Impact and Barriers of Modular Formwork use in Pakistan's Construction Industry

A thesis submitted in partial fulfillment of the

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in

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by

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This is to certify that the
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This thesis is dedicated to my parents and my respected teachers!

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ABSTRACT

In construction, the formwork supports and retains the freshly poured concrete till the time it cures. Formwork has an essential role in the structural works and its operations are labor exhaustive and time-consuming. Modular formwork systems of many types are in use all over the world. These smart systems have automated the process, improving the productivity and cost effectiveness due to their simple and systematic fixing and striping methods along with less skilled labor requirements, higher strength and smooth finished surface.

In Pakistan such modular formwork systems are not commonly used. It is important to determine the impact and barriers of such modular formwork systems on Pakistan's construction industry which could be done by comparing the same with the traditional steel formwork systems. For this purpose, the current study focused on modular formwork erection and striping methodology in view of manufactures guidelines and its comparison with traditional steel formwork.

In total, 14 on-going and completed projects were considered and related technical data for both systems was collected to assess the practical approach and impact on the productivity. Systematic literature review, field data, site observatory data and interviews with professionals helped in selecting the most appropriate formwork system considering the top ranked factors through a decision support system. It is found that the lifecycle cost of modular formwork system is economical. However, there is a lack of relevant skilled workforce. It is recommended that such a formwork system be specified in contracts. Lastly, it has become imperative for workers to be provided with necessary skills through training programs and vocational education systems.

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LIST OF ABBREVIATIONS

FRP	Fiber Reinforced Polymer
RCC	Reinforced Cement Concrete
RC	Reinforced Concrete
MIVAN	Aluminum formwork
IBS	Industrialized Building System
DOMINO	Lightweight, movable by crane PERI wall formwork
DRS	Dual Radius Side cut
PERI	Formwork manufacturer
DOKA	Formwork manufacturer
MAINI	Formwork manufacturer
SKYDECK	Panelized slab formwork
VARIO	Variable cross section column formwork
CF	Critical factors
BOQ	Bill of quantity
ROI	Return on Investment
CJ	Construction Joint
APCA	All Pakistan contractor's association
PAF	Preventions, appraisals, failures

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Chapter 1

INTRODUCTION

1.1 Preamble

Wet concrete is supported by a formwork system until it is fully cured. Formwork systems play a major role in structural works (Huang et al., 2004). Formwork is a false work with a proper support system that serves the purpose of shaping the concrete into a desired design based on requirement. It remains intact till sufficient strength is attained by the concrete to bear not only its own weight but also all upcoming dead and live loads (Malvankar, 2013; Dinesh, 2017). A formwork system is an essential factor in determining the success of a construction project with respect to speed, quality, cost and safety of its works. Formwork's financial impact has two components: material cost and labor cost. Figure 1-1 illustrates that in the material cost of any project, formwork's share is almost 15%±5% whereas it has almost 45%±5% share in total labor cost. Clients urge to complete the projects in minimum time to save cost (Malvankar, 2013).

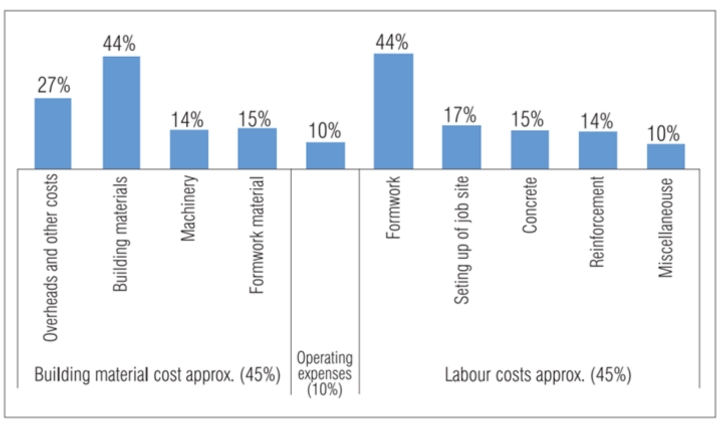

Figure 1-1- Formwork's Cost Share in a Typical Building Project

In a concrete skeleton, formwork's cost is 35-60% which is the leading sole cost item in reinforced concrete structures (Hanna et al., 1992). A total of 25% construction duration is approximately spent on formwork operations (Ling and Leo, 2000) and directly influences the succeeding construction activities, such as electrical, mechanical and finishing work (Proverbs et al., 1998). Consequently, the activity of formwork construction is often significant in a project, affecting it in terms of time, cost, quality and safety (Huang et al., 2004).

1.2 Conventional Formwork

In the traditional or conventional formwork system, workers construct formwork on site with the help of hand tools like hammers, drills and hand level. This method is also called stick-built formwork. This formwork includes cut to size sections, plywood panels, bolts, steel or aluminum bracing, angles, and nails(Safa et al., 2018).This type of formwork is usually built on site for unique shaped structural elements where standardized panels can't be used and are uneconomical It is used once and then dismantled(Ilinoiu, 2006).

The conventional formwork system is in use for RCC construction from long ago. Use of traditional formwork system has decreased slightly over the years in large construction projects because of standardized construction practices and more usage of pre-cast members (Brett, 1988). Timber is a commonly used material in stick-built form. Timber is widely used as bearers in soffit forms and as waling in wall forms. There are many advantages of timber compared to other materials. For example, timber can be easily cut, handled and joined on-site, but the advantages of metal and plastic reign where a high-quality finished surface and a continuous recurrence are required (Brett, 1988; Hanna et al., 1992; Peurifoy RL, 2010).

Adopting a suitable formwork system can help achieve sustainability in construction. Various formwork systems have different advantages and disadvantages but a formwork that best supports individual project requirement must be chosen. Scarcity of skilled and semi-skilled workers results in problems of cost and time overruns, substandard construction, poor finishes due to leakages, and corrosion of structures. This can be avoided by adopting modern formwork systems which do not require any repairs and rehabilitation during its life cycle (Karke and Kumathekar, 2014).

1.3 Conventional Steel Formwork

It is observed that the formwork system which is commonly used in construction projects of Pakistan is steel formwork. The concept of the conventional metal system is the same as the conventional wooden system, however, the main difference is the type of material used; especially in the shores (Ghowiba, 2016). According to Hanna (1999), the metal system can be formed of a wood joist, metal stringer and an aluminum prop; or a metal joist and stringer, and steel frame. According to Hurd (2005), in conventional metal systems for slab; using steel props or scaffolding pipes and joints, a support skeleton is prepared then wooden battens or I section steel beams are laid to receive horizontal steel plates which are leveled at the end. Similarly, in case of vertical formwork, first steel plates or marine ply sheets are erected then a bracing system is established using wooden battens and scaffolding pipes and the support system is erected lastly using scaffolding pipes. For leveling and alignment, wooden wedges are used. The whole process is labor intensive, time consuming and difficult.

1.4 Modular Formwork

A modular formwork system is a new method of formwork construction that is increasingly becoming famous in important construction projects. Traditional methods of formwork construction require more skilled labor as compared to a modular formwork. This system provides faster erection and stripping method, and longer anticipated usage rate over its life. Modular formwork systems are modifiable and capable to allow a project to be completed faster with a team like in high-rise building projects (Safa et al., 2018).

Long lasting and strong materials are used in manufacturing modular forms than those used in stick-built forms. Steel, aluminum, plywood, fiber and their combinations are examples of such materials. Modular forms include panel, pan and domes, void and duct, FRP column, stay-in-place form, and special-purpose/custom-made forms. Modular forms can be reused frequently at a coherent cost (Hurd, 2005).

1.5 Research Significance

Substandard formwork and scaffolding are the main reasons of accidents which take place during reinforced cement concrete (RCC) construction. Consequently, a focal point is required to be transferred to major dynamics of formwork, so as to complete fast projects well on time. On the other hand, when using a system formwork, considerable savings can be made with quicker return on investments (Karke and Kumathekar, 2014).

Traditional concrete formwork systems consume more labor and time. These systems are fabricated on site and require more time for final finish after their removal. Additionally, major fatalities are caused by the false works involved in formwork operation at construction sites and therefore hamper worker safety. As a result, the activity of formwork construction is important as it influences time, cost, quality and safety (Huang et al., 2004).

Pakistan is a developing country where construction trends need to be modernized, especially for mega projects where time is of essence and construction methodology matters significantly. Use of modular formwork system is not common. Contractors and construction companies are reluctant in using modular formwork methods. This study attempts to uncover its reasons.

1.6 Problem and Research Statement

In developing countries like Pakistan, it is essential to modernize the construction trends using smart and modular systems in construction. Despite availability of modern formwork techniques, the local construction industry is still using traditional systems. It is imperative to uncover details of this phenomenon by answering the following questions:

a. Why there is a slow transition towards modular formwork system?

b. What is the impact of modular formwork on cost and time as compared to traditional steel formwork?

c. What are the criteria adopted for selection of formwork system?

d. What are the problems of using modular formwork system?

The selected research topic, *"Impact and Barriers of Modular Formwork use in Pakistan's Construction Industry"*, will help to answer these questions through the data collection process in which contractors, consultants and clients will be involved. These interactive sessions will prove a milestone to adopt new construction trends.

1.7 Objectives

a. To identify factors affecting selection of an appropriate formwork system in Pakistan

b. Based on selected factors, comparison of modular formwork system with traditional steel formwork system highlighting the advantages, limitations and specific problems associated with each formwork system in the context of Pakistan's construction industry perspective.

c. To develop a decision support system for choosing a modular formwork system as compared to traditional steel formwork system

d. To assess major issues in implementing modular formwork system in Pakistan.

1.8 Summary

The chapter provides an introduction to the research by analyzing current available literature. Through examination of the literature a foundation was formed from which the need and significance of the research undertaking is highlighted. The chapter presents that specific problem statement that will be resolved using the research questions developed. In addition, the current study's research aim and objectives are drawn which will act as guidelines in successfully completing the study.

Chapter 2

LITERATURE REVIEW

2.1 Formwork Systems for Reinforced Concrete Structures

The important role of formwork has been emphasized by the literature studying RCC construction projects, and the requirement to utilize each and every feasible resource to decrease the cost of the forms (Hurd, 2005). Largely, construction progression must be deliberated to employ formwork in the most proficient way and allow the best possible investment to meet the schedule requirements. In developing the plan, the availability and cost of local labor and materials should also be considered (Huang et al., 2004).

In an RCC building's structural frame, the main single cost component is formwork and it varies on average between 35% and 45% of a RCC structure's unit cost. It can be even 60% for civil engineering structures. Formwork elements are often rented by the contractor to execute particular concrete works. Consequently, considering their constructability and analyzing competence of their operation at each stage of construction preparation, speeding up the construction schedule or increasing jobsite efficiency seem to be the smartest steps to decrease rent costs and as a result total building work costs (Krawczyńska-Piechna, 2017).

Formwork and its support system is a structural system and must be designed and constructed accordingly. The loads it supports may be provisional but they can be tremendously huge. Frequently they are dissimilar in nature to those forced on the finished concrete structure. Concrete is a very plastic and flexible material which will correctly reflect the shape, texture and finish of the surface against which it is cast. Any flaw or imprecision in this surface will be ineradicably inscribed on the concrete surface (Reynolds, 2017). Form-face materials must therefore be selected both to attain the intended surface finish and, in combination with all the supporting elements, to maintain accuracy and stability under all the loads forced during erection and concreting, and for some days into the life of the concrete structure (Naik and Rathod, 2015).

Formwork systems for buildings are categorized as either horizontal or vertical. Horizontal formwork systems include slabs or roofs and vertical formwork systems include vertical supporting elements of the structure, e.g., columns, core walls and shear walls (Hurd, 1995).

As time passed, the latest techniques of formwork for construction of structures have been used extensively. In the present competitive market, speed and competence are of major importance. Thus, by use of latest technology, the time period of a project is decreased with the help of advanced materials, equipment and techniques which are efficient and robust (Kazi and Parkar, 2016). With the introduction of latest techniques for formwork, there has been much comparison of the traditional techniques and latest techniques of formwork. With the help of MIVAN and tunnel form systems, cost and time reduction can be achieved. It has been proved that these techniques decrease cycle time as compared to traditional methods, and therefore overall cost saving can be achieved(Karke and Kumathekar, 2014). Sangale (2014), through a study found that Industrialized Building System (IBS) is expensive, but such system can be used to increase quality, decrease time, labor, and material requirements. Ganar and Patil (2015), compared conventional formwork technique and MIVAN technology and concluded that it is better than conventional technique.

One of the prime factors which sets milestone for the success of a construction project in terms of speed, quality, cost and safety of works is the formwork system. Currently, the majority of projects are required to be completed in the shortest time possible to reduce costs. For high-rise buildings, the most efficient way to accelerate works is to attain a very short floor cycle to have the structure of a typical floor completed in the shortest time (Raymond, 2013). Speed of work is not the only criteria to be followed because just speed may cause to compromise other factors like quality, resulting in issues of displacement, improper alignment and bad concrete (Malvankar, 2013).

2.2 Comparison of Traditional and Modular Formwork Systems

The formwork of ancient times used in the construction industry is timber formwork called traditional formwork system. Lumber, cane, brickwork and joinery are used in this type of construction. Timber formwork is appropriate and commonly used for small residential construction as it enables easy forming and fabricating at site. It is however not suitable for mega projects or apartment buildings. Fixing and striping process of timber formwork requires more labor hours but despite that, it costs less(Shin et al., 2012; Lo, 2017). Thus, low initial cost, low experience factor, low weight are some of the advantages of timber formwork while a lot of deviations in the structure, poor finish of the concrete surface, high labor requirement and a higher floor cycle are the disadvantages(Hurd, 2005).Also, the wooden scantlings and timber runners used in this type of formwork have a propensity to lose their structural and dimensional properties with the passage of time and after frequent usage, they cause safety issues. Major amounts of accidents happen in RCC construction because of low quality formwork and scaffolding. Therefore, focus must shift to this prime factor to overcome the challenges in order to complete faster projects (Hallowell and Gambatese, 2009; Ling and Leo, 2000).

Steel formwork system is frequently used in large construction projects or where the same shuttering is required to be used repeatedly. This system has been widely used in construction industry for many years therefore referred to as traditional steel formwork system. Steel formwork system is appropriate for circular and angular shapes e.g. tanks, columns, sewer tunnel and retaining walls. It is tough, durable and has longer life. It can be used many times. Steel shuttering can be fixed and removed easily and speedily, saving labor cost. It does not absorb water from the concrete and minimizes honeycombing. Proper maintenance is required for steel formwork system while extra material weight is one of the main disadvantages (Hurd, 2005; Richardson, 1977).

Traditional steel formwork systems typically include standard framed panels joined mutually from their backs with horizontal members called waling. The waling is provided with the basic requirement of resisting the horizontal force of wet concrete. One side of the wall formwork is first assembled ensuring that it is rightly aligned, plumbed and strutted. The steel reinforcement cage is then fixed and positioned before the other side of the formwork is erected and fixed. Plywood sheet or steel plates in combination with timber and scaffoldings support is the most common material used for wall formwork. The usual method is to make up wall forms as framed panels with the plywood facing sheet screwed on a timber frame or steel plates. This allows easy striping, turnaround and use on both sides so as to enhance the number of reuses. (Karke and Kumathekar, 2014; Zhan et al., 2016).

Modular formwork is a designed formwork system which is coupled with the help of planned/designed elements. These elements are steel, aluminum, pressure treated lumber and fiber reinforced polymer (FRP). Modular panels increase the efficiency and economy for formwork operation. When the concrete is partially set, the formwork systems are usually striped off having no effect on final structure (Lee et al., 2018). According to Ilinoiu (2006), sometimes formwork becomes an integral part of the structure. They are usually classified into two groups: insulating concrete formwork and stay-in-place structural formwork systems. Polystyrene foam is used in insulating concrete formwork. It can support wet concrete and insulation when the structure has been completed. An example of stay-in-place formwork is prefabricated FRP hollow tubes technology which remains with the fresh concrete to provides axial and shear reinforcement, as well as protection from unfavorable environmental effects. The latest and modern materials such as plastic, FRP, and aluminum are in use as an alternatives for the conventional formwork system due to the improvement in forming technology and fabrication process(Kannan and Santhi, 2013). There are two major advantages of modular formwork system over conventional formwork systems.

1. Speed of construction (reduced time in fixing and stripping)
2. Lower life-cycle costs (maximum number of re-use).

Safa et al. (2018), while comparing modular formwork system with traditional steel formwork system in mega construction projects, concluded that the benefits of modular formwork are much more than traditional systems where there is a high degree of consistency and recurrence; where high-skilled labor to construct complex formwork systems is not available, as for modular formwork systems labor requirements are minimal; where speedy project is required with time constraints to build formwork systems as well as where there are environmental benefits for decreased waste of construction equipment, however, in case of a small sized project, the use of modular formwork is challenging. Furthermore, when space is limited for mobilization of equipment, modular formwork can be a test. In developed countries, the current preference is toward using modular forms, by assembling big size panels, erection by mechanical resources, and repetition of the forms (Hurd, 2005).

According to Safa et al. (2018) modular formwork can be beneficial as outlined in Table 2-1 which compares the advantages and disadvantages of modular formwork.

Table 2-1- Advantages and Disadvantages of Using Modular Formwork

Sr#	Description	Advantages	Disadvantages
1	Formwork joining	Fast, simple with uniform sections	Advantage is relatively less at smaller projects
2	Materials used	Special material are used to prepare prefabricated modules	Initial cost Prefabricated modules is high and Smaller projects cannot afford it
3	Erection time	Erection rate is less	Erection rate is relatively more at complex and congested places
4	Labor	Level of skill required is less	-
5	Lifecycle of formwork	It can be used from 40 to 100 times depending on weather conditions, design, complexity	life cycle is relatively less when used at smaller projects
6	Finished surface	Smooth and fair face	For specially designed structural elements, special arrangements are required to achieve better finish

2.3 Various Formwork Systems and Conclusive Overall Trend

According to Malvankar (2013), formwork can be classified according to a range of categories as shown in Figure 2-1.

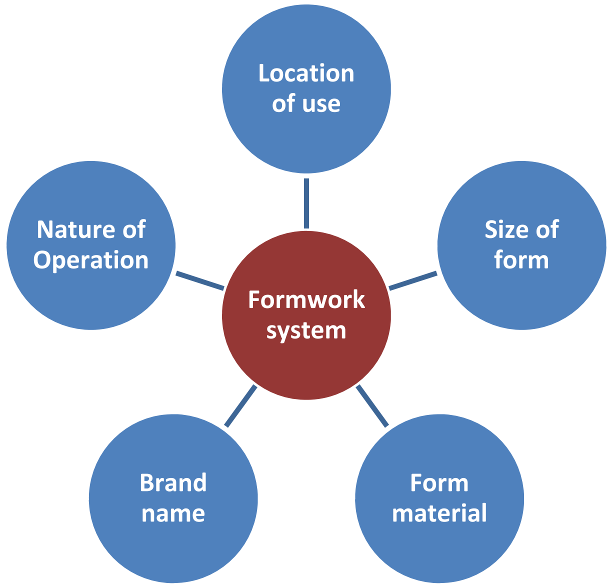

Figure 2-1- Categories of Formwork Classification

2.3.1 Classification according to sizes

a. Small-sized formwork: Wooden and aluminum formwork manual operation by carpenters.

b. Large-sized formwork: Operation requires crane facilities. It decreases the number of joints and reduces the number of lift stiffening components, studs and soldering.

2.3.2 Classification according to location of use

Different elements in the structure have explicit design and performance needs in the use of formwork. Some systems are more adaptive for special location of use, such as:-

a. Irregular frame structure – conventional traditional timber form.

b. Wall, column – girder form, frame panel form, climb form or jump form.

c. Slab – conventional timber form, modular slab formwork, primary-and-secondary beam method, panel form, drop head beam panel system, table form.

d. Repeated regular section – tunnel form, modular aluminum form.

e. Core walls, shells –climbing formwork, jump form and slip-form.

f. Pre-cast structure – steel/aluminum mold form.

2.3.3 Classification according to materials of construction

a. Timber: most popular formwork material
   - Low initial cost
   - High flexibility to complicated shape
   - Labor concentrated
   - Environmental unfriendly

b. Steel:
   - Hot-rolled or cold-formed sections
   - Heavy weight
   - Suitable for large-sized panels

c. Aluminum:
   - Stiff
   - Light weight
   - Higher material and labor cost
   - Outstanding finish

d. Plastic:
   - Recyclable
   - Tough
   - Lighter weight

e. Sacrificial concrete panels- Left in place formwork

2.3.4 Classification according to nature of operation

a. Crane independent- Manually handled formwork -Self- climbing formwork

b. Crane-dependent formwork

c. Gantry, travelling and tunnel type formwork system

2.3.5 Classification by method of application, type of material and equipment

Safa et al. (2018), categorized previously developed forming systems in order to provide a method of selection based on these qualities. Figure 2-2 provides the ontology of various formwork systems within methods and their components.

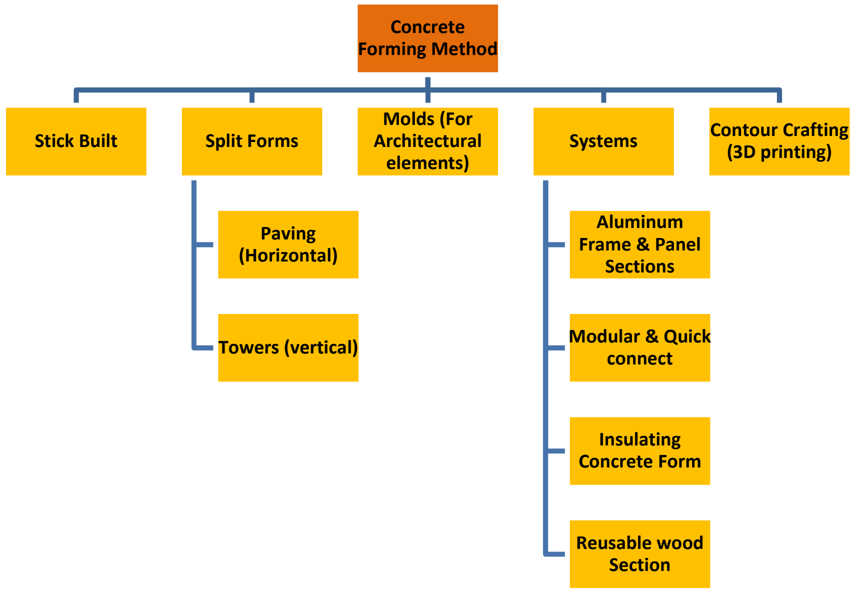

Figure 2-2- Concrete Formwork Systems

2.3.6 Present Overall System Trend

The present trend of formwork systems in use are traditional timber formwork system, traditional steel formwork system, semi traditional formwork system (plywood formwork with steel frame) and modular formwork system(Badir et al., 2002; Hanna, 1989).

In order to get better formwork usage on the construction project, right selection of formwork is the first issue that should be well thought-out. Efficient formwork employment should be understood as stipulation wherein formwork is being used to its fullest capacity. During the building performance, the efficiency of formwork utilization should be measured with a cost of formwork under-utilization; so when the formwork is available on the construction site but remains unused or when it should be struck but remains connected from the construction (Krawczyńska-Piechna, 2017).

The selection of a suitable formwork system needs the awareness and understanding of all formwork applications. Based on a historic perspective, a new description and nomenclature has been recommended to include all accessible types of formwork systems. In general, the early developments of formwork systems were aggravated by a wish to reduce construction time and costs. Time is a key factor for selecting a formwork system and it includes time to adjust steel reinforcement within shuttering, time to remove formwork, formwork preparation time and overall removal time. Likewise, labor hours to remove formwork, placing and setting formwork, overall final adjustment, correctness required for true verticality and edge margins, lifting mechanism and designer's requirements are also essential factors (Hanna, 1999). Designers and vendors know the fact to keep updated with the latest advancements in any material's fields so as to build up creative innovations which are needed to maintain quality and saving in the face of new formwork challenges. The drift is inclined toward prefabrication, assembling big sections, assembly on fast track basis by mechanical resources, and repetition of formwork(Shin et al., 2012).

Selection of the best formwork system depends on different categorizations of formwork system. Formwork can be classified according to their dimension, material and method of joining. Formwork can also be categorized on the bases of required purpose, brand, or easiness. Because execution parties feel easy to recognize a formwork with respect to dimension, material, and joining method which is a more accepted option. Conventional, modular, and prefab-traditional units are three main types of formwork systems (Jarkas, 2010).

Traditional timber and steel formwork systems are stick-built formwork systems whereas less skilled labor is required in modular formwork when compared with traditional methods of formwork construction. Prefabricated customized formwork unit is categorized between traditional and modular formwork systems(Safa et al., 2018). Prefabricated formwork is also called modular formwork which was invented with the help of heavy machinery with default setting and can be joined on-site to create the required size for concrete (Goodrum PM and Dadi G, 2012).

Previous formwork systems were commonly used just for one time. Today prefabrication, assembling big units, erection by mechanical resources, and cyclic use of forms are common. These developments are in line with the escalating automated production in construction projects (Malvankar, 2013).

2.4 Need for Modular Formwork System

In third world countries, where labor wages are low, traditional formwork systems are widely used in the construction industry. Few national building codes permit the repetition of timber and plywood in traditional forms. For example, Taiwan frequently utilizes lumber formwork systems in reinforced concrete structure. Lumber formwork can be used roughly 3 to 5 times; the number of repetitions and quality are primarily affected by three factors: working attitudes, competence and the removal process (Ling and Leo, 2000). Developed countries like Canada and the United States are using modular forms, gathering large sized units, fixing by automatic resources and recycling of the shuttering (Hurd, 2005). Massive efforts have been made over the past few decades into automating the formwork construction process. Many modular formwork systems have been developed to achieve this objective (Perng, 1996). These types of systems utilize standard-sized, prefabricated forms to make formwork construction easier by assembling the forms at the correct location in a proper way (Huang et al., 2004).

As per Hurd (2005), the basic parameters of modular formwork are:

a. Quality in the form of strength, firmness, position and size of the forms;

b. Safety of both workforce and the concrete skeleton;

c. Competence in function, the simplicity of handling, erection and dismantling, reuses within the best limits;

d. Cost offering the smallest amount, reliable in quality and safety. Overall construction sequence must be planned to utilize formwork in proficient way and to allow the maximum investment in formwork to achieve schedule necessities.

For project success in terms of speed, quality, cost and safety of works, formwork system plays an important role. These days, projects are desired to be completed in the minimum possible time to save costs. Short floor cycle is away to achieve speedy works for high-rise buildings to attain completion in the shortest possible time (Raymond, 2013). However, speed of work should not compromise quality standard. Problems such as misalignment, misplacement, deflective concrete or holding up other works causing serious stoppage can result in project delay and quality problems(Malvankar, 2013).

During selection process among different alternative methods and ways to attain the fastest and cheapest construction of buildings, it is essential to work out a base formwork which aids to help the planning team to select the most suitable system of formwork as per the explicit requirement of the project (Dinesh, 2017). Karke and Kumathekar (2014), analyzed that by using management and tunnel form systems, cost and time reduction can be achieved. They proved that such a technology reduces repetition time as compared to conventional methods and hence overall cost saving can be achieved. Sangale (2014), through their study concluded that IBS is expensive but such systems can be used to increase quality, reduce time, labor and material requirement.

In under developed countries like Pakistan, it is today's demand to modernize the construction trends using smart /modular systems in construction activities having appreciable impact on schedule and of course cost especially for fast track projects. Still use of modular formwork system is not common. Contractors/companies are hesitant and reluctant in using modular formwork methods, reasons for which must be investigated.

There is a need to undertake further investigation on the influence of formwork materials on the quality of concrete by considering the time taken to strike off formworks on sites which is normally greater than the recommended minimum time.

2.5 Modular Formwork, Broad Overview of System in Market

2.5.1 Wall Formwork

Modular formwork for wall is light in weight. It can be easily moved from one place to other with the help of crane panel formwork which has compact dimensions. This type of system is very useful for residential projects and for existing buildings. Using such type of forms sleeve foundations, parapets, retaining walls and beams can be formed in a very fast way. This type of formwork is very beneficial when crane is not available. Such type of modular wall formwork system has following properties.

a. **Easy and simple management** with the help of small-sized panels and light weight – especially when aluminum is used in panels.

b. Preferably appropriate for foundations due to inset tie points and matching accessories.

c. Fast panel connections with the DRS (dual radius side cut) Alignment Coupler as the only part for all panel links.

Figure 2-3- Application of Modular Wall Formwork

2.5.2 Slab Formwork

Modular formwork systems for slab are used for residential construction as well as for industrial and commercial projects with thicker slabs. These types of formwork systems have many ranges of accessories. They have high safety factor and are most appropriate for commercial plazas/markets. The organized assembly progression and lightweight system mechanism speed up working operations. Additionally, early striking with the drop head system decreases on-site material necessities. The small prop requirements make sure more freedom of movement under the slab formwork and make simpler the horizontal haulage of materials. Such type of modular slab formwork system has following properties.

a. Easy working with very lightweight and easy to handle mechanism.

b. Quick forming due to the simple and methodical assembly sequence and only a minimum of slab props.

c. Easy cleaning with the help of powder-coated elements, plastic components, and undercut panel edges.

d. Low on-site material necessities due to early striking with the drop head and fast deployment of the panels and beams in the next storey.

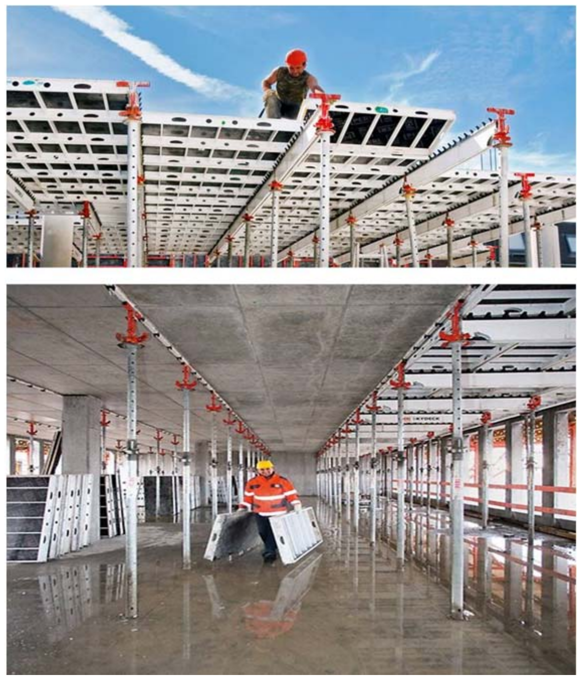

Figure 2-4- Modular Slab Formwork

2.5.3 Column Formwork

Modular formwork for column is a solution which is specific for a project as well as with universal usage for different dimensions of required column sizes. It consists of mainly girders, steel wafers and selected form items for lining. It can be tailored to outfit every cross-section, concreting height up to 50ft and required fresh concrete pressure. Concrete requirements as per architectural drawings can also be optimally satisfied using modular column formwork system. Such type of modular column formwork system has following properties.

a. Continuously flexible to match rectangular and square column cross-sections of all sizes.

b. **For architectural concrete surfaces** through project-explicit constructions with any type of form lining.

c. **For high concrete pressures** through individual arrangements of formwork girders and steel walers.

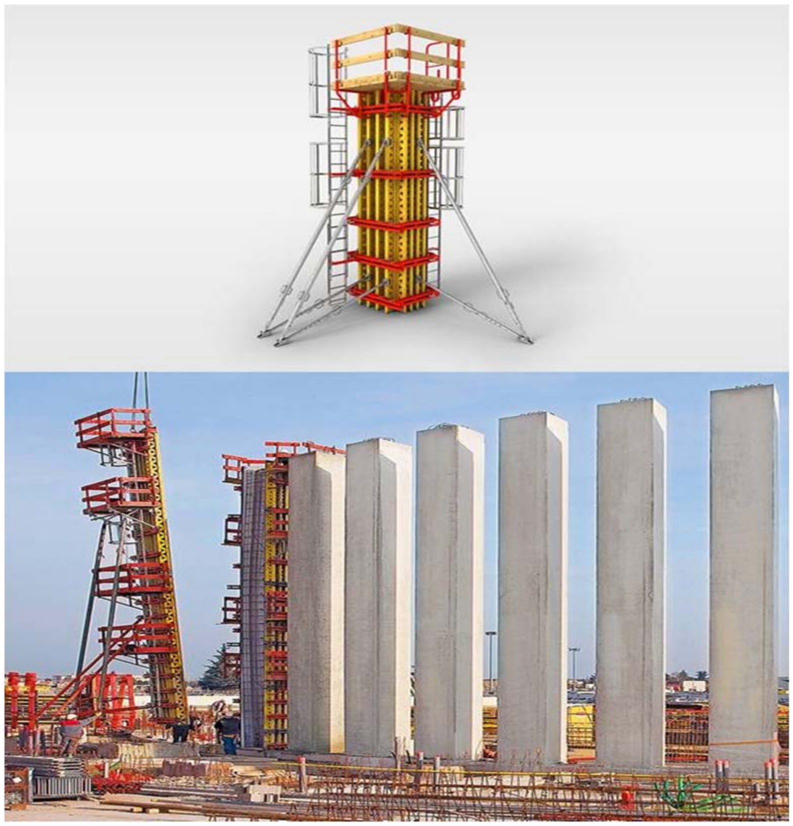

Figure 2-5- Modular Column Formwork

2.6 Factors Affecting Selection of Formwork System

Hanna (1989), presented an influence line diagram of factors affecting the selection process of formwork system. Although twenty-eight years have passed, the diagram and subsequent factors argued by Hanne (1989) are valid. Malvankar (2013), presented the same line diagram in his research. Not much research has been made in cautious planning of form reuse which is vital for the successful operation of modular formwork systems in building construction. High cost has diverted research focus on the choice of the formwork (Huang et al., 2004).

The literature on the subject matter suggested a variety of significant criteria for formwork range, but their significance in the selection problem has not been noticeably formulated. Furthermore, it couldn't be formulated without examination of local contractors' requirements, understanding the building customs and work setting. The organization of decisive criteria for the issue of formwork selection was made with a qualitative and semi-quantitative methodology by amalgamating the solving technique and expert understanding that can affect technological and hierarchical solutions in practice. A comprehensive literature review identified a number of factors affecting selection of formwork system. All these factors are tabulated in an excel sheet column and against each selected factor qualitative analysis was performed categorizing the factors as high, medium and low priority (Table 2-2).These priorities were allocated after detailed study of research literature using three formulae.

a. Research paper itself categorized the rank no using its research methodology
b. Research paper did not allocate rank but from study, priority level was envisaged.
c. Factors about which one specific literature was silent.

M			**1**	**H**									**1**	**H**					**1**	**H**	**1**	**H**	**10**	**5**	**1**	**0**	**H**	**5**	**0.83**
H	**1**	**H**			**1**	**H**	**1**	**H**	**1**	**H**													**10**	**10**	**0**	**0**	**H**	**5**	**0.58**
-							**1**	**M**			**1**	**H**											**6**	**3**	**2**	**0**	**H**	**5**	**0.5**
H			**1**	**H**	**1**	**H**	**1**	**H**															**9**	**6**	**0**	**0**	**H**	**5**	**0.45**
-																							**4**	**2**	**1**	**0**	**H**	**5**	**0.33**
-																							**4**	**4**	**0**	**0**	**H**	**5**	**0.33**
-															**1**	**H**							**4**	**3**	**0**	**0**	**H**	**5**	**0.28**
H							**1**	**H**															**4**	**3**	**0**	**0**	**H**	**5**	**0.28**
M	**1**	**M**	**1**	**M**			**1**	**H**															**8**	**2**	**5**	**0**	**M**	**3**	**0.26**
M							**1**	**M**															**5**	**1**	**4**	**0**	**M**	**3**	**0.25**
-																							**4**	**2**	**1**	**0**	**H**	**5**	**0.22**
-							**1**	**M**									**1**	**M**					**5**	**2**	**3**	**0**	**M**	**3**	**0.21**
-							**1**	**M**															**4**	**0**	**2**	**2**	**M**	**3**	**0.17**
-			**1**	**M**			**1**	**M**															**3**	**1**	**2**	**0**	**M**	**3**	**0.12**
-																							**2**	**0**	**1**	**1**	**M**	**3**	**0.08**
-	**1**	**H**																					**2**	**0**	**1**	**0**	**M**	**3**	**0.08**
-			**1**	**M**																			**2**	**0**	**2**	**0**	**M**	**3**	**0.075**
-			**1**	**M**																			**2**	**0**	**1**	**1**	**M**	**3**	**0.075**
-																							**1**	**0**	**1**	**0**	**M**	**3**	**0.03**

na et al., 1992); R5: (Smith and Hanna, 1993); R6: (Safa et al., 2018); R7: (Ghazali et al., 2016); R8: (Karke and Kumathekar, 2014); R9: (Ganar and et al., 2012); R13: (Arslan et al., 2005); R14: (Reynolds, 2017); R15: (Kim et al., 2014); R16: (Julio et al., 2004; Rubaratuka, 2013); R17: (Huang et al., After the above analysis, a semi-quantitative analysis was performed. In that the frequency of each factor category (i.e. high, medium, or low) was calculated, allowing for the results of a final grade and literature score to be produced. The literature score is normalized and ranked. From normalized score and cumulative score, top six factors are selected for further investigations within prescribed objective boundaries. The selected factors are appended in Table 2-3.

Table 2-3- Top Factors Affecting Selection of Effective Formwork System

Sr#	Factors	Literature Score	Normalized Score	Cumulative Score	Rank
1	Quality	0.833	0.159	0.159	1
2	Cost	0.588	0.112	0.272	2
3	Building design	0.500	0.095	0.368	3
4	Time factor/ Project Planning (Speed of construction)/ Repetition Cycle	0.450	0.086	0.454	4
5	Climate Factor	0.333	0.063	0.582	5
6	Safety	0.333	0.063	0.518	6

Chapter 3

RESEARCH METHODOLOGY

3.1 Background

The literature review chapter provided an overview and evolution of formwork assessment with regards to modern construction trends. Knowledge gap is identified in the light of extensive literature review. In Pakistan, modular formwork systems are not commonly in use. Although many comparative studies have been conducted in the world to highlight the advantages of modular formwork systems, as such their real impact on construction projects in terms of factors affecting selection of formwork system has not been carried out especially in Pakistan. The aim of the current research was to assess a practical approach and record its impact on the productivity of using modular formwork as compared to traditional steel formwork system. This research work focused on those factors which were figured out through systematic literature review. This research highlights advantages of modular formwork and barriers in using such systems as compared to traditional steel formwork. The current study also uncovers the main reasons due to which such modular formwork systems are not used in Pakistan. In order to fulfill this need, research methodology helped to achieve the objectives of this research as stated in Chapter 1.

3.2 Research Structure

Research structure was categorized into four phases as graphically shown in Figure 3-1.

3.2.1 Phase-I

In this phase previously published literature was reviewed in detail. Research articles published during last 15 years were studied in depth which revealed that certain studies are being carried out in continuations commonly focusing on formwork system. This phase resulted in identification of research gap, and development of problem statement and research objectives.

A detailed literature review was performed to identify factors affecting selection of an appropriate formwork system. Different studies have reported different factors according to their area, environment and study to select formwork system. After a detailed scrutiny, 70 research papers relevant to study were identified. Based on a thorough review of these papers, 20 were selected which helped identify 19 factors affecting selection of an appropriate formwork system. Since it was not possible to carry out further research on all these factors as canvas was too broad, the top ranking factors for further work were selected instead. These all factors were tabulated and detailed qualitative and semi-quantitative analysis were performed. In each paper, each factor was studied and ranked as high, medium or low with semi-quantitative analysis. This ranking as high, medium or low was based on three criteria;

a. In the referred paper, it was ranked itself.
b. In the referred paper, it was not ranked but literature review revealed its importance which was being translated in terms of rank.
c. In the referred paper, above two situations did not exist however either a factor was slightly discussed or it was totally ignored. Such factors were ranked as nil or low.

Semi-quantitative analysis was performed. Frequency of each factor was determined and it was finally graded as high, medium or low. Then each factor was assigned with qualitative number and literature score. Each score was normalized and cumulative normalized score was determined which was finally ranked. The analysis of data obtained through this process finally concluded six top ranked factors as appended in Table 2-2.

3.2.2 Phase-II

In the second phase of research, it was required to get these factors tested from Pakistan's construction industry because the selected factors may possibly vary in the local context. In the second stage of research, a questionnaire was prepared in which all selected factors were assessed from 18 well known contractors and shuttering specialized sub-contractors. This data was again analyzed in a systematic way which determined top six factors as very highly significant. Then, in order to conclude the factors, two streams of literature review and field data were compared with different percentage weight and then their variance was observed. This variance finally concluded top ranked factors. It is important to mention that the percentage variance was less than 5% and the main difference was in the ranking or order of factors. This data analysis completed second stage of research.

3.2.3 Phase-III

In the third stage of research, on-going good construction projects in Pakistan were visited which had used or were using modular formwork systems as well as traditional steel formwork systems. Information of related technical data from experienced construction firms and project managers were collected. In this phase meetings with international shuttering vendors and designers were included. Detailed site shuttering process was observed. Market rates for traditional steel formwork system components as well as modular formwork system were collected. In this phase field work covered four aspects.

a. Field site visits
b. Personal observations of formwork operation by spending time on sites
c. Interviews with construction experts
d. Collection of market rates and meetings with international formwork manufacturer and suppliers

3.2.4 Phase-IV

In the fourth phase, data was analyzed through quantitative and qualitative methods.

a. Quality- Qualitative analysis was made on factors determined from Phase-III
b. Cost- Quantitative analysis based on initial cost as well as life cycle cost
c. Time- Quantitative analysis based on field determined labor crew

d. Building Design - Universal formwork behaviors of both the systems with respect to different commonly used design thicknesses of structural elements
e. Safety- Built in features of modular formwork system comparison with traditional steel formwork system
f. Erection and Striping system - Qualitative analysis of two systems

This phase was summarized at the end with discussions, conclusion and recommendations in view of all research carried out.

In general, the tool, techniques and sources used to achieve the research objectives have been tabulated as Table 3-1.

Table 3-1- Tool,Techniques and Sources Used to Achieve the Research Objectives

Sr#	Objective	Tool and Technique	Sources
1	To identify factors affecting selection of an appropriate formwork system in Pakistan	Systematic literature review	Research paper, journals, article, thesis, standards andguidelines, field data through questionnaire
2	Based on selected factors, comparison of modular formwork system with traditional steel formwork system highlighting the advantages, limitations and specific problems associated with each formwork system specially in Pakistan's perspective	Qualitative analysis	Ongoing projects, direct interaction with shuttering experts, interviews and detailed discussions with shuttering related work force, field visit, field observations
3	To develop a decision support system for choosing amodular formwork system as compared to traditional steel formwork system	Qualitative and quantitative analysis	Shuttering components market rates and validity, modular formwork rates from international market and direct interactions with venders and interviews
4	To assess main problems in implementing modular formwork system in Pakistan and way forward	Brainstorming technique	Interview with ex-chairman APCA, ex-VP NESPAK, prime contrcators and field experts

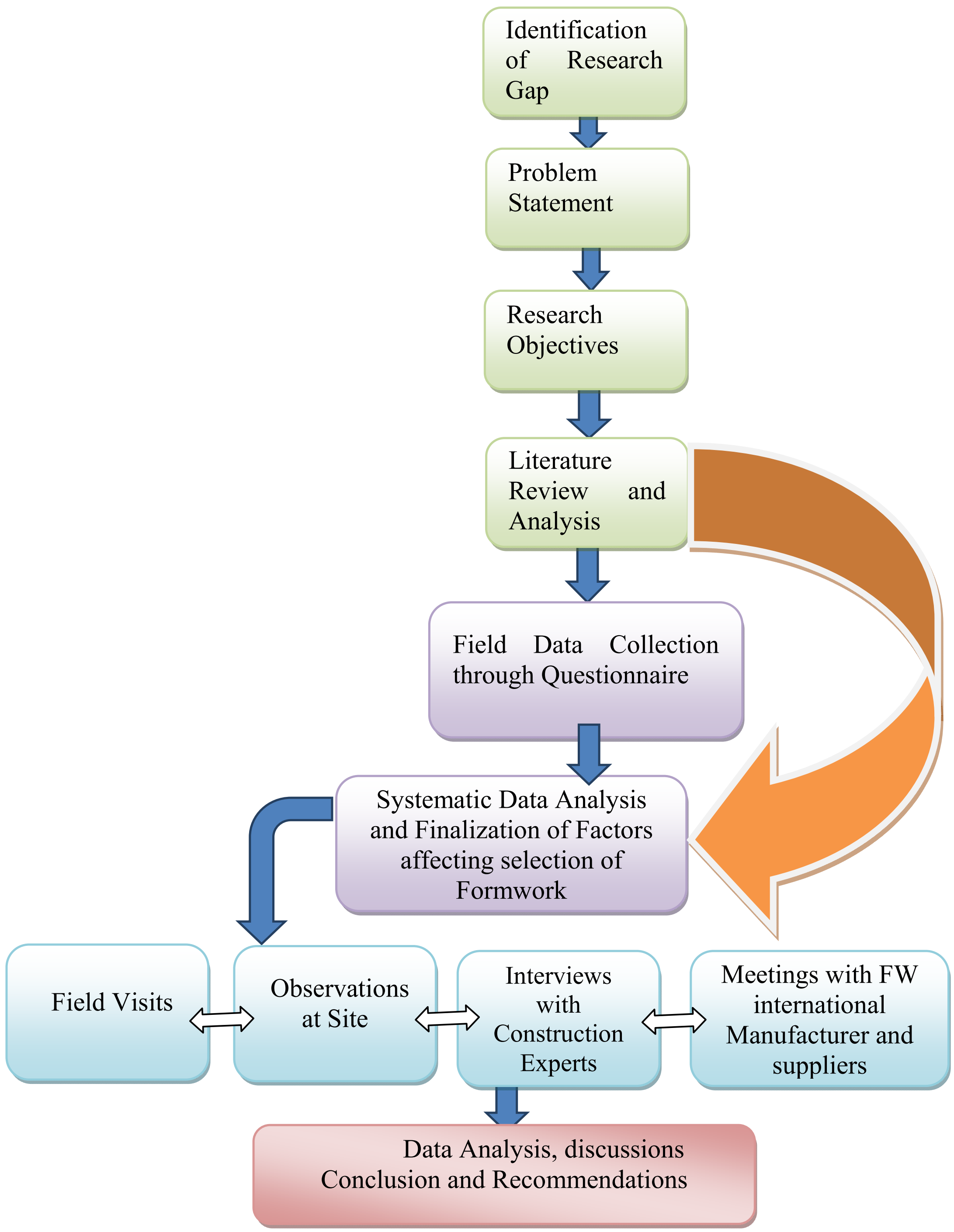

Figure 3-1- Research Flowchart

3.3 Advantages

Pakistan is an underdeveloped country. Construction practices need to be modernized, especially for mega projects where time is an essence and construction methodology matters. Use of smart formwork is a one of the steps towards quality, safety, efficiency and economy in construction industry. This research will yield the major time saving benefits from modular formwork with quality, safety and cost saving as compared to labor intensive and time consuming traditional formwork systems and will focus the reasons of why is it not being recommended in Pakistan.

This research of modular formwork systems will provide the constructors to adopt modern formwork systems with greater cost savings, time saving with ensured quality and safety. In Pakistan it is intended to adopt modern construction trends to cope with fast pace of construction already in use in the developed countries.

a. This research will help contractors to decide formwork system that will have increased productivity rate, cost efficient, time saving and less labor intensive.

b. It may prove a step towards innovative construction trends.

c. Better concrete finish and quality will be used especially in structural works using modular formwork systems

d. One may easily differentiate the operational process effecting time and cost between traditional steel formwork and modular formwork systems

Chapter 4

DATA ANALYSIS AND RESULTS

4.1 Data Collection from Pakistan's Construction Industry

The selected top most factors are screened from the literature, thus, their demographically contextual importance and ranking, particular to Pakistan's construction conditions were to be assessed. For doing so, 19 factors, initially screened from literature, were ranked by the local construction industry experts.

In this survey, eight prime contractors with Pakistan Engineering Council (PEC) category C-A and seven specialized shuttering contractors with more than 25 years of shuttering experience were engaged. Mostly the specialized shuttering contractors were illiterate therefore they were first briefed about modular formwork concept, usage, methodology and available rankings in the questionnaire and then the options were marked as per their view points. Similarly, data was collected from executive and senior management of prime contractors. Each factor was ranked ranging from very high to very low and semi-quantitative analytical technique concluded six top factors as "Very High" shown in Table 4-1. These factors are

a. Cost of formwork
b. Availability of formwork system
c. Erection and dismantling process
d. Quality of concrete surface
e. Time and speed of construction
f. Training or lack awareness

I	1	H	1	H	1	H	1	VH	1	H	1	M	1	H	1	H	1	H	1	M	1	H	1	H	4	5	2	0	0	VH
I	1	H	1	H	1	VH	1	H	1	VH	1	VH	1	H	1	VH	1	H	1	VH	1	H	1	VH	7	5	0	0	0	VH
I	1	H	1	H	1	VH	1	H	1	VH	1	VH	1	VH	1	H	1	H	1	VH	1	VH	1	H	7	4	1	0	0	VH
I	1	H	1	VH	1	VH	1	VH	1	H	1	VH	1	VH	1	VH	1	VH	1	VH	1	VH	1	VH	12	2	2	0	0	VH
L	1	H	1	VH	1	VH	1	VH	1	H	1	VH	1	M	1	H	1	VH	1	VH	1	H	1	M	9	2	2	0	1	VH
I	1	H	1	M	1	M	1	H	1	H	1	M	1	H	1	H	1	VH	1	VH	1	M	1	H	2	3	6	0	1	M
I	1	M	1	M	1	H	1	M	1	M	1	H	1	M	1	M	1	M	1	M	1	M	1	H	0	2	11	1	0	M
I	1	M	1	M	1	H	1	M	1	H	1	H	1	M	1	M	1	M	1	L	1	M	1	M	0	2	10	2	0	M
,	1	M	1	M	1	H	1	M	1	M	1	M	1	L	1	M	1	M	1	M	1	M	1	M	0	1	12	2	1	M
,	1	M	1	H	1	H	1	VL	1	M	1	M	1	H	1	M	1	VH	1	H	1	H	1	M	1	0	8	2	1	M
I	1	M	1	M	1	L	1	L	1	M	1	M	1	L	1	VL	1	M	1	L	1	L	1	L	0	0	9	7	1	M
I	1	L	1	L	1	VH	1	M	1	L	1	M	1	VL	1	M	1	L	1	M	1	VL	1	M	1	0	7	7	2	M
,	1	H	1	M	1	H	1	H	1	H	1	M	1	M	1	H	1	M	1	H	1	M	1	H	0	1	7	2	1	M
I	1	L	1	L	1	M	1	M	1	L	1	L	1	VL	1	L	1	VL	1	L	1	L	1	M	0	0	5	9	3	L
I	1	L	1	M	1	L	1	L	1	VL	1	L	1	VL	1	VL	1	VL	1	VL	1	VL	1	L	0	0	4	7	6	L
I	1	L	1	L	1	L	1	L	1	VL	1	VL	1	VL	1	VL	1	L	1	VL	1	VL	1	M	0	0	3	8	6	L
,	1	L	1	L	1	M	1	L	1	VL	1	VL	1	VL	1	VL	1	VL	1	VL	1	VL	1	VL	0	0	1	7	9	VL
I	1	L	1	M	1	M	1	L	1	VL	1	VL	1	VL	1	VL	1	VL	1	VL	1	VL	1	H	0	0	5	4	7	VL

akistan; R5: Allied Contractors; R6:Kincrete (Pvt) Ltd; R7: UCC (Pvt) Ltd; R8: FWO; R9:Ozair (Petty shuttering contractor); R10: MIDJAC; R11:
y Contrcator for shuttering; R14:Zalim Khan Petty Contractor for shuttering ; R15:MassuRahi petty Contractor for Shuttering ; R16:Saif Contractors for

4.2 Comparison of literature review data and field data

Further analysis decision based on purely literature review data or purely on field data results maybe criticized. Therefore, it was required to compare the two streams of results. These two streams were compared using the following different options.

a. 50 / 50 ratio i.e. 50% weightage to filed data 50% to literature review
b. 60 / 40 ratio i.e. 60% weightage to filed data 40% to literature review
c. 70 / 30 ratio i.e. 70% weightage to filed data 30% to literature review
d. 80 / 20 ratio i.e. 80% weightage to filed data 20% to literature review

For each above option, following analytical results were calculated with the help of excel sheet formulas.

a. Literature Score
b. Industry Score
c. Normalized Total Score
d. Cumulative Normalize Score
e. Rank

Results of all these four different weightings options are tabulated in Table 4-2 to see the variance in each weighted option.

Table 4-2– Comparison of Results with Different Weightages

Rank	50 / 50 ratio	60 / 40 ratio	70 / 30 ratio	80 / 20 ratio
1	7	7	7	7
2	1	1	1	1
3	12	8	8	8
4	8	12	12	12
5	3	3	3	4
6	11	4	4	3
7	5	5	5	5
8	4	11	9	9
9	9	9	11	14
10	18	18	18	11
11	10	10	10	15
12	16	16	16	2
13	15	15	15	10
14	19	14	14	18
15	14	19	19	16
16	6	6	2	19
17	13	2	6	6
18	17	13	13	13
19	2	17	17	17

4.3 Data Analysis to conclude Top Ranked Factors

For each option as appended in Table 4-2, the mean value, variance value, pooled value, and hypothesized mean difference were calculated and T test was run which reported variances less than 0.5. Besides T-test analysis, it is apparent in Table 4-2 that in all four options, five factors i.e. serial numbers 7, 1, 8. 12 and 3 are common and only one factor, No 11, present in 50/50 ratio which is odd because factor No. 4 is present in all other options. The finally concluded factors are 7, 1, 8, 12, 3 and 4.

a. Quality and surface smooth / aesthetic of Concrete finish
b. Cost
c. Time factor / Project Planning (speed construction) / repetition cycle
d. Building design
e. Safety
f. Erection and dismantling / construction process

4.4 Final Phase of Data collection and Analysis

In the final stage of research all six factors are observed, investigated and analyzed at 14 construction sites. At four sites, modular formwork system has been experienced. Hours and hours have been spent at sites to observe the output, efficiency, results, safety and quality of both systems. At each sites, the observations were noted and discussed with Project Manager. The process involved attempted to cover each of the six factors individually and collectively. Following projects were visited which were using or had used modular formwork system.

a. Terminal Building, New Airport, Islamabad
b. Establishment of 200 Bedded General Hospital Rawalakot, AJK
c. Construction of ICT/QA Building at AIOU Main Campus, Islamabad
d. Extension of Serena Hotel, Islamabad

In all these project sites, observation and analysis of those formwork systems which were general in nature (e.g. universal modular formwork system was selected) could be used for various sizes, thicknesses and loadings in order to conclude general results.

4.4.1 Quality

Quality of formwork refers to as quality of concrete (Musa et al., 2014). Quality of the desired concrete surface depends upon the quality of the sheathing of the formwork, hence, is directly proportional to sheathing quality of formwork. Sheathing quality of formwork can be improved by using better sheathing surface materials, easy fast cleaning and preparation of surface reuse, no of uses, its weight. Different aspects of quality were observed, noted and both systems have been compared. Table 4-3 describes the comparison and results which are purely qualitative duly verified by respective site in-charges and project managers.

Table 4-3- Quality of Concrete Obtained from Formwork System

Sr. No	Characteristics	Degree of Quality		Remarks
		Steel Formwork	Modular Formwork	
1	**50' high RCC wall in one pour**	Not possible in one pour	Easily doable	Steel formwork can be used easily up to 10' height. (Wright and Gallocher, 1995; Hanna and Senouci, 1997; Gallego et al., 2009). Refer Figure 4-1.
2	**Concrete surface**	Ordinary	Almost fare face	Preparation of steel formwork surface for next use takes more time(Libessart et al., 2014; Santos and Julio, 2007; Santos and Júlio, 2013)
3	**Concrete Cold Joint accumulation**	More	Less	Due to packing problems in steel formwork, less workable concrete is used which requires more use of vibrator which is normally avoided(Peurifoy and Oberlender, 1996; Woodson, 2009)
4	**Construction Joints**	Visible	Not visible	In steel formwork after every (10-15)ft height formwork fixing is repeated resulting more CJs(Bussell and Cather, 1995).
5	**Bulging of formwork cases**	More	Almost nil	Steel plate joints move out due to inadequate support system(Brett, 1988; Peurifoy RL, 2010).Refer Figures 4-2, 4-5
6	**Formwork failure during concrete**	More	Almost nil	Failure means collapse(Yates and Lockley, 2002; Hadipriono and Wang, 1986; Delatte, 2000)
7	**Repair of concrete surface**	Usual	Almost nil	Mortar repair are usually used in steel formwork system(Allen et al., 1992). Refer Figures 4-3, 4-4
8	**Requirement of cement slurry finishing touch**	More	Almost nil	(ACI, 2004; Julio et al., 2004). Refer Figure 4-5.

Figure 4-1- Modular Wall Formwork (50' high)

Figure 4-2 -Modular Wall Formwork (25' high)

Figure 4-3- Conventional Steel Formwork, Honey Comb Problem

Figure 4-4- Conventional Steel Formwork, Steel Cover Problem

Figure 4-5- Conventional Steel Formwork, Verticality Problem

4.4.2 Cost of Formwork system

Cost is the most important factor for selection of formwork systems that is conventional steel formwork system as well as modular formwork system (Rahim and Haron, 2013). For conventional steel formwork system, rate analysis for 3 basic structural elements (i.e. RCC wall, column and slab) based on current market rates was prepared and verified by the potential contractors as shown in Table 4-4. Modular formwork system is an import item therefore, quotations and rates including overheads, taxes, contingency charges and freight to Pakistan were collected from two international formwork manufacturers and suppliers and the lowest among them was selected for cost comparison with traditional steel formwork system as shown in Table 4-5.

Table 4-4– Rate Analysis of Conventional Steel Formwork Based on Market Price

Description	Unit	Quantity	Rate (Rs)	Amount (Rs)
Formwork Plates 2' X 4'		**Rate analysis for 1614 ft^2 (150 m^2)**		
Steel formwork steel plates 3mm thick	Kg	4,422.36	114.00	504,149.04
Steel formwork angle iron (40 x 40 x 5)mm	Kg	5,406.90	80.00	432,552.00
Fabrication of formwork	Kg	9,829.26	35.00	344,024.10
	Total			1,280,725.14
	Steel Plate per Kg			130.30
Wooden Battens				
Partal wood battens 3" x 4", 4' c/c	1,614ft	1.24	2,001.36	
(1614 X 0.25 X 0.33)	ft^3	165.11	1,500.00	247,668.30
	Total			247,668.30
	Wooden batten per ft^2			153.45
Scaffolding Pipe				
Scaffolding pipe	ft	3,641.00	115.00	418,715.00
Scaffolding joints	No	600.00	115.00	69,000.00
	Total			487,715.00
	Scaffolding pipe per ft^2			302.18
Oil	ft^2	1,614.00	0.50	807.00
Welding, grindingetc	ft^2	1,614.00	0.50	807.00
Tiebolt	ft^2	1,614.00	0.25	403.50
Misc, nut,bolt, nails etc.	ft^2	1,614.00	0.30	484.20
Total Amount				**2,018,610.14**
A. Rate of steel formwork for slab per ft^2 (Rs)				**1,251**
B. For RCC Wall, with through bolts per ft^2 (A x 1.5) (Rs)				**1,877**
C. For RCC Column per ft^2 (A x 2) (Rs)				**2,502**

Table 4-5– Formwork International Rates for Pakistan ex-Karachi Port Delivery

Sr. No	Structural Component	DOKA RATE 150 m^2 (US $)	PERI Rate 150 m^2 (US $)	Lowest Rate (Rs) (1 US$=Rs 105)	Rate per ft^2
1	Formwork system for wall	36,687	34,450	3,617,250	2,241
2	Formwork system for Column 600 x600 mm (3m Height)	4,345	3,250	341,250	4,265
3	Formwork system for slab	21,356	18,000	1,890,000	1,171

In the second step of cost analysis, cost of traditional steel formwork system and modular formwork system were compared. Two base lines were set for the comparison. First base line was initial cost analysis of the formwork systems and second base line was established as life-cycle benefit-cost analysis. As per Hastak and Halpin (2000) in construction, life-cycle benefit-cost model does not need financial quantification of benefits and it was explained through an example of highway bridge column rehabilitation but in our case financial quantifications have also been considered. Field and formwork manufacturers prescribed life cycle of 30 pours to compare the two systems with the aim to re-life the systems to enable them for next 30 concrete pours. Table 4-6 explicitly explains the difference between two formwork systems with respect to established base lines.

Table 4-6- Cost Comparison of Formwork Systems

Sr. No	Description	Conventional Steel Formwork (Rs)	Modular Formwork (Rs)	Results
1	**Initial Cost**			
a	Wall (150 m^2=1614ft^2)	3,029,478	3,617,250	Modular Formwork is16.25% expansive
b	Column (600 x600) mm, 3m	200,160	341,250	Modular Formwork is 41.35% expansive
c	Slab (150 m^2=1614ft^2)	2,018,610	1,890,000	Conventional steel is 6.4% expansive than modular formwork
2	**After 30 pours life span, Rehabilitation cost to make formwork system fit for next life cycle**			
a	Support system	Wooden battens become useless. Joints, scaffolding pipes depreciate at 50%	Remain intact except 5% theft/loss cases and minor repair	• Wooden battens do not stand with repeated use • Scaffolding pipes remain on cutting process during use • Joints after 20-30 times use, need their bolts to be changed plus theft/loss ratio is more
b	Plates	Depreciate and value at steel scrap cost	Only Marine ply need to be replaced	Marine ply is better sheathing than steel plate
c	Re-lifing Cost	Salvage value contribute 20%	Marine ply cost Rs. 3500/32ft^2 plus 10% rehabilitation	Modular formwork rehabilitation cost is less than conventional steel formwork
d	Wall (150 m^2=1614ft^2)	2,423,582	194,184	In re-lifing cycle, modular formwork proves to be very economical as compared to steel formwork
e	Column (600 x600) mm, 3 m	160,128	9,625	
f	Slab (150 m^2=1614sft)	1,614,888	194,184	
3	**Labor Cost**	28/ft^2	14/ft^2	Modular formwork saves 50% labor cost

Initial cost comparisons for three major structural elements are presented graphically in Figure 4-6 to illustrate the difference in cost inputs between conventional steel and modular formwork systems.

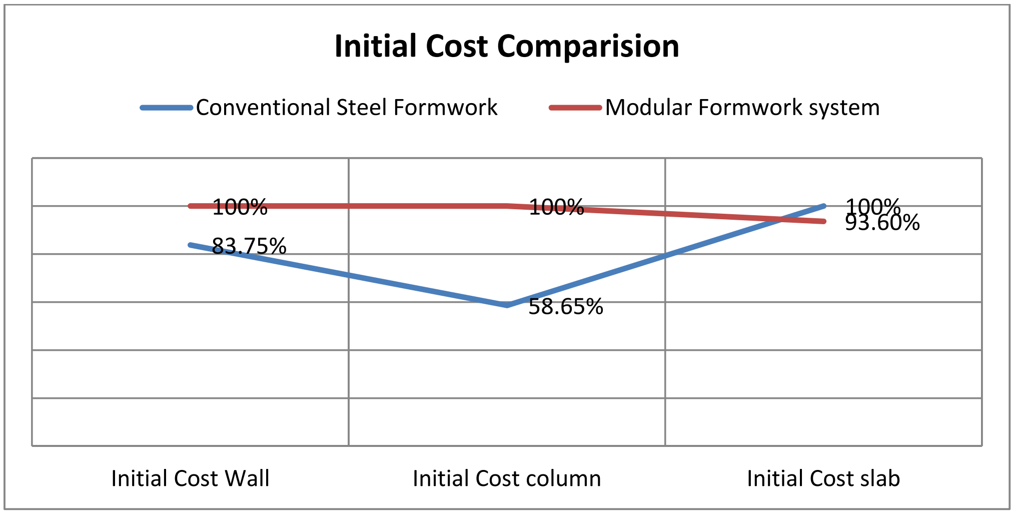

Figure 4-6- Initial Cost Comparison of Two Formwork Systems

Life-cycle benefit-Cost analysis revealed that steel formwork system after usage of 30 times; depreciate at80-82% whereas modular formwork only 5%. Thirty (30) pour life cycle and then refurbishment for next 30 pours is shown graphically in Figure 4-7 which clearly shows that modular formwork is much cheaper in the long run.

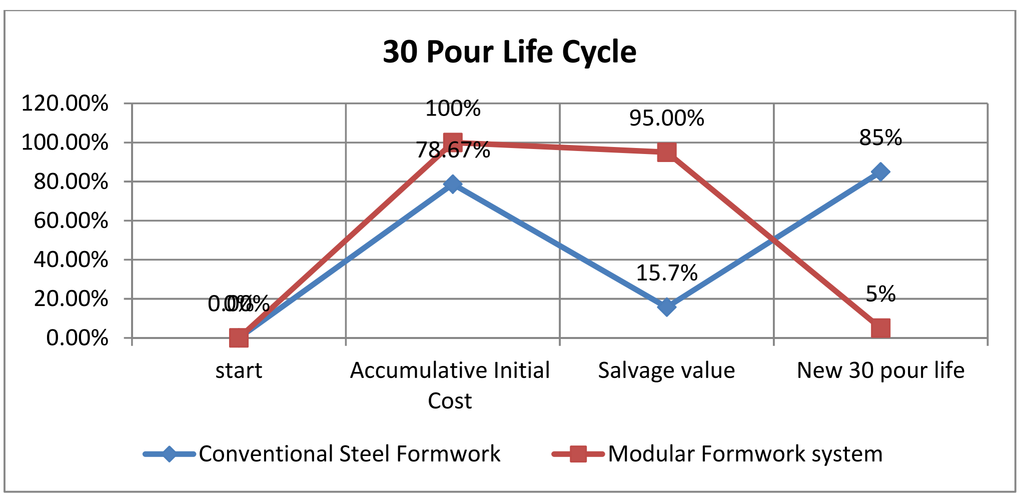

Figure 4-7- Life Cycle Cost Benefit Analysis of Two Formwork Systems

From the above results, a hypothetical model given in Equation 1has been derived for conventional steel formwork system in which all quantifiable factors have been incorporated in the same ratio as envisaged from market based rate analysis. The variables components of Equation 1 may depend on project design, specific requirements, project nature, complexity and specifications.

Cost of steel formwork = FW= 1563.7CX+1200SX+1000QX Equation 1

Where,

Base cost = C=0.8 - Field data authentication

Cost of Quality = Q=0.19- PAF, field data authentication

Safety cost = S= 0.01 - Direct cost observed by implementing safety measures

To check practical authenticity of this equation, total quantity of steel formwork (5000 ft²) used at Project Construction of Govt. Boys Degree College, Thorar, Distt, Poonch, was incorporated in the equation as shown in Table 4-7. Results of Equation-1 shows that at the start of any project, a constructor may estimate expense of using steel formwork and in order to make it equivalent to modular formwork, safety and quality measures are required to be incorporated although this does not convert steel formwork 100% equal to modular formwork. This may help in decision making process while selecting a formwork system at the start of a project.

Table 4-7- Practical Application of Equation -1

Sr. No	**Description**	**Cost** =1563.7CX	**Safety** =1200SX	**Quality** =1000QX	**Total**
1	Steel FW	62,54,800	-	-	62,54,800
2	Steel FW with extra measures	62,54,800	60,000	950,000	72,64,800

4.4.3 Time factor/Project Planning/Repetition cycle

All good projects are time bound. During execution process and in preparing construction schedule of project, we need to calculate estimated duration of each activity (Memarian and Mitropoulos, 2014; Kim and Teizer, 2014).

Formwork either fixed for vertical elements RCC wall and columns or for horizontal elements beams and slabs, involves repetition cycle. This repetition starts from preparation of formwork, fixing of formwork, and completes after pouring of concrete stripping of formwork and finally after cleaning and oiling ready for second use. This repetition cycle is based on time and utilization of labor inputs. Time is of essence to contactors in tight construction schedules in terms of cost. In order to compare the conventional steel formwork system with modular formwork system in terms of repetition cycle, a sample area of RCC wall150m² = 1614ft² was discussed and observed at establishment of 200 Bedded General Hospital Rawalakot, AJK site. This process produced results as shown in Table 4-8.

Table 4-8- Repetition Cycle Comparison of Formwork Systems

Sr.No	Formwork system	Crew deployed	Days consumed	Total man hours	Formwork erection rate (hr/m²)
1	Conventional steel	2 carpenters, 3 scaffolders, 6 helpers	5	320	2.13
2	Modular	2 carpenters, 3 helpers	3	120	0.8

The same way, for RCC column and RCC slab, based on field observatory data, formwork erection rate was determined as shown in Figure 4-8.

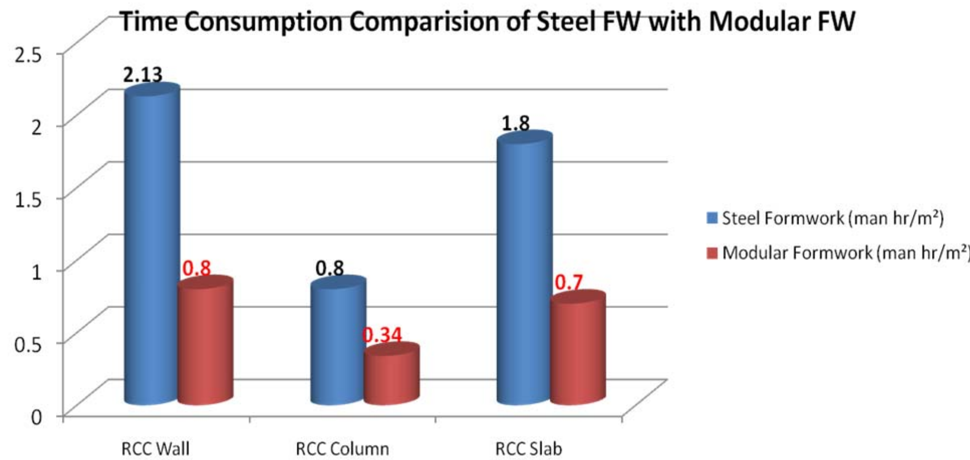

Figure 4-8– Time Consumption Comparison of Steel Formwork with Modular Formwork

Results clearly show that modular formwork system saves labor inputs, time and speed more than 50% as compared to conventional steel formwork system.

4.4.4 Building Design

Building design determines standardized portions and special portions. For standardized portion, standardized formwork system and plates are used in which repetition cycle can be easily and economically maintained. Special formwork panel/plates and system are required to be designed and manufactured for special portions. For such areas, specialized formworks cost accounts more than normal standardized formwork cost(Kim and Teizer, 2014). Another most important factor is design load. For building formwork system, normal loadings within permissible range, cost, time, performance, remains within normal range but for abnormal loading such as industrial units, bridges, and power plants, the load bearing components of formwork system enhances the cost. (Basbagill et al., 2013; Fischer and Tatum, 1997).

Without indulging into complex design calculations, the two formwork systems have been compared from general design aspects considering normal conditions as per following Table 4-9.

Table 4-9– Design Loadings Impact on Two Formwork Systems

Sr No	Design Aspect	Steel Formwork system	Modular Formwork	References
1	RCC Wall	Fit for (10-15) ft height with (5-7)" thickness	Fit for (20-30) ft height with (5-12)" thick	(Veenendaal and Block, 2014; Sarma and Adeli, 1998; Leung and Cao, 2010; Kim and Teizer, 2014; Harfmann and Chen, 1993; Abdelrazaq, 2010; Lloret et al., 2015)
2	RCC Column	Can be used for one specific dimension	Universal formwork system can be used from (2x2)' to (5x5)'	
3	RCC Slab	Normal loadings with (5-7)" thickness	Loadings with (5-12)" thickness	

It is essential to record that in any building or structure first standardized portions are identified that have repetition cycles of formwork. For such standardized portions a system is devised with economic measures however for special design features e.g. special front fascia, there will always be a special formwork design to be adopted for execution of such structural elements. Such special design will always cost more as compared to normal standardized portions. Modular formwork system is by default a designed formwork system which provides design solution for every type of structural element. Table 4-9 clarifies that for normal loadings too, modular formwork system is versatile and beneficial.

4.4.5 Safety during Formwork

Modular formwork system provides built in safety measures including the following:

a. Highly safe system with proper design calculations of formwork

b. Use of high quality and load tested tie rods and components

c. Concrete Pouring plate forms provides additional safety for working crew, inspecting RE and Project Manager team

d. Worldwide proven safe system

e. Safety wedge locking of panels

Conventional steel formwork system does not provide such systems. However, these safety measures may be adopted specifically as per instructions of the Engineer. In doing so additional labor and material cost may incur which may range from 0 to 5% of formwork cost as evident from results of Table 4-7. During inquiry of modular formwork system supplies, an attempt was made to separately conclude cost of safety measures. But during the investigation, it is revealed that the international manufacturers of formwork work on international safety standards which are integral part of product, service and result. At all projects where modular formwork has been observed, it certified that construction safety is actually first in using modular formwork system in execution. In Figure 4-9, it can be observed that at Pakistani construction site, where modular formwork has been tested with conventional steel scaffolding system, safety, protection and access systems have been developed which are actually integral part of a complete modular formwork system.

Figure 4-9- Safety Measures Adopted to Achieve Modular Formwork Benefits

4.4.6 Erection and Dismantling Construction process

The two systems have different erection and dismantling processes which became more obvious during field observations, experience and interaction with site project managers. Major differences are being tabulated in Table 4-10.

Table 4-10– Difference between Erection and Dismantling Process of Two Systems

Sr. No	Erection and Dismantling Process	Conventional Steel Formwork	Modular Formwork	Remarks
1	Labor Intensive	More	Less	
2	Time Consuming	More	Less	
3	Movement and fixing of big size panels	Mechanical means e.g. cranes etc.	Hand driven trolley provided by manufactures	Refer Figure 4-6
4	Weight	more	less	
5	Support system	Congested due to scaffolding. Same is being endorsed by Rubio-Romero et al. (2013).	Provide ample space to work and move	
6	Safety	less	more	
7	Preparation time for next use	More (Steel surface is difficult to scrap)	Less (Marine ply is easily scrap able)	Steel surface is difficult to scrap from cement fumes and oiling
8	Smart	less	more	
9	Surface Quality	less	more	(Arslan et al., 2005)
10	Wastage of materials	more	less	(Karke and Kumathekar, 2014)

4.5 Advantages, limitations and Specific problems

Topic of research under discussion is purely related to field practical execution process and primarily stakeholders and owner of this operation is the "contractor". It is also a real fact that contractors consider, 'cost' the most important factor of the business. Therefore, when two systems of formwork were compared, cost acted as baseline factor.

In Pakistan, steel formwork has been in use for many years. Shuttering carpenters and scaffolding workers are well trained. Helpers work with skilled workers and after few months, become skilled workers. At construction sites, prime contractors work in two ways i.e. either hire shuttering men on muster roll including their foreman or sublet shuttering job to specialized sub-contractor with material or without material. Steel shuttering material is an important asset for companies since inception. Shuttering trend towards steel formwork system is being adopted as a custom without realizing that there may be other good alternatives with more output, quality, safety and economy.

Whenever projects start, the Project Manager considers easy approach. For steel formwork system, shuttering material is easily available whether it is being arranged rental or purchased. Similarly manpower is always no problem to hire. We have no shortage of skilled manpower and overall construction environment supports use of conventional steel formwork system. But it is essential to understand that construction trends have changed in the modern world. Fast, easy, safe and economical solutions are appreciated all over the world. Use of modular formwork system is one way towards this approach. During discussions with foreign suppliers, it revealed that suppliers are providing training of workers free of cost at construction sites across Pakistan. Secondly, the rebate and profit margin is comparatively being kept low as compared to other countries, in order to support usage and to create a market. The reasons which have been understood during investigating of why modular formwork system is not being adopted in Pakistan besides so many benefits which have been found are as follows:

a. Initial cost is more
b. Shuttering is not easily available

c. Availability of trained manpower

Contractors informed that use of modular formwork system also caused some disadvantages which are mainly:

a. When workers were trained. They black mailed to increase wages
b. Delivery of shuttering material from abroad, e.g. Dubai takes more time
c. Use of modular formwork provided good quality, safety and final product but Employers consider same rates in BOQ as adopted for conventional steel formwork systems

In Pakistan, usually contractors are unaware of modular formwork system and consequently the benefits. However, now a days the requirement of quality work, emphasized to adopt modular formwork system.

4.6 Decision support system for adopting modular formwork system

Decision support system is not limited to developing an equation that by putting values in that will help to decide whether to go for modular formwork system or not. The purpose was to develop a framework that would help to analyze and decide that a formwork system requirement was needed for a project. The decision support system includes cost implications initially as well as in the long run, quality concerns, time saving requirements of project especially for fast track projects. All these and more have been analyzed after deep site coordination, on site observations, visits and data collection. The analysis of data actually provided a decision support system to decide adoptability of modular formwork system in Pakistan as compared to traditional steel formwork system. However, this decision support system alone is not capable for implementation in construction industry because of following reasons

a. Who will study this research to conclude modular formwork system is better?
b. Who will think to implement a formwork system that would guarantee safety of workers?
c. Who will be ready to initially invest more?

d. Who will care about life cycle cost of system and long-term investment?

e. Who would desire to provide repair less, cold joints free and fair face concrete without extra cost?

The answers to all above questions, is the ‘contract’. It needs to be understood by employers, consultants and field experts. This study may help and proved to be decision support system if it is being implemented through contract in specifications and in BOQ nomenclature in the relevant concrete items.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter concludes the research by stating and summarizing the results, findings and recommending ideas which may bring change in constructions trends in Pakistan. The insight will definitely help the reader to know the crux of the study and provide a way forward for modernization of construction industry in Pakistan.

5.1 Conclusions

1. All six factors i.e. quality and surface smooth/aesthetic, cost, time factor/project planning (speed of construction)/repetition cycle, building design, safety and erection and dismantling/construction process provide the basis for selection of appropriate formwork system considering cost as baseline factor. Safa et al. (2018), endorsed this finding in its conclusion that cost and duration have significant value while deciding an appropriate formwork system.
2. Initial cost of conventional steel formwork is almost 22% less than modular formwork system.
3. Life cycle cost of modular formwork system is 80% less than traditional steel formwork system.
4. Quality comparison in view of genuine site execution problems revealed that conventional steel formwork has no match in quality with modular formwork system. Moreover, safety and quality standards are built-in properties of modular formwork system. There is no need of extra investment to address quality and safety related concerns. However, conventional steel formwork system incurs extra cost in establishing safety measures e.g. safety grills, inspection plate forms, ladders, and more. It requires ensuring proper safety support system for successful completion of structural element concreting.
5. Modular formwork system provides built-in design solutions including free of cost design of formwork according to structural requirements. For abnormal loadings, when we go for conventional formwork system design, it costs more because of extra safe provisions to accommodate fear of structural collapse and

because of non-availability proper design solutions. In this study, discussions and results are based on normal loadings for which modular formwork system is proved to be the best having universal usage for different thicknesses and loadings.

6. Modular formwork system is easy to fix, easy to strip due to its planned designed mechanism.

Traditional steel formwork erection rate	-	1.58 hr/m²
Modular formwork erection rate	-	0.61 hr/m²

5.2 Limitations of Modular Formwork system

1. Initial cost investment is more.
2. Shuttering is not easily available. It needs to be imported from Dubai, UAE which takes more time.
3. Availability of formwork is on rental basis; contractors prefer readily available steel formwork system on rental basis.
4. Lack of trained work force.
5. Blackmailing of trained work force to increase wage.
6. Contracts don't encourage the use of modular formwork system.
7. Communication gap between industry and researchers.

5.3 Recommendations

1. Adoption of modular formwork system through contractual clauses and specifications is required to be ensured.
2. Training of local manpower on such modular systems through the government, poly-technical institutes and even at construction sites may help to change the trend.
3. Local formwork manufacturers may contribute by manufacturing modular systems in Pakistan. It may prove an emerging business in Pakistan’s construction industry.
4. Modular formwork system is a smart solution of this labor intensive and time-consuming execution operation.
5. Spectrum of research on short listed factors affecting selection of an appropriate formwork system is broad. Each one of them is required to be further

investigated based on data of a selected mega project from notice to commence to defect liability period.

6. Both systems of formwork have minute differences in operational details which are further required to be researched.

7. Based on this study collaboration with PEC C-A category contractors may open new horizons of research.

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Annexures

Table - Questionnaire Table for collection of data from contractors

Name of Student: Sheikh Shujaat Ullah Khan Roll#: 00000172310

MS-CEM, Thesis Research, National University of Science and Technology, H-12, Islamabad
Impact / Barriers of Modular Formwork use in Pakistan's Construction Industry

Please mark ✓ where appropriate.

Respondent Data

Name:____________________________________ Designation: _____________________

Organization:____

Sr. #	Factors Affecting Selection of Formwork	Very High	High	Medium	Low	Very Low
		1	2	3	4	5
1	Cost					
2	Availability of Formwork					
3	Safety					
4	Erection and Dismantling/ Construction process					
5	Life span/Durability					
6	Easily flexible size/Weight					
7	Quality and surface smooth/Aesthetics					
8	Time factor/Project Planning (Speed of construction) / Repetition Cycle					
9	Suitability of work for labor/ Labor efficiency / Market Trend/ Area Practice					
10	Inaccessible to work/Supporting yard facility					
11	Climate factor					
12	Building Design					
13	Wastage of materials					
14	Training program/Lack of awareness					
15	Manpower requirement					
16	Hoisting Equipment					
17	Standardization/Pre-planning of formwork					
18	Strength(Fresh concrete Pressure, KN/m^2)					
19	Accuracy in construction					

Signature Date