AN ANALYTICAL STUDY OF EFFECTIVE FORMWORK SYSTEMS FOR HIGH-RISE BUILDING CONSTRUCTION IN SRI LANKA

Gunatilaka W.A.D.A.

(098858)

Degree of Master of Science in Construction Project Management

Department of Civil Engineering

University of Moratuwa

Sri Lanka

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Gunatilaka W.A.D.A.

(098858)

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

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DECLARATION

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Gunatilaka W.A.D.A.

098858

The above candidate has carried out research for the Masters dissertation under my supervision.

Signature of the Supervisor:.....Date:.....

Dr.LeslyEkanayake,

Senior Lecturer,

Department of Civil Engineering,

University of Moratuwa.

ABSTRACT

Formwork system is the most important factor determining the project success especially, in high-rise building construction projects in terms of speed, quality cost and safety of the work as it accounts 40% of the total project cost of the structure. The contractor needs to complete the project in the shortest time possible as a means to minimise the cost and the clients wants the building to start the business as early as possible. The most effective way to speed up the works in high-rise buildings is to achieve a very short floor cycle to have the structure of typical floors completed in the shortest time. That directly depends on the selected formwork type for the particular construction project. Thus, appropriate selection of an effective formwork system is crucial factor in successfully completing any high-rise building project.

Two case studies were carried out to analyse the cost for different types of formwork: modern conventional method; semi-system formwork; and, Aluminium panel system formwork use in construction projects. Case study projects were selected among high-rise buildings projects more than 25 stories which are located in Colombo metropolises in Sri Lanka.

The results indicated that the cost of formwork does not directly affect to the total project cost but the type of formwork is highly affected to the total project cost especially, in high-rise building construction projects. Accordingly, the Aluminium panel system formwork reduces the project duration and hence, the total project cost and gives construction structure a very high quality finish though the Aluminium panel system is very expensive itself. Moreover, this study reveals most cost effective formwork system for high-rise buildings more than 25 stories is the Aluminium panel system comparatively. Thus, this outcome is useful to decision makers to select the most appropriate formwork system for high-rise building construction.

Keywords: Aluminium panel system, Conventional method, Cost effective, Floor cycle, Formwork system, High-rise building, Modern conventional method; Semi-system formwork

DEDICATION

I dedicate this dissertation to my dearest wife and children.....

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LIST OF ABBREVIATIONS

BOQ	– Bill of Quantities
OSHA	– Occupational Safety and Health Administration

CHAPTER 1 – INTRODUCTION

1.1 Background

The development of formworks is parallel with the growth of concrete construction throughout past decades. The increasing acceptance of concrete as a major construction material presents the form builder a new range of problems in the development of appropriate sheeting materials and maintenance of rigid tolerances(Brand, 1995).The construction of a concrete building requires supporting the slabs (horizontal formwork) as well as columns and walls (vertical formwork). Formwork is a temporary structure which provides support and containment for fresh concrete until it can support itself. It moulds the concrete to the desired shape and size and controls its position and alignment. Concrete forms are engineered structures that are required to support loads such as its own weight, fresh concrete, construction live loads (including materials, equipment, workers, various impacts and sometimes wind). The forms must support all the applied loads without collapse or excessive deflection (Chen and Mosallam, 1991; Hurd, 1989).Formwork is a classic temporary structure in the sense that it is erected quickly, highly loaded for new hours during the concrete placement, and within a few days disassembled for future re-use. Further, classic in their temporary nature are the connections, braces, tie anchorages and adjustment devices which form need (EWA, 1988).

A quality reinforced concrete structure offers many advantages over structures made with other building materials. The quality of the surface finish of the concrete is directly affected by the forms and form material. Therefore, in designing and building formwork, the contractor should aim for maximum economy without sacrificing quality or safety. Size shape, alignment of slabs, beams and other concrete structural elements depend on accurate construction of the forms (Hurd, 1989). Thus, according to Hurd (1989) forms must have characteristics of:

- Built to the correct dimensions;
- Sufficiently rigid under the construction loads to maintain the designed shape of the concrete;

- Stable and strong enough to maintain large members in alignment; and,
- Substantially constructed to withstand handling and reuse without losing their dimensional integrity.

The proper selection of materials and equipment, careful planning of fabrication and erection procedures and efficient re-use of forms can expedite the job, assure the best use of labour, and save money. This is accomplished with advanced planning and scheduling (Moore, 1977). Formwork is the largest cost component in construction; thus, it controls:

- Cost of the construction project;
- Quality of the concrete surface;
  - ✓ Finished concrete surface is of acceptable quality
  - ✓ In the correct location and orientation
  - ✓ Able to produce the required shape and surface
- Speed of the construction; and,
- Safety of the people involved in the construction

Therefore, it is evident that the type of the form work used in the construction is very important as all the above factors are totally affected by the type of the formwork used.

1.2 Research Problem Definition

According to Gnida (2010) high-rise building is a multi-story building tall enough to require the use of a system of mechanical vertical transportation such as elevator. One of the major problems in the construction of high–rise buildings is the long time duration of the project. It is required to minimise the floor cycle of the building in order to expedite the construction and reduce the project time. If the floor cycle cannot be minimised with the ordinary methods used in the construction industry it is impossible to expedite the construction (Cordova and Desler, 2003). When using the ordinary traditional methods or the systems, it will lead more time duration

especially, in the high-rise buildings construction projects. When considering a construction of a storied building 60% of the work to be done is concrete work. The construction sequence is same for any of the concrete work item such as foundation, walls, columns beam or a slab. The standard ways of doing the concrete work item (the main structural elements) is erect formwork, fixing reinforcement, and, finally poring of concrete in to the formwork. The time taken to fabricating of reinforcement and the placing or poring of concrete is morally constant due to the quantity of the work that can be done in the standard way constant per day(Bullock,1988).Therefore, in order to reduce the floor cycle, the only factor that can be considered is the time taken to erecting of formwork system. It is considerably influencing to the duration of the project. In the construction of a storied building project especially, high-rise building project, it is very much important to select an appropriate type of formwork system.

High rise construction projects duration is directly affected by the type of formwork system used for the project. Particularly the floor cycle of the building is depending on the type of formwork system used for the construction. If the ordinary type (modern conventional type) of the formwork system is used in a project the floor cycle of the building will be about 15 – 20 days. But a project is using the Aluminium panel formwork system the floor cycle the floor cycle will be reducing up to 7 – 10 days. That shows how the formwork type affect the duration of the construction which is directly affected to the total project cost. Formwork operations accounts for a large portion of the building structure, representing 40-60% of the cost of the concrete frame work and 10% of the total building cost (Hanna, 2005).Moreover, formwork has an important role in the cycle times per floor in the building construction projects. Therefore selection of an appropriate formwork system not only affects the entire construction duration and cost, but also affects subsequent construction activities such as electrical, mechanical and finishing work (Tam et al., 2005).

Considering above facts it is clear that the total project cost and duration are directly affected by the type of formwork system used in the construction project. However,

in practice, the selection of an appropriate formwork system has depended mainly on the intuitive and subjective opinion of practitioners with restricted experience (Shin et al., 2008). Consequently, the need for proper mechanism to select an appropriate formwork system for high-rise construction has arisen. Therefore, it is very much important to conduct analytical cost study of the different types of formwork systems used in the high-rise building constructions projects in Sri Lanka. Thus, this study helps to decision makers to select a most cost effective formwork system and avoid lengthy project durations particularly, in the high-rise building projects, which are higher than 25 stories. This is relatively an under researched area and new to Sri Lankan construction industry.

1.3 Objectives

- To identify different types of formwork systems used for high-rise building construction in Sri Lanka.
- To analyse cost of different formwork systems in high-rise building projects.
- To determine the influence of different formwork systems for project time, cost and quality.
- To identify the effective formwork system for floor cycle of a high-rise building project.

1.4 Methodology

Comprehensive literature survey was carried out to explore the theoretical status and research issues. Analytical cost comparison was carried out explore the most effective formwork system for high-rise building construction projects using past cost data. Case study projects were selected among high-rise buildings projects more than 25 stories which are located in Colombo metropolises in Sri Lanka. Analytical

cost study was framed material cost; preliminary running cost; cost of machinery; cost of finishes; and, cost of waste disposal of different formwork types when apply in each project: modern conventional method; semi-system formwork; and, Aluminium panel system formwork.

1.5 Scope and Limitations

The scope of the research was investigation regarding the research problem in high-rise building projects in construction context. Therefore, the researched was limited to the two high-rise building projects more than 25 stories which are located in Colombo metropolises in Sri Lanka.

1.6 Main Findings

The results revealed that the type of the formwork is directly affected to the total project cost but not the cost of the formwork itself. The different types of formwork systems affect the various project aspects: floor cycle; surface of the concrete obtained; machinery usage; waste disposal; scaffolding requirement; and, labour and technical staff requirement; thus, directly impact on the total project time and thereby, total project cost. Further, the different types of formwork systems affected in such a manner that the quality of the formwork and the technology used in the formwork are directly related to the end product. Consequently, the Aluminium panel system formwork reduces the project duration and hence the total project cost and gives construction structure a very high quality finish though Aluminium panel system is very expensive itself. Moreover, this study reveals most cost effective formwork system for high-rise buildings more than 25 stories is the Aluminium panel system comparatively.

1.7 Structure of the Report

Chapter 1 – Introduction

Chapter 1 of this report introduces broader research area and identifies research problem with aim, objectives, methodology, scope and limitations of this study. Finally, Chapter 1 highlights the main findings and the structure of the report.

Chapter 2 – Literature synthesis

Chapter 2 discusses theoretical status and research issues through comprehensive literature review and synthesis in order to understand different formwork technologies use in high-rise construction, problems encountered in construction, areas of cost reduction, etc.

Chapter 3 – Research methodology

Chapter 3 describes the research process used in this study.

Chapter 4 – Analysis and discussion of results

Chapter 4 presents and discusses the research findings from the study.

Chapter 5 – Conclusions and recommendations

Chapter 5 draws conclusions of the research with respect to the research issues to be addressed and explains recommendations of the research, limitations and opportunities available for further research under this area of study.

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1.8 Summary

This chapter has presented broader research area of this study and identified research problem with aim, problem definition, objectives, methodology and scope and limitations of this study. Finally, main findings were summarised and the structure of the report was explained. The next chapter explores the theoretical status and research issues through comprehensive literature review.

CHAPTER 2 – LITERATURE SYNTHESIS

2.1 Introduction

The aim of this chapter is to explore the theoretical status and research issues through comprehensive literature review in order to understand and establish the significance of research problem statement.

2.2 Introduction to Formwork Systems

A quality reinforced concrete structure offers many advantages over structures made with other building materials. Concrete is a durable material that reduces building maintenance cost and provides a longer service life. A concrete structure will reduce energy usage because of its mass and high resistance to thermal interchange. The use of concrete will lower insurance cost by virtue of its high resistance to fire. Buildings made of concrete are also more secure against theft and vandalism. Concrete floors and walls reduce the transfer of noise, yielding a quieter environment and happier occupants. Reinforced concrete possesses considerable strength for resisting seismic and wind loads. These factors make the selection of reinforced concrete as economical alternative (Hurd, 2005).

Fresh concrete is a plastic material that takes the shape of the container or form into which it is placed. Formwork system development has paralleled the growth of concrete construction throughout the twentieth century (James, 1988). A form is defined as a temporary structure or mould for the support of concrete while it is setting and gaining sufficient strength to be self-supporting. Formwork has a broader definition: it is the total system of support for freshly placed concrete including the mould or sheathing which contacts the concrete, as well as all supporting members, hardware, and necessary bracing (Ling and Leo, 2000). Forms are essential to concrete construction. They mould concrete to the desired size and shape and control its position, alignment, and surface contour. And, as defined above, formwork is more than a mould. It is a temporary structure that supports its own weight, the weight of the freshly placed concrete, construction loads such as materials,

equipment, and workers, and other possible live loads during construction such as heavy snow in cold countries on a slab (Ling and Leo, 2000).The construction of a concrete building requires formwork to support the slabs (horizontal formwork) as well as columns and walls (vertical formwork). The terms concrete formwork and concrete form carry type same meaning and are used interchangeably in this book. Formwork is defined as a temporary structure whose purpose is to provide support and containment for fresh concrete until it can support itself (Bullock, 1988). It moulds the concrete to the desired shape and size, and controls its position and alignment. The forms must support all the applied loads without collapse or excessive deflection (Mark and Ghosh, 1983).

The appearance of the finished concrete depends on the face texture and stiffness of the formwork. As concrete has come of age and been assigned increasingly significant structural tusks, formwork builders hence had to keep pace. Form designers and builders are becoming increasingly aware of the need to keep abreast of technological advancements in other materials fields in order to develop creative innovations that are required to maintain quality and economy in the face of new formwork challenges. Formwork was once built in place, used once, and subsequently wrecked. The trend today, however, is toward increasing prefabrication, assembly in large units, erection by mechanical means, and continuing reuse of forms. These developments are in keeping with the increasing mechanisation of production in construction sites and other fields (Denis, 1981).

2.3 Formwork Economy and Significance

Formwork is the largest cost component for a typical multi-storey reinforced concrete building. Formwork cost accounts for 40 to 60 percent of the cost of the concrete frame and for approximately 10 percent of the total building cost(Hanna, 2005). A large proportion of the cost of conventional formwork is related to formwork labour costs. Formwork cost is not the only significant component of the formwork life cycle. Other important aspects of the formwork operation include speed, safety, and quality (Adrian, 2004).

Speed

Speed of construction is defined as the rate in which concrete building is raised and can be expressed in terms of number of floors erected per week or months. Speed of construction can be also measured in terms of inches or millimetres of concrete poured per hour. Formwork is typically supported by several levels of shores and re shores that carry the loads until the concrete gains enough strength to support its own weight and all other externally applied loads. Shores are vertical members made of wood that support recently built concrete that have not developed full design strength. On the other hand, re shoring occurs when the original shoring is removed and replaced in such a manner as to avoid deflection of the cured concrete. As a result, several floors may be blocked preventing the progress of any other construction activities. Faster formwork cycle from erection to stripping would allow for faster removal of shoring and re shoring and faster overall project progress. (El-Reedy M., 2010)

Safety

Formwork operations are risky, and workers are typically exposed to unsafe working conditions. Partial or total failure of concrete formwork is a major contributor to deaths, injuries, and property damages within the construction industry. Another common hazard occurs during stripping of formwork in which loose formwork elements fall on workers under the concrete slab being stripped (Murty, 2001).Structural collapses account for 25 percent of all construction failures. More than 50 percent of concrete structure failure during construction is attributed to formwork failure. Formwork failures result from faulty formwork structural design, inadequate shoring and re-shoring, improper construction practices during construction, inadequate bracing, unstable support or mudsills, and insufficient concrete strength to sustain the applied load after construction. Contractors are generally responsible for stability and safety of concrete formwork. Contractors are guided by several federal, state and local codes and regulations that regulate formwork safety. Most of these documents provide general guidelines for safety but provide no guarantee against failure. Contractors typically are trying to achieve fast

removal of formwork elements without comprising the safety and integrity of structures (Murty, 2001).

Quality

The quality of the resulting concrete is dictated by the quality of formwork materials and workmanship. Many concrete-related problems such as discoloration, stains, and dusting are attributed to concrete formwork. Also, some deformed concrete surfaces are due to deformed formwork systems caused by repetitive reuse and inadequate support to formwork (Murty and Jain, 2000).

2.4 Types of Formwork use in the Construction Industry

Formwork can be classified according to variety of categories, relating to the differences in sizes, the location of use, construction materials and nature of operation or simply by the brand name of the product. In this study the classification according to the materials used to build the formwork is important and the classification is as follows.(Koel L., 1997)

- Conventional Type
- Modern Conventional Type
- Semi System Formwork
  - ✓ Table Formwork
  - ✓ Slip Formwork
- Aluminium Panel System Form Work

2.4.1Conventional type formwork

This is the very basic formwork type commonly use in the building construction projects (see Figure 01-04 in Appendix A). It is easy to erect, handle, dismantle and use but time factor is very high and its short life span reduces the number of re-uses. Traditional slab formwork system comprising timber members, bamboo props, masonry work and carpentry work, etc. to complete work item. (Richardson J.G.A., 1982) The system works through mostly timber members or other lumber supporting rows of stringers which are placed three to six feet or one to two meters intervals,

with joints placed between the stringers. Timber is the most common material for traditional form work and its freely available everywhere. Timber is comparatively cheaper and could be easily shaped or formed as desired. However, it is quite difficult to assume the strength of the timber. Thus, a scientific approach of design becomes difficult and its needed lot of assumptions, safety precautions for used in the high rise buildings. In this formwork most commonly untreated wood is used. Southern yellow pine and Douglas fir, sometimes called Oregon pine are widely use in structural forms. They are easily worked and these are strongest in the softwood group. (Richardson J., 2003) Both hold nails well and are used in forms of sheeting, studs and Wales etc. There are advantages and disadvantages in the conventional type of formwork system. This type is suitable for small construction work with maximum of two to three storeys. However, this is not suitable for the large projects or high-rise building construction projects. This can be utilized for the individual housing by using small level contractor or labour contractor work. (Lee G. and Mcadam P., 2010)

Advantages of conventional type formworks

- Low initial cost.
- Low experience needed.
- Low weight.
- Versatile usually contains sugars that act as a retardant preventing sticking
- Wide availability.

Disadvantages of conventional type formworks

- Poor finish patching almost demanded if in a place where finished concrete will be seen.
- Low per unit use (No. of reuse is low).
- High labour input.
- Must wait till concrete is well set (24 hours) for strip.
- Leaves a dusty finish as there are sugars in the sap of soft woods.
- Difficult to assume the strength of timber

2.4.2 Modern conventional type formwork

Modern conventional type formwork is much better than the traditional slab formwork method (see Figure 05-08 in Appendix A). Only the difference being that metal props are used instead of bamboo or timber supports and use of plywood sheets instead of timber planks. This system is reusable and more methodical than the traditional method. The finish of the concrete is better and easier to remove after the used.This is the most commonly used system mainly because of its ease handling and freely availability of its components. The skin is stiffened by wooden runners. These stiffeners rest on pipe supports and jacks are placed and those are sometimes supported by the scaffolding system. (Laws A., 2009)

Advantages of conventional type formworks

- Initial cost is low.
- Skilled labour requirement is low.
- Can use even in small places and when there are lot of deviations in the structure.
- Better finish than the conventional type.

Disadvantages of conventional type formworks

- Poor finish of the concrete surface.
- Reusability is low (specially ply wood sheets).
- Requires lot of labour.
- Time taken to erect the formwork is high (floor cycle will be 22-26 days).
- Machinery involvement is high.
- Waste generation in the site is high.

2.4.3 Semi-system formwork

A table form/flying form is a large pre-assembled formwork and false work unit, often forming a complete bay of suspended floor slab (see Figure 09-11 in Appendix A). It offers mobility and quick installation for construction projects with regular plan layouts or long beam and slab layouts. It is routinely used for residential flats, hotels, hostels, offices and commercial buildings. Generally, a series of individual

false work components including primary beams and props are connected to form a complete table, with plan area of up to about 100 m^2. Trusses are often used, linked by cross-braising. The formwork can be mounted on caster wheels or trolley units, allowing it to be moved horizontally. The basic construction sequence using this formwork is as follows. (Cheetham G., 2010)

- The assembled table formwork units are rolled in to position and sealed along the joints to form the floor to be cast.
- Steel reinforcement is fixed in place.
- Concrete is placed and cured.
- Once struck, the formwork units are lowered and rolled out from underneath the newly formed slab.
- They are then taken by crane and placed at the next position or level.

<u>Advantages of semi system formwork (Oberlender G. and Peurifoy R., 2010)</u>

- Speedy construction for large layouts.
- Floor cycle for 100m2 area is about 10-16 days.
- Fully assembled units can be manoeuvred quickly into place, rather than transporting individual components from one location to another and resembling.
- High quality surface finishes can be achieved when appropriate quality control is used.
- The individual components of the formwork system are highly engineered and can be precisely adjusted.
- As the tables create large bay sizes the need for infill areas and decking joints is minimised. The high degree of repetition simplifies work practices.
- Reduced workforce requirement on site.
- In the initial assembly of the formwork can be labour intensive depending on the size of the table unit.
- It is easier to plan construction activities due to the repetitive nature of the work.
- The formwork system is reusable with little waste generated compared to traditional formwork. The assembled units are intended for use throughout the duration of a project without dismantling

- Increased speed and time efficiency on-site.
- Table form systems have been found to be very cost effective for structures with flat slabs.
- The repetitive nature of the work, combined with the engineered nature of the formwork, allows site teams to finely tune their operations, which in turn leads to minimal concrete wastage.

Disadvantages of semi system formwork (Ratay R., (1996)

- High cost of the system.
- Machinery involvement is high.
- Adequate carnage is required for lifting the completed table unit. Lifting operations must be carefully controlled and comprehensive lifting plans are required.
- The system requires enough space around the new construction to fly the table unit beyond the building line on every use.
- The supporting slab must be capable of carrying high loads at bearing locations; back propping may be needed underneath the slab.
- Lateral movement of tables must be carefully controlled using appropriate castors and trolleys.
- Planning is required to ensure sufficient space for assembling the table units
- Assembly requires a workforce conversant with the system.
- Working platforms and safe access have to be provided separately.

2.4.3.1 Safety consideration of using semi-system formwork

The following safety consideration should be followed when using semi-system formwork. (Williamson G.T. and Faherty K.F., 1997)

- Table formwork systems can include stlandered health and safety features, such as guard rails. Edge protection is normally fixed after or during the assembly of the table form units.

- Table top decking and guard rails can be assembled at low levels and lifted on to the table false work when complete. The framework units can also be assembled at ground level, minimising work at height.
- Decking with non-slip surfaces can be used to enhance safety.
- Interconnected truss members provide a reasonably robust assembly and create a stable working platform
- The repetitive nature of the work ensures that site operatives can quickly become familiar with health and safety aspects of their job.

2.4.4 System formwork

The term "system formwork" is to differentiate the conventional formwork, typically the timber one. System formwork has the standard prefabricated modular components with large casting panel (see Figure 12-15 in Appendix A). The system formwork can suit the required shape of concrete structures. Minor conventional formwork to complement the deficiency of the system formwork is still required on site. System formwork has good casting quality, speedier erection and more recycle times compared to the conventional formwork. However, the initial investment of system formwork is higher than the conventional one. Therefore, the more times it is used, the more economical it will be. A good example is the repeated typical floors of a high-rise building. This is the most advanced formwork as this is fast, simple and adaptable. This produces quality work with smooth concrete surfaces. This is a totally pre-engineered system where in the complete methodology is planned to the finest details. In this system the walls, columns and slab are casted in one continuous pour on concrete. These forms are made strong and sturdy, fabricated with accuracy and easy to handle. As the components are made out of Aluminium they are very light weight. The system can be reused for several times. The re-propping is simple hence short cycle time can be achieved. The basic element of the formwork is the panel, which is an extruded Aluminium rail section, welded to an Aluminium sheet. This produces a lightweight panel with an excellent stiffness to weight ratio, yielding minimal deflection under concrete loading. Panels are manufactured in the size and shape to suit the requirements of specific projects. (Hao H. and Deeks A.J., 2004)

Advantages of system formwork

- Can be obtained a smooth concrete surface.
- Speedy construction as the floor cycle of a 1000m2 area is only about 6-10 days.
- Can be erected using unskilled labour.
- No waste will be generated in the site as the system can be reused for lots of times (About 200 times).
- Low machinery involvements as the Aluminium panels are light weight.
- High quality formwork ensures consistence of dimensions.
- Panels can be reused up to 250 times.
- On removal of the mould a high quality concrete finish is produced to accurate tolerances and verticality.
- Total system forms the complete concrete structures.
- Custom designed to suit project requirements.
- Unsurpassed construction speed.

Disadvantages of System formwork

- High cost of the system.
- Not suitable for low rise buildings.
- Large volume of work is necessary to be cost effective.

2.4.4.1 Conventional formwork vs. system formwork

Advantages of system formwork over conventional formwork used in construction projects are:

1. More seismic resistance: - The box type construction provides more seismic resistance to the structure;
2. Increased durability: - The durability of a complete concrete structure is more than conventional brick bat masonry;
3. Lesser number of joints thereby reducing the leakages and enhancing the durability;
4. Higher carpet area- Due to shear walls the walls are thin thus increasing area;

5. Integral and smooth finishing of wall and slab- Smooth finish of Aluminium can be seen vividly on walls;
6. Uniform quality of construction – Uniform grade of concrete is used;
7. Negligible maintenance – Strong built up of concrete needs no maintenance;
8. Faster completion – Unsurpassed construction speed can be achieved due to light weight of forms;
9. Lesser manual labour- Less labour is required for carrying formworks;
10. Simplified foundation design due to consistent load distribution; and,
11. The natural density of concrete wall result in better sound transmission coefficient.

2.4.4.2 Facts to be considered when using system formwork

- Ties used in shutter connection should be carefully grouted.
- Shrinkage cracks likely to occur around door and window openings in the wall can be minimized by providing control strips in the structure which could be concreted after a delay of about 3 to 7 days after major concreting (This can be happened in using all the type of formworks).
- Heat of hydration can be reduced by the use of fly ash.

The formwork assembling at the site is a quick & easy process. On leaving the factory all panels are clearly labelled to ensure that they are easily identifiable on site and can be smoothly fitted together using formwork modulation drawings. All formwork begins from corners and proceeds from there. (El-ReedyM., 2010)

The system usually follows a four step cycle;

- Step 1:

  The first activity consists of erection of vertical reinforcement bars and one side of the vertical formwork for the entire floor or a part of one floor.
- Step 2:

  The second activity involves erection of the second side of the vertical formwork and formwork for the floor

- Step 3:

Fixing reinforcement bars for floor slabs and casting of walls and slabs.

- Step 4:

Removal of vertical form work panels after 24hours, leaving the props in place for 7 days and floor slab formwork in place for 2.5 days.

2.4.4.3 Sequence for striking and erecting system formwork

The striking and erecting system formwork are followed construction sequence explained below (see Figure 16-25).

1. Erect all formwork on 2nd floor.
2. Strike all vertical formwork on 2nd floor. (Concrete was poured on previous day)
3. Position working platform bracket on 3rd floor level and secure nut on rod in inside building.
4. Making of 3rd floor platform.
5. Remove kickers from 2nd floor level and erect formwork on 3rd floor.
6. Remove platform timbers and railings from 2nd floor working platform bracket and pass up to be stacked on 3rd platform. This operation to be carried out on day of concreting- level 3 walls and level 4 slabs.
7. Strike all vertical formwork on 3rd floor (Concrete was poured on previous day).
8. Remove nuts from tie rod on 2nd floor working platform bracket.
9. Hoist 2nd floor working platform bracket up to 3rd floor level.
10. Position working platform on 4th floor level and secure nuts on bolts on inside of building.

2.5 Comparison of Different Features of Formwork Systems

Table 2.1 shows features of different formwork systems use in construction industry.

Table 2.1: Features of different formwork systems

Characteristics	Construction method			
	Traditional formwork	Modern conventional formwork	Semi system formwork	Aluminum system formwork
No cranes or other heavy equipment required	●			●
Able to pour walls and floor slabs with beams with one lift				●
Strike floor slabs formwork without moving props				●
Can form concrete in place as part of work cycle				●
Can form concrete columns and beams together	●	●		●
No skilled labor required				●
Suitable for single or two storied buildings	●	●	●	●
Suitable for high - rise buildings		●		●
Formwork system adapts to different designs			●	●
Able to form all concrete elements	●			●
Can pour all walls, columns and beams together with floor slabs, permitting cellular design & savings in steel concrete				●
Lowest formwork to forming area ratio				●
Confirms to architects design with no need modifications to suit the system	●	●		●
Self-correction feature providing unmatched forming accuracy				●
Environmentally friendly - no huge debris, no messy disposals		●	●	●

2.6 Areas of Cost Reduction

1. Planning for maximum reuse

A form designed for max reuse is stronger and more expensive, but it can save on the total form cos. (Aoyoma H., 2001)

2. Economical from construction
   - Use shop – built forms - Provides greatest efficiency in working conditions and in the purchase and use of materials and tools.
   - Create shop area on the site- To form sections too large or transportation cost too high.
   - Use job – built - For small jobs or where forms must be fitted to terrain.
   - Buy prefabricated forms (large number of reuses).
   - Rent prefab forms (better flexibility in regulating volume of work).

3. Setting and stripping
   - Repeat the same functions to increase the crew efficiency as the job progresses.
   - Use metal clamp or special wedge pin connections that are secure, yet easy to assemble and dismantle.
   - Add extra features that make handling, erection and stripping easier such as handles, lifting eyes.

4. Cranes and hoists
   - Size of form sections should be limited to the capacity of the largest crane planned for the job.
   - Stair towers may be completed early in the schedule to be used for moving men and materials.
   - Leave one bay open to permit mobile crane and concrete truck movement.
5. Bar setting
   - Form design can permit the rebar to be pre-assembled before installation (more favourable condition).

6. Concrete placement
    - High lifts in wall construction make placing and vibration difficult.
    - Placing rate is limited by form design.

2.7 Safety in General

Safety at a construction site is the responsibility of everyone involved, from the contractor to equipment suppliers and the workers themselves. If everyone is aware of performing their jobs with the utmost consideration given to safety, then there will be fewer accidents, with the added benefit of increased productivity at the work site. When using formwork, the temporary or permanent moulds used to hold wet concrete until it sets, a contractor should be aware of certain safety precautions. The following are the basic safety concerns when using formwork: (Hao H. and Deeks A.J., 2004)

Proper access;

- Fall protection;
- Accurate handling of formwork;
- Proper assembly; and,
- Proper formwork ties.

At the same time formwork must be:

- Strong to carry the full load and side pressure from freshly placed concrete, together with construction traffic and equipment; and,
- Sound (made of good quality, durable materials).

To ensure the forms are correctly designed and strong enough for the expected load OSHA (Occupational Safety and Health Administration) regulations and local code requirements for formwork should be followed. The Employer must ensure that:

- The dismantling of formwork is done in a safe manner that is planned and controlled in accordance with AS 3610 – 1995 Formwork for concrete;
- Safe work methods are reviewed and amended regularly as conditions change;

- All persons involved in the work are provided with appropriate training and instruction, which also covers the safe work method statements;
- The risks associated with objects falling are identified and that appropriate controls are implemented and maintained; and,
- All parts of formwork and false-work assemblies are stable and secure at all times during the forming and stripping operations, as well as during temporary storage on site.

2.8 Formwork Failures

Formwork failures are the cause of many accidents and building failures that occur during concrete construction which usually happen when fresh concrete is being placed. Generally some unexpected event causes one member to fail, then others become overloaded or misaligned and the entire formwork structure collapses. (Ratay R., 1996)

The main reasons for formwork failure are:

1. Improper stripping and shore removal;

   Premature stripping of forms, premature removal of shores, and careless practices in re-shoring can produce catastrophic results.

2. Inadequate bracing;

   This is one of the more frequent causes of formwork failure, however, other effects are that induce lateral force components or induce displacement of supporting members. Inadequate cross bracing and horizontal bracing of shores is one of the factors most frequently involved in formwork accidents. High shoring with heavy load at the top is vulnerable to eccentric or lateral loading. Diagonal bracing improves the stability of a structure as struts to solid ground.

3. Vibration;

   Forms sometimes collapse when their supporting shores or jacks are displaced by vibration caused by:

   - Passing traffic;

- Movement of workers and equipment on the formwork
- The effect of vibrating concrete to consolidate it.

Diagonal bracing can help prevent failure due to vibration.

4. Unstable soil under mudsills;

   Formwork should be safe if it is adequately braced and constructed so all loads are carried to solid ground through vertical members. Shores must be set plumb and the ground must be able to carry the load without settling. Shores and mudsills must not rest on frozen ground; moisture and heat from the concreting operations, or changing air temperatures, may thaw the soil and allow settlement that overloads or shifts the formwork. Site drainage must be adequate to prevent a washout of soil supporting the mudsills. (Koel L., 1997)

5. Inadequate control of concrete placement; and,

   The temperature and rate of vertical placement of concrete are factors influencing the development of lateral pressures that act on the forms. If temperature drops during construction operations, rate of concreting often has to be slowed down to prevent a built up of lateral pressure overloading the forms. If this is not done, formwork failure may result. Failure to regulate properly the rate and order of placing concrete on horizontal surfaces or curved roofs may produce unbalanced loadings and consequent failures of formwork.

6. Lack of attention to formwork details

   Even when the basic formwork design is soundly conceived, small differences in assembly details may cause local weakness or overstress loading to form failure. This may be as simple as insufficient nailing, or failure to tighten the locking devices on metal shoring.

Formwork collapse causes injuries, loss of life, property damage, and construction delays. So it is essential to erect the formworks carefully and select the best formwork type for the construction.

2.9 Planning for Formwork

The contractor should plan for formwork at the time of making bid considering the following factors.

- Placing schedule and stripping requirements
- Capacity of equipment available to handle form sections and materials
- Capacity of mixing and placing equipment
- Construction joints
- Reuse of forms as affected by stripping time
- Relative merits of job – built, and ready – made forms
- Weather (protection requirements and stripping time)

So have to compare with the alternative methods to determine the most effective plan.

2.10 Formwork Erection

As formwork is the largest cost component in construction industry the contractors should be keen on the type of formwork used in the construction project.

The summarized methodology of erecting formwork is as follows.

- Level surveys
- Setting out
- Control of deviations
- Erect formwork
  - Method of erecting formwork
  - Advantages and Disadvantages
- Erect deck formwork
- Setting kickers
  - ✓ Connecting Kickers to wall panels
  - ✓ Aligning Kickers
- Standby during concreting -Things to be looked during concreting
- Strike wall formwork

- Strike deck formwork
- Clean, Transport and Stack formwork
  - ✓ Cleaning
  - ✓ Transporting
  - ✓ Striking
- Strike Kicker formwork

2.11 Summary

This chapter discussed the formwork technologies use in construction industry and various other aspects related to formwork systems through a comprehensive literature review and synthesis. The next chapter describes research methodology of this study.

CHAPTER 3 – RESEARCH METHODOLOGY

3.1 Introduction

The purpose of research is to identify and established the most cost effective formwork system for the high-rise building construction of higher than 25 stories. The aim of this chapter is to describe the whole research process of this study.

3.2 Research Approach

This study adopted case study research methodology in order to do an in-depth inquiry regarding most cost effective formwork system for the high-rise building construction of higher than 25 stories. Case study research method provides an opportunity for the intensive analysis of many specific details often overlook by other methods (Moon, 2007; Kohn, 1997). It was led to use case study as the appropriate strategy, since this study is going to explore most cost effective formwork system for the high-rise building construction in Sri Lanka.

3.3 Research Process

The research process of this study, which was based on case study research method comprised following stages; initial impetus; literature review; problem statement; case study design; data collection; data analysis; and, write-up. The succeeding sections follow this sequence in explaining the whole research process of this study.

3.3.1 Initial impetus

The initial impetus to conduct this research was mainly driven through an opportunity given by the Department of Civil Engineering for fulfilment of dissertation study for post graduate candidates for the award of Master of Science degree. The research topic was triggered through the researcher under broader research area of ‘formwork technologies in construction’ and further narrowed to ‘selection of effective formwork system for high-rise construction’ as a current issue

to be addressed in the construction industry in Sri Lanka. The selection of an appropriate formwork system has depended mainly on the intuitive and subjective opinion of practitioners with restricted experience. Consequently, the need for proper mechanism to select an appropriate formwork system for high-rise construction has arisen. Therefore, it is very much important to conduct analytical cost study of the different types of formwork systems used in the high-rise building constructions projects in Sri Lanka. This is relatively an under researched area and new to Sri Lankan construction industry.

3.3.2 Literature review

The comprehensive literature review was carried out to explore the theoretical status and research issues such as definitions, concepts, empirical studies, gaps of this area and establish the significance of research problem statement. The literature search was done in publications such as conference papers, web publications, thesis, dissertations, books, and journal articles available in common databases (for example, Emerald full text search) and university library. It was extended gradually by finding references and key authors, within already found publications.

3.3.3 Research problem statement

One of the major problems in the construction of high–rise buildings is the long time duration of the project. It is required to minimise the floor cycle of the building in order to expedite the construction and reduce the project time. When considering a construction of a storied building 60 percent of the work to be done is concrete work. The construction sequence is same for any of the concrete wok item such as foundation, walls, columns beam or a slab. The standard ways of doing the concrete work item (the main structural elements) is erect formwork; fixing reinforcement; and, finally poring of concrete in to the formwork. The time taken to fabricating of reinforcement and the placing or poring of concrete is morally constant due to the quantity of the work that can be done in the standard way constant per day(Bullock, 1988). Therefore, in order to reduce the floor cycle, the only factor that can be

considered is the time taken to erecting of formwork system. It is considerably influencing to the duration of the project. In the construction of a storied building project especially, high-rise building project, it is very much important to select an appropriate type of formwork system.

High rise construction projects duration is directly affected by the type of formwork system used for the project. Particularly the floor cycle of the building is depending on the type of formwork system used for the construction. If the ordinary type (modern conventional type) of the formwork system is used in a project the floor cycle of the building will be about 15 – 20 days. But a project is using the Aluminium panel formwork system the floor cycle the floor cycle will be reducing up to 7 – 10 days. That shows how the formwork type affect the duration of the construction which is directly affected to the total project cost. Formwork operations accounts for a large portion of the building structure, representing 40-60% of the cost of the concrete frame work and 10% of the total building cost (Hanna, 2005).Moreover, formwork has an important role in the cycle times per floor in the building construction projects. Therefore selection of an appropriate formwork system not only affects the entire construction duration and cost, but also affects subsequent construction activities such as electrical, mechanical and finishing work (Tam et al., 2005).

Considering above facts it is clear that the total project cost and duration are directly affected by the type of formwork system used in the construction project. However, in practice, the selection of an appropriate formwork system has depended mainly on the intuitive and subjective opinion of practitioners with restricted experience (Shin et al., 2008). Consequently, the need for proper mechanism to select an appropriate formwork system for high-rise construction has arisen. Therefore, it is very much important to conduct analytical cost study of the different types of formwork systems used in the high-rise building constructions projects in Sri Lanka. Thus, this study helps to decision makers to select a most cost effective formwork system and avoid lengthy project durations particularly, in the high-rise building projects, which are

higher than 25 stories. This is relatively an under researched area and new to Sri Lankan construction industry.

3.3.4 Case study design

In case study design there were two aspects to be considered: identification of unit of analysis or case and case selection. Unit of analysis or 'case' for this study was 'project' (see Figure 3.1) since this study is going to investigate most cost effective formwork system for high-rise building construction projects in construction industry.

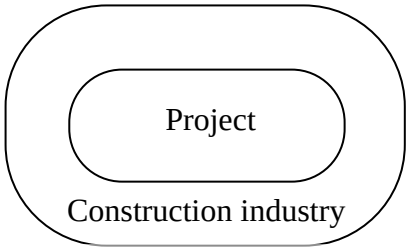

Figure 3.1: Unit of analysis

Second step was selection of cases. Generally, case study research, sample is a purposive sample where researcher obtains a sample that is uniquely suited to the intent of the study. This study focused on learning the phenomenon of 'effective formwork system for high-rise construction.' Thus, this study selected two high-rise building projects more than 25 stories which are located in Colombo metropolises in Sri Lanka. This study selected multiple cases against a single case, as it provides multiple sources of evidence and potential replication of findings. The next step of the research process which based on case study method was to decide on research technique for data collection.

3.3.5Data collection

Data collection of this study was carried out across two residential building projects more than 25 stories which are located in Colombo metropolises in Sri Lanka. Case study-1(Emperor Apartment Tower) 35 storied building has used semi-system (DOCA) formwork and Case study-2 (On Three 20 Building) 38 storied building has used Aluminium panel system formwork. Data were mainly collected from project BOQ (Bill of Quantities), material, labour and plant records of the contractor, construction programme, etc of each project.

3.3.6 Data analysis

Data collected from two case study projects were underwent analytical cost calculation of each project (see Appendix C). For the purpose of this study total project cost of the building project was defined (see Equation 3.1).

Total Project Cost = Cost for the materials and labour + Preliminary running cost + Machinery and equipment cost + Waste material handling cost + Cost for safety in the site + Cost for finishes + Walking/working platform cost + …etc.

Equation 3.1: Total project cost of building project

When considering a project the cost for the materials are common to all but, the labour requirement and the duration will be varies depend on the technology and the construction methodology used in their project to project. Especially, in a high-rise building construction project the total project duration will be affect by the floor cycle time of the floors. The cycle time will be totally affected by the type of formwork used in the project. The cost for labour is affected by the duration of the project and the technology used in the project. At the same time there will be more labour involvement in the project when using ordinary methods and technologies.

Accordingly the preliminary running cost can be defined (see Equation 3.2).

Preliminary Running Cost = Salaries to the management and technical staff + Electricity + Telephone + Welfare + Security + Safety equipment + Office maintenance + . . .

Equation 3.2: Preliminary running cost of building project

Preliminary running cost differs from project to project. In a large construction project such as a high – rise building construction the preliminary running cost much more higher than others due involvement of lot of equipment, technology machineries, waste disposal and labour etc. When the project duration is high the preliminary running cost also is high for the project. So the preliminary running cost is totally affected by the total project duration. The preliminary running cost is constantly running throughout the project period whether the works are going on or not. There for this will be directly affected to the projects surplus or the profit.

If the project gets delayed, it is necessary to keep some machinery in the site for long period of the time until the work getting to the normal. When is getting late to finish the structure, it is necessary to keep the tower cranes and other machinery in the site. So it will increase the running cost of the project. When the cycle time of floors of the building is high it will take a lot of time to finish the structure. So the machinery will be there in the site for a longer time. It will add to running cost to the project. If the cycle time of floors is less it take shorter time period to finish the structural work. So in such the tower cranes can be removed from the site in short time duration which will be reduces the running cost as well as quicker the finishing work of the building. So it will save the cost for the project.

One of the biggest cost components in the construction industry is waste material handling and disposal. In a project where there is a small quantity of waste material the cost of handling them also small. Most of the time in high rise buildings waste

materials generates much more than others and especially from the he formwork system which have been used in the project. In terms of plywood using for formworks is minimised, the amount of waste material generation also can be minimized in the site. If it is possible to use a formwork which can reuse throughout the whole construction of the building and there are no plywood is used, the waste material generation is reduces in considerably. Therefore, it will be considerably influences the project cost.

The cost of finishes in a building is contributed to total cost too. When the surface of the structure is smooth and there are no discontinuities it is easy in doing finishing work and can be expedite the work. If there are more discontinuities it will cost a lot when at the finishing stage. When there are less finishes to be done the time taken to finishes will also be less. That leads to reduce the total project duration. That means the total project cost will be decreased. If the project has been using modern conventional type of formworks the concrete surface is not even and there are lots of discontinuities. But when using Aluminium panel system formworks, the smooth surfaces will be getting and it will be less finishing cost at the stage.

The methodology adapted in this study is calculation of the total cost of a selected project when using the three different types of formworks. Thus, analytical cost study was framed material cost; preliminary running cost; cost of machinery; cost of finishes; and, cost of waste disposal of different formwork types when apply in each project: modern conventional method; semi-system formwork; and, Aluminium panel system formwork. The conventional type of formwork is excluded from analytical cost study since it is not suitable for a high-rise building construction project. The following cost components were calculated for analytical cost comparison purposes (see Appendix C).

- Rates for the all three types of formworks.
- Duration of the project when using different types of formworks.
- Preliminary running cost per day.
- Machinery and equipment cost.

- Waste material handling cost in each occasion.
- Cost for finishes in each occasion, etc.

3.3.7 Write-up

The final stage of the research process was to write-up the dissertation. This was progressively developed from time to time, rather than at the end of the data analysis process. The write-up of the dissertation was started with descriptive writing (see Chapter 2 to Chapter 4) and led to narrow chapter (see Chapter 5) that provides conclusions and recommendations for construction industry.

3.4 Summary

This chapter discussed the research methodology which consisted of research approach, design, and research techniques employed at this study. The next chapter draws conclusion of the study.

CHAPTER 4 –ANALYSIS AND DISCUSSION OF RESULTS

4.1 Introduction

The results of the case study analysis are presented in this chapter. This chapter is structured around to illustrate case study descriptions, within case analysis and overall discussion of results.

4.2 Case Study Descriptions

The calculations are done for two selected high-rise building construction projects when different types of formworks are used in each project. Table 4.1 shows features of each case study projects.

Table 4.1: Descriptions of the case study projects

Descriptions	Case Study-1	Case Study-2
Project name	Emperor Apartment Tower	On Three 20 Towers
Duration	21 months	40 months
Total project cost	Rs. 2,203,680,746.50	Rs. 1,849,425,000.00
No. of stories	35	38
Typical Floor area	950m^2	600m^2
Formwork area	46,500m^2	34,200m^2
Type of formwork used	DOCA (Semi-system)	Aluminium panel system
Total area for finishes	65,000m^2	56,650m^2
Horizontal area for finishes	33,250m^2	20,600m^2
Vertical area for finishes	31,750m^2	36,050m^2

4.3Within Case Analysis

4.3.1 Case study-1 (Emperor Apartment Tower)

The results obtained from analytical cost calculation (see Appendix-C) for case study-1 (Emperor Apartment Tower) are illustrated in Table 4.1. All the values are given in Rupees Millions and to two decimal places. In this project the used formwork type was semi-system (DOCA) formwork. The building is a 35 storey building. Case study results shows least total project cost is achieved when Aluminium panel system formwork is used comparatively (see Table 4.2 and Figure 4.1).

Table 4.2: Summary of the analysis (Emperor Apartment Tower)

	Aluminium panel system formwork	**Semi-system formwork (DOCA)**	**Conventional formwork**
Duration	14 months	21 months	31 months
Formwork cost	48.63	43.81	36.8
Preliminary cost	144.07	216.1	319
Finishes affected by the formwork	43.34	52.24	69.54
Waste disposal affected by the formwork	0	13.45	19.66
Machinery affected by the formwork	14.45	25.81	40.55
Total	**2102.93**	**2203.68**	**2325.26**

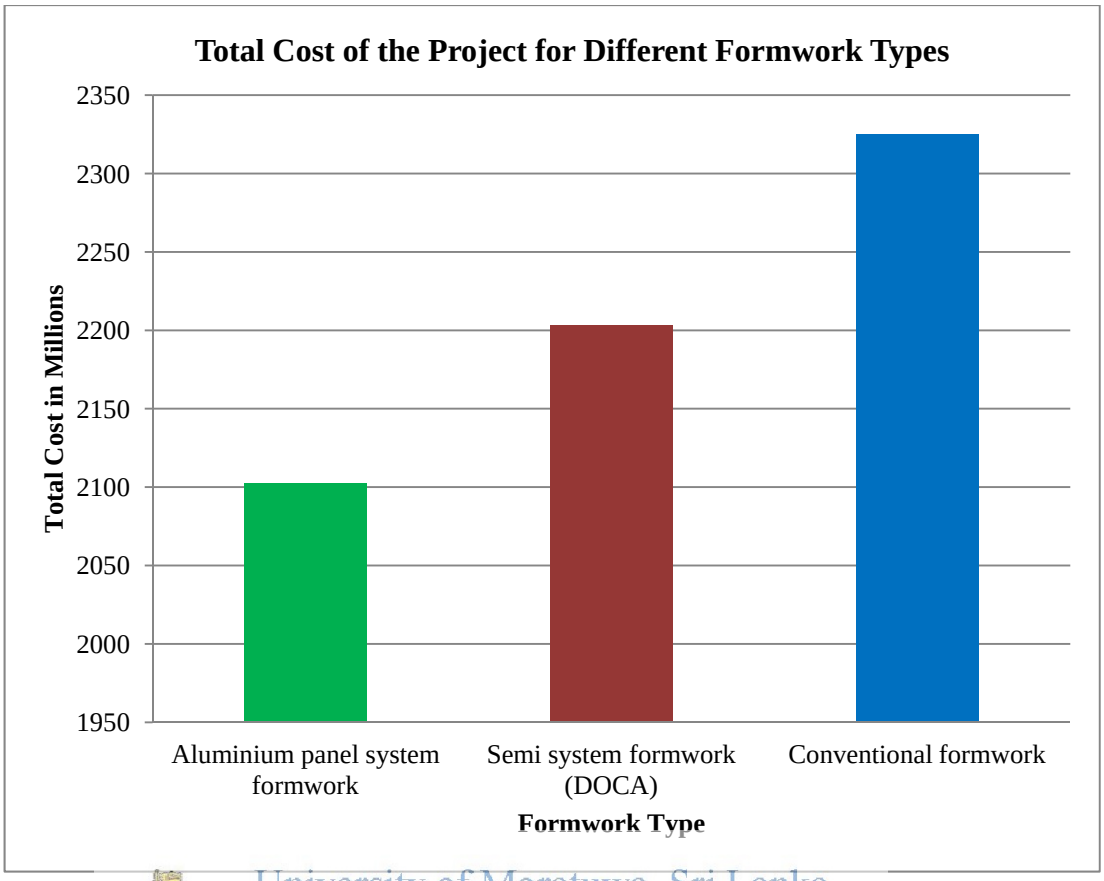

Figure 4.1: Total project cost when using different formwork types (Emperor Apartment Tower)

The initial cost of the formwork materials of these three types are varies as illustrated in Figure 4.2. The highest cost for the formwork is noted in the Aluminium panel formwork system and the least cost for the formwork is noted in the modern conventional type of formwork. Thus, the results indicated that the initial cost of the formwork system does not affect the total cost of the project. Further, the most significant fact noted in this analysis is the least construction cost is obtained when using the most expensive formwork type. On the other hand, the highest project cost is obtained when the least expensive formwork type is used. Therefore, it is clear that the total cost of the project is totally affected by the type of the formwork but not the initial material cost of the each formwork system. When comparing the project cost and cost for different type of form works, it is very clear that cost of those form work systems are not affected to the project cost but it has been directly affected to

the project duration and which will obviously leads to reduces the it surplus or the profit.

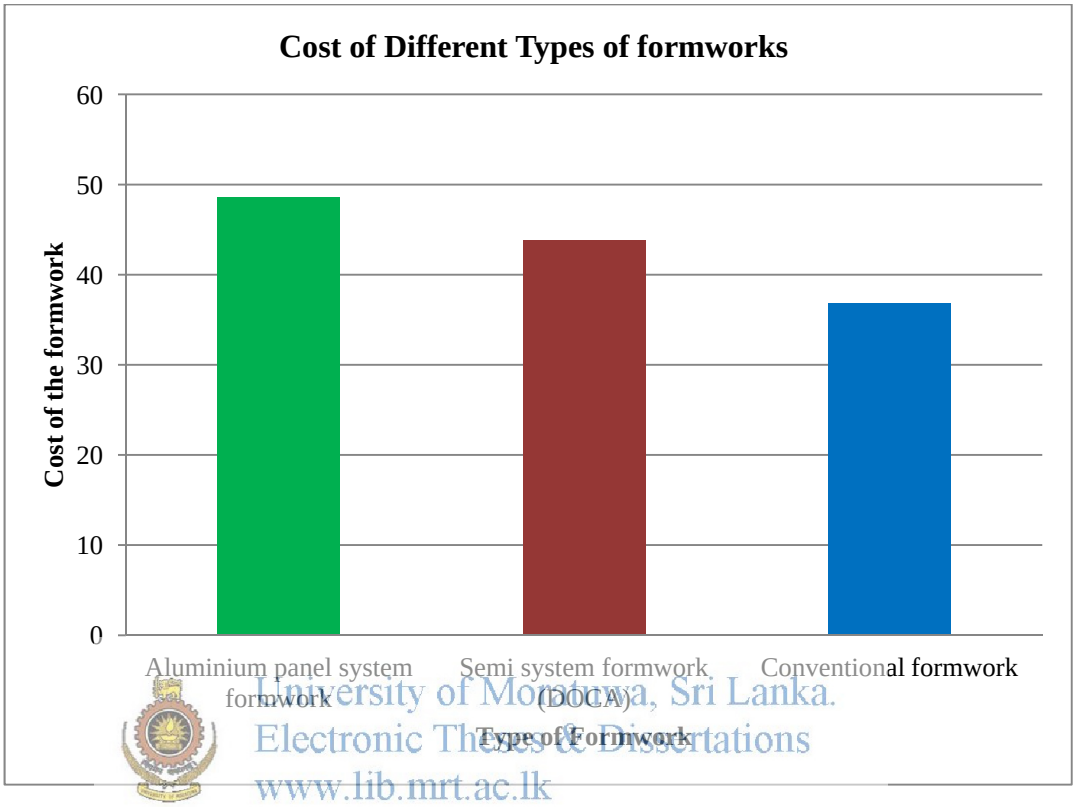

Figure 4.2: Cost of Different formwork types (Emperor Apartment Tower)

4.3.1.1 Impact on project duration

Duration of a project is directly affected by the floor cycle of the building. And also higher the number of storeys the amount affected to the total project duration also higher. Figure 4.3 shows how the total project duration of a 35 storied building is affected by the type of formwork: Aluminium panel system formwork; semi-system formwork (DOCA); and, modern conventional formwork system which are having the floor cycle of 8 days, 14 days and 22 days respectively. According to the FIGUERE 4.3, the lowest duration is obtained when using Aluminium panel system formwork which has the lowest floor cycle of 8 days. The highest project duration is obtained with modern conventional type formwork which has the floor cycle of 22 days. According to the analysis there is a 14 (22 - 8) day saving per floor when applying Aluminium panel system formwork than modern conventional formwork. The total time saving is 490 (14 x 35) days for 35 storied building. Therefore, it is

clear that the total project duration is directly affected by the type of formwork system.

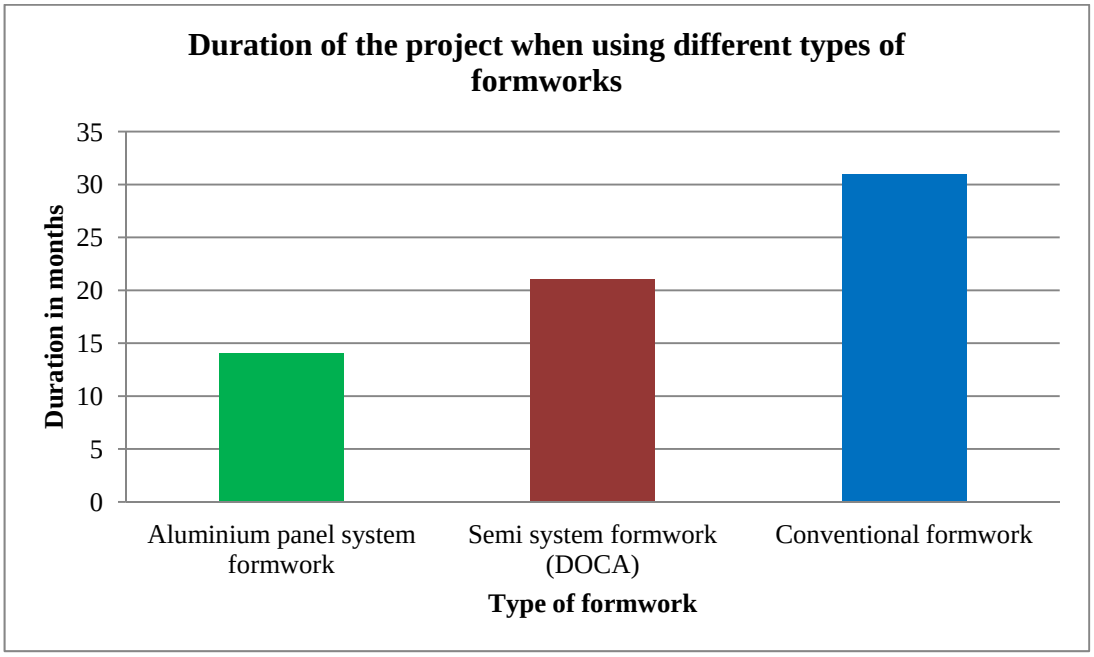

Figure 4.3: Duration of the project with the formwork type (Emperor Apartment Tower)

4.3.1.2 Preliminary running cost

Preliminary running cost is a considerably higher cost component in a construction project. It includes salary of the staff; cost for electricity; cost for management; telephone; etc. under the preliminary cost and it is directly affected by the duration of the project. That means when the project duration is high, the preliminary running cost is higher. Thus, the project to be more profitable if the duration of the project could be keep in short as much as possible. According to Figure 4.4, it is clear that the lowest preliminary cost is obtained when using the Aluminium panel system formwork which has the shortest project duration. At the same time it is the most expensive formwork type among from the above three types. But the significant factor behind the Aluminium panel system formwork which leads the very shorter project duration.

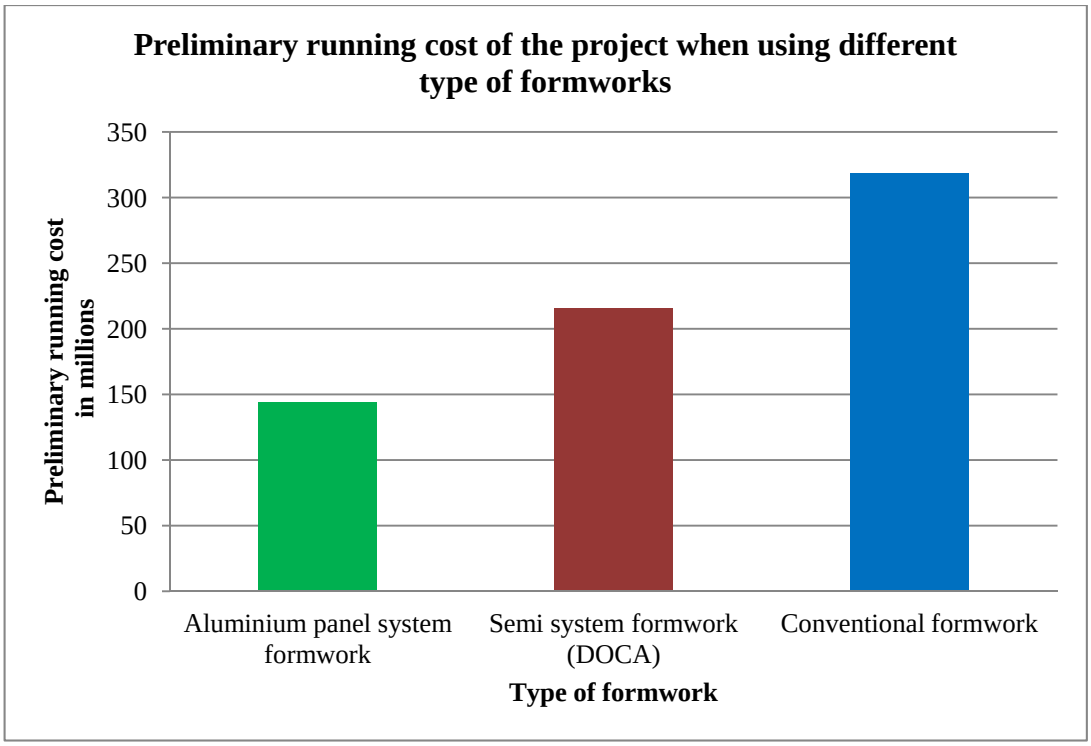

Figure 4.4 : Preliminary running cost with different formwork types (Emperor Apartment Tower)

4.3.1.3 Cost for the finishes (affected by the formwork)

Finishes of a building requires a large amount of money and it is a big cost component in the construction project sum. Therefore, some of the parts are directly affected by the formwork used in the project. When the concrete surface is smooth and there are lesser or no discontinuities in the surface the amount of money to be spend for the finishes is lesser. When considering the following three formwork types, Aluminium panel system formwork gives a good quality surface without any discontinuities in the concrete because the formwork can be assemble very neatly ensuring the surface is smooth and levelled. However modern conventional type is used, the concrete surface will not be smooth and there are discontinuities at the plywood joints. Thus, there will be lot of work involved when finishing stage. Plastering will be needed to level the surface. But when system formwork is used plastering will not be necessary and skim coating is more than enough. The Figure 4.5 shows how the cost for finishes differs with the formwork type.

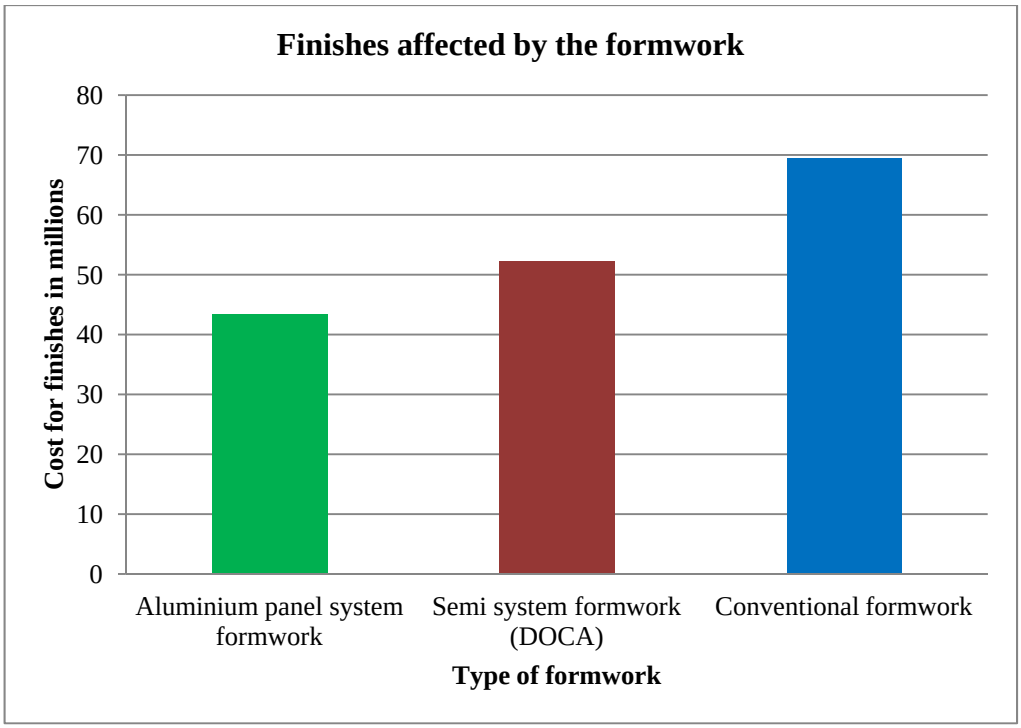

Figure 4.5: Cost of finishes affected by the type of formworks (Emperor Apartment Tower)

4.3.1.4 Machinery cost

In the contruction industry the machinery plays a great role. There are a lot of heavy and big machinery involve in the construction projects specially in high rise buildings due to vertical movement of materials it should be used michnical divises while the constructions of the building going on. Among those materials, the materials of the formwork system playes a great role. If the formwork is errct in modern conventional type and semi system formwork type there will be very heay materials to be transported to the top to bottom.Therefore use of a tower crane in the construction site is essential. But if the construction project is using the Alluminium panel system formwork there will be not heavy materials involved in the construction. The Aluminium panels which used in the construction are very light and a tower crane will not be essential and the builder hoists are more than enough to meet the requirements in the site. As the machinery involvement is different in the project when using different types of formworks, the cost for machinery also differs with it (see Figure 4.6).

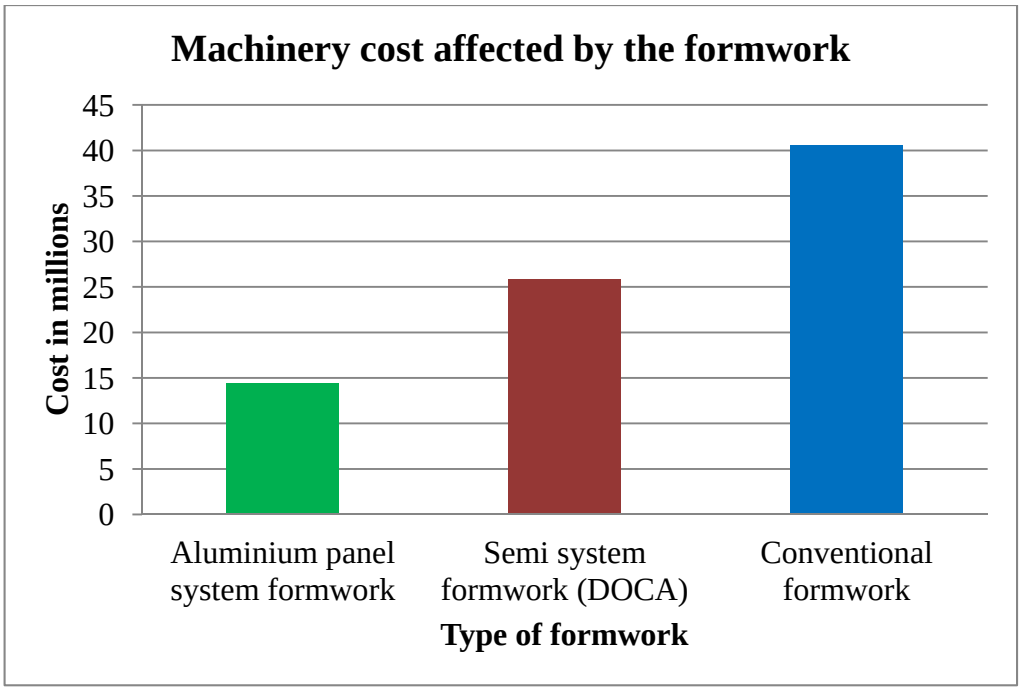

Figure 4.6: Machinery cost affected by different type of formworks (Emperor Apartment Tower)

4.3.1.5 Cost for waste disposal

Waste disposal is a major and essential item in construction projects. In the projects where located in urban areas and there is not much space in the site. Waste disposal is critical as there is no space to dump them in the site. Therefore, it will have to spend lot of money in waste disposal. But one can have the question, what are the wastes generated in the construction sites? There will be lot of water generated in the site when modern conventional type formwork is used in a high – rise building site. That is because the materials use in the formwork (plywood, timber props, kickers, etc) can use only about 4-5 times and so have to dispose them and have to bring new materials to the site. The same issue is arises when using semi system formworks in the site as ply wood is using as form work material. When using Aluminium panel system formworks the waste generated due to formwork is negligible. Thus, it is not necessary to allow extra cost to dispose waste generated due to formworks. Figure 4.7 shows how the cost for waste disposal is differs with the type of formwork. Thus, it is very clear that there is a considerable cost saving in using Aluminium panel system formworks in high-rise building construction project.

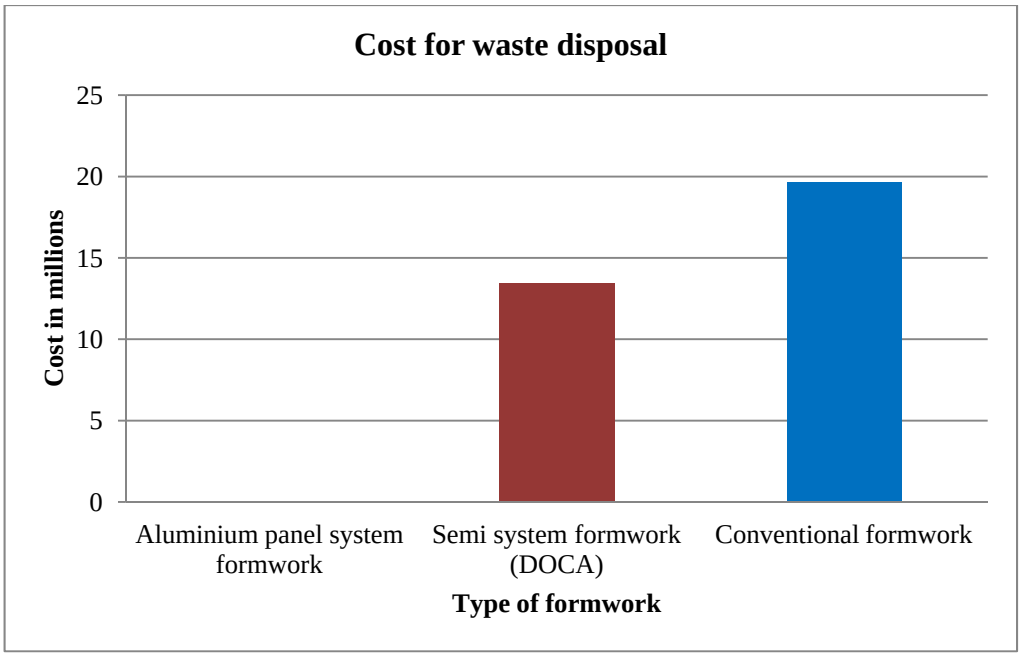

Figure 4.7: Cost for waste disposal with the type of formwork(Emperor Apartment Tower)

4.3.2 Case study-2 (On Three 20 Building)

The results obtained from analytical cost calculation (see Appendix-C) for case study-2 (On Three 20 Building) are illustrated in Table 4.3. All the values are given in Rupees Millions and to two decimal places. In this project the used formwork type was Aluminium panel system formwork. The building is a 38 storey building. Case study results shows least total project cost is achieved when Aluminium panel system formwork is used comparatively (see Table 4.3 and Figure 4.8). At the same time Aluminium panel system formwork is the most expensive formwork type among those three types.

Table 4.3: Summary of the analysis (On Three 20 Building)

	Aluminium panel system formwork	**Semi system formwork (DOCA)**	**Conventional formwork**
Duration	40 months	47 months	57 months
Formwork cost	35.6	33.69	27.8

Preliminary cost	227.36	267.15	323.99
Finishes affected by the formwork	38.23	40.94	62.76
Waste disposal affected by the formwork	0	12.63	19.46
Machinery affected by the formwork	16.91	40.63	50.16
Total	**1849.43**	**1926.56**	**2027.52**

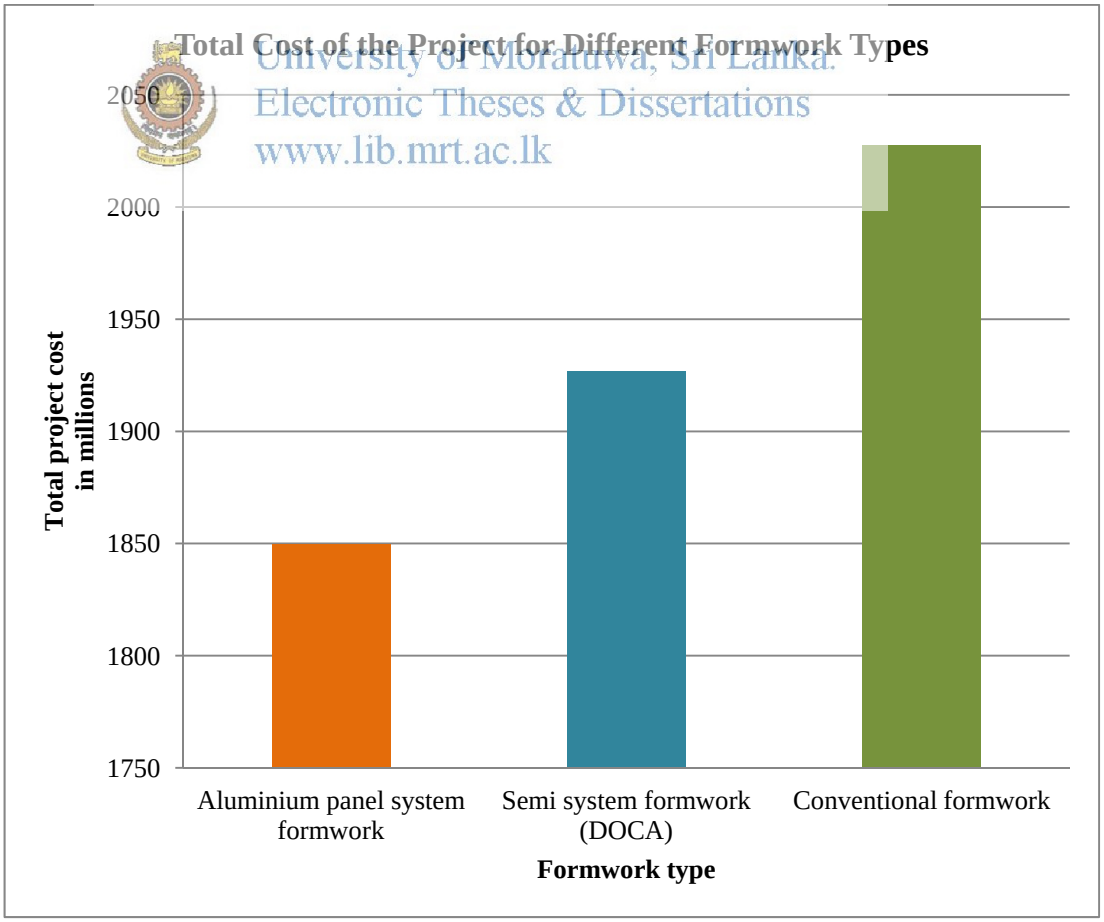

Figure 4.8: Total project cost when using different formwork types (On Three 20 Building)

Case study data showed that though the formwork is very expensive the lowest total project cost is obtained when Aluminium panel system formwork is used (see Figure 4.9). At the same time, the cost reduction of the project due to the formwork type used is very high. Further, the cost for that specific formwork type (Aluminium panel system formwork) is not much expensive when compare to the other formwork types. The total projects costs are 1843.43 million rupees, 1926.56 million rupees and 2027.56 Million Rupees respectively for the formwork types: Aluminium panel system formwork; semi-system formwork; and, modern conventional formwork. But the formwork cost for those three types of formworks are respectively 35.6 million rupees, 33.69 million rupees and 27.8 million rupees. Here the advantage of using Aluminium panel system formwork is higher than the extra cost for the formwork.

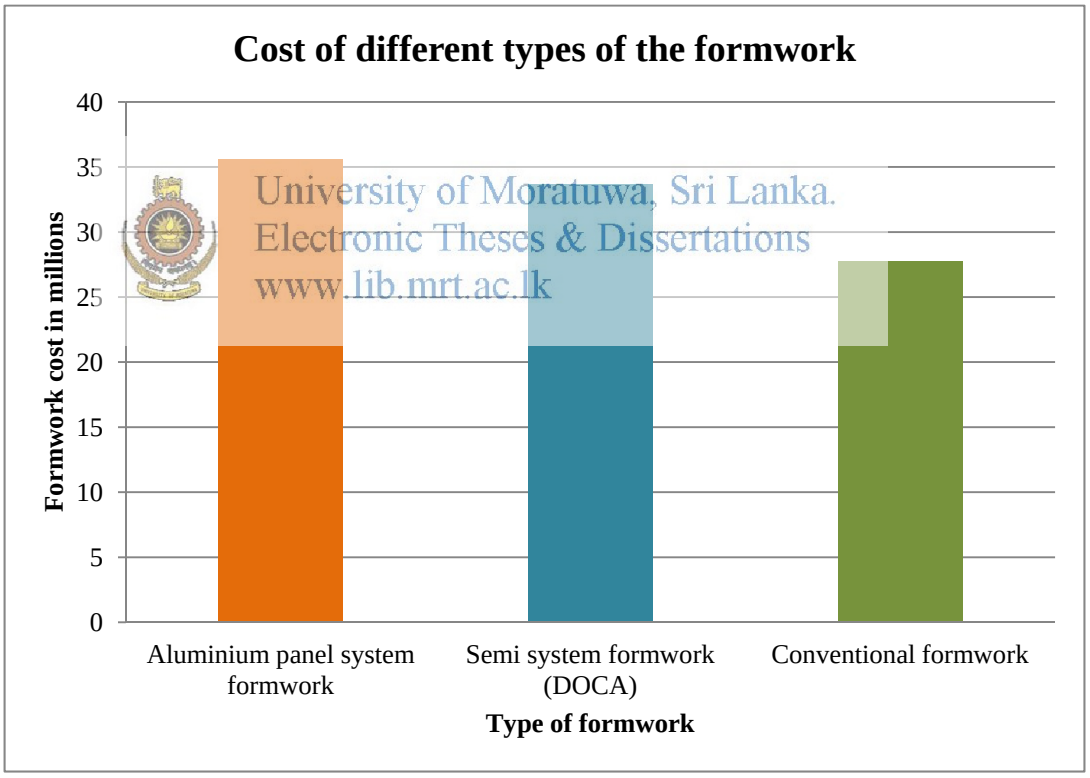

Figure 4.9: Cost of Different formwork types(On Three 20 Building)

4.3.2.1 Impact on project duration

The result obtained from the analysis for the case study -2building also similar to the result of the case study-1. Here also the lowest project duration is there for the Aluminium panel system formwork (see Figure 4.10) which has the floor cycle of 9 days and the highest project duration for modern conventional type of formwork with 22 day floor cycle. The saving of days per floor when using Aluminium panel system formwork is 13 (22-9) days than modern conventional type formwork. As there are 38 stories in the building total time saving is 494 (13 x 38) days. Therefore, the conclusion is the total project duration is directly affected by the type of formwork used in the construction.

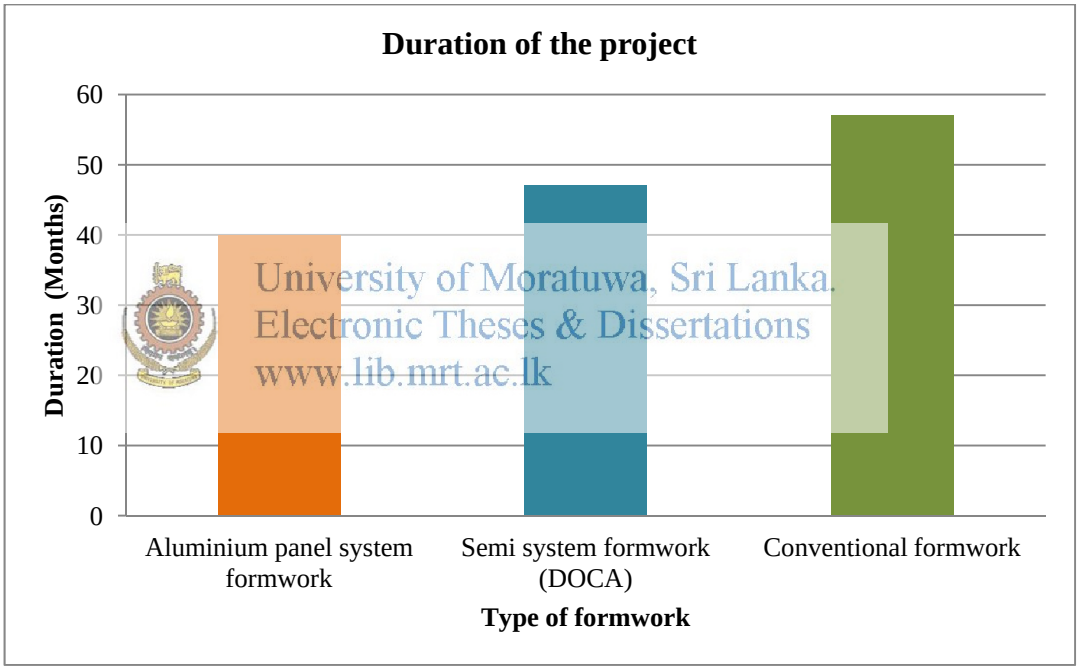

Figure 4.10: Duration of the project with the formwork type (On Three 20 Building)

4.3.2.2 Preliminary running cost

Variation of the preliminary running cost component showed in Figure 4.11 for this project is similar to the previous project (See Section 4.3.1.2).

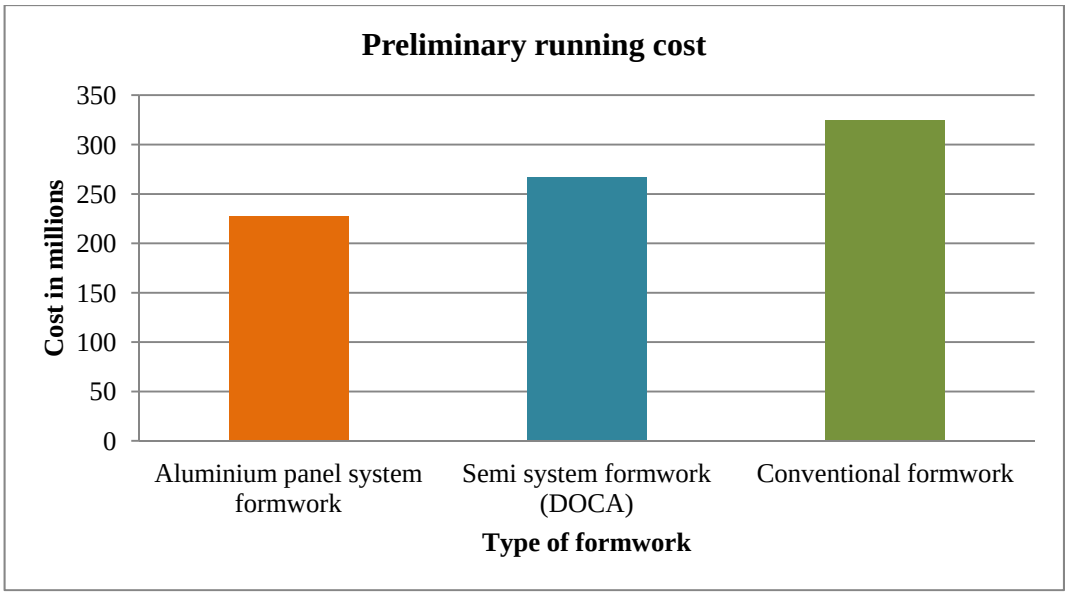

Figure 4.11: Preliminary running cost with different formwork types (On Three 20 Building)

4.3.2.3 Cost for the finishes (affected by the formwork)

Variation of the finishes cost component showed in Figure 4.12 for this project is similar to the previous project (See Section 4.3.1.3).

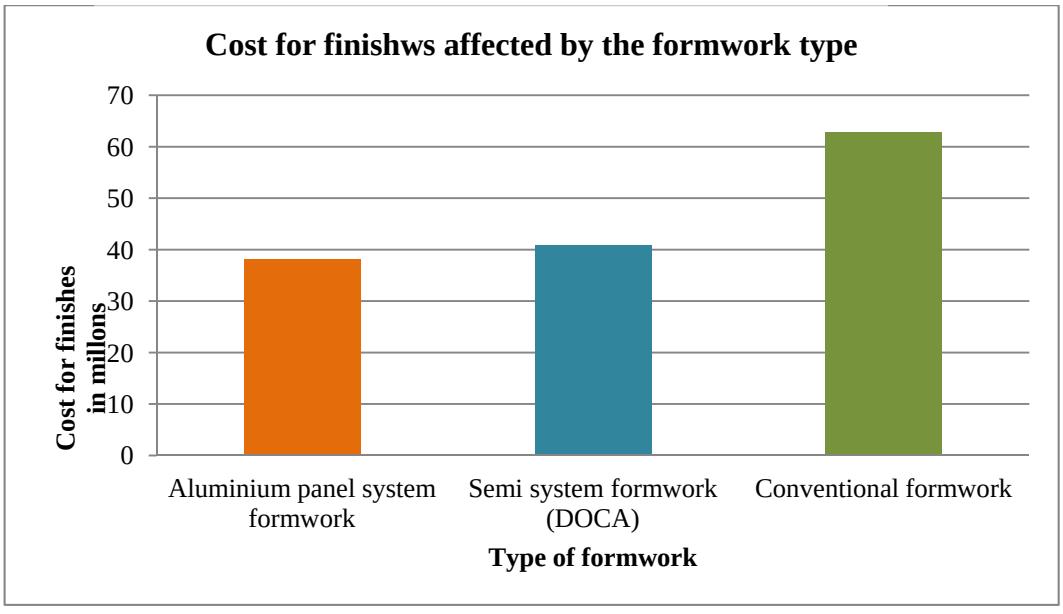

Figure 4.12: Cost of finishes affected by the type of formworks (On Three 20 Building)

4.3.2.4 Machinery cost

Variation of the machinery cost component showed in Figure 4.13 for this project is similar to the previous project (See Section 4.3.1.4).

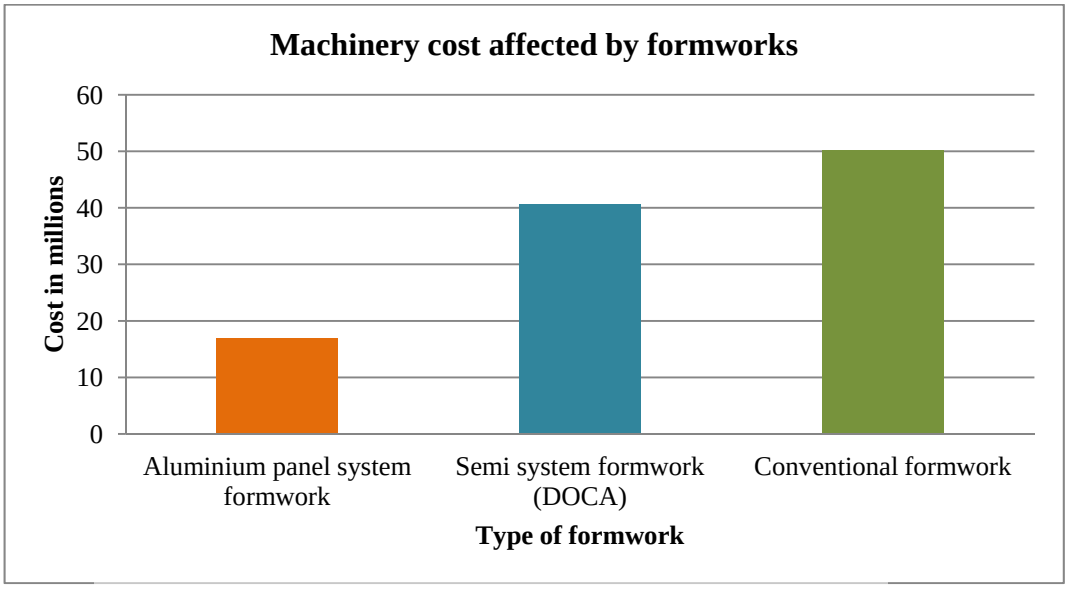

Figure 4.13: Machinery cost affected by different types of formwork (On Three 20 Building)

4.3.2.5 Cost for waste disposal

Variation of the waste disposal cost component showed in Figure 4.14 for this project is similar to the previous project (See Section 4.3.1.5).

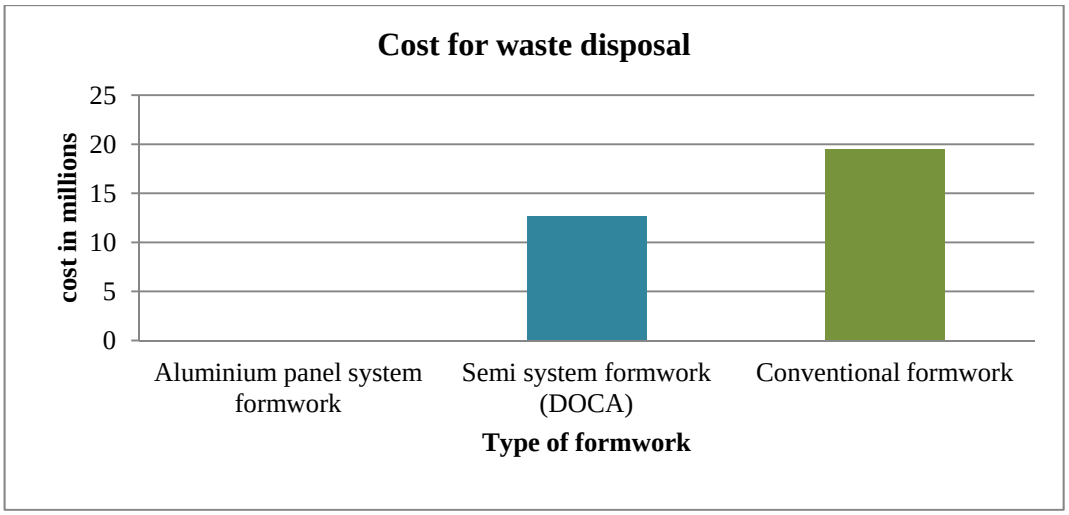

Figure 4.14: Cost for waste disposal with the type of formwork(On Three 20 Building)

4.4 Overall Discussion of Results

4.4.1 Reasons for the cost reduction in system formworks

The case study results revealed that least total project cost is achieved when using Aluminium panel system formwork (see Table 4.4).Further, the total cost of the project is totally affected by the type of the formwork but not the initial material cost of the each formwork system.

When using Aluminium panel system formwork, the cycle time is only about 6-10 days. But when using semi system (DOCA) formwork the cycle time is about 12-16 days while it is about 20-24 days in modern conventional type of form works. The floor cycle is high means the total project duration is high. The project duration is high means the total project cost is also high. Therefore, the formwork type which has the shortest floor cycle will have the shortest duration and hence it will have the lowest total project cost. The biggest cost component affected to the total project cost is the preliminary running cost. Because the preliminary running cost per day is a very high amount in such a big construction project.

Apart from the cost saving due to the short project duration there are many other areas which affect the cost reduction. There is a large amount of cost saving in finishes, machinery cost and waste disposal. When consider about the finishes, the amount of finishes to be done is affected by the formwork as the quality of the concrete surface is depend on the type of the formwork. In aluminium panel system formwork it can be obtain a very smooth surface while a rough and discontinuous surface can be obtained when using modern conventional type formworks. An intermediate surface can be obtained when using semi system formworks. When the obtained concrete surface is smooth the extent of finishes requirement is less. When using modern conventional formworks the concrete surface is not even and need to make the surface even by plastering. But if the concrete surface is even a plaster is not needed and skim coating is more than enough to finish the surfaces. So the cost of plastering will be saved with the aluminium panel system formworks. But if the modern conventional type is used plastering should be done. It will cost a lot as the rate for plastering is about 600 rupees per m^2. With the semi system formwork it can be obtained a smooth surface but not smooth as with the aluminium panel system

formwork. But there will be a cost saving than the modern conventional type. So it is enough to do skim coating the surface and paint the surface. But here it will cost a little more for skim coating than in the aluminium panel system formwork. Because the concrete surface obtained in this type of formwork is a little bit rougher than with the aluminium panel system formwork.

Machinery also plays a vital role in a construction industry. Normally in construction site lots of heavy materials are used and hence lots of heavy and big machinery are used. At the same time formwork materials play a great role in the site. In a high rise building sites the most difficult task is to handle formwork materials as they are very heavy. In the early stages it costs a lot for formwork materials handling in the site as they are very heavy in the era of using modern conventional formwork type and semi system formwork type. As steel panels are used in semi system formworks use a tower crane is essential. But when Aluminium panel system formwork is introduced the machinery usage has decreased as the use of tower crane usage is not essential in the project. The Aluminium panels are very light weight and man power can be used to lift the materials from floor to floor as the constructions proceed. So there will be a lot of cost saving in the construction project as a tower crane is not needed and builder hoists are facilitate to lift the other construction materials and labour in a site.

The other major cost saving area is waste disposal. When using a formwork system which uses plywood and other materials which can reuse only for few times, there will be lots of waste generated in the site. At the same time the wastes should be disposed in the site or out of the site to precede the other constructions. Most of the occasions there will not be space in the same site to dispose them and hence they should be transported to the dumping sites and even have to get the permission to dispose the waste. That process involves lots of money. But if it can use a formwork type that it is not generating waste the total amount of money for waste disposal can be saved. As the Aluminium panel system formwork can be reused for many times there will not be waste in the site and hence it will save a considerable amount of money of project. And also it can re sale recover the cost of system formwork will also be a benefit for the project.

Table 4.4: Summary of case study analysis

Project	No. of stories	Total project cost (LKR in millions)		
		Aluminium panel system formwork	**Semi system formwork (DOCA)**	**Modern Conventional Formwork**
Emperor Apartment Tower (Case Study-1)	35	2,102.93	2,203.68	2,325.26
On three 20 building (Case Study-2)	38	1,849.43	1,926.56	2,027.52

4.5 Summary

This chapter presented and analysed the research findings of the empirical investigation. The next chapter provides conclusions and recommendations. Further, chapter 5 presents limitations of the research study and guides to further research studies.

CHAPTER 5 – CONCLUSIONS AND RECOMMENDATIONS

5.1Introduction

Chapter 4 presented and analysed the empirical findings of the research. The aim of this chapter is to provide conclusions and recommendations. Further, this chapter presents limitations of the research study and guides to further research studies.

5.2 Conclusions

The main aim of research is to identify and established the most cost effective formwork system for the high-rise building construction of higher than 30 stories. The results indicated that the lowest project cost is achieved when the using Aluminium system panel formwork for the construction project. However, it is obvious that, Aluminium panel system formwork is the most expensive formwork system out of the other three types of form work systems. The highest project cost is noted when using of modern conventional type of formwork for the project. However, it is the least expensive formwork type commonly used in the construction industry. Therefore, it is clear that the cost of formwork not directly affected to the total project cost but the type of formwork is highly affected to the project cost in especially, high rise building construction projects

Even though the Aluminium panel system formwork is very expensive, it has much more quality than others and reduces the total project cost. It identified the floor cycle of the building will be 6-10 days when using the Aluminium system formwork, because the time taken to erect the formwork is comparatively less than other types (modern conventional type 20-24, semi system 12-16). Though the time taken to harden the concrete is constant which saves the time in erecting the formwork. So this will leads to reduces duration of a project and which will reduces the project cost. If a project delays even by a bay it will leads to exceed the total project cost. Meanwhile it will give high quality concrete surfaces which will be more advantage and cost savings at the finishing stage. If the modern conventional type is used there

will be lot of discontinuities in the concrete surface and the cost of finishing will be very high at the finishing stage.

The other two main areas which affect the total project cost due to the used formwork type in the project are machinery usage and waste disposal. When consider about the machinery, lots of machinery are involved in the construction projects as lot of heavy materials are used in the construction site. One of those is formwork materials. When modern conventional type of formworks and semi system formworks are used in the site, a tower crane is essential due to the formwork materials are very heavy. But the Aluminium panel formwork materials are very light and can be handled easily use of manpower to lift the formwork materials from floor to floor. Therefore a tower crane is not essential and builder hoists are enough to lift the other construction materials. Accordingly this is also one major factor which will be reducing considering amount of project cost.

The other major cost component which is affected by the formwork is waste disposal. What will be the waste generated due to the formwork? If the modern conventional type is used the used ply wood sheets, timber members, kickers...etc. It will become waste after using for few times. However Aluminium panel system formwork is used there will be no any waist material and it can be reused for many times. Disposal of waste material also one of a major issue and will be a cost in a project. And also after the construction is over the system can be simply dismantle and sell back. There will be nothing to dispose even after completion of the project. To dispose waste will be another added cost and that amount can be saved if the Aluminium panel system formworks are used in the project.

Therefore this study find the most cost effective form work system is to be used for a high-rise building project especially, higher than 25 storied is Aluminium Panels system formwork.

5.3 Recommendations

As the conclusion of this studies the most economical and cost effective type of formwork for high rise buildings (more than 25 stories) is ***Aluminium Panel System Formwork.*** If the Aluminium panel system formwork is used there will be a lot of cost savings in the total project sum and there are many cost effective features and advantages for high quality project performances. When considering all the above findings and facts it is clear that using Aluminium Panel System Formworks in the construction of high rise building project is the most economical system .Therefore, this study recommends the Aluminium Panel System Formwork in high-rise buildings projects.

5.4 Limitations of the Research

The scope of the research was investigation regarding the research problem in high-rise building projects in construction context. Therefore, the research was limited to the two high-rise building projects more than 25 stories which are located in Colombo metropolises in Sri Lanka. The general stability of the case study research is limited to the case study sample population and can't generalize to a wider population or universe. This study used multiple case studies and finding similar results across cases had improved generalisability of findings to the selected sample population: two high-rise building projects more than 25 stories which are located in Colombo metropolises in Sri Lanka.

5.5 Recommendations for Future Research

Research into cost effective formwork system for construction for building project must be located within the broader study. It is clear from the above literature review of the current situation that there is a lack of understanding of researchers in the formwork systems. The following questions highlight areas for further research:

- There is a need for broad and in-depth empirical research into the system to minimize the cost, improve quality and reduce the floor cycle duration further to reduce the project cost without compromising project quality.

- In depth study is needed to develop formwork system like Aluminium panel system formwork for low-rise buildings.

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APPENDIX A: FORMWORK SYSTEMS

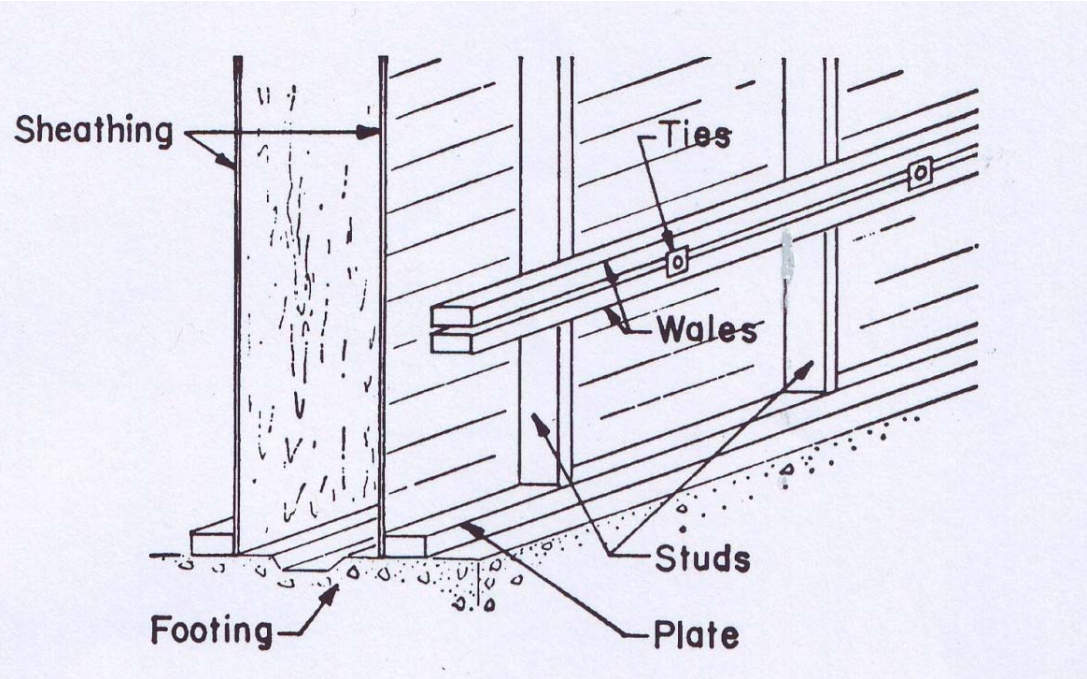

Figure 01: Typical wall form with its components

Figure 02: Conventional type formwork

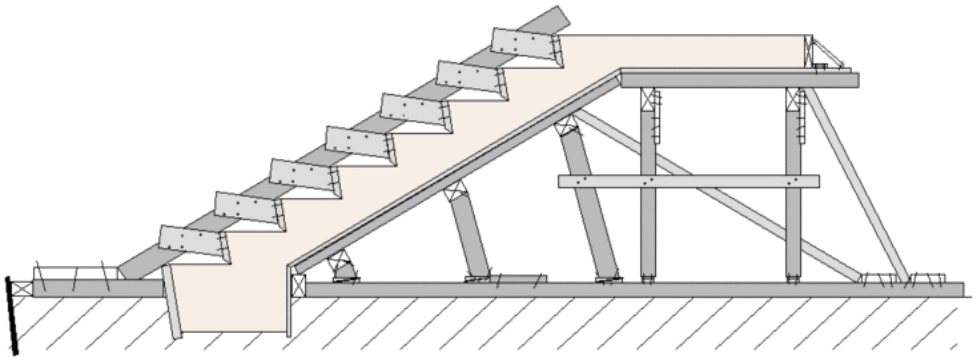

Figure 03: Side view of traditional timber formwork for flight of stairs

Figure 04: Poor finish in conventional type formwork

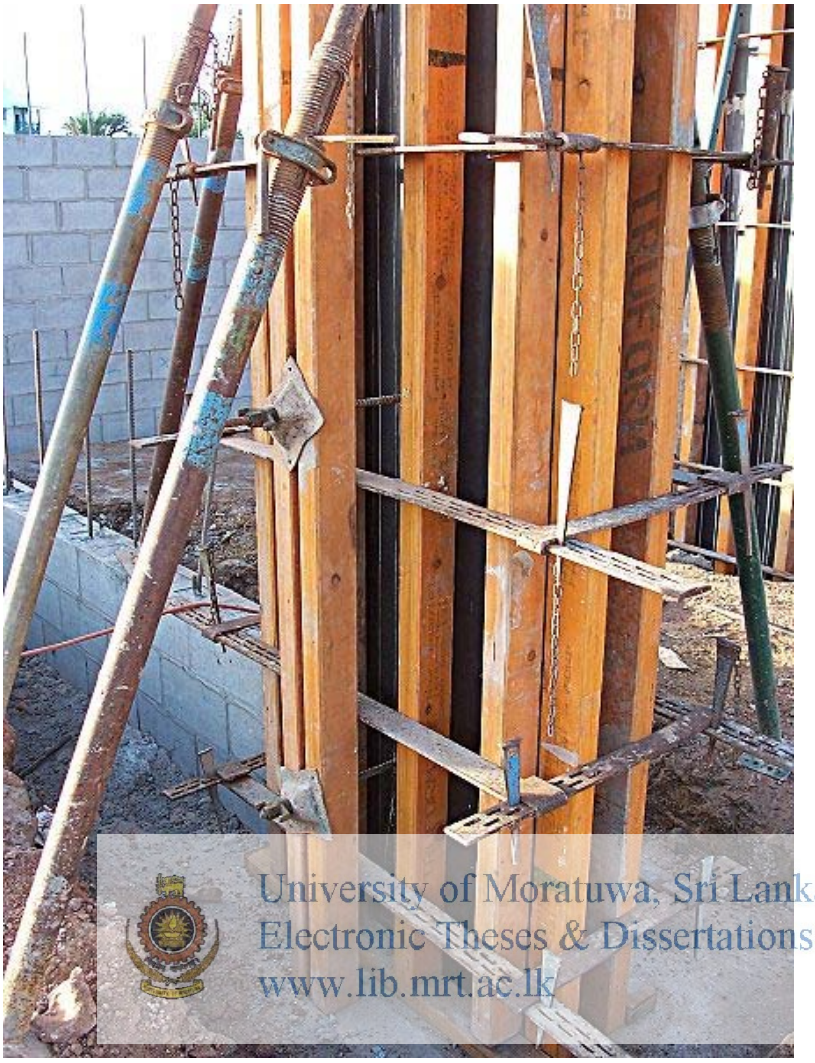

Figure 05: Modern conventional formwork for a concrete column

Figure 06: Modern conventional formwork for slabs and beams

Figure 07: Modern conventional formwork for a slab

Figure 08: Modern conventional formwork

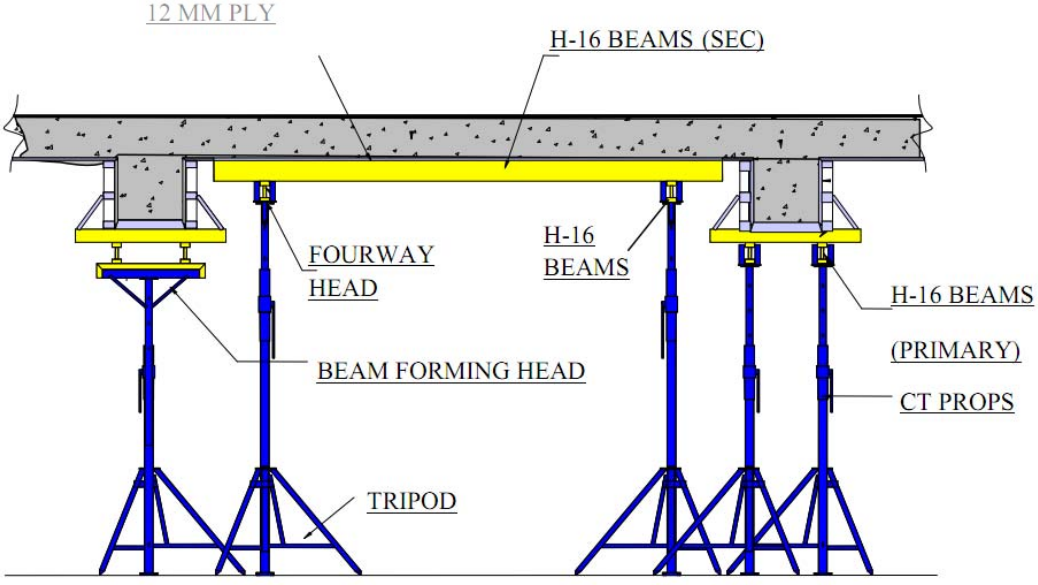

Figure 09: Semi system formwork for slabs and beams

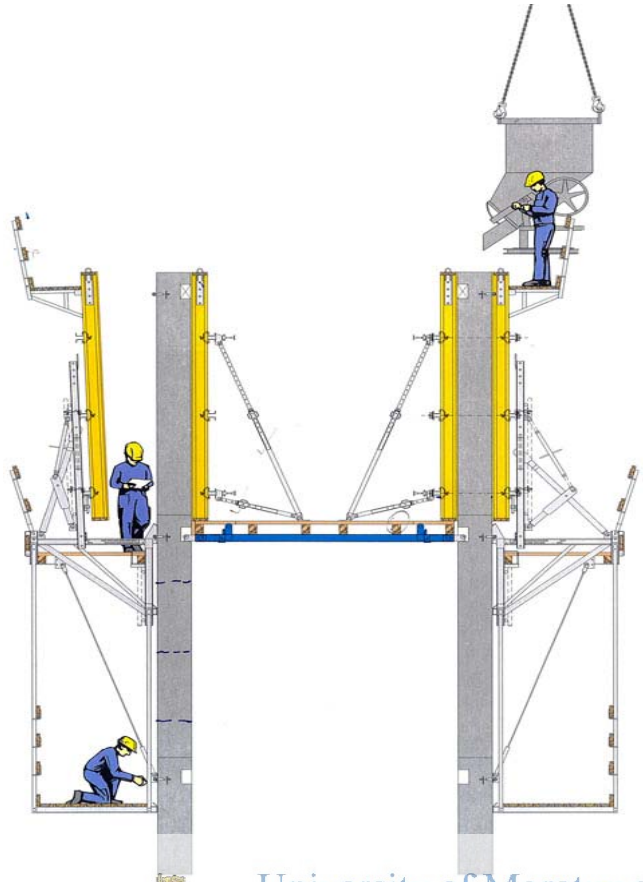

Figure 10: Semi-system formwork for a column

Figure 11: Semi-system formwork

Figure 12: Typical system formwork

Figure 13: System formwork for walls and slab

Figure 14: System formwork

Figure 15: System formwork for columns

APPENDIX B: SEQUENCE FOR STRIKING AND ERECTING OF SYSTEM FORMWORK

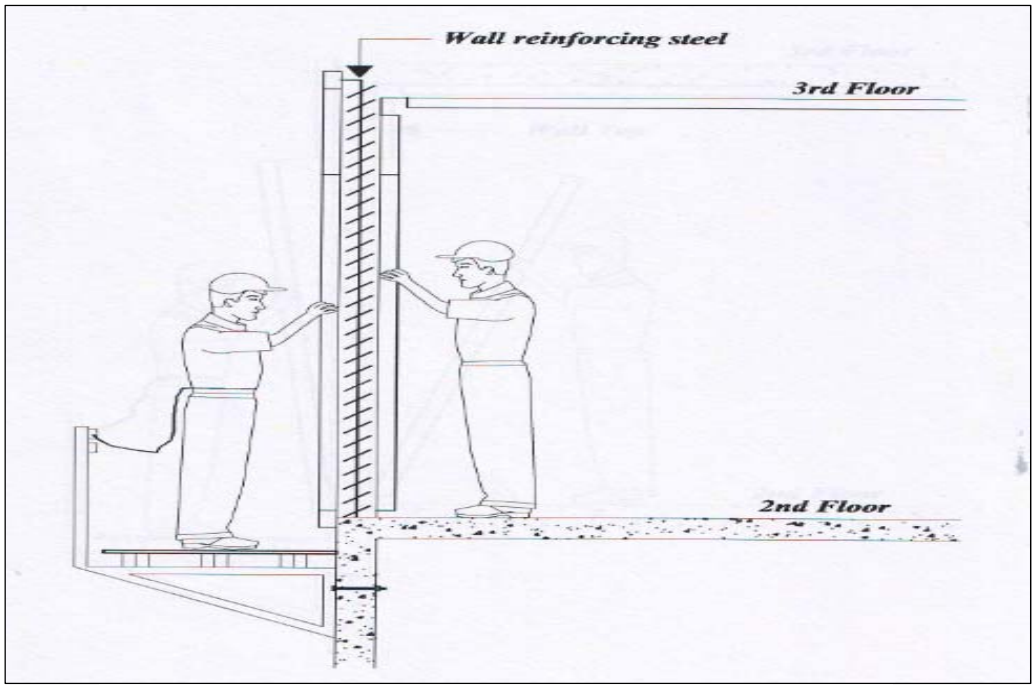

Figure 16: Sequence 1

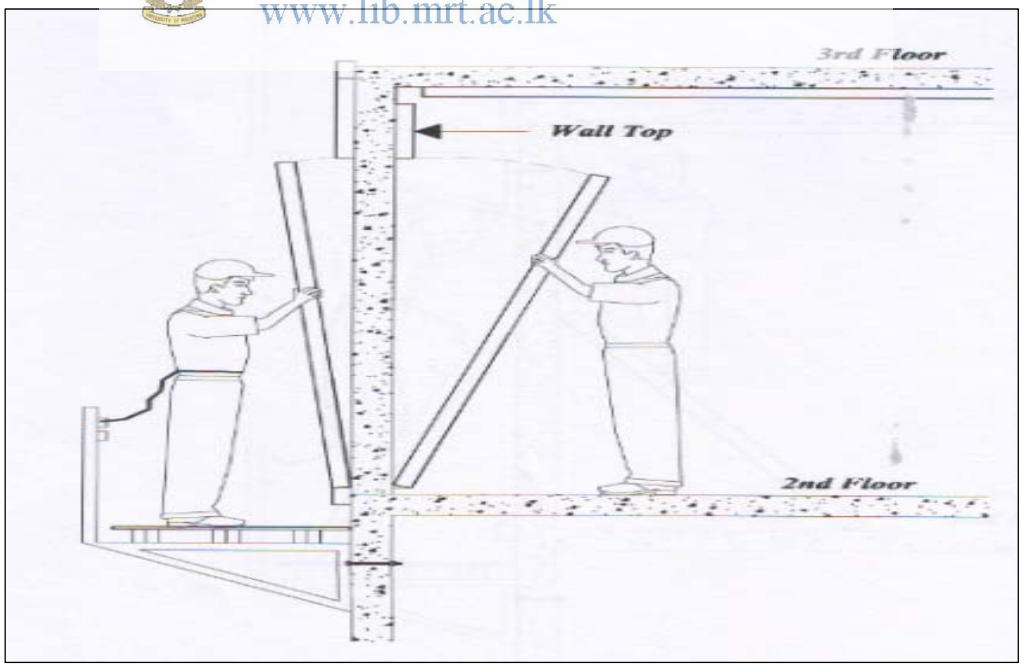

Figure 17: Sequence 2

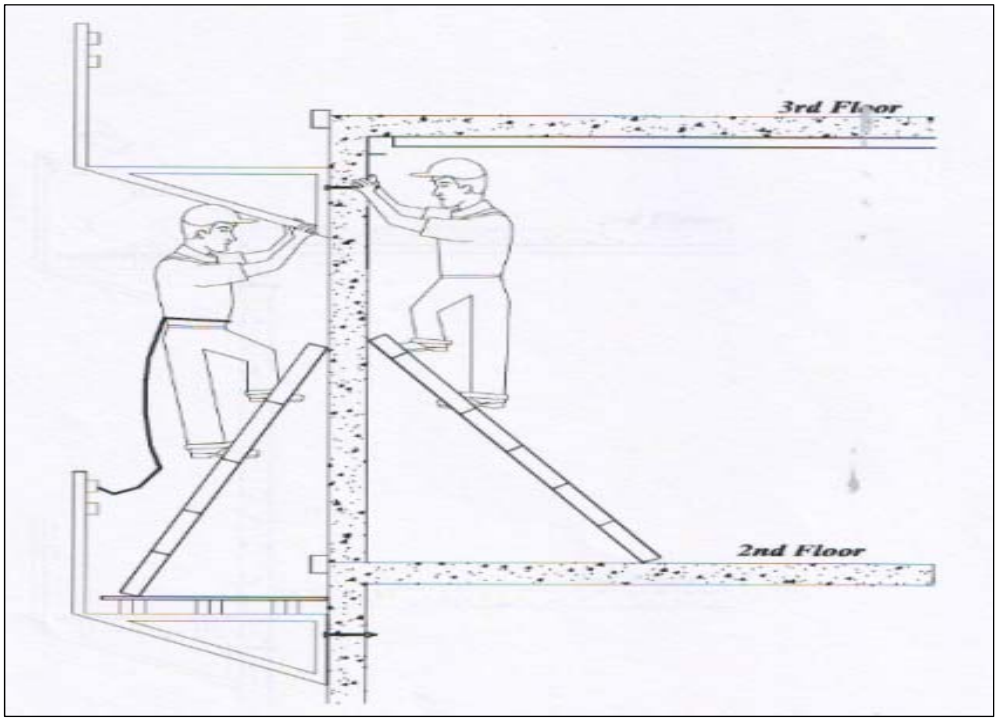

Figure 18: Sequence 3

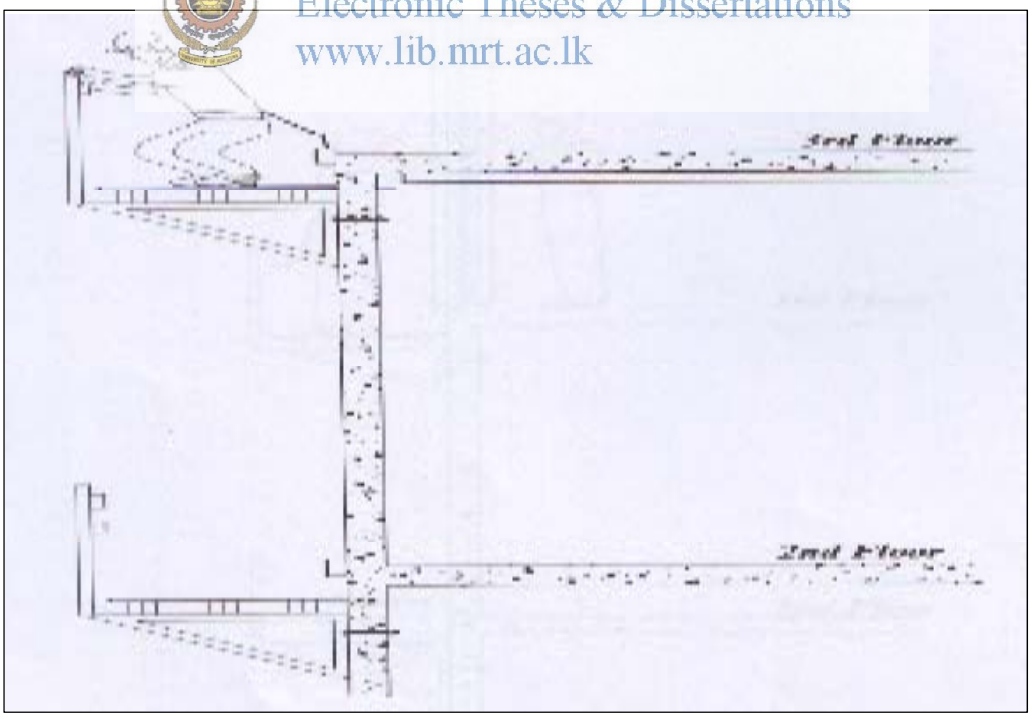

Figure 19: Sequence 4

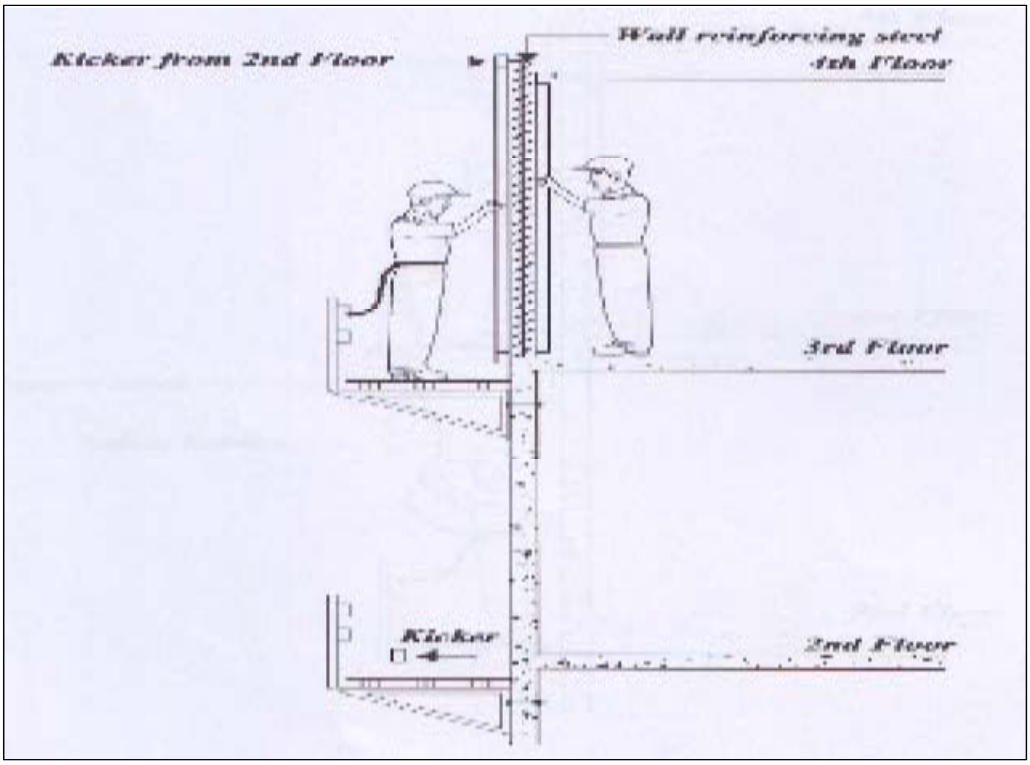

Figure 20: Sequence 5

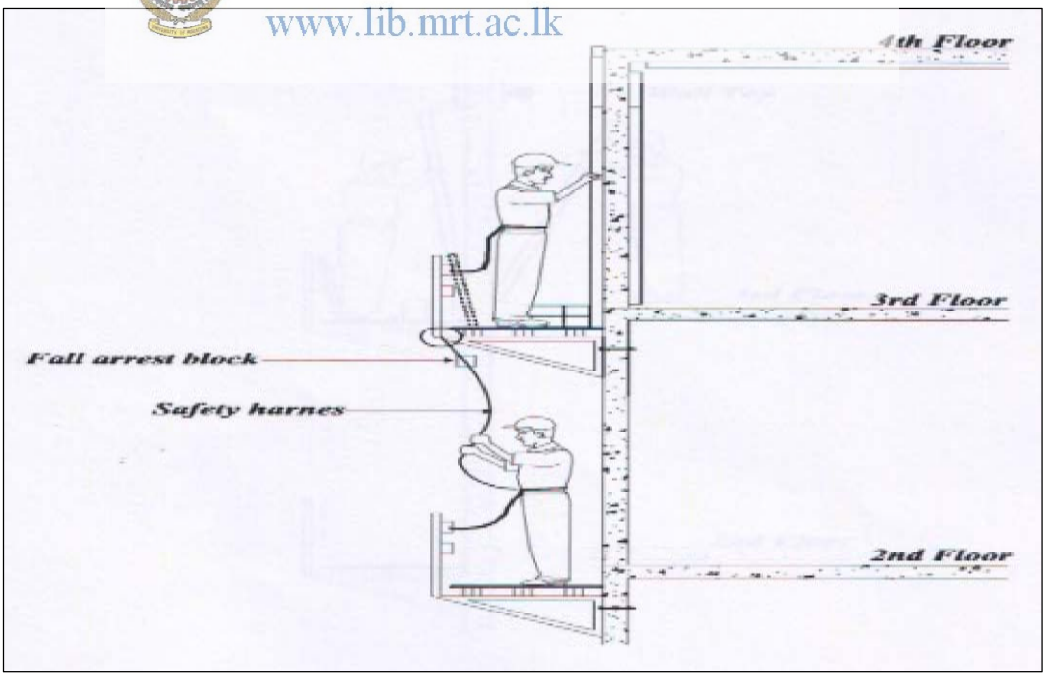

Figure 21: Sequence 6

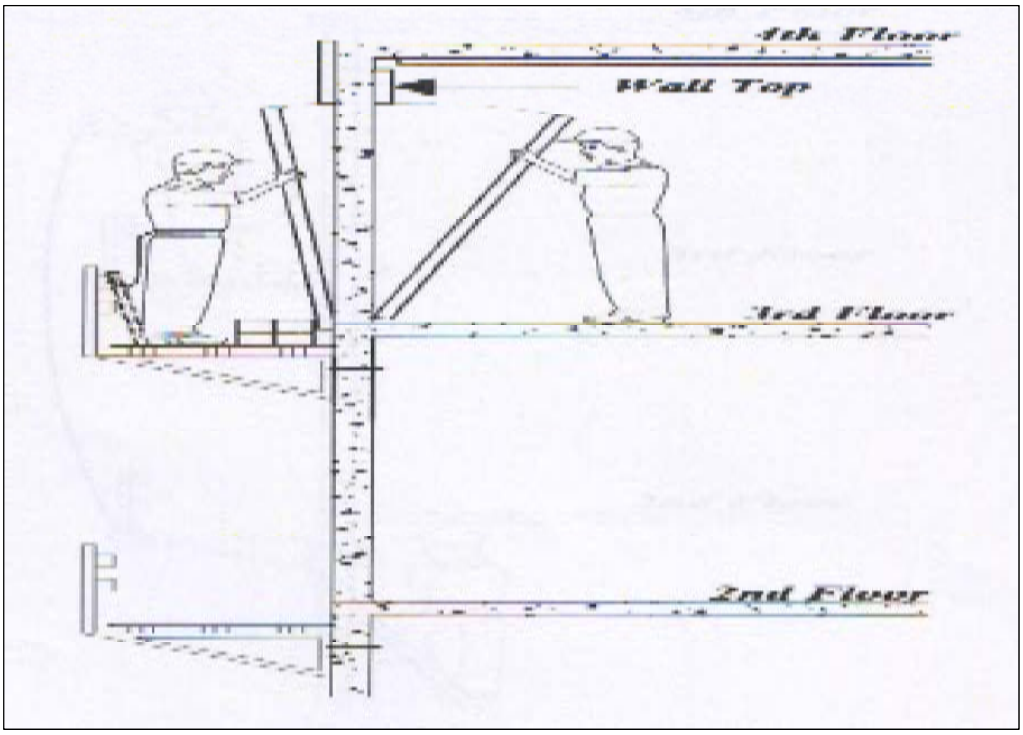

Figure 22: Sequence 7

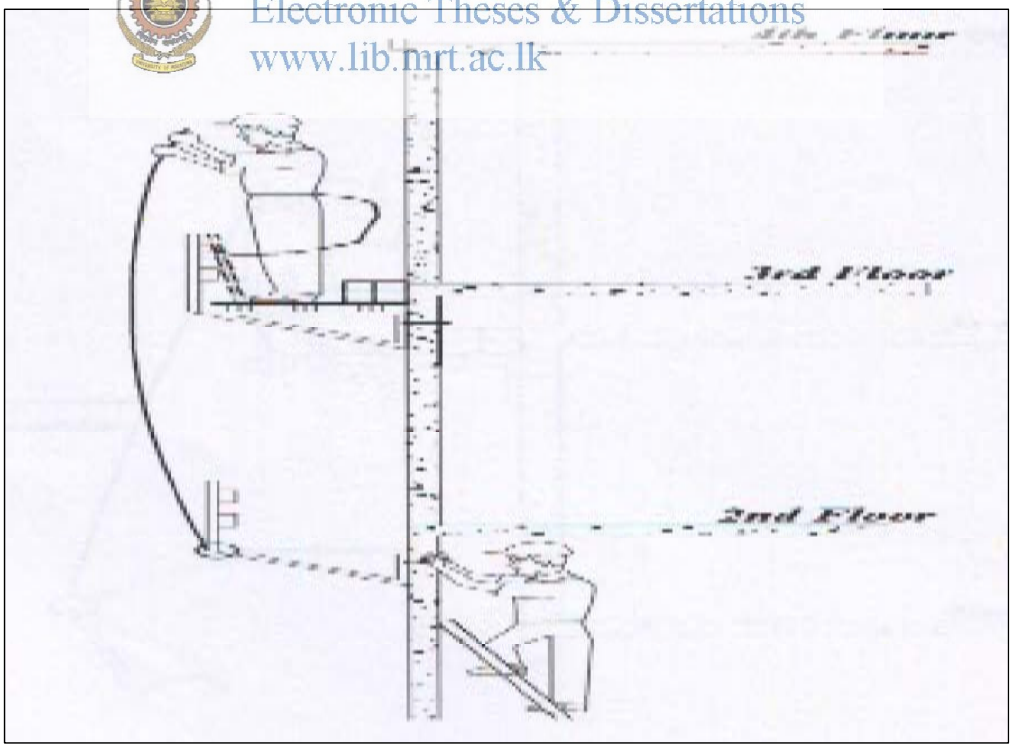

Figure 23: Sequence 8

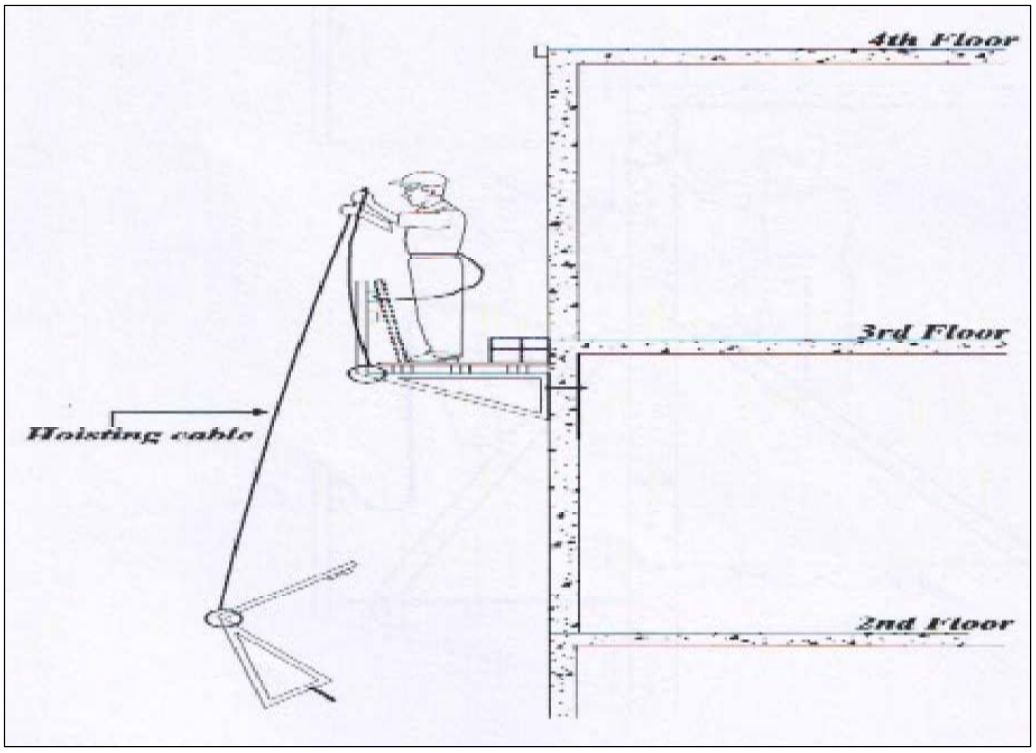

Figure 24: Sequence 9

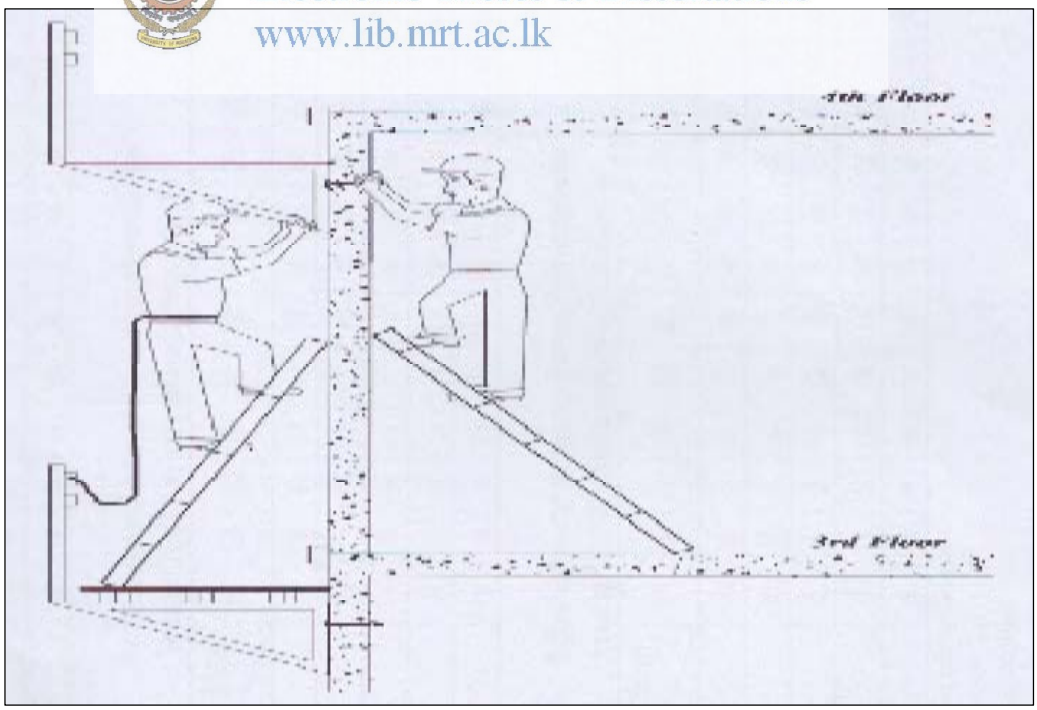

Figure 25:Sequence 10

APPENDIX C: FORMWORK COST CALCULATIONS

Case Study-1

Calculating the preliminary running cost

According to the BOQ,

The total preliminary cost = Rs. 216,104,452.20

Preliminary cost per day = Rs. 216,104,452.20 / (21 x 30)

= Rs. 343,022.94

Assume the preliminary running cost per day is same for all the three occasions.

Cost break-down for semi system (DOCA) formwork

According to the BOQ and actual data from the project,

Total project cost : Rs. 2,203,680,746.50

Duration of the project

Floor Cycle = 14 days

Duration of the project = 21 months

This was the actual time taken to complete the project.

Formwork cost of the project

Material cost (DOCA system) = Rs. 22,635,470.58

Material cost (plywood sheets) = Rs. 4,378,800.00

Material cost (other) = Rs. 3,000,000.00

Total cost for the materials =Rs.22,635,470.58+4,378,800.00+3,000,000.00

= Rs. 30,014,270.58

Labour = Rs. 13,800,000.00

The labour requirement for this type of formwork is about 30 skilled labours and 20 non-skilled labours per 100m^2. At the same time supervisory staff requirement is

about 1 engineer, 2 assistant engineers, 1 supervisor, 2 assistant supervisors and 8 survey helpers for the whole construction per day.

Total cost for the formwork = Rs. 30,014,270.58 + 13,800,000.00

= **Rs. 43,814,270.58**

Cost for finishes

Cost for painting = Rs. 31750 x 400.00 + 33250 x 425.00

= Rs. 26, 831,250.00

The rates for painting on the walls (vertical surfaces) and on the ceiling (horizontal surfaces) are respectively Rs.400.00 per m^2 and Rs. 425.00 per m^2.

Cost for skim coating = Rs. 31750 x 375.00 + 33250 x 400.00

= Rs. 25,206,250.00

The rates for skim coating on the walls and on the ceiling are respectively Rs.375.00 per m^2 and Rs. 400.00 per m^2. Always the rate for horizontal surfaces is a little higher than the vertical surfaces as the labour cost is a little bit higher there.

Other costs : Rs. 205,455.06

Total cost for finishes :Rs.26,831,250.00+ 25,206,250.00+ 205,455.06

: **Rs. 52,242,955.06**

Cost for waste disposal

The waste generated from this type of formwork is mainly plywood. Ply wood can be re-used only for 6 times. So there will be lot of waste generated in the site and have to dispose them. It will add lot of cost to the total project cost. According to the data obtained from the project;

Hire for the dump truck : Rs. 7500.00/day

No. of loads : 700

Labour involvement	: 10 per load
Cost	: 700 x (7500.00 + 10 x 800)
	: Rs. 10,850,000.00
Other cost	: Rs. 2,606,000.00
Total cost for waste disposal	: Rs. 10,850,000.00 + 2,606,000.00
	: Rs. 13,456,000.00

Cost for machinery

When using the semi system formwork in the construction, the machinery involvement is as follows (only the machinery involvement for formwork related activities is considered).

- Tower crane : 1 No.

  Monthly rent for the tower carne is Rs.650,000.00 and the cost for installation is 2,000,000.00. But here the installation cost for the tower crane shall not be considered as the tower crane should be used in the other construction activities.

  Total cost = Rs. 14 x 35 x 650,000.00/30

  = Rs. 10,616,666.67

- Builder hoists : 3 No.

  Monthly rent for a hoist is Rs.310,000.00 and have to use 3 hoists in the project.

  Cost for hoists = Rs. 3 x 14 x 35 x 310,000.00/30

  = Rs. 15,190,000.00

Total machinery cost affected by the formwork,

= Rs. 25,806,666,67

Other machinery cost = Rs. 29,035,433.33

The cost for machinery	= Rs. 25,806,666,67 + 29,035,433.33
	= Rs. 54,842,100.00
Preliminary running cost	= Rs. 343,022.94 x 21 x 30
	= **Rs. 216,104,452.20**

Cost break-down for Aluminium panel system formwork

Duration of the project,

Floor cycle	= 8 days
Saving of days than semi system formwork	= 14 – 8
	= 6 days
Total saving of time	= 6 x 35
	= 210 days
	= 210/30
	= 7 months
Duration of the project	= 21-7
	= **14 months**

Cost for formworks of the project

When using Aluminium panel system formworks, one system is enough for the whole building as it can be re-used more than 100 times. So if there are similar buildings the system can be used for them also. At the same time after the project the system can be sold. Those are some extra benefits of this type of formwork. But in the calculation it has considered that the system is used only for the building considered.

Rate for the formwork (With first time erection)	: Rs. 28,500.00 per m^2
Total area of formwork needed	: 1315 m2
Cost for formwork materials (With first time erection)	: Rs. 28,500.00 x 1315
	: Rs. 37,477,500.00

Labour for erection of other floors : Rs. 11,151,071.00

Total cost for formwork : Rs. 37,477,500.00 + 11,151,071.00

: **Rs. 48,628,571.00**

Cost for finishes

Cost for painting = Rs. 31750 x 400.00 + 33250 x 425.00

= Rs. 26, 831,250.00

The rates for painting on the walls (vertical surfaces) and on the ceiling (horizontal surfaces) are respectively Rs.400.00 per m^2 and Rs.425.00 per m^2.

Cost for skim coating = Rs. 31750 x 244.00 + 33250.00 x 269.00

= Rs. 16,665,630.00

The rates for painting on the walls and on the ceiling are respectively Rs.244.00 per m^2 and Rs.269.00 per m^2. Here this rate is lower than the rate for skim coating when semi system (DOCA) formwork is used. When using the Aluminium panel system formwork the concrete surface is smoother than the previous one.

Other costs : Rs. 38,915.89

Total cost for finishes : Rs. 26, 831,250 + 16,665,630 + 38,915.89

: **Rs. 43,535,795.89**

Cost for waste disposal due to formworks used in the site

When using Aluminium panel system formworks there will not be waste generation in the site. So there will be no cost for waste disposal.

Cost for machinery

When using the Aluminium panel system formwork in the construction, the machinery involvement is as follows (only the machinery involvement for formwork related activities is considered)

- Tower crane : 0 No.

  In this case it is not necessary to have a tower crane in the site. As the Aluminium formwork panels are not heavy they can be handled by manpower.

- Builder hoists : 5 No.

  Monthly rent for a hoist is 310,000.30 and has to use 3 hoists in the project.

  Cost for hoists =5 x 8 x 35 x Rs.310, 000.30

  = Rs.14, 466,666.67

Total machinery cost affected by the formwork

= Rs. 14,466,666.67

Other machinery cost = Rs. 22,276,333.33

The cost for machinery = Rs. 14,466,666.67 + 22,276,333.33

= Rs. 36,743,000.00

Preliminary running cost : Rs. 343,022.94 x 14 x 30

: **Rs. 144,069,634.80**

Total project cost : **Rs. 2,102,930,299.00**

Cost break-down for modern conventional type formwork

Duration of the project,

Floor cycle = 22 days

Extra days than semi system formwork = 22 – 14

= 8 days

Total saving of time = 8 x 35

= 280 days

= 280/30

= 9.33 months

= 10 months

Duration of the project = 21 + 10

= **31 months**

Formwork cost of the project

Material cost = Rs. 20,700,000.00

Labour = Rs. 16,100,000.00

The labour requirement for this type of formwork is about 50 skilled labours and 80 non-skilled labours per 100m^2. At the same time supervisory staff requirement is about 3 engineers, 8 assistant engineers, 8 supervisors, 12 assistant supervisor, 16 survey helpers for the whole construction per day.

Total cost for the formwork = Rs. 20,700,000 + 16,100,000

= **Rs. 36,800,000.00**

Cost for finishes

Cost for plastering = Rs. 31750 x 600.00 + 33250 x 650.00

= Rs. 40,662,000.00

The rates per plastering on the walls and on the ceiling are respectively Rs.600.00 per m^2 and Rs.650.00 per m^2. The rate for plastering of horizontal surfaces is a little higher than the plastering of vertical surfaces as the labour involvement is a little higher there.

Cost for painting = Rs. 31750 x 400.00 + 33250 x 450.00

= Rs. 27,662,500.00

The rates per painting on the walls and on the ceiling are respectively Rs.400.00 per m^2 and Rs.450.00 per m^2. Paining on the plaster is a little more than the painting on the concrete.

Other costs	: Rs. 1,215,436.27
Total cost for finishes	: Rs. 40,662,000 + 27,662,500 + 1,215,436.27
	: **Rs. 69,539,936.27**

Cost for waste disposal due to formworks used in the site

The waste generated from this type of formwork is mainly plywood, 2 x 2, kickers…etc. Ply wood can be re-used only about for 4 times. So there will be lot of waste generated in the site and have to dispose them. It will add lot of cost to the total project cost. According to the estimates done,

Hire for the dump truck	: Rs. 7500.00/day
No. of loads	: 1100
Labour involvement	: 10 per load
Cost	: 1100 x (7500.00 + 10 x 800)
	: Rs. 17,050,000.00
Other cost	: Rs. 2,606,000.00
Total cost for waste disposal	: Rs. 17,050,000 + 2,606,000
	: **Rs. 19,656,000.00**

Cost for machinery

When using the conventional type formwork in the construction the machinery involvement is as follows (only the machinery involvement for formwork related activities are considered)

- Tower crane : 1 No.

  Monthly rent for the tower carne is 650,000 /= and the cost for installation is 2,000,000/=.

  Total cost = 22 x 35 x 650,000.00/30

  = 16,683,333.33

- Builder hoists : 3 No.

Monthly rent for a hoist is 310,000.00 and have to use 3 hoists in the project.

Cost for hoists = 3 x 22 x 35 x 310,000.00/30

= Rs. 23,870,000.00

Total machinery cost affected by the formwork

= Rs. 40,553,333.33

Other machinery cost = Rs. 42,637,141.67

The total cost for machinery = Rs. 40,553,333.33 + 42,637,141.67

= Rs. 83,190,475.00

Preliminary running cost : Rs. 343,022.94 x 31 x 30

: **Rs. 319,011,334.20**

Total project cost : **Rs. 2,325,263,241.00**

Case Study -2

Calculating the preliminary running cost

According to the BOQ,

Considering only one tower

The total preliminary cost = Rs. 227,364,678.90

Preliminary cost per day = Rs. 227,364,678.90/ (40 x 30)

= Rs. 189,470.57

Assume the preliminary running cost per day is same for all the three occasions.

Cost break-down for Aluminium panel system formwork

According to the BOQ and actual data from the project,

Total project cost : **Rs. 1,849,425,000.00**

Duration of the project

Floor Cycle = 9 days

Duration of the project = 40 months

This was the planned duration to complete the project.

Formwork cost of the project

Here the three towers are constructed together. Three system formworks for the three towers will be bought to the project. So the three towers can be considered as three projects and considered one tower for the purpose of the analysis. One system formwork is enough for a tower as the system formwork can be reuse over 100 times. The form work system will be re sale after use of 100 times and it will be an extra benefit of using system formworks. But in the analysis it will not be considered.

Total cost for the materials = Rs. 900 x 28500

= Rs. 25,650,000

Labour = Rs. 9,950,000

Total cost for the formwork = Rs. 25,650,000 + 9,950,000

= Rs. 35,600,000

Cost for finishes

Cost for painting = Rs. 36050 x 400.00 + 20600 x 450.00

= Rs. 23,690,000

The rates for painting on the walls (vertical surfaces) and on the ceiling (horizontal surfaces) are respectively RS.400.00 per m^2 and Rs.450.00 per m^2.

Cost for skim coating = Rs. 36050 x 244.00 + 20600 x 269.00

= Rs. 14,337,600.00

The rates for painting on the walls and on the ceiling are respectively Rs.244.00 per m^2 and Rs.269.00 per m^2. Here this rate is lower than the rate for skim coating when

semi system (DOCA) formwork is used. When using the Aluminium panel system formwork the concrete surface is smoother than the other situations.

Other costs : Rs. 211,435.56

Total cost for finishes :Rs.23,690,000.00+14,337,600.00 + 211,435.56

: **Rs. 38,239,035.56**

Cost for waste disposal

The waste generated from this type of formwork negligible. Therefore no cost should be allocated to waste disposal when using Aluminium panel system formworks.

Cost for machinery

When using the system formwork in the construction the machinery involvement is as follows (only the machinery involvement for formwork related activities is considered)

- Tower crane : 1 No.

  Monthly rent for the tower carne is 750,000 .00 and the cost for installation is 2,500,000.00.

  Total cost = Rs. 9 x 38 x 750,000.00 / (30 x 9)

  = Rs. 950,000.00

- Builder hoists : 4 No.

  Monthly rent for a hoist is 350,000.00 and have to use 3 hoists in the project.

  Cost for hoists = Rs. 3 x 9 x 38 x 350,000.00/30

  = Rs. 15,960,000.00

Total machinery cost affected by the formwork,

= Rs. 16,910,000.00

Other machinery cost = Rs. 24,452,260.00

The cost for machinery = Rs. 16,910,000.00 + 24,452,260.00

= Rs. 41,362,260.00

Preliminary running cost = Rs. 189,470.57x 40 x 30

= **Rs. 227,364,684**

Cost break-down for semi system (DOCA) formwork

Duration of the project

Floor cycle = 14 days

Excess days for this type = 14 - 9

= 5 days

Total excess time = 5 x 38

= 190 days

= 190/30

= 6.33 months

= 7 months

Duration of the project = 40 + 7

= **47 months**

Cost for formworks of the project

Material cost (DOCA system) = Rs. 16,352,621.33

Material cost (plywood sheets) = Rs. 4,478,800.00

Material cost (other) = Rs. 2,000,000.00

Total cost for the materials =Rs.16,352,621.33+4,478,800.00+3,000,000.00

= Rs. 22,831,421.33

Labour = Rs. 10,860,000.00

The labour requirement for this type of formwork is about 30 skilled labours and 20 non-skilled labours per 100m^2. At the same time supervisory staff requirement is about 1 engineer, 2 assistant engineers, 1 supervisor, 2 assistant supervisors and 8 survey helpers for the whole construction per day.

Total cost for formwork : Rs. 22,831,421.33 + 10,860,000.00

: **Rs. 33,691,421.33**

Cost for finishes

Cost for painting = Rs. 36050 x 400.00 + 20600 x 450.00

= Rs. 23,690,000.00

The rates for painting on the walls (vertical surfaces) and on the ceiling (horizontal surfaces) are respectively Rs.400.00 per m^2 and Rs.450.00 per m^2.

.

Cost for skim coating = Rs. 36050 x 295.00 + 20600 x 315.00

= Rs. 17,123,750

The rates for skin coating on the walls and on the ceiling are respectively RS.295.00 per m^2 and Rs.315.00 per m^2. Always the rate for horizontal surfaces is a little higher than the vertical surfaces as the labour cost is a little bit higher there.

Other costs : Rs. 156,945.67

Total cost for finishes :Rs.23,690,000.00+ 17,123,750.00+ 156,945.67

: **Rs. 40,940,695.67**

Cost for waste disposal due to formworks used in the site

Hire for the dump truck : Rs. 8500.00/day

No. of loads : 600

Labour involvement : 10 per load

Cost : 600 x (8500.00 + 10 x 850.00)

: Rs. 10,200,000.00

Other cost : Rs. 2,426,000.00

Total cost for waste disposal : Rs. 10,200,000.00 + 2,426,000.00

: Rs. 12,626,000.00

Cost for machinery

When using the Aluminium panel system formwork in the construction the machinery involvement is as follows (only the machinery involvement for formwork related activities is considered)

- Tower crane : 1 No.

  Monthly rent for the tower carne is 750,000.00 and the cost for installation is 2,500,000.00.

  Total cost = Rs. 14 x 38 x 750,000.00/30

  = Rs. 13,300,000.00

- Builder hoists : 4 No.

  Monthly rent for a hoist is Rs.350,000.00 and have to use 3 hoists in the project.

  Cost for hoists =4 x 14 x 38 x 350,000.00/30

  = Rs.24, 826,666.67

Total machinery cost affected by the formwork

= Rs. 38,126,666.67

Other machinery cost = Rs. 19,129,147.67

The cost for machinery = Rs. 38,126,666.67+ 19,129,147.67

= Rs. 57,255,814.34

Preliminary running cost : Rs. 189,470.57 x 47 x 30

: **Rs. 267,153,503.7**

Total project cost : **Rs. 1,926,560,299.00**

Cost break-down for modern conventional type formwork

Duration of the project

Floor cycle	= 22 days
Excess time taken to this type of formwork	= 22 – 9
	= 13 days
Total excess time	= 13 x 38
	= 494 days
	= 280/30
	= 16.46 months
	= 17 months
Duration of the project	= 40 + 17
	= **57 months**

Formwork cost of the project

Material cost	= Rs. 17,700,000.00
Labour	= Rs. 10,100,000.00

The labour requirement for this type of formwork is about 50 skilled labours and 80 non-skilled labours per 100m^2. At the same time supervisory staff requirement is about 3 engineers, 8 assistant engineers, 8 supervisors, 12 assistant supervisor, 16 survey helpers for the whole construction per day.

Total cost for the formwork	= Rs. 17,700,000 + 10,100,000
	= **Rs. 27,800,000.00**

Cost for finishes

Cost for plastering	= Rs. 36050.00 x 600 + 20600 x 650.00
	= Rs. 35,020,000

The rates per plastering on the walls and on the ceiling are respectively Rs.600.00 per m^2 and Rs.650.00 per m^2. The rate for plastering of horizontal surfaces is a little higher than the plastering of vertical surfaces as the labour involvement is a little higher there.

Cost for painting = Rs. 36050 x 450.00 + 20600 x 500.00

= Rs. 26,522,500

The rates per painting on the walls and on the ceiling are respectively Rs.450.00 per m^2 and Rs.500.00 per m^2. Paining on the plaster is a little more than the painting on the concrete.

Other costs :Rs. 1,215,436.27

Total cost for finishes :Rs. 35,0230,000.00 +26,522,500.00 + 1,215,436.27

:**Rs. 62,757,936.27**

Cost for waste disposal due to formworks used in the site

The waste generated from this type of formwork is mainly plywood, kickers, joists, bracings…etc. Ply wood can be re-used only about for 4 times. So there will be lot of waste generated in the site and have to dispose them properly. It will add a cost to the total project cost. According to the estimates done,

Hire for the dump truck : Rs. 8500.00/day

No. of loads : 1000

Labour involvement : 10 per load

Cost : 1000 x (8500.00 + 10 x 850.00)

: Rs. 17,000,000.00

Other cost : Rs. 2,455,000.00

Total cost for waste disposal : Rs. 17,000,000.00 + 2,455,000.00

: Rs.19,455,000.00

Cost for machinery

When using the conventional type formwork in the construction the machinery involvement is as follows (only the machinery involvement for formwork related activities are considered)

- Tower crane : 1 No.

  Monthly rent for the tower carne is 750,000.00 and the cost for installation is 2,500,000.00.

Total cost = Rs. 22 x 38 x 750,000.00/30

= Rs. 20,900,000.00

- Builder hoists : 5 No.

  Monthly rent for a hoist is 310,000.00 and has to use 3 hoists in the project.

  Cost for hoists = 3 x 22 x 38 x 350,000.00/30

  = Rs. 29,260,000.00

Total machinery cost affected by the formwork

= Rs. 50,160,000.00

Other machinery cost = Rs. 42,238,800.00

The total cost for machinery = Rs. 50,160,000.00+ 42,238,800.00

= Rs. 92,398,800.00

Preliminary running cost : Rs. 189,470.57 x 57 x 30

: **Rs. 323,994,674.70**

Total project cost : **Rs. 2,027,523,841.00**