

1. Install a story of shores and forms and place the fresh concrete.
2. Remove the re-shores from the lowest re-shored level.
3. Remove the forms and shores from the lowest shored level.
4. Place the re-shores under the slab, which forms and shores were just removed- According to the AC1 Standard 347-94R (1994). the re-shores should be installed snugly under the slab just stripped Therefore, the re-shores carry no load when they are first placed The above four operations are used for shoring system using shores and re-shores.

However, in the case of using shores only, the second and fourth operations are eliminated.

There are numerous construction procedures for multistory concrete buildings; two of them are most commonly used (Mosallam and Chen, 1991). Both essentially repeat the above four basic operations. but in different sequence. In the first procedure, the freshly placed concrete is always supported by two levels of shores and one level of re-shores. The second is similar to the first except the use of shores rather than re-shores in the

lowest level. Mosallam and Chen (1991) summarize these procedures in ten steps, as follows:

2.9.1 Two levels of shores and one level of re-shores

- Step 1:** Place the first level of concrete slab.
- Step 2:** Place the second level of concrete slab.
- Step 3:** Remove the shores under first level of concrete slab.
- Step 4:** Place the re-shores under first level of concrete slab.
- Step 5:** Place the third level of concrete slab.
- Step 6:** Remove the re-shores under first level of concrete slab.
- Step 7:** Remove the shores under second level of concrete slab.
- Step 8:** Place the re-shores under second level of concrete slab.
- Step 9:** Place the fourth level of concrete slab.
- Step 10:** Remove the re-shores under second level of concrete slab.

2.9.2 Three Levels of Shores

- Step 1:** Place the first level of concrete slab.
- Step 2:** Place the second level of concrete slab.
- Step 3:** Place the third level of concrete slab.
- Step 4:** Remove the shores under first level of concrete slab.
- Step 5:** Place the forth level of concrete slab.
- Step 6:** Remove the shores under second level of concrete slab.
- Step 7:** Place the fifth level of concrete slab.
- Step 8:** Remove the shores under third level of concrete slab.
- Step 9:** Place the sixth level of concrete slab.
- Step 10:** Remove the shores under fourth level of concrete slab.

Appendix (A1) illustrates the procedure described above in the two cases. Steps 5 to 8 of construction procedure consisting of two levels of shores and one level of re-shores has been chosen to illustrate the four basic

construction operations. The configuration of Step 5 is shown in Appendix (A1) in which level 3 is king placed the construction load is distributed among the interconnected slabs through the shoring system. Since the concrete has no strength initially, a small value for the modulus of elasticity of the newly placed concrete slab ($E_c = 4700\sqrt{f'_c}$ MPa) (ACI Codes in SI units) assumed in the analysis.

In Appendix (A2) the removal of re-shores under level 1, Step 6, this removal is equivalent to applying a load to the first level slab, in a downward direction, which is equal to the compressive force in the re-shores prior to their removal. And shows the removal of shores under level 2, Step 7. The equivalent compressive forces in those shores prior to their removal are applied to the interconnected slabs above and below the vacated story. Installation of the re-shores under level 2, Step 8, In this operation the re-shores are snugly placed with no structural disturbance to the system.