AN ANALYTICAL STUDY OF PROJECT MANAGEMENT CHALLENGES IN UTILIZATION OF PROPRIETARY FORMWORK SYSTEMS IN HIGH RISE BUILDING CONSTRUCTION IN SRI LANKA

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Dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science in Project Management

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DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best my knowledge and belief, it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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ABSTRACT

An Analytical Study of Project Management Challenges in Utilization of Proprietary Formwork Systems in High Rise Building Construction in Sri Lanka

Selection of a formwork system for construction projects is mainly based on the individuals' experience which may not be the optimum. Since, best possible way to gear up the work is achieving the shortest possible floor cycle in typical floor construction, this directly depends on the type of the formwork selected.

This research, therefore, aims to analyze the project management challenges in utilization of proprietary formwork systems in high rise building construction in Sri Lanka. To fulfill the aim of the research several objectives of the research are formulated. They are to, identify adoptable forming systems in high rise construction, influential factors impact the Project Management in the selection of a proprietary formwork system, proprietary formwork systems available and their limitations, and develop a guideline for selection of a proprietary formwork system to ensure quality management in construction projects.

To fulfil the research objectives, based on the comprehensive review of the literature a theoretical framework is hypothesized by identifying the influential factors discussed, and an online survey on Conventional and Proprietary formwork systems has been carried out among project managers in the construction industry to identify most influential factors in the selection process of a proprietary formwork system.

The results indicated that the systematic erection of formwork will definitely reduce the time and cost respect to conventional method. As the structures in high rise construction projects are complex and designed as precise, concrete fair face finishers are a major requirement of a system formwork as the finishing details are the governing factors. Therefore, it is very conclusive that the selection of a system formwork is highly based on the reusability of the system within the project and the speed of work. Thus, the outcomes of this process are useful to decision makers to use as a framework to assist in selecting the most appropriate formwork system.

Keywords: *Formwork Systems, High Rise Buildings, Proprietary formwork systems.*

DEDICATION

I would like to dedicate

This piece of work first & foremost,

To my Parents and the Family,

Whose affection, love, encouragement

And prays of day & night make me able to

Get such success and honor,

And teachers, who taught me

To think, understand and express.

I earnestly feel that without their inspiration,

Able guidance and dedication I would not be able

To pass through the tiring process of this research

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LIST OF ABBREVIATIONS

BIM	–	Building Information Modeling
CPM	–	Critical Path Monitoring
LOB	–	Line of Balance
MEP	–	Mechanical, Electrical and Plumbing
RII	–	Relative Importance Index
4D	–	Four Dimensional
ISO	–	Institute of Standards Organization

CHAPTER ONE

INTRODUCTION

1.1 Research Background

Formwork system is the most important factor that impacts the project management, determining the project success, especially in high-rise buildings in terms of speed, cost, quality and safety of the work as it constitutes fairly large amount of the total construction cost of the structure. The selection of a formwork system for a project is mainly influenced by the building design, site constraints, contractors' experiences with different systems as well as the availability.

1.1.1 Formwork systems

The advancement of formwork systems have been parally grown up with the growth of concrete construction technology. The advancement of technology, increase of population and the space limitation lead the way to construct high-rise buildings (Pawar and Atterde 2014) by inventing new machinery and new techniques.

The type of the formwork used in a construction project plays a major role in terms of the cost, quality and speed. Selection / design of a formwork system for a project is influenced by the building design, site constraints, the contractor's experience with different systems, and its availability (Hanna and Willenbrock 1992). Since, this basically depends on an individual's experience, it may not be the optimum system.

The life cycle of any concrete building passes through several basic stages such as, conceptual and feasibility studies, design, estimating, scheduling, construction, and finally the occupancy, operation and maintenance. The second stage, design and engineering have a distinct difference between design and engineering. Design may be defined as the process during which the concept or idea is developed, refined, and implemented into detailed instructions. On the other hand, engineering is defined as the process during which the elements' shape and size (dimensions) are determined and the formwork system selection is being done during the design process.

1.1.2 Effect of formworks on the repetitive nature

The repetitiveness of multiple activities on the construction site is the nature of a high-rise building construction. It is project manager's responsibility in deciding on the most suitable formwork system in order to maintain the continuity of workflow, control labor and equipment idle times and reduce the hired machinery costs (Ranjbaran, 2007), which are the benefits of being a high rise building. The simultaneous repetitiveness in vertical and horizontal directions may create many constraints to the execution of the work (Thabet and Beliveau, 1994). In order to overcome from such constraints, researchers and stakeholders had to develop solutions for execution of tasks under such restrictions. Since the difficulties in adapting to the critical path monitoring (CPM) method to schedule repetitive tasks were investigated in several studies (Reda, 1990; Hegazy and Wassef, 2001), created the other scheduling techniques using the Line of Balance (LOB) method. LOB method permits on site operations in continuous flow from one activity to another by balancing different resources and tasks concurrently (Hegazy, 2002). By the present day, many researchers have worked on combining both the CPM and LOB methods to enhance the scheduling in repetitive construction (Suhail and Neale, 1994), others have used Four Dimensional (4D) modeling techniques provided by Building Information Modeling (BIM) technologies to streamline the construction sequence and to avoid possible on-site clashes (Staub-French and Khanzode, 2007).

Therefore, the effect of formwork system plays very vital role in high rise building constructions.

1.1.3 Definition of a formwork system

Formwork system is a mould used in the construction of a structure where, fresh concrete is placed only up to concrete get hardened. Shutters or forms are the other common terms used for this made up sections.

1.1.4 Economical selection of a formwork system

The main purpose of selecting a formwork system is to reduce the construction cost. Proper selection as well as planning of the formwork system may reduce to construction cost great extent since cost of formwork pays a remarkable amount of the total construction cost due to the incapability to reduce the construction cost of changing the well specified other building components.

In most reinforced concrete buildings, the contractor evaluates different schemes to get the optimum formwork system and achieves an efficient construction sequence. It is also possible to prepare the building forms on the job site by setting up an on site fabrication area or building forms in a central yard and transporting to the site. Choose between building, buying, or renting forms is also a valid consideration. A fair cost estimate for different schemes is required to determine which is most economical. The decision about whether to invest company funds in a particular system is always crucial. In the other hand, selecting of a suitable formwork system may also affect the construction time as well as the accumulation of waste by reducing the total construction cost. Therefore, it is a good practice to choose a suitable system of formwork for construction work.

1.1.5 Types of formwork systems

Structural works are the main framework of the any construction project. They set the ladder of the other downstream architectural, Mechanical, Electrical and Plumbing (MEP) discipline activities. Therefore, in order to keep up the project on schedule, execution of on-time and continuous structural framing is deemed essential (www.masterbuilder.co.in). With an adequate amount of labor and material, the choice of formwork systems are directly affects the progress of the constructions, and has a great influence to the interconnected works such as walls, shafts, and slabs where many other works of different fields are involved. Another factor affects the progress of the construction work is the quality of the cured concrete. Since, repair of concrete consumes a significant amount of time as well as it directly affects the speed and quality of finishing work, the quality of formwork system used and the provided tolerance range is deemed essential to ensure the progress of the work. Smaller tolerance ranges of formwork systems may lead towards incorporation of prefabricated systems and also the remote assembly that can speed up the construction activities.

1.1.6 General parameters in formwork selection

An innovative formwork technology is required for modern day high–rise building construction works to challenge with the limitations of space, budget, and time. Even though, many researchers have introduced several parameters which affect the selection of formwork systems, as shown in Table 1.1 (Gnida, 2010) those have mainly divided into two categories as internal and external parameters seems to be valuable. Here, internal parameters compliance under the designers and the contractor's responsibilities and the external parameters are compliances under the owner requirements, project milestones and location, corresponding local rules and regulations.

Table 1.1: Internal and External parameters of the selection of formwork system (Ginda, 2010)

Internal Parameters	**Limitations affect the choice of Formwork Systems**
Geometry	Repetitive
	Simple / Complex
	Changing Geometry
Concrete	Pouring Rate / Pressure of Concrete
	Concrete Finish
	Curing Time
Sequence of Work	Cycle Time
Formwork Choice	Existing Formwork material to be Reused
	Rental or Purchase
	Best Value for Current Project VS Flexibility for Future Projects
Space	Constraint of Existing Road or Building
	Storage Area
	Assembly Area

Internal Parameters	Limitations affect the choice of Formwork Systems
Wind	Wind Load
Crane	Capacity
	Availability
Safety	Special Requirements Needed
Construction Planning	Milestones
	Working Schedules / Shifts
	Project Duration
	Holidays
Local Rules and Regulations	Permits
	Restricted Noise
	Safety Requirements

Another study has also been carried out for the formwork system selection based on the height of the building and the weather conditions in Figure 1.1 (Ciribini and Tramajoni 2010), which presents another option for formwork selection based on different height ranges depending on the good or bad weather conditions deemed effective in the selection of a suitable formwork system.

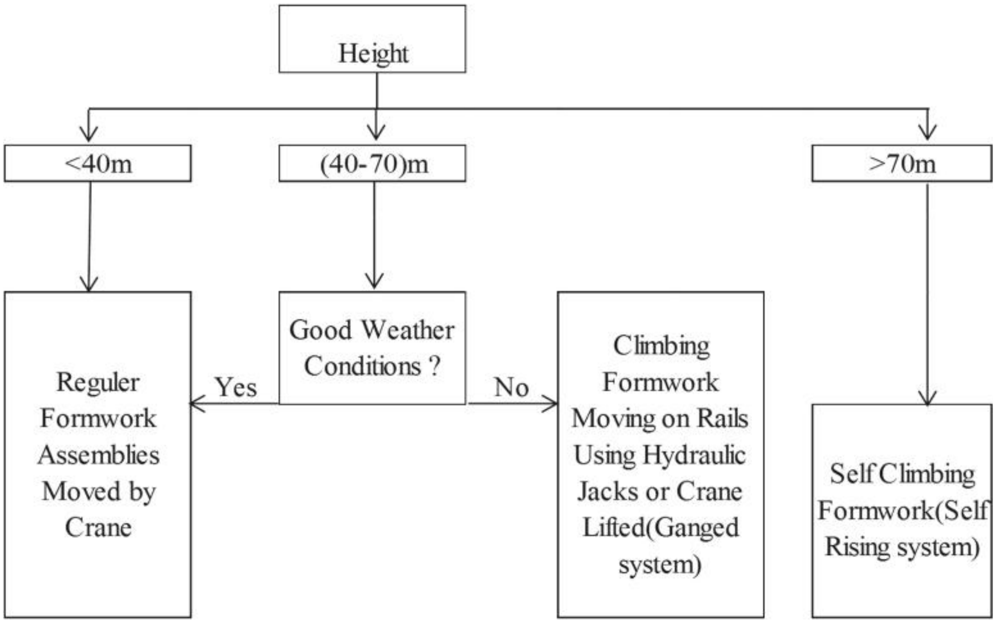


Figure1.1: Selection of formwork based on the Building Height and weather conditions (Ciribini and Tramajoni 2010)

1.1.7 Influences of formwork systems on safe work environment

Safety is the biggest challenge in high rise construction projects. Sines, an injury caused to a labor from a height due to an unsafe environment considered as the most serious cause of accident, this may adversely affect the progress of the project (Hinze and Russel, 1995; Huang and Hinze, 2003). Therefore, many researchers and stakeholders are continuously developing methods as well as tools to enhance safety standards of the construction projects. The work environment of the construction site is also affected by many factors contribute to the progress as well as the labor productivity. For example, noise creates a huge contribution to workers stress. Noise created due to the machines and equipment used and also due to space congestion may create hearing problems for site workers (Barkokébas et al., 2012). The height factor of a high-rise building is also an additional risk factor, since changes in height affect the workers' perception towards the danger as well as their response in hazardous situations (Hsu et al., 2008). Therefore, safety measures may also thoroughly considered during the selection and design stage of formwork.

1.2 Motivation for the Research

At present day, most construction projects in Sri Lanka are high rise buildings. So Achieving the shortest possible floor cycle in the typical floor construction is the most effective way to speed up the work. Therefore, formwork systems are playing the main role in determining the success of a building construction project in terms of speed, cost, quality and safety.

Such type of acceleration can be easily achieved even in the Sri Lankan construction industry by the means of six to seven day cycles even for buildings having floor areas up to 3,000 square meters. Since, the present days building construction work are very complex in terms of scale, structural and architectural design, building services and many other facilities requirements, use of an efficient and appropriately designed formwork system is very essential. Therefore, the major challenges that the project management faced during the design and utilization of the most effective formwork system, as well as an effective resource planning strategy implementation in the use of the formwork are very conclusive for the success of a construction project.

Targeting only on the speed may also contradict the achievement of other quality aspects. Misalignment, misplacement, deflective concrete and delaying of other works could be the serious interruptions to the end result. Therefore, motivation for undertaking this research is to carry out a comprehensive literature and a documentary survey of proprietary formwork systems, including stakeholders and their relationships to identify and analyze the conditions and constraints in the selection and application of a formwork system and methods that the local construction industry can be adopted in the construction of various types of high-rise buildings.

1.3 Research Aim

To analyze the Project Management challenges faced during utilization of proprietary formwork systems in construction projects performances for the conventional formwork system in Sri Lanka.

1.4 Research Objectives

Purely aiming on the quality management in construction projects by implementing proprietary formwork systems for constructions,

- To identify the adoptable forming systems in high rise Building construction projects.
- To identify the most influential factors impact the Project Management in the selection of a proprietary formwork system to achieve higher quality output.
- To identify the proprietary formwork systems available in Sri Lanka.
- To identify the limitations in proprietary formwork systems used in the local construction industry.
- To develop a guideline for selection of a proprietary formwork system to ensure quality management in construction projects.

1.5 Methodology

In order to fulfill the first objective of this research, a comprehensive literature and documentary survey has been conducted on proprietary formwork systems, including stakeholders and their relationships. The literature has been reviewed from Technical

Specifications of various proprietary formwork suppliers, textbooks, research papers, journals and the Internet. The information sorted out with the conventional construction methods to identify the influential factors of proprietary formwork systems for the local construction field. The identified influential factors have been reviewed to discuss the impact on quality management aspects in construction projects.

Then, the information gathered from the Literature survey has been analyzed with relevant details of conventional scaffolding systems to recognize the advantages and dis-advantages of two different systems considering the enhancement of quality management. The identification of influential factors, issues of the existing strategies and quality management concerns on replacing the existing system has been explored by conducting unstructured interviews with resource people, Brainstorming sessions, analyzing manufacture's handbooks and statistical evaluations especially on quality management aspects and Time/Cost management aspects as well.

Finally, the identified influential factors and Conclusions of the evaluation has discussed to obtain a better understanding on advantages and dis-advantages of implementing a proprietary formwork system for the Construction Industry in Sri Lanka. The outcomes of the process are to be published to implement a framework which assists the decision making process of evaluating the validity and applicability of a proprietary formwork system for a particular construction site for a quality output.

1.6 Scope and Limitations

The study focuses on the salient issues involved in the selection of the most suitable formwork system for a high-rise building development with the intention of identifying most influential factors in the selection process of a proprietary formwork system over the conventional formwork. The factors collected and outlined the planning and design process as well as practical considerations that should be familiar with when selecting the system. The outcomes of the process will be implemented as a framework in the decision making process for evaluating the applicability of a system.

The research was limited only in Sri Lankan context. Consequently the framework was developed as applicable to Sri Lanka.

The guidelines presented are meant to provide a greater awareness and understanding of the use of the most suitable formwork system and they should not, however, be deemed as restrictions to either design creativity or to potential alternatives raised.

1.7 Chapter Breakdown

Chapter one of the report contains the background information regarding the research stating the formwork systems backgrounds of high rise building construction and its effects on the repetitive nature, definition, economical selection, types, general parameters in selecting and influences on safer work environment. Furthermore, it describes the motivation to the research, aims, objectives and the methodology of the research.

Chapter two contains the research methodology with a narration of the literature survey, research gap and an implementation of a questionnaire survey.

Chapter three presents a comprehensive review of forming systems including brief descriptions of different types of horizontal and vertical forming systems.

Chapter four presents a brief description of the factors impacts the Project Management in selecting the most suitable proprietary formwork systems, including design and construction related factors, specifications, affordability, local conditions as well as organizational aspects.

Chapter five describes the different types of proprietary formwork systems available in Sri Lanka with respect to their design and construction related factors, specifications, affordability, local conditions and organizational aspects.

Chapter six consists of the developed framework of an industrial survey of proprietary formwork systems to identify most influential factors for local conditions along with the results as well as the analysis.

Chapter seven consists of the conclusion and the recommendations.

CHAPTER TWO

METHODOLOGY

2.1 Introduction

The Research methodology is widely viewed as a systematic approach to addressing the research questions by collecting, analyzing and interpreting data (Hussey & Hussey, 1997). Selecting a suitable research methodology, however, depends on the nature of the research questions to be answered by the researchers (Creswell & Plano Clark, 2011). To facilitate the researcher, the research methodology proposes numerous research methods which can be employed for collecting, analyzing, and interpreting data (Creswell & Plano Clark, 2011). The method used to achieve the objectives is comprehensively described in this chapter.

2.2 Literature Survey

Basic information and knowledge on various research methodologies and their respective research methods are reviewed with the intention of identifying suitable research methodology for the research. The literature was based on the adoptable forming systems, hypothesized theoretical framework on factors impact the project management in selection, identifying the proprietary formwork systems locally available and their limitations.

2.3 Research Gap

The findings of the literature survey and the fourteen years work experience in the construction industry as a constructor as well as a consultant Engineer enabled to establish the research gap. The non-application of guideline for selection of a proprietary formwork system was thus established.

2.4 Questionnaire Survey

A questionnaire was prepared to cover the areas identified as the most influential factors that impact the project management in the selection of a proprietary formwork system in chapter four. Some direct questions as well as indirect questions were included in the questionnaire. Engineers involved in construction and project management were selected to administer the questionnaire survey as an online survey since, they are the most influenced and experienced people on the matter at the managerial level in the construction industry.

The participants of the questionnaire were requested to rate the importance (as Not relevant, Less influential, Influential, Highly influential & Extremely Influential) of following factors based on their knowledge and experiences.

- Design of Structural Elements
- Repetitiveness of the Layout
- Concrete Surfaces finish
- Reusability of the system
- Accessibility to construction site
- Initial cost of the formwork system
- Technical skills and Knowledge
- Weather Conditions
- Availability of labour in the area
- Complexity of the project
- Possibilities of modifications
- Accuracy in construction
- Economy in construction
- The shape of the Building/Structure
- Magnitude of the building
- Speed of work
- Head room & spans of the building
- Requirement of machineries
- Maintaining & Repairing costs
- Safety measures
- Capacity of the Contractor Organization
- Product availability from manufacture
- Buy back opportunity
- Wastage of formwork material
- Resistance to earthquake

The participants' responses were rated according to following rating system to convert the responses into an analytical

- 1 point – Not relevant
- 2 Points – Less Influential
- 3 Points –Influential
- 4 Points – Highly Influential
- 5 Points – Extremely Influential

The analysis was carried out using Relative importance index method and the scores assigned to each factor by the respondents were entered and consequently the responses from the 38 questionnaires were subjected to statistical analysis for further insight.

The contribution of each of the factors for the selection of a proprietary formwork system was examined and the ranking of the attributes in terms of their criticality as perceived by the respondents was done by use of the Relative Importance Index (RII) which was computed using the following equation.

$$\boldsymbol{RII} = \frac{\sum \boldsymbol{W}}{\boldsymbol{W\,A * N}} \quad (\mathbf{0} \leq \boldsymbol{RII} \leq \mathbf{1})$$

Where:

W – Is the weight given to each factor by the respondents and ranges from 1 to 5, (where “1” is “Not relevant” and “5” is “Extremely Influential”);

WA – Is the highest weight (i.e. 5 in this case);

N – Is the total number of respondents.

Collected data were analyzed by using statistical and graphical methods. The contribution of each of the influential factors was identified in the analysis and ranked by the use of RII. Based on the analysis 15 most influential factors were discussed in the conclusion and recommendation chapter. The graphical representation of research methodology has been given in figure 2.1

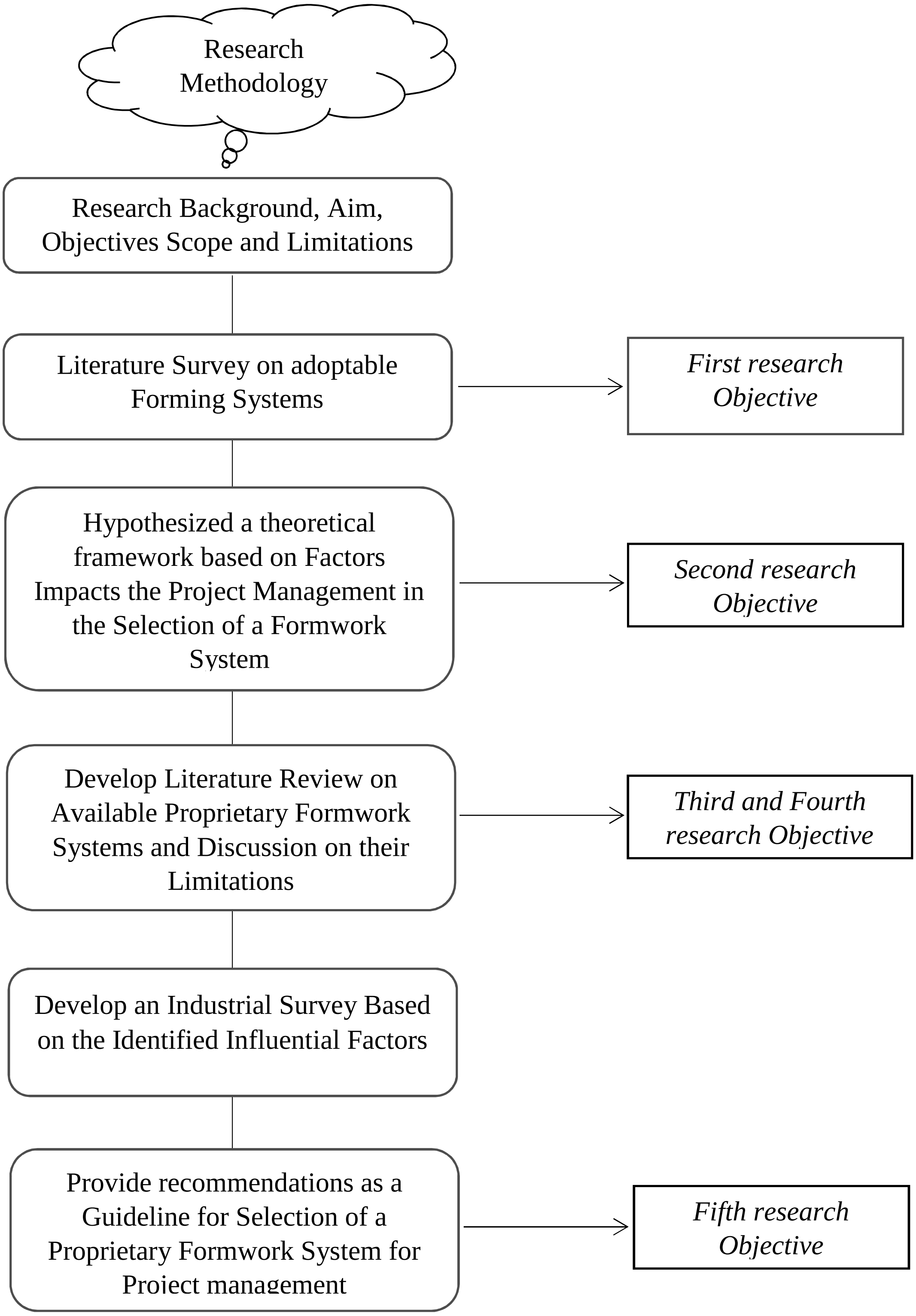


Figure 2.1: An Overview of the Research Methodology

CHAPTER THREE

FORMING SYSTEMS

3.1 Forming Systems

There are several ways to form any given concrete building. One of them will typically be the lowest cost method. Selecting the lowest cost method of forming requires searching through a maze of forming systems and their attributes. A brief description of the forming systems currently used for different structural elements will be discussed as follows.

3.2 Horizontal Forming Systems

The system of formwork used to temporarily support the horizontal concrete work is defined as a horizontal formwork system. The seven horizontal forming system types which can be used for different types of slabs are discussed as follows.

- Conventional wood systems (stick forms)
- Conventional metal systems (improved stick forms)
- Flying truss systems
- Column mounted shoring systems
- Tunnel forming systems
- Joist-slab forming systems
- Dome forming systems

Joist-slab and dome forming systems are of steel or fiberglass light weight panel system used to place above the plywood sheathing and this can be used with the help of first five horizontal formwork systems listed above (Hanna 1998). Crane set systems and hand set systems are the other way of classification of horizontal forming systems (Hanna 1998). Conventional wood systems and conventional metal systems are examples of handset systems due to the handling ability of different formwork elements with lesser labour force (Hanna 1998). On the other hand flying formwork systems, column-mounted shoring systems, and tunnel formwork are the examples for crane-set systems (Hanna 1998) due to the requirement of a suitable crane service to handle formwork components. A detailed discussion of each forming system as follows.

3.2.1 Conventional wood systems

The system also referred as the stick form system which is used as a formwork for slabs, beams, and foundations are generally built of lumber, plywood and a combination of lumber and plywood (Hanna and Sanvido 1989). The pieces of the formwork are basically made and erected in situ and stripped piece by piece. Once cleaned and stacked properly, can be reused in a few times. Figure 3.1 (Hanna and Sanvido 1989) shows the conventional wood system, wood stringers and joists supported by shores with a plywood deck surface. The deck may also be made of large panels tied or ganged together and supported by scaffold-type shoring.

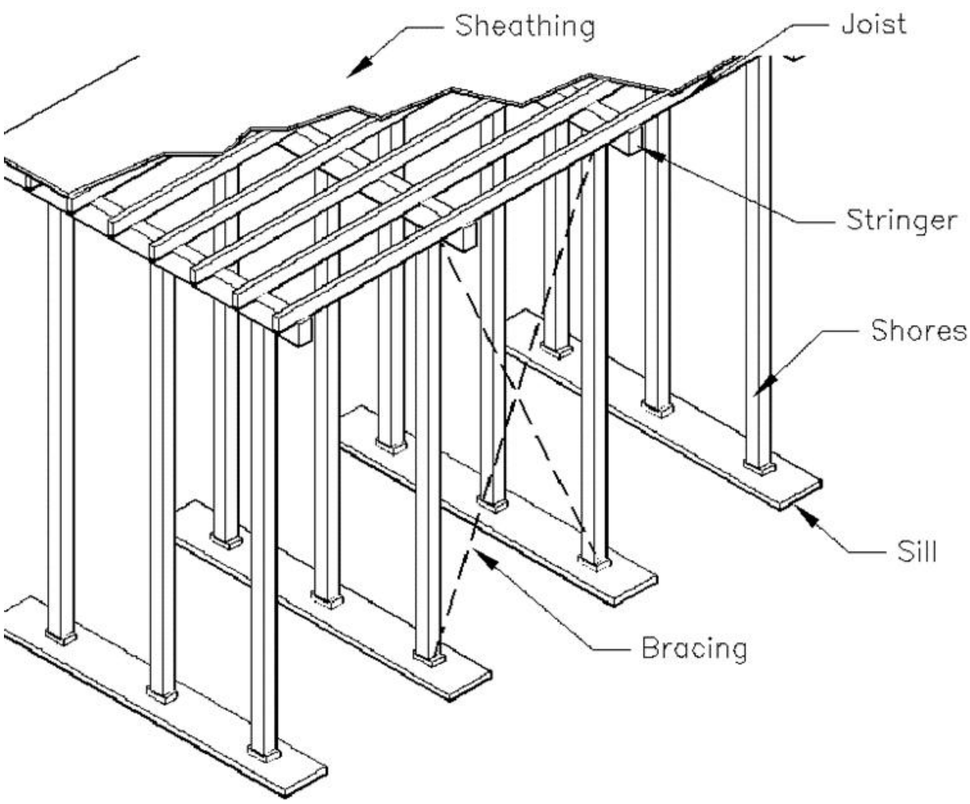


Figure 3.1: Conventional Wood Systems (Hanna and Sanvido 1989)

3.2.2 Conventional metal systems

Conventional aluminum systems may be either handset or paneled. Handset systems constitute the aluminum stringers and joists supported by the wood or aluminum shores with a plywood deck surface (Figure 3.2 (Hanna and Sanvido 1989)). The deck may also be made of large panels tied or ganged together and supported by scaffold type movable shoring system.

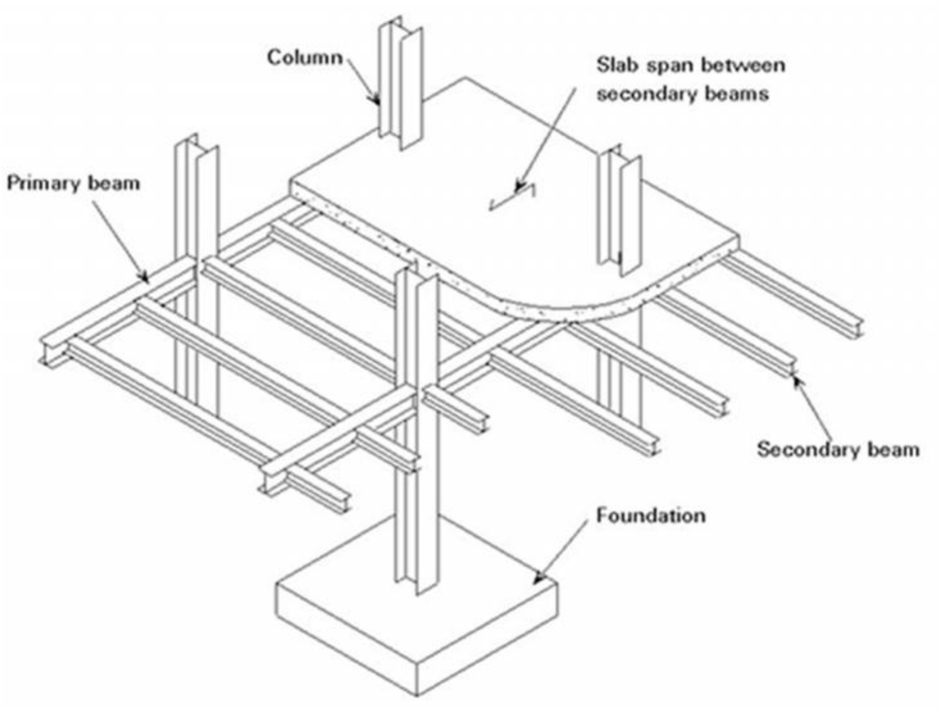
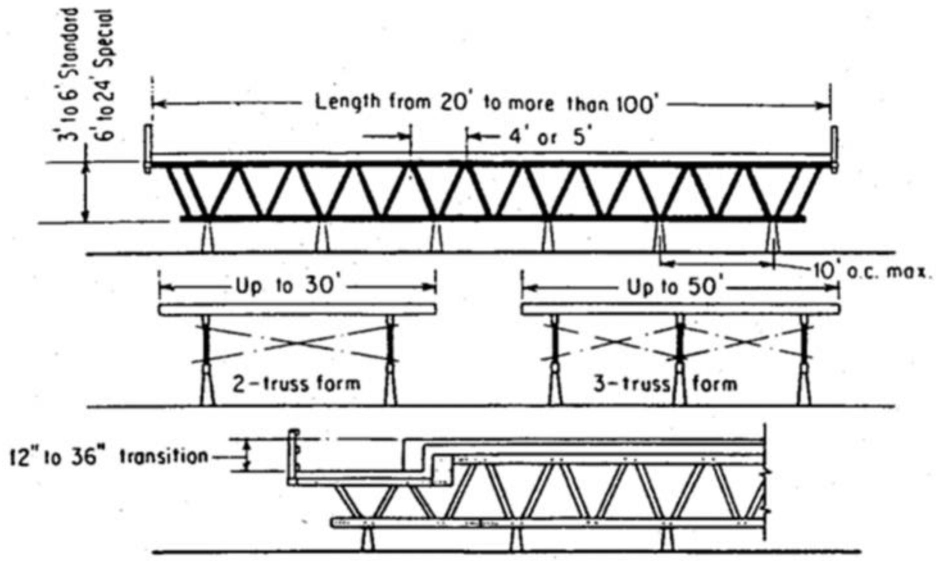


Figure 3.2: Conventional Metal Systems (Hanna and Sanvido 1989)

3.2.3 Flying truss systems

Flying truss forms are of large sheathing panels supported by steel or aluminum trusses supported by screw jacks which allow forms to be adjusted to the right level as shown in Figure 3.3 (Hanna and Sanvido 1989). Stripping of the formwork can be done by lowering down the trusses from the slab by turning down the jacks after the concrete has gained its strength (Hanna and Sanvido 1989). Thereafter, the truss mounted form system can be moved by the use of the crane to the next location.



Representation of Flying Truss System

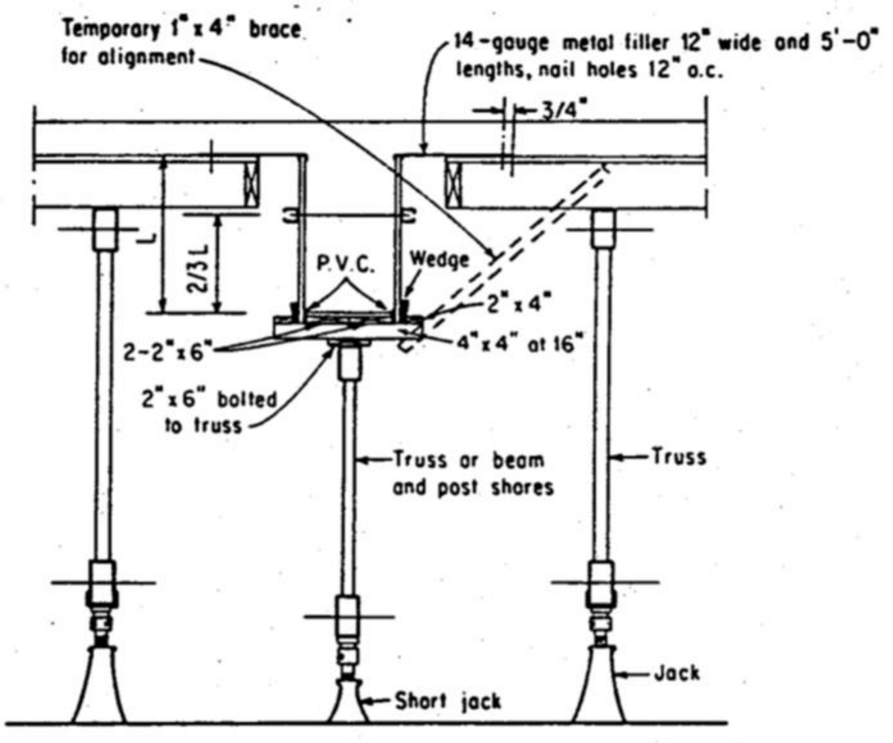


Figure 3.3: Flying Truss Systems (Hanna and Sanvido 1989)

3.2.4 Column-mounted shoring systems

Generally, formwork under cast-in-place slabs has been supported by shores resting on the floor or below ground. Up and down adjustable brackets were attached to the load bearing walls with the use of the long span of the building to support the formwork panels since, itself is the other way to cast the slab without using the shoring system (Hanna and Sanvido 1989).

The plywood decking system can be assembled on the ground or in place, after fixing on the columns shown in Figure 3.4 (http://sciglobal.com/25k3.php). Plywood decking is supported by joists (headers) attached to the stringers (steel beams). For stripping, jacks are lowered until the framing beam of the deck rests on the rollers attached to the bracket (Hanna and Sanvido 1989). The entire frame assembly is then rolled out and carried by crane to the next floor.

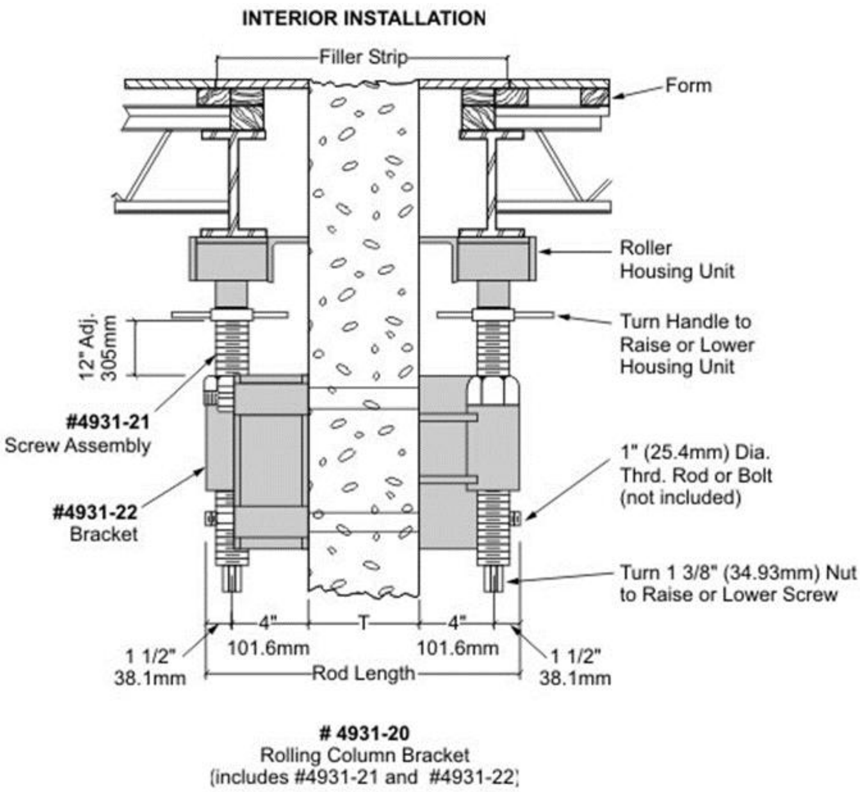
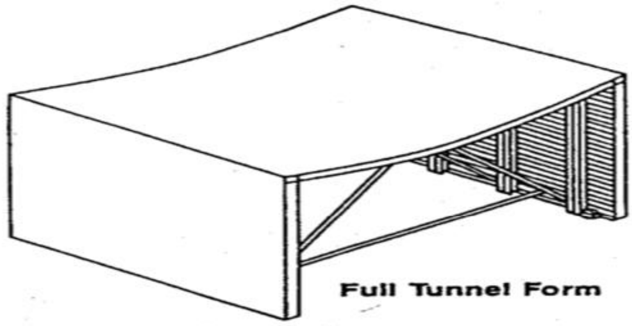


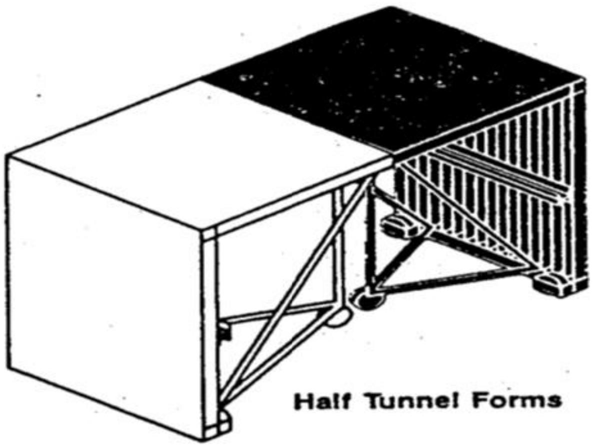
Fig.3.4: Column-Mounted Shoring Systems (http://sciglobal.com/25k3.php)

3.2.5 Tunnel forming systems

The system is V-shaped or inverted L-shaped steel formwork and capable of casting both the slab and supporting walls at the same time (Figure 3.5 (a) (Hanna and Sanvido 1989)). The tunnels will be collapsed for stripping, after the concrete gained the required strength and will be moved to the next position (Figure 3.5 (b) (Hanna and Sanvido 1989)). Full tunnels are used for narrow room spanning and half tunnels are used for wide rooms spanning (Hanna and Sanvido 1989).

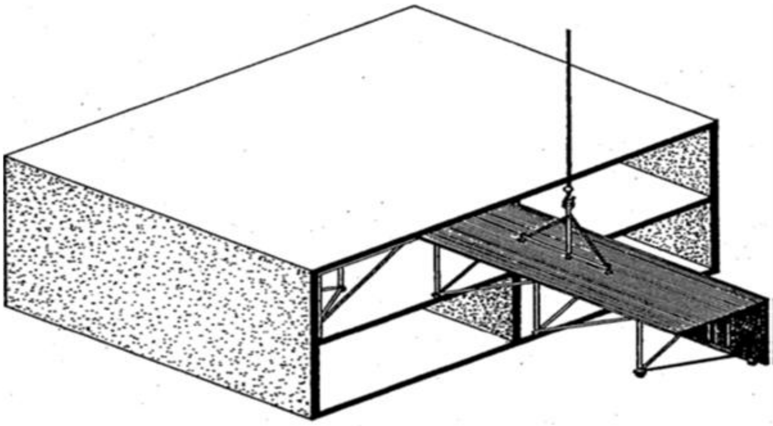


Full Tunnel Form



Half Tunnel Form

(a) U or L Shape Tunnel Forms



(b) Stripping of Half Tunnel Form

Figure 3.5: Tunnel Forming Systems (Hanna and Sanvido 1989)

3.2.6 Joist-slab forming systems

The system is a monolithic combination of equally spaced joists, placed in one direction facilitating the slab to be cast as a single unit with the beams and columns (Figure 3.6 (a) (Hanna and Sanvido 1989)). The slabs may be formed as standard steel spans as well as plywood forms. Table 3.1 (Hanna and Sanvido 1989) presents a comprehensive expression of the dimensions of the standard form spans and the special fillers with respect to the module sizes for one way joist construction.

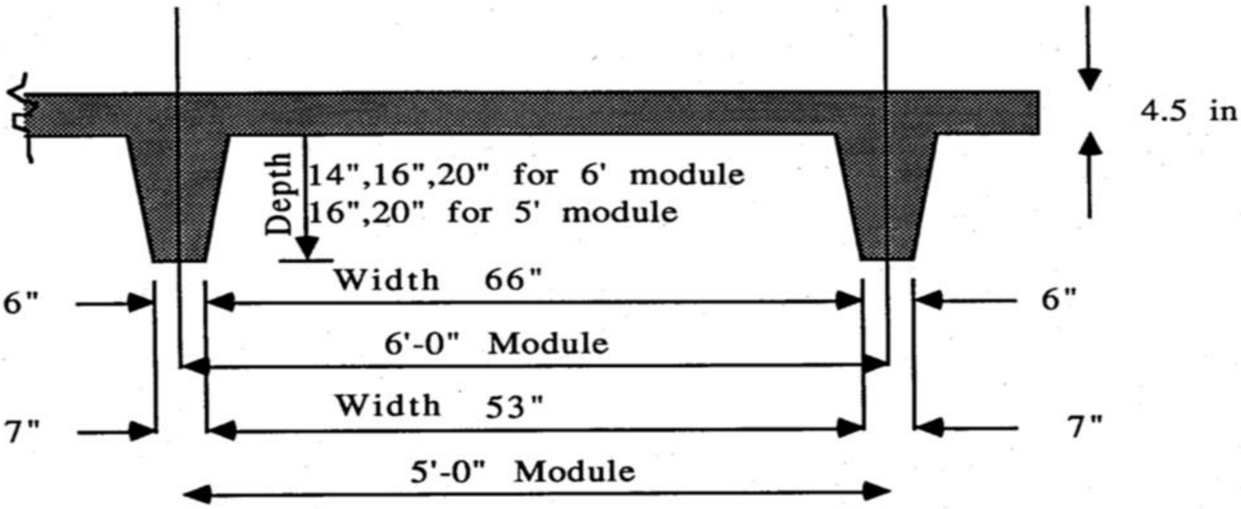


Figure 3.6 (a): Typical Wide-Module Joist Slab Systems (Hanna and Sanvido 1989)

Table 3.1: Dimensions of Forms for One Way Joist Construction
(Hanna and Sanvido 1989) (All dimensions in inches)

Module	Standard Forms		Special Filler Forms	
	Width	Depth	Width	Depth
2'	20	8, 10, 12	10, 15	8, 10, 12
3'	30	8, 10, 12, 14, 16, 20	10, 15, 20	8, 10, 12, 14, 16, 20
4'	40	12, 14, 16, 18, 20, 22, 24	20, 30	12, 14, 16, 18, 20, 22, 24
5'	53	16, 20	-	-
6'	66	14, 16, 20	-	-

3.2.7 Dome forming systems

Dome forming systems are basically used for waffle slab construction and are based on two, three, four, and five feet standard modules. The two feet size modules utilize 19 x 19 inches domes, with 5 inches ribs between them, and the 3-feet size modules can be formed with 30 x 30inches domes and 6inches ribs (Hanna and Sanvido 1989). Figure 3.6(b) (Hanna and Sanvido 1989) presents standard modules commonly used for waffle slab construction.

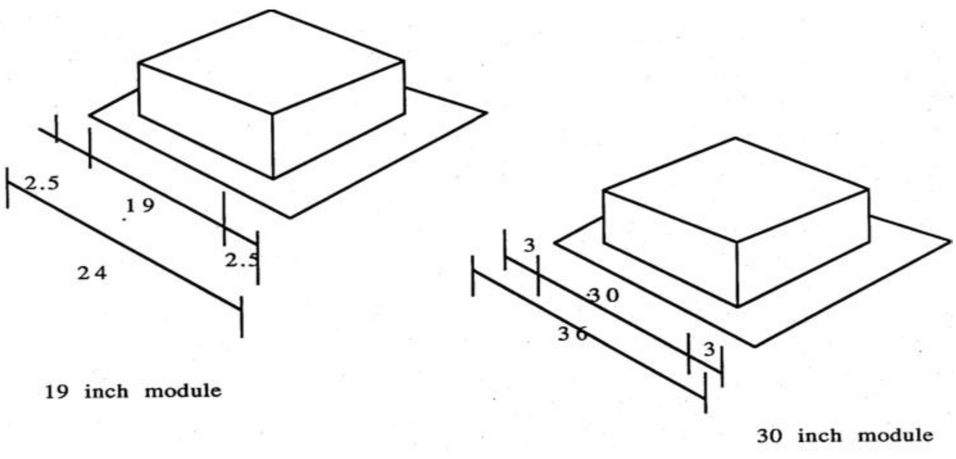


Figure 3.6 (b): Dome Form for Waffle Slab (Hanna and Sanvido 1989)

3.3 Vertical Forming Systems

The forming systems used to support vertical elements of the structure (columns, core walls, and shear walls) defined as a vertical forming system. Its basic functions are to resist the lateral wind and earthquake loads and to transfer the floor loads to the foundation (Hanna and Sanvido 1989). Conventional formwork, ganged forms, jump forms, slip forms, and self-raising forms are the most commonly used vertical formwork systems in local construction industry. Vertical forming systems can be further classified as crane independent systems and crane dependent systems (Hanna and Sanvido 1989). Self-raising and slip forms are categorized as crane independent systems as well as the gang formwork and jump forms are categorized as crane-dependent systems (Hanna and Sanvido 1989). In crane independent systems, formwork panels are vertically moved by the use of other vertical transportation methods.

3.3.1 Conventional wall forming systems

Forming systems consist of plywood sheeting or lumber that capable of retaining concrete until it reaches the required strength is known as wood forming system (Hanna and Sanvido 1989). It is also known as job-built wood system. The system could also be either conventional or wooden system forming method. Vertical wooden studs are used to support the sheathing. Horizontal wales are used for forms and as a support for the wooden studs as well. Single or double type horizontal wales are commonly used to support the wooden studs as shown in Figure 3.7 (Hanna 1998).

However, double wales are preferred to single wales, which may refrain from drilling the single wales (Hanna and Sanvido 1989). Use of the inclined bracing system is to withstand the system from possible adverse construction and wind loading effects (Hanna and Sanvido 1989).

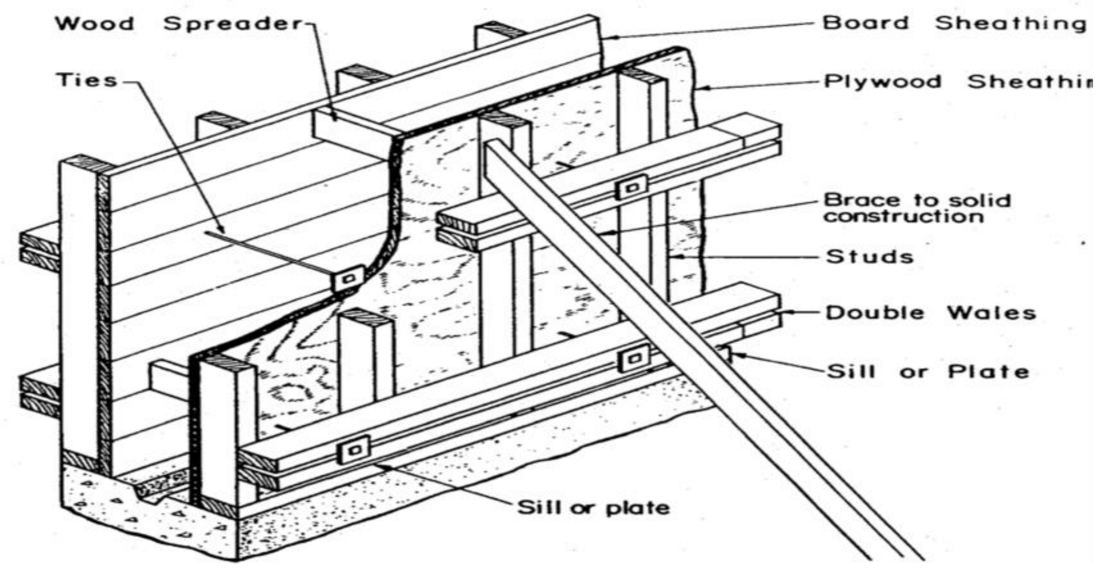


Figure 3.7: Conventional Wall Systems (Hanna 1998)

3.3.2 Ganged forming systems

The system is made by jointing large panels and braced with steel or aluminum frames or high strength backs. These on ground assembled are placed in position by the use of cranes. In taller wall construction, these panels are raised to the next position by the means of a crane. Figure 3.8 (http://secure.moonfruit.com) shows some of the standard ganged forms available for contractors. Preciseness of dimensions and higher reusability are the main advantages of manufactured forms over site made forms (Hanna and Sanvido 1989).

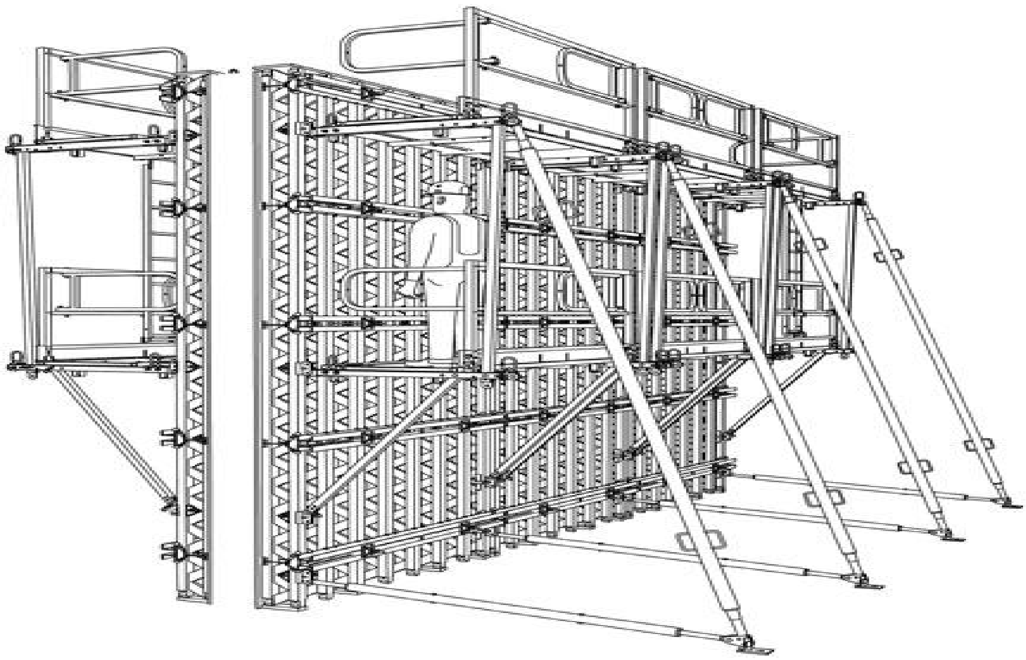
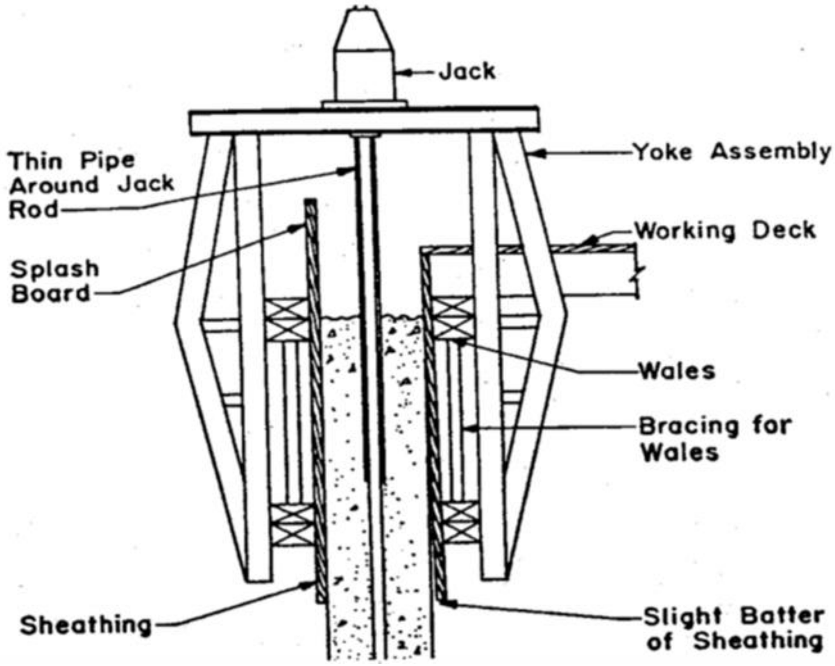


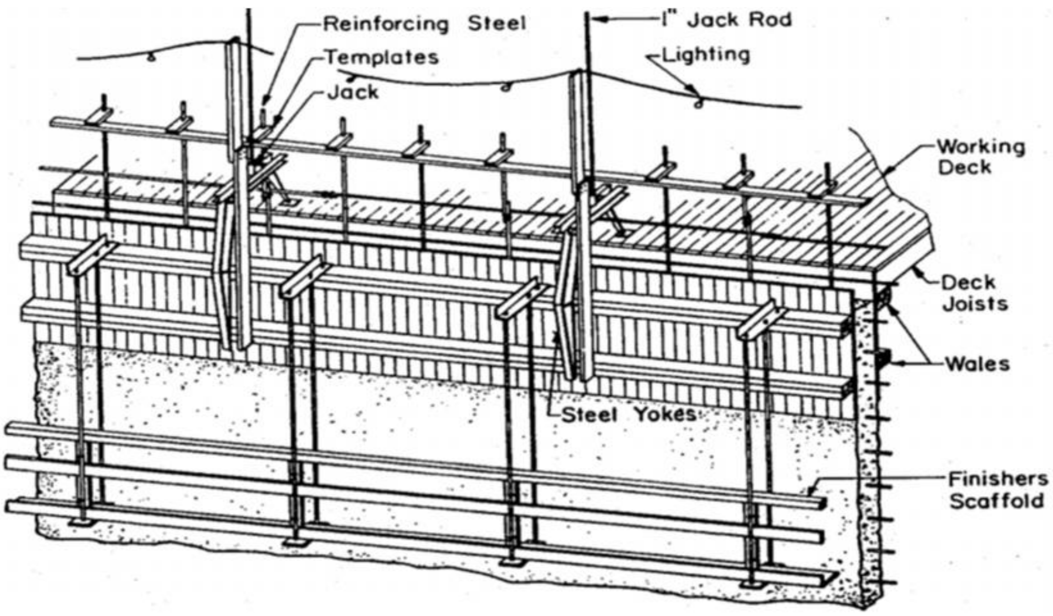
Figure 3.8: Standard Ganged Forms (http://secure.moonfruit.com)

3.3.3 Slip forming systems

Slip forming system is usually used to cast structural cores consist of inner and outer forms such as walls, towers and piers (Civil Engineering: Formwork 2010). Fabrication of the system is done by the use of steel or wood and supported by strong vertical yokes (Building Construction and Finishing 2015). The rigidity to the sides of the forms is provided by tiding the yokes together at the top. Locomotion is accomplished by jacks on a smooth steel rod or pipes anchored to the concrete from foundation level of the structure (Building Construction and Finishing 2015). The jacks may be electric, pneumatic or hydraulic and operate at speeds up to 24 inches/hour. Jacks usually have carrying capacities between three and 25 tons, and are spaced four feet on centers as shown in Figure 3.9 (a) (Hanna and Sanvido 1989). Attached working platform in the inner form can slide up with the system to provide adequate space for workers to place concrete and fabricate reinforcement. A secondary working platform is also provided at the outer form so that the workers can continue the finishing work of the newly cast concrete (Figure 3.9 (b) (Hanna and Sanvido 1989)). The continuous process of filling the concrete and moving the forms upward can be carried out even as an around the clock operation since, the concrete is poured at the top end as it is drawn upward.



(a) Typical Schematic Cross Section of the Slip form (Hanna and Sanvido 1989)



(b) Typical Slip form with Deck and Finishing Scaffolding in Wales

(Hanna and Sanvido 1989)

Figure 3.9: Slip Form Systems (Hanna and Sanvido 1989)

3.3.4 Jump form systems

Jump form systems are more productive where the construction of wall and column are continuing before constructing the floors and, when there is no floor available to support the wall formwork. Jump forms are framed panels with more than one platform attached (Hanna and Sanvido 1989). The forms can be of full height and supported on the inserted form panel below (Hanna and Sanvido 1989). Two sets, each one floor height, which alternately jump past each other can also be used (Hanna and Sanvido 1989). Moreover, the single jump system has also been proven to reduce the cycle time to three or four days per floor (Naylor, 2006) with a proper protection mechanism to the formwork from adverse external weather conditions. Figure 3.10 (Hanna and Sanvido 1989) shows a typical jump form cycle with three basic operations named, strip, fly, and reset.

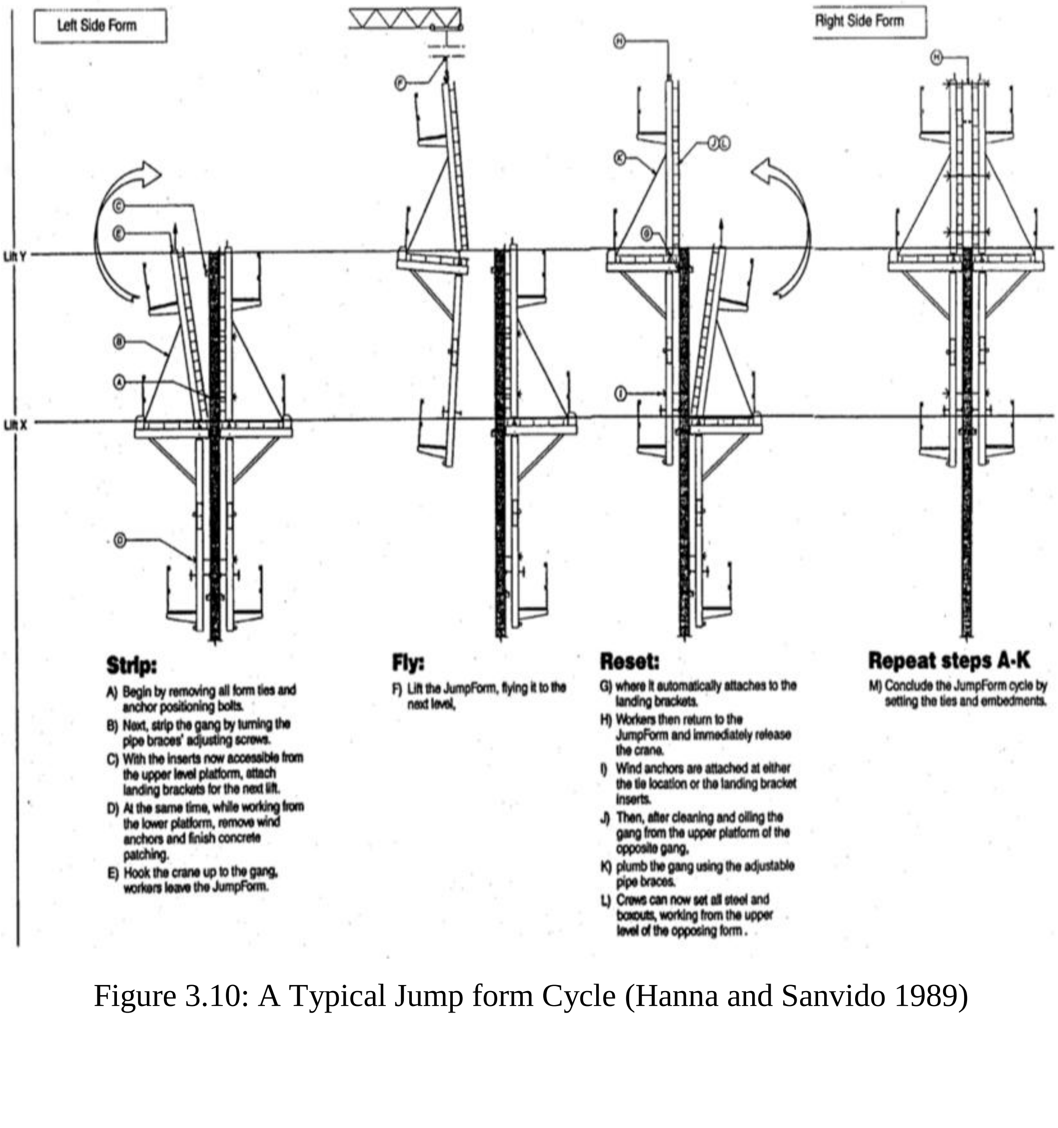


Figure 3.10: A Typical Jump form Cycle (Hanna and Sanvido 1989)

3.3.5 Self-raisin forming systems

The self-raisin system is an assembly of an upper form and lower lifters (self-raisers) (IJARESM 2014). Lifters attached to the already cast wall below in the form of self-raisers, provides an adequate working platform the form to immediately below the forms (IJARESM 2014). It is to be considered that at least first two floors above the ground level should construct with a conventional or any other suitable forming systems prior to the use of self-raising due to the inadequate work space available in the lower level (IJARESM 2014). Before lifting the lifters to a new position, top concrete has to gain an adequate strength to bear the weight of the lifters. Figure 3.11 (Hanna and Sanvido 1989) presents a sequential steps involved in self-raising forms which has explained below.

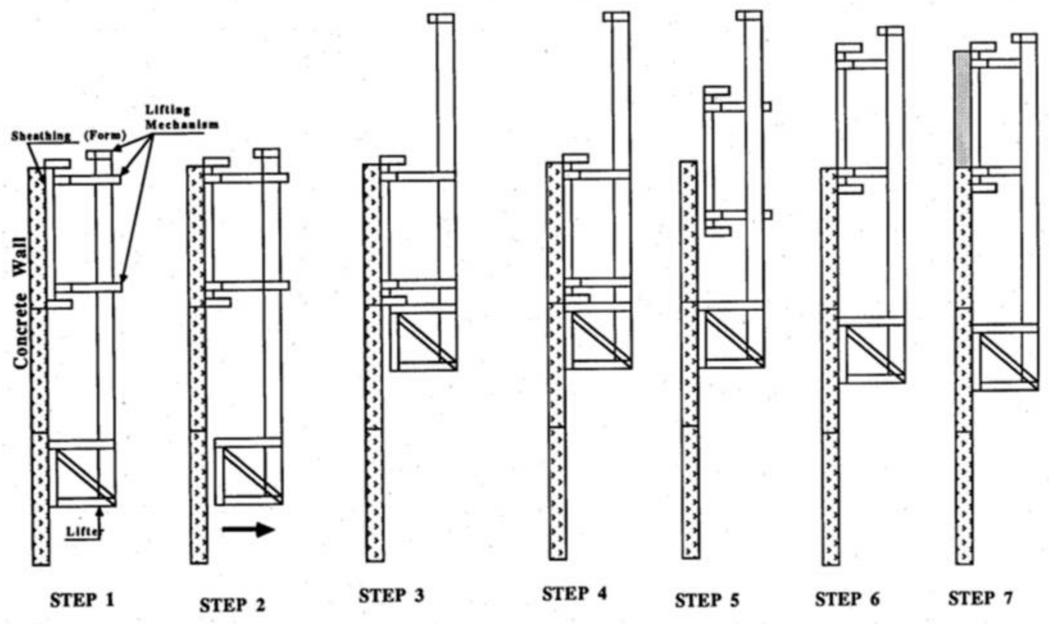


Figure 3.11: A Typical Self-Raising Form Cycle (Hanna and Sanvido 1989)

Step 1. Forms and lifters were placed vertically along the already cast wall as the last lift after the concrete was poured.

Step 2. Lifters are unscrewed and pulled outward the wall laterally by releasing the jacks.

Step 3. Electric, hydraulic or pneumatic jacks are used to lift the lifters to the new position.

Step 4. Lifters are re anchored to the wall below by stripping jacks.

Step 5. Forms fixed are unscrewed, stripped, and lifted up to a new position with the help of jacks.

Step 6. Lifted forms are fixed in the new casting position.

Step 7. Once the forms are fixed and alignments are confirmed, concrete is placed.

3.4 Summary

This chapter has reviewed the different types of horizontal and vertical forming systems commonly used for concrete work in the construction industry. Five different horizontal forming systems were introduced as possible candidates for slab forming. Joist and waffle slabs were considered as special cases because they can be used with any of the five basic forming systems. Five vertical forming systems categorized as crane independent and crane dependent were also described.

CHAPTER FOUR

PROJECT MANAGEMENT CHALLENGES AND IMPACTS IN THE SELECTION OF A PROPRIETARY FORMWORK SYSTEM

4.1 Introduction

This chapter discussed the conditions and constraints impacts the Project Management in deciding the most suitable Proprietary Formwork system for a construction project. Project management in a construction project is all about achieving the targets/working scopes within the anticipated time and cost frameworks along with safe working conditions without sacrificing the quality.

Aiming purely at speed, more often there will be many scarifications on the other quality targets such as displacement, misalignment, deflective concrete and holding up other works for a long time and ultimately contravene the expectation of Project Management efforts.

Most of the project management impacts in the selection of a Proprietary Formwork system can be categorized under the design related, construction related, affordability, local conditions and organizational aspects. The cost of formwork for slab, column and wall cost is considerably large as a portion of the cost take of the structural framework. In the other hand, the selection of the formwork system is made by the project management of the construction organization with the association of the consultants' representatives of the client, and the decision heavily depends on their experiences.

4.2 Design Related Factors

The design related factors can be further subdivided into three elements such as structural element design, building shape and layout and the magnitude of the building as described below.

4.2.1 Structural element design

The structural form of the buildings is mainly affecting the selection process of formwork system of the building project because, the influence of the design related factors plays a major role in increasing or decreasing the time required to fabricate, erect, and dismantle of the formwork (Smith, 1993). Specifications for the formed surface finish, changes of wall intersection positions as well as angles and changes in wall thicknesses to be provided on architectural requirements are ample examples for a design factor that impacts productivity. Therefore the contractors should allocate sufficient time for such unavoidable conditions and constraints at the bidding stage.

The building framing system carries significant influence in the selection of formwork system specially the arrangement of Slab in the buildings. Buildings with a structural core in the form of a vertical shaft limit the use of other formwork systems other than those of self-climbing nature formwork systems (Raymond (n.d.)). For buildings with regularly arranged shear wall design is the best selection is large-panel type steel forms or other types of gang forms (Raymond (n.d.)). Considerations of the structural loading conditions of the slab deemed very vital in the selection of a formwork system. Major characteristics that should take into account in high rise building design are the possible lateral forces due to wind force and earthquakes. Lateral load resisting systems decide the nature of structural form and it concludes the form of formwork system to be adopted.

4.2.2 The Building shape and layout

Use of forms specially prepared for a specific project is comparatively expensive than the readily available standard forms. Designing a joist or waffle slab is a good example, due to the consideration of standard sizes of spans available as a base of the design. The designer can save substantial construction costs on formwork design by the use of consistent elements and simple design.

Simple block-shaped buildings are much easier to construct than buildings in awkward shapes, such as projects with curved, inclined, stepped, undefined or sculptured features (Raymond (n.d.)). As a general rule, awkwardly shaped buildings can be more easily dealt with by using more traditional formwork systems for their better adaptability (Raymond (n.d.)). Buildings having few cast in situ walls and regularly spaced columns in very simple layouts as in office and commercial buildings construction work is very easy. While, in some constructions having very complicated load bearing internal and external walls construction process may be more difficult. Some factors which enable the contractor to decide the adoptable suitable formwork system over traditional formwork systems were identified as a variation of column and wall locations, beam depth and locations, floor to floor height and Opening sizes of the doors and windows (Scribd 2017). Buildings with irregular shapes and different structural elements also limit the possibility of using a proprietary formwork system for the construction work. Climbed forms and steel forms are the most common examples because, frequent adjustments to the forms may accumulate extra cost as well as cost extra time.

4.2.3 Magnitude of the building

The magnitude of a building is mainly classified by the no of floors and the floor area of the building. The reusability of the repetitive nature of formwork system is repeating the same layout in every floor to assure that the workers learn quickly and effective reusability of the same forms, thus increase the productivity and decrease the labor cost (Smith and Hanna 1991). Furthermore, it is important to mention that the reusability of formwork systems for sufficient times leads to increase the cost effectiveness of the formwork system.

Some high rise buildings may have regular reduction of sizes for beams, columns and walls (Raymond (n.d.)) as well as some non-standardized dimensions due to the architectural design and layout or structural ascends (Addis Ababa University (n.d.)). It is obvious that higher number of floors make more profit from the decision of adopting system formwork for a particular project.

Therefore, it is favorable to use a system formwork especially in block shaped high rise structures since it requires highly repetitive floor cycles. However, use of an expensive type of formwork system is not advisable in constructions like basements and podiums due to the limited degree of repetition of forms.

4.3 Specification of the Task

The specification of the task can be further sub divided in to two elements such as surface finishes and speed of the work as follows.

4.3.1 Surfaces finishes

Fair-faced concrete provides higher quality formwork in terms of surface treatment of the panels due to the tightness of the formwork joints and dimensional accuracy (The Masterbuilder 2013). Hence it provides higher productivity while satisfying the architectural requirements on surface finishes.

Even though the surface finish is not being critical finish for most horizontal concrete work such as floor slabs, expectations for joist and waffle slabs is high regarding the surface finish of concrete. Architectural concrete requires a careful selection of a formwork system due to the stiffer form lines, tighter joints, smoother finishes and more cared in implementing chamfers (Griffith (n.d.)). Therefore the type of the formwork is to be selected very carefully to achieve the required architectural surfaces.

4.3.2 Speed of work

Achieving the targets by speed up the construction is the main advantage of using a formwork system. Speed of construction highly affects the cost since, it determines the time the building will be available for use and reduces the financial charges (Hanna 1998). In the building projects, the construction areas widely spread in horizontal direction, introduction of additional sets of formwork could be a better option to speed up the work since it may create more independent work at the site. But, in high-rise buildings, this may not be the optimum solution to speed, because in such cases the floor cycle is still playing a main role in the critical path. However, selection of a formwork system with proper design and suitable arrangements will effectively enhance the efficiency of the typical cycles. Therefore, the factors, mainly affect the speed of the construction can be basically depend on the construction sequence, floor cycle and the rate of placement of concrete.

4.4 Construction Related Factors

The construction related factors can be further divided into four subdivisions such as headroom and building span, accessibility to work, repetitive nature and reusability of Formwork and provision of construction joints.

4.4.1 Headroom and building span

Higher headroom increases the amount of falsework required and can also create accessibility and safety problems (Raymond (n.d.)). Providing headroom by placing a minimum or lesser amount of formwork can also make a instability to formwork system, thus the placing of concrete more difficult. Working headroom of more than five meters is frequently encountered in buildings with transfer structures, entrance foyers such as shopping malls and many other functional, institutional and public buildings (Raymond (n.d.)). Buildings with larger spans are a good example to those creates similar issues in high headroom situations. In the other hand, incorporation of large beam sizes and heavy reinforce bars may further complicate the selection as well as the erection of formwork in long-span structures.

4.4.2 Accessibility to work

The accessibility to building site for construction operations creates a great influence selection of an appropriate formwork system. Therefore, Proper consideration should be paid for access to all components of construction while planning a site layout at the feasibility study stage (Formwork Paper (n.d.)). Lesser accessibility to work in the construction phase creates many adverse effects to the quality of the work such as segregation of concrete, formation of cold joints and temporary discontinuation. For example, when a shaft-type core wall is constructed in an advanced phase, the shaft may stand independently for a long period of time before it is connected to the horizontal elements (Formwork Paper (n.d.)). In such cases adequate accessibility should be provided to the construction area to avoid unnecessary quality issues.

In the construction sites of exceptionally congested due to the area or heavy traffic, excessively sloped, structures with extremely sensitive designs and with many physical or contractual restrictions may create many difficulties in the optimum selection of a formwork system. Since there is no any specific hard and fast rules to improve the situation the problems are to be tackled according to the individuals' experiences and this may not be the optimum (Raymond (n.d.)).

4.4.3 Repetitive nature and reusability of the formwork system

Reusability of traditional timber formwork is usually limited due to the durability of the plywood sheeting (Raymond (n.d.)). The optimum number of times of the timber form can be used is usually 12 to 14.Thus, it is still sufficiently economical to use timber formwork for high-rise buildings at heights in accordance to the multiple of the usual re-used times (The Masterbuilder 2013). Even though, the metal formwork systems easily reusable for many times the selection are discouraged due to its higher initial cost. Low rise development projects are a good example, due to the lesser reuses with limited floor constructions. Therefore, a careful study on the cost, speed, performance and the quality of the output of (Formwork Paper (n.d.)) various formwork systems should be carried out prior to make a decision.

4.4.4 Provision of construction joints

It is obvious in widely spread concrete structures, a large number of construction joints are to be provided due to the subdivision of concrete works into effectively workable sizes. Provision of construction joints can challenge the output and affect the quality of the concrete (The Masterbuilder-July 2013). Therefore, in such cases selection of formwork system should be done with the consideration of satisfactions of such requirements.

4.5 Affordability of the system

The affordability of the system can be further explained as cost, plant and machinery required technical skills and knowledge, availability and delivering products of the formwork and safety as follows.

4.5.1 Cost (initial, maintaining, repairing)

The cost is the most vital factor for deciding a formwork system for a construction project and it is important the knowledge of the financial provisions for formwork before taking the decision of introducing proprietary. It is project management’s duty to work out on these in detail at the time of bid and planning stage as well Addis Ababa University (n.d.)). The cost is basically with components as Initial cost Maintaining cost and Repairing/reusing cost.

The Initial cost also known as the make-up cost is the cost allocated for transportation, purchasing the materials, assembly and erection of materials and machinery. Maintenance is the cost associated with cost of stripping, repair and storage as well.
Since formwork material is very valuable asset for the company, much return is expected investment once proper care is given during handling and storage. Formwork should be handled carefully and correctly, maintained, repaired if necessary and finally, cleaned regularly and stack properly for future use (The Masterbuilder 2013). Repairing and Reuse cost of formwork can be easily reduced by careful handling and proper stacking of the used forms and reused them in an effective manner.

Reusability of the traditional timber formwork is comparatively very low due to the poor quality and durability of the plywood sheathing (Addis Ababa University (n.d.)). The optimum number of uses for timber form usually ranges from 12 to 14. Thus, it is still sufficiently economical to use timber formwork for high-rise buildings at heights in accordance to the multiple of the usual re-used times (The Masterbuilder 2013). Even though, the metal formwork systems easily reusable for many times, the selection are discouraged due to its higher initial cost. Low rise development projects are a good example, due to the lesser reuses with limited floor constructions.

4.5.2 Plant and machinery required

There are many factors to be considered in preparation of a construction plan for selecting an optimum formwork system (Addis Ababa University (n.d.)). Therefore, it is important to consider the availability of lifting appliances for the erection of forms, ability of appliances to access the work spot to assist simultaneous operations as the structural works also proceeds, the requirements of any other special equipment for striking the formwork and method of transportation of dismantling formwork panels to the next location as construction work continues (Raymond (n.d.))

In high rise building construction sites space available for work is highly confined and congested due to limited allocations of crane time and space available. For an example, since the reinforcement activities are most critical at the infrastructure construction stage reinforcement lifting of building level is the most crane time consuming activity (Addis Ababa University (n.d.)). Therefore, the capability of crane time allocation to formwork transportation is comparatively very less to the reinforcement activities in high rise building construction.

4.5.3 Technical skills and knowledge

For any complex the project, engineering personals should be able to analyze the comprehensive technical drawings, efficient material planning and constant design. Prominent professional support from supervisors ensures the efficient use formwork materials in the construction. In close cooperation with the site manager material use and requirements are to be optimized. On-site briefings, Coordination and optimization, transparent cooperation, Continuous performance checks are essential to deliver quality output in use of the proprietary formwork system (Addis Ababa University (n.d.)). Keep in mind the qualification and attitudes of the available work force, improving their technical knowledge is also a major issue, since they are very reluctant adopt with technically sound construction methods (The Masterbuilder 2013).

4.5.4 Availability and delivering products of formwork

On the formwork system manufactures side following services should be specified and facilitated to ensure no obligations in the other legal and economic circumstances.

- Origin of Manufacturing
- Product Delivery method,
- Durations on delivering the product,
- Possibility of making an adjustment for the design
- Possibility of visiting the site by the manufacture if needed

4.5.5 Safety

Safety considerations on the equipment and the workers play an important role in the productivity of a construction project (Scribd 2017). It may begin in the planning stage and it should continuously monitor by the management throughout its construction period (Scribd 2017). Therefore, providing working platforms on the formwork system including guard rails and toe boards, not dismantling the forms between raises to control injuries in stripping may improve safety and productivity at a great height. Controlling the raising of the forms by the workers in the form is also accountable safety precaution instead of using a crane operating in distance away. If crane operating system is being used, an attendance of a signalmen is must at the operation level, thus the operation of lifting of forms can be stopped immediately in an emergency situation.

4.6 Local Conditions

Local conditions can also be described under following categories as the complexity of the built environment, weather conditions as well as areas of practice.

4.6.1 Complexity of the built environment

In the construction sites of exceptionally congested due to the area or heavy traffic, excessively sloped, structures with extremely sensitive designs and with many physical or contractual restrictions may create many difficulties in the optimum selection of a formwork system (Shin 2008). Since there is no any specific hard and fast rules to improve the situation the problems are to be tackled according to the individuals' experiences (Raymond (n.d.)) and this may not be the optimum.

4.6.2 Weather conditions

Formwork systems are highly sensitive to weather conditions. Especially the conventional and other wooden forms have a very high possibility of deforming in adverse weather conditions. Therefore, special precautions to be taken while using as well as stacking the used forms to protect from extreme weather conditions. Typically, when using vertical forming systems to place fresh concrete, the system is supported by the wall already cast below, thus the supported wall should reach the required strength to support the fresh concrete above it (Hanna 1998). Therefore, the rate of strength gain of lower wall is influenced by the ambient temperature, moisture content, and the freezing and thawing cycles (Hanna 1998). For example, in slip-form, since the work has to continue around the clock, if the slip-form stops because of weather conditions, it may impact the structure as well as the cost (The Masterbuilder 2013).

4.6.3 Area of practice

Use of a system formwork may reduce the cost of labour than conventional formwork system to in the areas that the labor force is unskilled and expensive (Addis Ababa University (n.d.)). But the other way around is also deemed possible if the labour force is skilled and inexpensive considering the material cost and work force (Hanna, 1998). As a result of this criterion in some areas, preassembled conventional formwork or system formworks are used due to the unavailability of inexpensive and skilled labour force (Addis Ababa University (n.d.)).

4.7 Organizational aspects

Organizational aspects can be further explained as organizational capital, availability of the plant and machinery facilities as well as availability of technical personnel and described as follows.

4.7.1 Organizational capital

Most of the proprietary formwork systems have a high initial cost, but through the repetitive reuse it becomes economical (Argaw 2010). Therefore, the organization should be capable enough to take the risk of having projects to use the system formwork for a project and the confidence of having sufficient project reuse or rent out the respective formwork systems. Therefore, generally this type of approach is bearable to organizations which are solid with their financial status.

4.7.2 Plant and machinery facilities

Availability of the right types of machines in the adequate quantities is the biggest asset to the construction company due to the ability to meet targets within the allocated budget as well as organizing the replacement of machines due to sudden breakdowns and depreciation of machineries. Regular maintenance checks are the key factor of getting the maximum usage of machines and it should be productive to considering the ultimate cost of the formwork system. The possible occurrence of bottlenecks should be avoided in availability of plants and machinery required in handling and maintaining the formwork systems and organization should be capable enough of achieving expected profit utilizing required machineries.

4.7.3 Available technical personals

Availability of Technically competent persons in the organizations makes the reputation of the organization high and also delivering the task in optimum productivity (Smallwood and Ulrich 2004). Therefore, the organizations with sound technical staff with experience foreman and workers with the System formwork help to share the knowledge and get the job done in a precise manner. Cleaning, repair and maintenance services with the required technology at the stockyard guarantees the longevity of products and best results in construction.

CHAPTER FIVE

MOST COMMONLY USED PROPRIETARY FORMWORK TYPES AND THEIR LIMITATIONS

5.1 Introduction

The expectation of this chapter is to discuss about the most commonly used proprietary formwork systems in high-rise building projects in Sri Lanka in order to develop a framework incorporating the best practices of proprietary formwork strategies as a guide to implement as a quality management tool in construction projects.

In case of a construction project the project duration is the governing factor in terms of the total cost (IJRET 2017). Although the material requirements are also very unique, since it depends on its structural design, requirement of the labour force and the duration of the project are highly influenced by the selection of the technologies and the construction methodologies (IJRET 2017) to each project.

Since the speed of a high rise building construction project has a direct influence in the selection of the type of the formwork to be used, it is the most critical factor that should pay more concentration (IJRET 2017). Use of latest technologies for the superstructure work will be minimizing the labor requirement and the time duration of the project (IJRET 2017).

Therefore, formwork system is the time controlling factor for high-rise building construction projects as it directly affects the floor cycle. Selection of the most suitable formwork system may drastically reduce the time consumed in main structure construction and hence the total construction duration of the project.

5.2 MIVAN Formwork System

It is the most advanced formwork systems. It is fast, simple and adaptable (Patil and Prof. Desai (n.d.)). The system produces total quality output to the work with minimum maintenance while paying prime consideration to the durability. Totally pre-engineered system where in the complete methodology is planned to the finest details (Patil and Prof. Desai (n.d.)).

5.2.1 Structural element design

The panel is the basic element of the formwork system. The extruded aluminum rail sections welded to aluminum sheets with the average weight around 18-20 kg per meter square produces very lightweight panels with a higher stiffness to weight ratio (Patil and Prof. Desai (n.d.)). The system of assembly allows very lesser deflection to the concrete loading.

The high strength panel made up sections of aluminum alloy includes 4 mm thick skin plate and 6mm thick ribbing behind to offer more stiffness to the panels (Patil and Prof. Desai (n.d.)). Standard sizes of the panels are 2000x600, 2000x300, 1200x300 and 850x300 mm with a higher load carrying capacity of 7-8 Tones Per square meters approximately (Patil and Prof. Desai (n.d.)). Following are examples of the regularly used formwork components in the construction, figures 5.1, 5.2 and 5.3 (Patil and Prof. Desai (n.d.)) show the standard elements of wall panel, beam component and deck component of MIVAN formwork system respectively.

Figure 5.1: Wall Panel (Patil and Prof. Desai (n.d.))

Figure 5.2: Beam Component (Patil and Prof. Desai (n.d.))

Figure 5.3: Deck Component (Patil and Prof. Desai (n.d.))

5.2.2 The Building shape and layout

The technology is suitable for construction of a large number of repetitive floors with common shapes (Patil and Prof. Desai (n.d.)). Use of common size of forms to construct walls and slabs leads laying of forms within a short period of time in one concrete pour. Shapes and sizes of the panels are manufactured to suit the requirements of specific projects. Cast in situ concrete wall and floor slabs cast monolithic provides the structural system in one continuous pour (Construction Updates 2017). Erection of large size forms of floor slabs and walls is done as on site work and are fabricated as sturdy and strong with accuracy and easy handling methods.

5.2.3 Magnitude of the building

MIVAN formwork is more suitable for constructions having large sized panels in numbers of repetitive floors, lift cores and staircases with a common shape (Patil and Prof. Desai (n.d.)). The door, window and service duct frames are placed in the inner side of the form before concreting as a special arrangement (Patil and Prof. Desai (n.d.)). A special consideration has given in preparation of forms for façade panels, staircase flights as well as other pre-fabricated items integrated into the superstructure (Patil and Prof. Desai (n.d.)).

5.2.4 Surfaces finishes

Selection of high quality formwork system incorporated with a proper surface treatment to the panels, tight formwork joints and dimensional accuracy is a must to produce a fair faced concrete output. A product with exact dimensions as designed can be achieved with the use of a precisely fabricated formwork system. The requirements are slightly relaxed when the concrete surface is to be finished at a later stage due to the unsurpassed speed of construction due to saving time for the required time in masonry and plastering, there could be some relaxations of the requirements (Sida 2015). When durability is the prime consideration, use of a high quality forming system requires very less maintenance work (Patil and Prof. Desai (n.d.)).

5.2.5 Speed of work

The system has ability to complete larger amount of work in daily basis than traditional formwork thus the target completion dates can be achieved. Capability of formation of all walls at one stretch avoids time consuming for brick laying and plastering. Early removal of forms leads to the immediate start of finishing works like window fixing, wall tiling and plumbing work (Patil and Prof. Desai (n.d.)). Prefabrication of many finishing items like door and window frames can be done simultaneously on the superstructure construction stage due to the dimensional accuracy of the concrete work (Patil and Prof. Desai (n.d.)). Therefore, installation work can be done very fast with lesser material wastage.

5.2.6 Headroom & building span

The components of the system are designed as a single unit of structural frame with adequate provisions for headroom as cope for allocating sufficient labour force on the finishing and other parallel work (Construction Updates 2017). Therefore, an uninterrupted progress in finishing work and all other trades can be effectively achieved.

5.2.7 Accessibility to Work

Less congestion on area where the formwork is being placed can be achieved due to the possibility of providing more spacious headroom.

5.2.8 Repetitive Nature and Reusability of the Formwork

Due to the higher durability of the component, it can be used in several times without affecting the quality and with no dimension corrections to the panels (IJRET 2017). They also offer a large number of repetitions (around 250) with proper handling (Construction Updates 2017) and careful stagnations after use.

5.2.9 Provision of Construction Joints

The method of monolithically construction of concrete slabs and walls provides an exact dimensional quality outcome with requiring very few construction joints, very lesser pour arrangements as well as zoning compared to the conventional slab, beam and column construction techniques.

5.2.10 Cost (initial, maintaining, repairing)

Use of fast and innovative production techniques saves operational, maintenance and financial costs as well as the project duration (IJRET 2017). Providing a smooth concrete surface leads to use of very thin skim coat layers hence, to very smooth finish in a short period of time with the use of lesser work force (IJRET 2017). Since most of the superstructure work is done as concrete slabs and walls, no time or labour force is required in building brick walls and plastering work.

5.2.11 Plant and machinery required

Once the formwork manufactured accurately, it can fix to the position it designed without any alterations. Since it may not need continuous adjustments, wastage of formwork material and concrete can be minimized (Patil and Prof. Desai (n.d.)). In the case of prefabricated finishing items site work can be easily managed with less skilled workers. Use of light weight of the panels reduces the capital cost of heavy lifting equipment(Patil and Prof. Desai (n.d.)).

5.2.12 Technical Skills and Knowledge

The system is designed with the help of very sophisticated art design software and considering most economical possible panel sizes (Patil and Prof. Desai (n.d.)). A combination of skilled technical personals and the use highly sophisticated software along with the experience and skill of the designers ensures an efficient construction process by incorporating the optimum assembly procedures (GoDaddy 2017).

5.2.13 Availability and delivering the products of formwork

The panels are manufactured in MIVAN'S dedicated factories in Europe and South East Asia (Patil and Prof. Desai (n.d.)). Once they are assembled they are subjected to a trial erection in order to eliminate any dimensional or on site problems (Patil and Prof. Desai (n.d.)). All the formwork components are received at the site within three months after they are ordered (Patil and Prof. Desai (n.d.)).

5.2.14 Complexity of the built environment

The panel is the basic element of the formwork system. The extruded aluminum rail sections welded to aluminum sheets to produce very lightweight panels with a higher stiffness to weight ratio (GoDaddy 2017). Since, the shapes and sizes of the panels are manufactured to suit the requirements of specific projects, can be easily used under the complexities of the built environments (Patil and Prof. Desai (n.d.)).

5.2.15 Weather conditions

The formwork material is made from aluminum, therefore it is identical for corrosion resistance than other metals. Therefore MIVAN formwork system is most suited for any type of climatic conditions (Patil and Prof. Desai (n.d.)).

5.2.16 Area of practice

Since the material of forms is made from aluminum and its very light weight, large sized panel sections can also be effectively handled by a single worker (GoDaddy 2017). Thus the individual workers can effectively handle all necessary elements, assembling the system without requiring any skilled labours or any heavy lifting equipment (GoDaddy 2017). With a proper plan and a practical knowledge of the system and the way of repetition of work tasks on a daily basis, the system can easily meet up with the assembly line techniques in the construction site with ensuring a quality work output by labourers under proper supervision.

5.2.17 Organizational capital

Since the conditions and aluminum material of MIVAN formwork system, the Initial capital cost of this formwork system is considerably very high (Patil and Prof. Desai (n.d.)). However, total operating cost and capital cost will be minimized by the use of economical panel sections as well as use of the more efficient construction processes by following the optimum assembly procedures (Patil and Prof. Desai (n.d.)).

5.2.18 Plant and machinery facilities

MIVAN formwork is light in weight. Accordingly, it is not necessary to use of a tower crane for handling purposes due to its simplicity in assembly (Patil and Prof. Desai (n.d.)). Hence, very little unskilled labour force is required for handling purposes. Machinery and equipment requirement for MIVAN formwork is very cost effective for the organization.

5.2.19 Available technical skills

A minimal labour requirement is adequate for carrying and establishing of formwork at the construction stage with minimal supervision staff (Patil and Prof. Desai (n.d.)). Therefore, it is cost wise more beneficial to carrying out work with minimal staff and labour force.

5.3 MFE Formwork system

MFE offers a complete design and construction service and projects can be undertaken in a range of alternative contractual arrangements (MFE Formwork Manual 2013).

5.3.1 Structural element design

The MFE formwork system technology has been developed and successfully used for over 20 years as a revolutionary aluminum formwork construction system for forming cast in situ reinforced concrete building structures (MFE Formwork Manual 2013). The system comes up with very high specifications and very strict tolerances for structural elements is shown in figure 5.4 (MFE Formwork Manual 2013). Since the panels are manufactured in standard and nonstandard shapes produced for each and every project, it is very easy to cast different shapes of structural elements with different shapes and sizes (MFE Formwork Manual 2013). The high strength aluminum alloy 4mm thick panels are specially designed extruded sections incorporated with modern technologies as welded, to form a robust component and yielding minimal deflection under concrete loading (MFE Formwork Manual 2013).

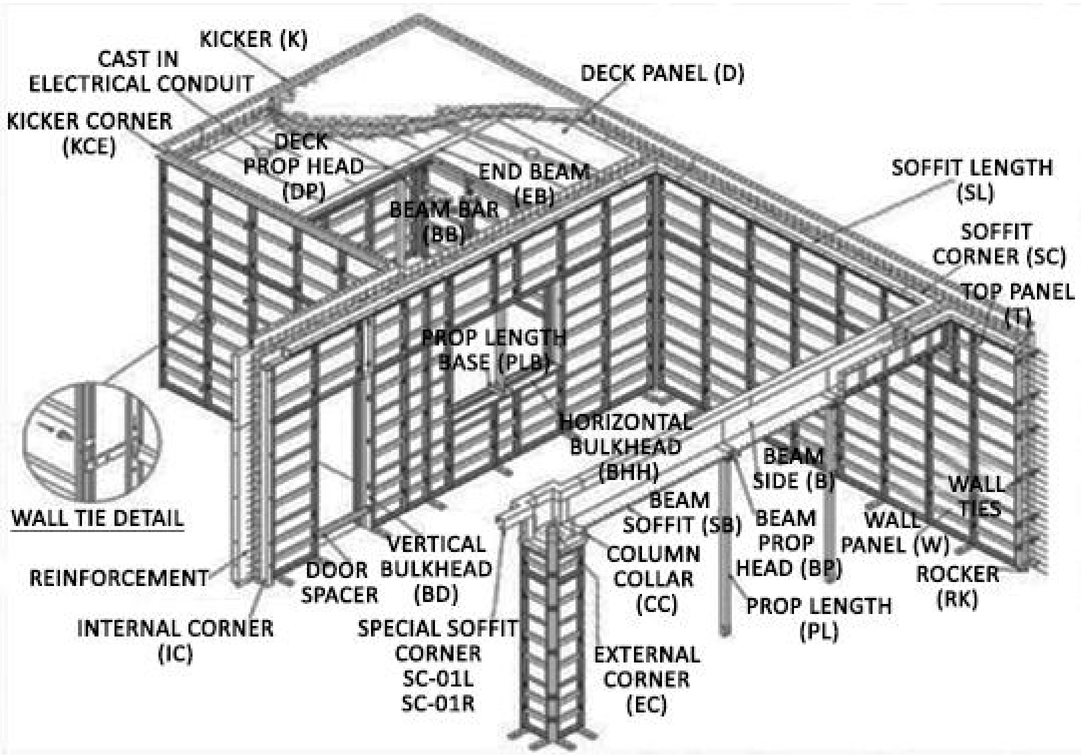


Figure 5.4: System assembly of MFE system (MFE Formwork Manual 2013)

5.3.2 The building shape and layout

The MEF form work system is a unique system. The elements such as all walls, floor slabs, lift cores, columns, beams, stairs, balconies together with door and window openings are cast in situ in a single site based operation (MFE Formwork Manual 2013). The resulting system assembly is very accurate in dimensions and provides very high quality of finished concrete surfaces (MFE Formwork Manual 2013). In the same time this technology is fast and very cost effective. Therefore, this system can be easily adopted for different types building shapes and layouts (MFE Formwork Manual 2013).

5.3.3 Magnitude of the building

The system can be used for a broad range of applications, such as straightforward wall and slab construction of more complicated structures involving stairs, bay windows, balconies and air conditioning hoods (MFE Formwork Manual 2013). The system has unsurpassed construction speed (high rise 1 floor for 4 days) (MFE Formwork Manual 2013). Therefore, the system is equally suitable in high rise as well as low rise construction work with any type of complexities.

5.3.4 Surfaces finishes

The high quality finish of concrete will assure verticality of structure and high accurate tolerance of finish. The surface finish produced for the concrete allows achievement of a high quality finish to the slab and walls without requiring any expensive plastering (IJARESM 2014).

5.3.5 Speed of work

Since the plastering work is no needed for the construction work, speed construction shall be achieved (MFE Formwork Manual 2013). Furthermore, installation of door and window frames can be done with minimum resizing. Slab cycle can be reduced from about 20-30 days to 5-6 days per floor with the application of the international standard quality maintaining techniques for the system (MFE Formwork Manual 2013). Standard components of the formwork system can be reused in other projects with effective maintenance and proper stacking by reducing costs for formwork for other projects. Hence MFE can be maintained speed construction work for concreting.

5.3.6 Headroom & building span

The combination of the engineered nature of the formwork and the repetitive nature of the system, allows site management to fine tune the operations (MFE Formwork Manual 2013). The assembly with the incorporation of work platforms to the systems is the biggest advantage in terms of facilitating safe working environment and optimum utilization of work space available.

5.3.7 Accessibility to work

Less congestion on area where formwork is being placed, due to the possibility of providing more spacious headroom to carry other work simultaneously.

5.3.8 Repetitive nature and reusability of the formwork

The simplicity and repetitive nature of the system assembly provides great influences on programing the accurate construction sequences as well as the cycle time well in advance (MFE Formwork Manual 2013). Panels of the system can be used more than 300 times of repetitions with high accuracy of dimensions and quality (MFE Formwork Manual 2013). Since aluminum is the highest value recyclable of all metals, after the usage form work which can be recycled reducing capital cost.

5.3.9 Provision of construction joints

The method of monolithically construction of concrete slabs and walls provides an exact dimensional quality outcome with requiring very few construction joints, very lesser pour arrangements as well as zoning compared to the conventional slab, beam and column construction system (MFE Formwork Manual 2013).

5.3.10 Cost (Initial, Maintaining, Repairing)

The rapid growth of the present days of the construction industry enables the introduction of advanced and innovative formwork systems in order to deliver the customer requirements in time as well as to be competitive in the industry. Even though the initial cost of a formwork system high, due to the easy to handle techniques offered by the system enables erection work faster (MFE Formwork Manual 2013).

Therefore, especially in high rise building construction, this may save precious time as well as money with a proper maintenance (MFE Formwork Manual 2013).

5.3.11 Plant and machinery required

The degree of pre engineering inherent simplicity enables unskilled labour to be used (MFE Formwork Manual 2013). Very light weight components can be handled by a single labour minimizes the need of heavy lifting equipment operations (MFE Formwork Manual 2013).

5.3.12 Technical skills and knowledge

A team of qualified designers assigned from all engineering disciplines provides complete services in all aspects of structural, architectural, construction and building services design (MFE Formwork Manual 2013). The system is designed with the help of modern design software and considering most economical possible panel sizes (MFE Formwork Manual 2013). A combination of skilled technical personals and the use highly sophisticated software along with the experience and skill of the designers ensures an efficient construction process by incorporating the optimum assembly procedures (GoDaddy 2017).

5.3.13 Availability and delivering the products of formwork

The system is first formed in 1991 and has worked over 20 countries in the region and has offices in Malaysia, India and Dubai (MFE Formwork Manual 2013). Panels are manufactured in standard and nonstandard sizes and shapes as per the requirements of each and every project. Once produced, the system is subjected to a trial assembly to ensure hassle free on site installations (MFE Formwork Manual 2013).

5.3.14 Complexity of the built environment

An effective management of construction activities with the association of this specially designed aluminum formwork system assembly higher productivity of the construction site can be achieved (MFE Formwork Manual 2013). Since panels are manufactured in standard and nonstandard sizes and shapes produced to the requirements of each and every project (MFE Formwork Manual 2013). Unskilled labours can handle formwork system too.

5.3.15 Weather conditions

Aluminum is the manufacture material which has automatically highly corrosion resistive nature due to oxide layer. Therefore MEF formwork system is most suitable for any kind of climatic conditions in the world (MFE Formwork Manual 2013).

5.3.16 Area of practice

The simplicity and the repetitive nature of the system enable accurate programming of construction sequence as well as the cycle time in advance (MFE Formwork Manual 2013). The ability of unskilled labours to work with the system reduces the requirements of skilled labours.

5.3.17 Organizational capital

The initial cost for the MFE form work is very high. However the system can be repetitively used for more than 300 times without affecting the dimensional integrity and quality only with the use of unskilled labor force (MFE Formwork Manual 2013). The recycling ability under the normal industrial processes will be more beneficial after the usage too.

5.3.18 Plant and machinery facilities

Since the MEF form work system is made as total aluminum system, no requirement of any wooden props, panels or bracings (MFE Formwork Manual 2013). As the process of erection is done manually, the formwork can be arranged without using any single machinery other than handling machineries (MFE Formwork Manual 2013). Moreover, Hammer is the only tool being used for fixing purposes of formwork (MFE Formwork Manual 2013).

5.3.19 Available technical personals

The requirement of technical persons for fixing of MFE formwork is very less and unskilled technical staff shall be carried out the formwork arrangement (MFE Formwork Manual 2013). Guidance of experienced MFE supervisory staff provided at the site along with the proper handling of equipment desired work cycles can be easily established (MFE Formwork Manual 2013).

5.4 PERI Formwork system

PERI's development engineers have focused on minimizing the shuttering costs and the number of individual components (PERI formwork Manual 2010).

5.4.1 Structural element design

Innovation in formwork has led to small, lightweight modular systems that provide versatile formwork solutions on-site (Figure 5.5 (Bookwalter 2005)). Purely aimed at developing a manhandled system with, lightweight units with the use of aluminium, high tensile steel, fiberglass and plywood for different components (PERI formwork Manual 2010). It is very easily assembled formwork system can use for any type of structural element with a higher factor of safety (PERI formwork Manual 2010).

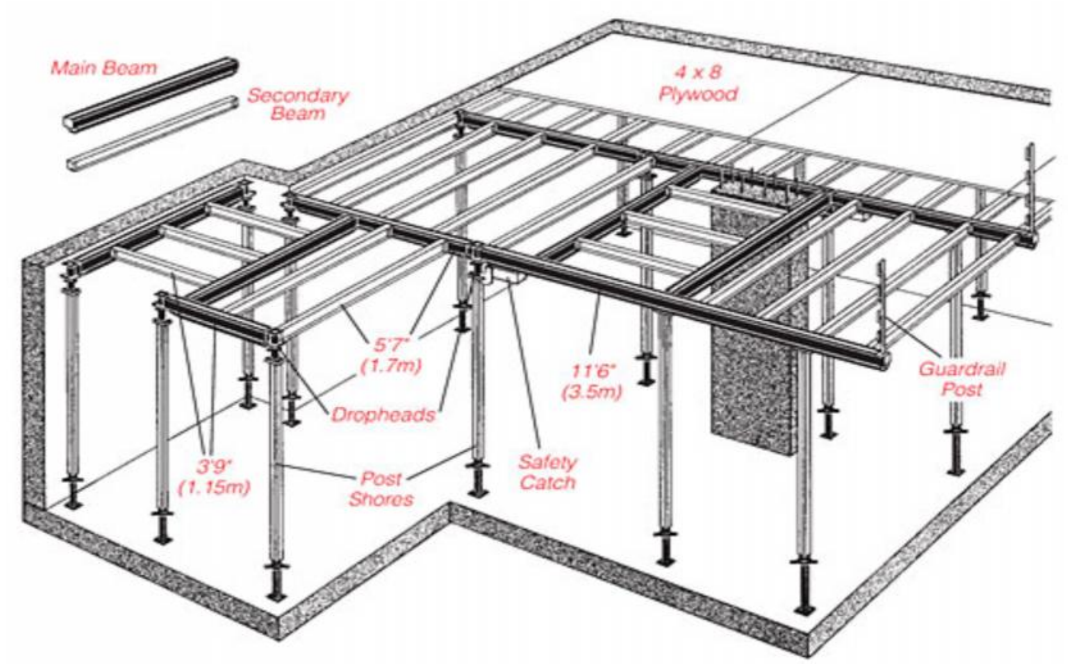


Figure 5.5: System assembly of PERI formwork system (Bookwalter 2005)

5.4.2 The Building shape and layout

The system is basically designed to use in high-rise building constructions (PERI formwork Manual 2010). It offers protection across three concurrent levels of construction, thus the facility of being able to enclose the work area allows operators to feel safe and secure (PERI formwork Manual 2010). The system also offers a considerably higher amount of protection on adverse weather conditions.

5.4.3 Magnitude of the building

The highly productive system is designed to increase speed, quality and efficiency of a construction with minimum use of the labour force and crane time (Addis Ababa University (n.d.)). Therefore, the system is most suitable for construction of multi storied vertical elements such as shear walls, core walls, lift shafts and stair shafts (IJARESM 2014).

5.4.4 Surfaces finishes

The fair face concrete finish is required; the system may require lining the panels with a secondary layer of a material. However, the system can still be more economical than traditional formwork.

5.4.5 Speed of work

Lesser on site preparation work due to a pre-assembled system of forms, higher speed as well as higher quality finish can be achieved (PERI formwork Manual 2010). In other hand, the method of monolithically construction of concrete slabs and walls provides an exact dimensional quality outcome (PERI formwork Manual 2010). Hence, the time consumed on rework is reduced.

5.4.6 Headroom & building span

Since only one prop is required for an area of 3.45 m^2 as per the specified by the system, this may provide more space for transporting or storing the construction material and other machineries (PERI formwork Manual 2010).

5.4.7 Accessibility to work

Considering the PERI, only 0.29 props per square meter of slab area is needed (PERI formwork Manual 2010). In other words, the system need only one prop is needed for an area of $3.45m^2$, means lesser congestion in the area the formwork is being placed (PERI formwork Manual 2010).

5.4.8 Repetitive nature and reusability of the formwork

The repetitive nature of the system allows the site team to have a better control on the operations due to the repetitiveness in certain types of super structure work, which leads in reducing wastage as well as the time (PERI formwork Manual 2010). Therefore PERI system offers a suitable and fast solution for forming frequently repetitive floor plans - horizontally or vertically (PERI formwork Manual 2010).

5.4.9 Provision of construction joints

Monolithically construction of concrete slabs and walls provides an exact dimensional quality outcome with requiring very few construction joints, very lesser pour arrangements as well as zoning compared to the conventional slab, beam and column construction system (PERI formwork Manual 2010).

5.4.10 Cost (initial, maintaining, repairing)

Use of highly engineered connection methods with the combination of simple methods of assembly and disassembly of very light weight components speed up the onsite assembly work with the use of very lesser skilled and unskilled labour force respectively (PERI formwork Manual 2010). Therefore, the system saves precious time and money with a proper maintenance.

5.4.11 Plant and machinery required

Due to the simplicity of the basic assembly, it is possible to handle the components with the minimum use of a crane as well as manually to the next position (PERI formwork Manual 2010).

5.4.12 Technical skills and knowledge

The initial assembly of the system could be skilled labour intensive (PERI formwork Manual 2010). But the workforce requirement for onsite handling work is considerably reduced.

5.4.13 Availability and delivering products of formwork

The system provides imaginative design support and workable solutions under any kind of complications created by the project due to its nature (PERI formwork Manual 2010). With the excellent service provided by in time delivering of pre-fabricated panel units, large amount of labour cost and time could be saved.

5.4.14 Complexity of the built environment

Require adequate space around the periphery of the ongoing construction to facilitate the table unit beyond the building line. Another requirement is the capability of slab below the arrangement to bear the loads transferring at bearing locations (PERI formwork Manual 2010).

5.4.15 Weather conditions

The system is suited for any type of climatic conditions since the material used for formwork is aluminum (PERI formwork Manual 2010). Therefore PERI formwork is more applicable for any kind of construction such as buildings, bridges, towers etc.

5.4.16 Area of practice

The great combination of the engineered nature of the formwork and the repetitive nature of the system, allows site management to fine tune the operations (PERI formwork Manual 2010). Also, due to the simplicity of the assembly of the system, requirement of skilled labour force can be reduced. Therefore, the system is suitable for any area as well as any type of practices.

5.4.17 Organizational capital

The initial cost for PERI formwork system is considerably higher (PERI formwork Manual 2010). However the repetitive use of formwork without loss of quality or dimensional integrity will cause an operational cost reduction. The recycling ability under the normal industrial processes will be more beneficial after the usage too (PERI formwork Manual 2010).

5.4.18 Plant and machinery facilities

PERI formwork is made from aluminum and plywood sheets as well, therefore no need of wooden props, bracing or panels (PERI formwork Manual 2010). As the erection process is manual, tower cranes are only used in lifting up the panels to the floor above (Metal World 2017). Therefore, tower cranes can pay more concentrate on other handling operations.

5.4.19 Available technical personals

Less numbers of the labour force are required for PERI formwork arrangement. Workers are provided with comfortable platforms, ensuring safe and efficient work routines as on the ground (PERI formwork Manual 2010).

CHAPTER SIX

SUITABILITY OF PROPRIETARY FORMWORK SYSTEMS

6.1 Introduction

An online survey of Proprietary formwork systems has been carried out among Civil engineers who are practicing in the Sri Lankan Construction industry. Their expertise and knowledge was also obtained to identify most influential factors in the selection process of a proprietary formwork system.

6.2 Detail of the Survey

- No of Participants – 38 Civil Engineers
- Minimum Experience in field of participants – 3 years

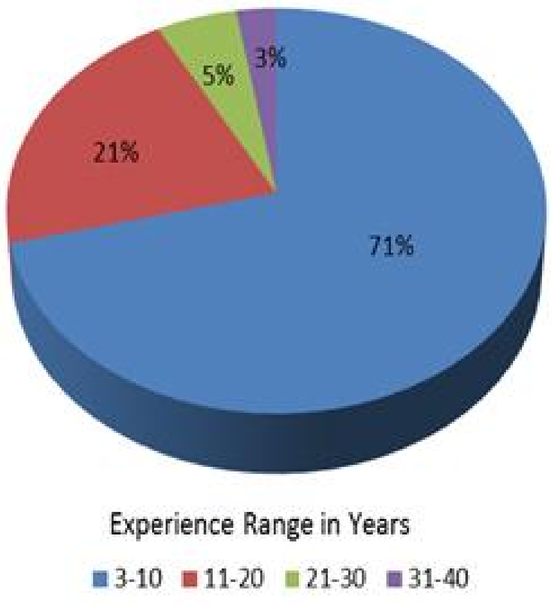


Figure 6.1 Work Experience of the Participants

Ranking of the attributes in terms of the criticality as perceived by the respondents was done by the use of the RII was computed using the following equation.

$$\mathbf{RII} = \frac{\sum \mathbf{W}}{\mathbf{WA} * \mathbf{N}} \quad (\mathbf{0} \leq \mathbf{RII} \leq \mathbf{1})$$

Where:

W – Is the weight given to each factor by the respondents and ranges from 1 to 5, (where "1" is "Not relevant" and "5" is "Extremely Influential");

WA – Is the highest weight (i.e. 5 in this case);

N – Is the total number of respondents.

6.3 Details of Experience of Participants

The details of the experience on the system formworks of the participants in the tabulated form and the graphical form as follows.

Table 6.1: Details of Participant

Participants No	Experiences on types of system form-works
1	Conventional formwork, Mivan, Doka, MFE, Shenzhen
2	Conventional formwork, Doka, Aluminum
3	Conventional formwork, Peri, Mivan
4	Conventional formwork, Peri
5	Conventional formwork
6	Conventional formwork, Mivan, Doka, MFE, TAC
7	Conventional formwork, Mivan
8	Conventional formwork, Peri, Mivan, MFE
9	Conventional formwork
10	Conventional formwork
11	Mivan
12	Conventional formwork, Peri, Doka
13	Conventional formwork, Mascon

Participants No	Experiences on types of system form-works
14	Peri
15	Conventional formwork, Peri
16	Conventional formwork
17	Conventional formwork, Peri, proprietary aluminum formwork
18	Conventional formwork, Mivan
19	Conventional formwork, Peri, Mivan, Doka, MFE
20	Conventional formwork, Peri
21	Conventional formwork, Peri
22	Conventional formwork, Aluminum Formwork
23	Conventional formwork, Peri, Aluminum System Formwork
24	Conventional formwork, Peri
25	Conventional formwork, Peri, Mivan
26	Conventional formwork, Peri
27	Peri, Mivan
28	Conventional formwork, Peri, Aluminum formwork
29	Conventional formwork, Peri
30	Conventional formwork
31	Conventional formwork, Mivan, Chinese system
32	Chinese brand
33	Conventional formwork
34	Conventional formwork
35	Conventional formwork, Peri, Mivan
36	Conventional formwork
37	Conventional formwork, Peri
38	Conventional formwork, Peri

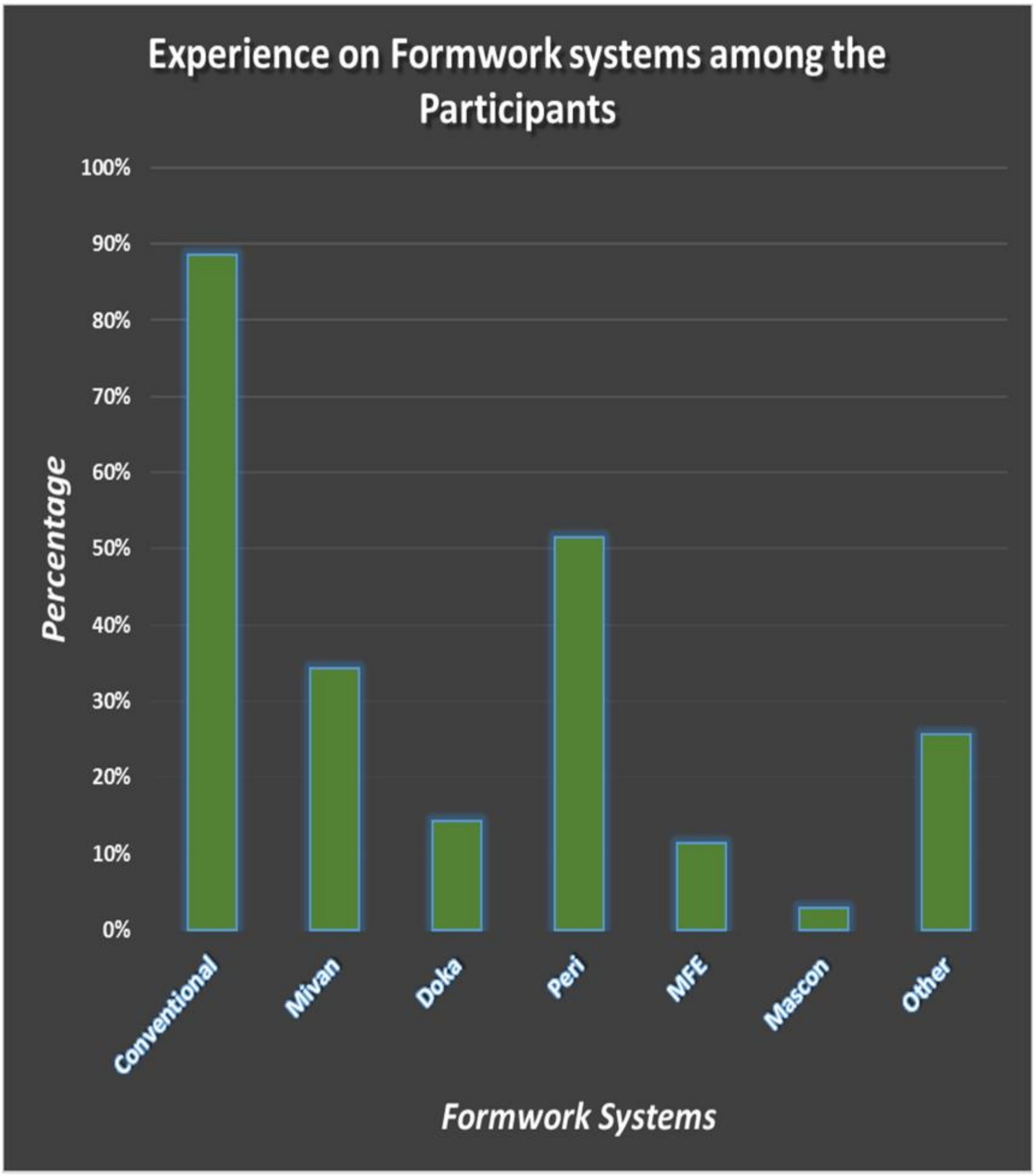


Figure 6.2: Experience on Formwork Systems among participants

6.4 Results of the Survey

The contribution of each of the influential factors for the selection of a proprietary formwork system can be ranked by the use of RII can be tabulated as follows.

Table 6.2: RII values of the Influential Factors

Influential Factors in a Proprietary Formwork System	**Relative importance index gained from the Survey**
Design of Structural Elements	0.634
The shape of the Building/Structure	0.800
Repetitiveness of the Layout	0.931
Magnitude of the building	0.789
Concrete Surfaces finish	0.731
Speed of work	0.886
Reusability of the system	0.857
Head room & spans of the building	0.589
Accessibility to construction site	0.566
Requirement of machineries	0.600
Initial cost of the formwork system	0.726
Maintaining & Repairing costs	0.577
Technical skills and Knowledge	0.629
Safety measures	0.646
Weather Conditions	0.451
Capacity of the Contractor Organization	0.651
Availability of Labour in the area	0.554
Product availability from manufacture	0.606
Complexity of the project	0.703
Buy back opportunity	0.594
Possibilities of modifications	0.674
Wastage of formwork material	0.669
Accuracy in construction	0.783
Resistance to earthquake	0.406
Economy in construction	0.731

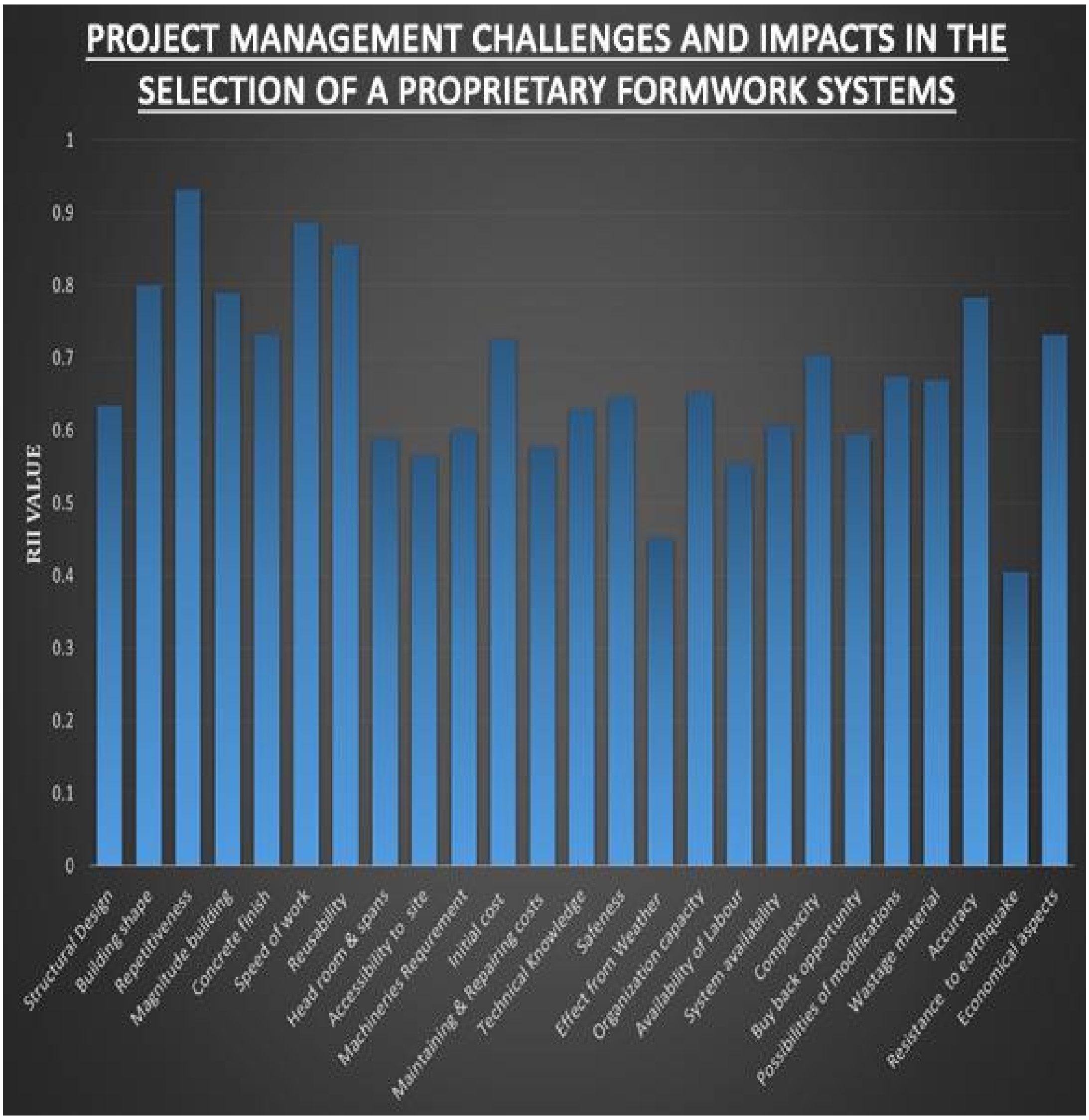


Figure 6.3: Graphical Representation of RII values of the Influential Factors

6.5 Data Analysis

Based on the data collected from the survey 15 most influential factors on introducing a proprietary formwork system for high rise construction project, were identified in Table 6.3.

Table 6.3: Most Influential Project Management Impacts on Proprietary Formwork Systems

No	Influential factors	RII values	
1	Repetitiveness of the Layout	0.93	**Category 01**
2	Speed of work	0.89	
3	Reusability of the system	0.86	
4	The shape of the Building/Structure	0.80	
5	Magnitude of the building	0.79	
6	Accuracy in construction	0.78	**Category 02**
7	Concrete Surfaces finish	0.73	
8	Economy in construction	0.73	
9	Initial cost of the formwork system	0.73	
10	Complexity of the project	0.70	
11	Possibilities of modifications	0.67	**Category 03**
12	Wastage of formwork material	0.67	
13	Capacity of the Contractor Organization	0.65	
14	Safety measures	0.65	
15	Design of Structural Elements	0.63	

In addition to the most influential factors identified, following reasons for not adopting to Proprietary Formwork Systems in Sri Lankan context, will be an unavoidable to take several years to build up the momentum for innovation were also identified.

1. Limited training opportunities for the professionals and workers as well as insufficient research and developments to be preferred at most construction firms or other supporting units.
2. No guarantee in a consistent market environment for the development and continual application of an innovative technology in construction.

3. Only in exceptionally large scale and complex nature projects in terms of the site condition as well as structural and building design confine the application of more advanced and sophisticated formwork system.

6.6 Summary of the Comparison of the Limitations

Table 6.4 Presents the summarized comparison of the limitations in the selection of formwork systems based on the influential factors identified in the above discussed proprietary formwork systems over the conventional formwork system with the consideration of literature review as well as the interviews conducted by a person with the well experienced professionals of the industry with the aim of selection of most suitable system formwork.

Table 6.4: Summarized Comparison of selection of formwork system based on the identified influential factors

INFLUENTIAL FACTORS	FORMWORK SYSTEMS			
	Mivan	Peri	MFE	Traditional
Structural element design	Minimal deflection	Lightweight units	Very strict tolerances	Timber formwork
The Building shape and layout	Repetitive floors with common shapes	Protection across three concurrent levels of construction	Easy to cast different shapes	Any type of building shapes.
Magnitude of the building	Large sized panels in numbers of repetitive floors.	Vertical concrete elements in high-rise structures.	Broad range of applications	Easy to produce, time-consuming

INFLUENTIAL FACTORS	FORMWORK SYSTEMS			
	Mivan	Peri	MFE	Traditional
Surfaces finishes	Concrete to be cast to the exact dimensions Plasters are not required	Plasters are not required Concrete to be cast to the exact dimensions	High quality wall finish without any expensive plastering	Plastering is required
Speed of work	Faster than traditional formwork.	Faster than traditional formwork.	Faster than traditional formwork.	Time consuming for large structures.
Head room and building span	Provide more headroom	Provide more room horizontally	Optimum utilization of available work space	Less head room
Accessibility to work	Less congestion	Less congestion	Less congestion	More congestion
Repetitive nature and reusability of Formwork	Large number of repetitions (around 250).	Fast solution for repetitive floors – horizontally or vertically.	More than 300 times of repetitions with high accuracy	Short lifespan with less repetitive nature
Provision of construction joints	Very few construction joints.	Very few construction joints.	Very few construction joints.	More construction joints
Cost (Initial, Maintaining, Repairing)	Saves on site running, operating and financing costs.	Total cost will be comparatively very low	Saving time and money with proper maintenance.	Low Initial cost but higher maintenance cost
Plant and machinery required	Possible with minimal crane use.	Possible with minimal crane use.	Possible with minimal crane use.	Lifting machineries such as tower cranes are required.

INFLUENTIAL FACTORS	FORMWORK SYSTEMS			
	Mivan	Peri	MFE	Traditional
Technical skills and Knowledge	Softwares with experienced, skilled designers and technical	Skilled labour intensive depending on the size of the table unit.	Combination of design software and experience of designers	Large workforce with lesser technical skills
Availability and Delivering products of Formwork	Delivering within three months after they are ordered.	Delivering pre-fabricated units, save time, labour and costs.	Panels in standard and nonstandard sizes and shapes to ensure hassle free installation	Available at any country.
Complexity of the built environment	Easily used under the complexities	Need space around the construction to fly the table unit	Effectively managing activities, increases productivity	Complex construction including any kind of shape
Weather Conditions	Aluminum formwork with corrosion resistance	Aluminum formwork with corrosion resistance	Aluminum formwork with corrosion resistance	Severely affect the durability of components.
Area of practice	System to bring assembly line techniques to construction site with proper supervision	Repetitive nature combined with Engineered nature, allows tuning operations.	Simplicity & repetitive nature allows programme construction sequence accurately	Severely affect the quality of work & durability of components

INFLUENTIAL FACTORS	FORMWORK SYSTEMS			
	Mivan	Peri	MFE	Traditional
Organizational capital	High initial and low operational cost	High initial and low operational cost	High initial and low operational cost	Comparatively low initial cost. Higher capital and operational cost.
Plant and machinery Facilities	Highly influential	Highly influential	Highly influential	Less influential
Available technical personals	Minimal labour & supervision staff	Minimal labour & supervision staff	Minimal labour & supervision staff	More skilled labour & minimal supervision staff

CHAPTER SEVEN

CONCLUSION AND RECOMMANDATIONS

7.1 Introduction

This chapter expressed the conclusion made based on the analysis on the most influential factors identified by the industrial survey. Moreover, the recommendation is also meant to improve any weaknesses of the research in the future. Any suggestion made will lead to the correction and improvement of the research.

7.2 Conclusion

According to the above analysis, it is very conclusive that the selection of a system formwork is highly based on the reusability of the system within the project and the speed of work. It is obvious that Shape of the Structure will cause to define the system into particular design and if the shape of the structure is simple and universal the designed panel may use with another structure with minimum modifications. Magnitude and Repetitiveness of the Layout will increase the reusability with quality materials. The systematic erection of formwork will definitely reduce the time and cost respect to conventional formwork systems with will cause to expedite work and finish the structural aspects of the project ahead of the construction programs and expectation.

When the structures in construction projects are in a complex and designed as precise, concrete fair face finishers, a requirement of a system formwork is high as the finishing details are the governing conditions. In such cases even the magnitude and receptiveness will not be a significant factor as gaining the ultimate finish is the most important. And also the cost of the system, including initial and maintenance is governs secondary role as the expectation of the construction projects comes in first concerns. Therefore, it is pretty conclusive that factors in category 02 are important based on the requirement of the client and contractors and they play a significant matter when they are chosen to be important.

The factors in category 03 such as Possibilities of modifications, Wastage of formwork material, Capacity of the Contractor Organization, Safety measures and Design of Structural Elements do not have a significant effect in the decision making process of implementing a proprietary formwork system for a particular project but it is important to the mentioned fact to be considered in designing process of the formwork system for a particular structure.

7.3 Recommendations

Since the selection of a system formwork is highly based on the reusability of the system within the project and the speed of work, some recommendations need to be suggested to improve the current research in the future. It is suggested that any further study on Influential Factors of Proprietary formwork systems should go into more details of implementing certain reliable systems. In the other hand, in future researches, the comparison of the quality of the formwork system between the Institute of Standards Organization (ISO) 9001 certified companies and non ISO 9001 certified companies could also be made. This will lead to determine whether the quality of the formwork system, improve under the ISO 9001 certified companies.

In addition to the above, the research can be further improved by conducting some interviews with foreign authorities and senior project managers with some foreign construction exposure in order to gather more reliable data as well as information.

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APPENDIX

QUESTIONARE SURVEY

Identifying most influential factors in introducing system form-works in High Rise Building Construction Projects.

This survey is a part of my MSC research and your contribution is highly appreciated. The survey will be carried out as a closed survey withing selected competent personnel in Sri Lankan Civil Engineering industry.

This survey is to identify most influential factors in decision making process of implementation of system form-work for a high rise building construction projects.

You are kindly requested to submit your answers based on the Experience and Knowledge on system form-works in Sri Lankan Civil Engineering industry.

Please do not hesitate to contact me for any clarification or comments. (071 364 30 81)
Kavinda Wijetunga

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* Required

Your Name *

....

Current Organization *

....

Experience in the field Civil Engineering (Years) *

....

Experiences on types of system form-works *
What are the form work systems you have used in your career.

- [ ] Conventional form-work
- [ ] Peri
- [ ] Mivan
- [ ] Doka
- [ ] MFE
- [ ] Mascon
- [ ] Other: ....

Most significant factors which governs the type of formwork for a high rise building construction project.

I have listed 25 factors which have influence on deciding whether it is effective to use a system form work for a particular high rise building construction project.

You are kindly requested to mark your preference based on your experience to identify Most significant factors among following points in taking the decision of introducing a system formwork for a high rise building construction project.

How do you rate the influence of following topics to decide the Form-work system for a high rise building construction project.

	Not Relevant	Less Influential	Influential	Highly Influential	Extremly Influential
Design of Structural Elements	○	○	○	○	○
Shape of the Building/Structure	○	○	○	○	○
Repetitiveness of the Layout	○	○	○	○	○
Magnitude of the building	○	○	○	○	○
Concrete Surfaces finish	○	○	○	○	○
Speed of work	○	○	○	○	○
Reusability of the system	○	○	○	○	○
Head room & spans of the building	○	○	○	○	○
Accessibility to construction site	○	○	○	○	○
Requrement of machineries	○	○	○	○	○
Initial cost of the form-work system	○	○	○	○	○
Maintaining & Repairing costs	○	○	○	○	○
Technical skills and Knowledge	○	○	○	○	○

How do you rate the influence of following topics to decide the Form-work system for a High Rise Building Construction Project.

	Not Relevant	Less Influential	Influential	Highly Influential	Extremly Influential
Safety measures	○	○	○	○	○
Weather Conditions	○	○	○	○	○
Capacity of the Contractor Organization	○	○	○	○	○
Availability of Labour in the area	○	○	○	○	○
Product availability from manufacture	○	○	○	○	○
Complexcity of the project	○	○	○	○	○
Buy back opportunity	○	○	○	○	○
Possibilities of modifications	○	○	○	○	○
Wastage of formwork material	○	○	○	○	○
Accuracy in construction	○	○	○	○	○
Resistance to earthquake	○	○	○	○	○
Economy in construction	○	○	○	○	○

What are the reasons for not using Proprietary Form-work