

RESOURCE OPTIMIZATION WITH THE USE OF PRECAST SLAB SYSTEMS

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DECLARATION OF THE CANDIDATE AND SUPERVISOR

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ABSTRACT

Resource optimization is one of the key themes of sustainable development. With the fast growing construction industry over the past few decades, the consumption of natural resources has been on the rise. Rapid urbanization in Sri Lanka demands more and more multistoried buildings, resulting in a large quantity of resource utilization. The slab system which consumes lots of material and time is a key element of multi-storied structures. The slab system also creates the highest amount of construction waste to the environment. Therefore, the research covered in this paper has been focused on a novel slab system developed with optimized resource utilization.

The proposed slab system comprised of a pre-cast plank system designed as a hollow slab consisting of 60 mm thick precast concrete panel, lightweight filler material using compressed straw boards and an in-situ screed concrete layer on top. The precast pael of 5 m span and 1.2 m wide consist of two trusses and BRC mesh.

The proposed slab system optimizes material consumption in the form of false work, formwork. The reusable steel mold used as formwork eliminates the use of timber and plywood. Erecting and assembling the proposed pre-cast system will consume much less time compared to that of in-situ construction. Steel shutters will create a better surface finish so that the systems need less labour and material for the application of finishing coats. Pre-stressing of the slab can further optimize the system by reducing reinforcement requirement.

The propose slab system can promote cost effective construction with optimized use of materials and labour resulting in faster construction and higher quality of the end product compared to the conventional slab system. Reuse of waste products such as paddy straw as a filler material and also reusing steel molds will further enhance the life cycle cost in the form of environmental benefits.

Keywords: Precast concrete; Slab construction, Resource optimization, Sustainability

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LIST OF ABBREVIATIONS

Abbreviation	Description
ICC	International Construction Consortium
SBS	Suspended Beam Slab
NERD	National Engineering Research and Development
GDP	Gross Domestic Product
ADPT	Analytical Design Planning Technique
GI	Galvanized Iron
CECB	Central Engineering Consultancy Bureau
BRC	British Reinforcement Company
SKL	Skilled Labour
USKL	Unskilled Labour
NDT	Nephrology Dialysis and Transplant
SLS	Sri Lankan Standard
CS	Conventional Slab
PPS	Precast Plank Slab

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CHAPTER 01

INTRODUCTION

The Sri Lankan building construction industry developed rapidly during the last decade with the booming economic and social development of the country, after the end of the civil war which affected the development of the country for three decades. This industry is a key contributor to the economic and social development of the country. Therefore fast-growing urban residential requirement, commercial facilities, and infrastructure for public service facilities in main cities and suburbs create huge demand for new buildings within the limited affordable lands. The demand for building leads the vertical construction in urban cities. But most of the high-rise building construction projects were seeing significant time and cost overrun due to the shortage of resources to fulfil massive demand in industry and adopted traditional construction practices due to the lack of awareness about comparative advantages of modern advance building construction technologies.

Floor Slab construction is one of the key elements in multi-storied building construction which consumes a major proportion of resources. Therefore the project period, project cost and quality mainly depend on the performance of the floor slab construction method. Therefore, floor slab construction in a building is the crucial event to concentrate and manage on economical and fast track construction practices. Further, the adoption of environmental friendly concepts to the slab construction leads to optimum utilization of available resources sustainably.

The current Sri Lankan building construction industry widely uses in-situ cast conventional floor slab construction methods by using different types of formworks and false work systems like plywood formwork and system formwork methods. The precast construction systems are rarely adopted in limited high-rise building projects in Sri Lanka and still not much popular in building constructions and its very few over the conventional practices.

The precast concrete elements in building construction are the advanced technology available in all over the world. It is being widely applicable in most of the European countries. Recently precast technology is becoming a popular selection for building construction in Asian countries to satisfy their fast growing building demand with rapidly diversifying to sustainable construction technologies. Precast technology is internationally considered as a mature technology even though it is not widely used in Sri Lankan buildings due to unawareness of the advantages when compared with conventional construction practices.

The precast construction technology was invented in England at the beginning of the 20th century and evolved rapidly all over the world [1]. The precast solutions for floor slab systems are mostly considered as a composite prefabrication system, which involves some elements of the slab structure cast in the factory environment under the controlled conditions, while the balance is cast in the site. Three types of precast technologies as International Construction Consortium (ICC) Suspended Slab System (SBS) slab system, (ICC) Easy Slab system, and National Engineering Research and Development (NERD) composite slabs are commercially available for present Sri Lankan building construction. Further, the precast plank slab system is introduced for some particular projects as an initiative of advance composite slab system for the high-rise buildings in Sri Lanka.

Therefore, the main intention of this research was to study resource optimization of the precast slab system over the conventional in-situ cast slab system based on newly introduced precast plank slab system. Further, a comparison was carried out for evaluating the performance of precast plank slab over the existing commercial product named ICC SBS slab system. The said performance evaluation was executed through a case study about an actual application of building construction in Sri Lanka to identify the most reliable slab construction method for sustainable building construction practices.

1.1. Background

The building construction industry is revered as a key contributor to the economic and social development of the country. The construction industry is the highly booming subsector in the Sri Lankan economy in the last decade. The construction sector has contributed to 6.6% in 2009 to 8.7% in 2013 towards the overall Gross Domestic Product (GDP) [2] of the country. Therefore, the construction industry illustrates a significant impact on the Sri Lankan economy by obtaining a vast range of development goals through infrastructure development. Building construction plays the major sector of the construction industry by consuming the majority of available resources and produces the infrastructures for the development of residential, commercial and public service sectors. Therefore, the development of building construction technologies to optimize the use of affordable resources by fulfilling the cost, time and quality expectations of investors and occupants will be the key factor of the social and economic growth of the country.

The main constraint to the development of the current building construction industry is the lack of quality materials and the skilled labour scarcity of the country. Therefore, the investors,

designers, and contractors of building construction industry are finding alternative technologies for floor slab construction which is a key building element that consumes a majority of materials, Labour and time of the project.

Advance construction technologies such as precast construction methods are available in place of the conventional method in the construction of building elements to fulfill the project expectation with the optimum use of resources. But all parties are struggling to select the precast construction technologies due to the lack of awareness and insufficient details available about the comparative advancement over the conventional building construction methods. Therefore, precast technology is not much popular in the Sri Lankan building industry.

An essential requirement is there in Sri Lanka to develop a comparative study about the construction of key building elements with the precast technologies and conventional in-situ cast methods. Development of a comparative study may further helpful for diversifying the existing building construction methods into sustainable methods to achieve cost, time, quality and environmental expectations of the building projects.

The precast plank slab system is an important initiative of precast slab technology for the modern high-rise building construction. Therefore, it is an essential requirement to do the comparative analysis about the advancement of precast plank slab system with the commonly used conventional methods and existing precast slab systems of the Sri Lankan building sector. The results of the said study may produce guidance to select the most reliable slab construction method in future high-rise building projects with the fast urbanization of Sri Lanka.

1.2. Research Problem

The comparative evaluation of the resource optimization by the use of modern precast Plank slab systems in Building Construction over the conventional In situ-cast and existing Precast slab systems is recently not available in Sri Lanka.

1.3. Objectives

The main objective of the research was to produce a comprehensive analysis of the effectiveness of precast slab systems for sustainable building construction compared to the conventional slab systems through resource optimization in the building construction.

The following information was produced through the research study to the future reference of building construction practitioners

- Statistics and comparative analysis of cost and time consumption for precast Plank slabs over the conventional slab system
- Comparative statistics about the labour requirement for slab construction with the use of each technology
- Statistics and comparison of material used for each slab system
- Determination about the suitability of Precast plank slab system for the Sri Lankan building construction industry

1.4. Research Methodology

The research was carried out based on a case study about the slab construction methodologies applicable for building projects in Sri Lanka.

Target Projects – Select two actual building projects which consist a minimum of three stories from each type of slab construction technology as precast plank slab system, ICC SBS system (existing precast slab method) and conventional in-situ cast Slab system.

A comprehensive literature review and detail analysis of real building construction projects were conducted as a data collection methodology.

To achieve the above research objectives following methodology was adopted.

- Literature review – Conduct a comprehensive review of past research studies about the precast concrete technology and slab systems to find out the data related to these research objectives. It also provides an idea about the scope covered up by existing researches on this topic and finds the available information about the comparative analysis of past studies.
- Case study – Select two similar building projects from each slab system such as the precast plank slab system and conventional cast in-situ slab system for the study and consider the two projects from the ICC SBS system for the comparison purpose. The data records about cost, resource utilization, and Project durations to be collected by referring to the project documents, financial information, interview with the project staff and the precast manufacturing plant officials.
- Data Analysis – the collected data will be analyzed and compared for each type of slab construction method based on different parameters such as material, labour, cost and time to fulfill the research objectives.

1.5.Limitations of the Study

This study carried out based on the existing details about the resource utilization and financial data of the completed projects. Therefore, the areas compared among each slab project are limited to the comparison of resource optimization due to lack of information about the embodied energy of each slab construction method.

But for future studies, the research should be extended to compare the embodied energy of each slab system by considering the project life cycle for the determination of the real advancement of the precast plank slab system.

CHAPTER 02

LITERATURE REVIEW

2.1. General

The building construction industry is rapidly growing in all over the world due to the fast growing population of the countries and the fast urbanization of developing countries. The rapid economic growth and limited affordable lands for residential and commercial development will boost the vertical building construction in urban areas. The modern building construction industry is diversifying to the advance construction technologies to take the maximum use of the limited available recourses in economical construction within the limited time periods. Precast construction practices are adopting building construction as a successful alternative to conventional construction methods. This chapter covers the theoretical and practical studies which already carried out about the precast construction practices and various comparative studies about the conventional and precast construction techniques for the sustainable development of the building construction industry.

According to the historical data described in a paper “Study of precast Construction” [1], the ancient Roman builders used the poured concrete into the mold to build the complex parts of the irrigational structures such as culverts, aqueducts, and tunnels as initial use of precast construction. The modern precast construction panel methods were invented in 1905 in Liverpool, England. Then the precast concept was adopted all over the world and evolved as a sub industry.

At the concept of precast (prefabrication) building the majority of structural components are standardize and produced by casting in a reusable mold and cured in controlled environment or plant located away from the building and transport to the site for assembly [3]. These elements are manufactured by industrial methods based on mass production to build a large number of building in a short time at low cost. The main features of this construction process are identified as the division and specialization of the human workforce and the use of tools, machinery, and other equipment, usually automated, in the production of standard, interchangeable parts, and products. Further, depending on the load bearing structure, precast systems can be divided into the four categories such as large panel System, Frame System, Slab Column System With walls and Mixed System.

2.2. Environmental Impact

The environmental impact on building construction is mainly arisen due to the solid waste generated and the use of nonrenewable energy for the construction process. The study based on the building life cycle analysis on public school buildings constructed in Spain to cater the higher demand of school facilities science 2002 to 2005 [4]. According to the study the percentage impact of building process on the environment of Spain is identified as 32% of energy consumption, 30% of greenhouse gas CO₂ emission and 24% the use of Earth's crust extraction materials, 30%-40% solid waste generation and 17% potable water consumption through the resource extraction, production use and waste stages of buildings.

The study was focused on the effectiveness of closed material cycle in the building sector with the recycling, production, and use during the building life cycle by considering the prefabrication technology adopt with the 60%-65% portion of school building construction due to the fast construction requirements. The obtained results from this study interpret the positive environmental impacts in CO₂ emission and Solid waste generation of precast construction techniques when compared to the conventional method as following Figure 2.1

Life cycle total CO ₂ emissions and without considering use phase (kgCO ₂ /m ²).					Total solid waste generation during building life cycle (kg/m ²).		
	Life cycle CO ₂ emissions		Without considering use phase		Total solid waste generation		
	kgCO ₂ /m ²	Percentage	kgCO ₂ /m ²	Percentage	kg/m ²	Percentage	
Non-prefabricated	1359	100	752	100	Non-prefabricated	4178	100
Concrete	1229	90	690	92	Concrete	2490	60
Timber	1106	81	526	70	Timber	2229	53
Steel	1461	107	852	113	Steel	1253	30

Figure 2.1: Life Cycle CO₂ emission and Solid waste Generation of each construction Technology

Source: Research "Environmental impacts of prefabricated school buildings in Catalonia" [4]

The above study further finds the higher building material recyclability and construction waste recyclability through the building life cycle analysis including design, production, assembly and disassembly of precast and non-prefabrication building sector.

The comparative analysis of "Designing out waste in high-rise residential buildings with pre-casting methods and traditional construction practice" was studied about the produce of waste to the environment by the construction industry of Hong Kong [5].

The study says that 80% of construction waste produced in Hong Kong due to the concreting works of traditional construction methods. The construction waste generated from both direct works and temporary works and categorized into three major types such as natural waste, indirect waste, and direct waste

The precast construction technique is considered as an effective means to reduce the construction wastage. Less construction waste is produced by the precast construction due to the less of site activities and the reduction of reworks and non-standing works. The potential of using precast technology for the construction is still not popular due to the uncertainty of details and designs through the execution of constructions. Hence, this study proposed techniques such as the modeling of information requirement, the design structure matrix technique and other related methods that help to evaluate the outcomes of the design decision with precast concrete construction techniques.

According to the technique adopt information modeling Analytical design planning technique (ADPT) of this study will enabling the designers to visualize the complex high-rise buildings process at the beginning of the project and increase the optimizations and lead the construction waste on site with precast systems will become more popular.

The study about decision support methodology for prefabrication decision on green building projects [6] focused on finding the decision making tool to select the prefabrication techniques to the building construction with the growing interest in sustainable construction. The prefabrication strategies result in many outcomes align with the goals and values pursued on green projects such as material optimization, waste reduction and energy efficient through the construction and use of the buildings.

These studies extend to propose decision support methods to determine the construction method as prefabrication instead of the conventional system. It allows project teams to make effective prefabrication decisions through understanding of building construction methods and building performance at the early stage of the design.

The study about the sustainable performance criteria for construction method selection in concrete buildings [7] has extracted seven latent factors which mainly considered for the selection of construction criteria either precast construction or conventional construction method in concrete building works. The considered actors are categorized into three sections such as four factors under the economic category, two factors belong to a social category and one factor of the environmental category and described the analysis as following

- Long term Cost

Long term cost can be reduced with the use of prefabrication by considering the criteria such as time to return on investment, Loading capacity, Durability, life cycle cost and cost of maintenance

- Constructability

The prefabrication construction methods positively contribute to the improvements of constructability which mean improved supply chain excellent integration of building services such as Electrical, Plumbing, and mechanical works, lead time of construction time and easy buildability.

- Quality

Higher quality of concrete components of prefabricated buildings is ensured by the well structured environment in manufacturing plant which confirms the climate controlled environment, well trained workers and the rigorous quality supervision throughout the fabrication.

- First Cost

Normally the first cost of the conventional construction methods is economical with the effect of material, transport and labour cost of factory environment and in-situ cast methods. But the maximum repetition of standardizing building elements designing early stage of similar type of building will lead the mass production and reduce the first cost than conventional methods.

- Impact on health and community

The sites used prefabrication concrete systems are clean and safe due to the lack of obstructions which improve the health and safety of labours, occupants and surround the community.

- Architectural Impact

Use of pre-stressing in precast methods enabling the long spans than the conventional concrete buildings and provide the potential space to architects and engineers to the decorative finishes, physical spaces, and architectural appearance.

- Environmental Impact

Prefabrication has many environmental benefits in the construction stage and life cycle of the building with the optimum material and energy consumption, reduction of waste, pollution and

further improved the recyclability than the conventional construction practices. The potential benefits of prefabrication was identified as following prefabrication Table 2.1

Table 2.1: Benefits of prefabrication

	1 st Cost (Budget)	Time (Scheduling)	Quality	Sustainability
Potential Benefit Areas	Reduced material waste and increased material recycling	Preconstruction speed (e.g. design, planning, and procurement)	Customer requirements (e.g. aesthetics, expected functions, and life-span)	Health and safety during construction
	Direct labor (i.e. field workers) savings	Manufacturing & delivery speed	Design/Engineering tolerances	Improved occupant health
	Indirect labor (e.g. field overhead) savings	Increased speed of construction on-site	Streamlined information flow & management processes through design, manufacturing, and construction	Economic development in local communities
	Design speed			Material reuse and/or recycling
	Equipment requirements			Flexibility/adaptability
	Reduced rework			Reduced operation & maintenance requirements
	Reduced transportation			

Source: Research paper Decision Support Methodology for Prefabrication Decision on Green Building Projects [6]

2.3. International Context

Precast techniques in building construction is the fastest growing construction method in all over the world with the commercial and social development of the countries. After the World War II comprehensive prefabricated building systems were evolved with the prefabricated slabs, vertical structural elements, facades, partitions, and stairs and cubical for sanitary units. The demand of precast construction was grew with the faster development of new towns, suburbs and large scale residential, commercial and public Building development. European countries such as Denmark, Netherlands, Sweden and Germany are the highest precast users in the world. In Asian context Japan and Singapore lead the implementation of precast building construction. According to the study about the evolution of prefabricated residential buildings in Hong Kong by Lara Jaillion and C.S. Poon [8] the prefabricated building construction was evolved in privet and public sector buildings with use of different types of precast elements since last decades. When considering the prefabricated elements precast facades (51%) are the most frequently used and semi precast slabs have been used in t9% of the building industry.

According to the study on implementation of precast technology in India, [9] the shortage of houses is the one of major problem face by India and as per censes 2011 the households identified as living in slums are about 13.7 million. The India facing a shortage of 20million houses in urban areas for cater the housing scarcity among the poor population and India

decided to construct housing schemes with 20 million houses by 2022. Further the Indian government identified that affordability of this massive housing deficit cannot be tackled with the traditional and conventional construction practices. Therefore an alternative construction technology will be required for the successful implementation of projects like Housing for all in India. The precast technology is identified as emerging technology which can play a major role in the success of the housing construction task within the limited time frame. In most of the developing countries like India, the cost of execution with conventional construction methods are cheaper than adopting new technologies like precast construction due to the various challenges.

According to the case study based on two buildings with similar sizes and constructed with two different methods of conventional and precast technology derived that the 22%-33% faster in construction and 16%-29% higher cost in precast construction methods with compared to the conventional methods.

Further this study identified a lot of challenges which constrained the adoption of precast construction practices in projects and industry as categorized below

- Standardization, Procurement, and technological aspects
- Documentation and design aspects
- Skill development and human resources
- End –User perspectives (Acceptability and Social dimensioning)

The economics of scale, high initial investment, the additional burden of taxes and lack of skill manpower directed the precast technology is an economically unfeasible option for the Indian construction industry. The following proposals were presented by the experts in the industry to overcome the above challenges through the brainstorming sessions within the Indian perspective.

- Government major investment in precast sector
- Reduction of additional taxes
- Distribution of information about precast technology through online knowledge gateway
- Ensuring the quality through third party testing

- Universities and Engineering Education institutes should promoting the precast technology with research and development programmes and offering courses related to precast technology to catering awareness
- The skill level of workforce required for implementing precast technology has to upgrade through the effective training program.
- With the scope of huge repetition and standardization will be viable the cost factor of the execution of precast technology.

2.4. Comparative Studies on Precast and Conventional Construction Methods

The precast construction practices are not much popular in present construction industry of Asian countries including Sri Lanka due to the lack of information about comparative studies of precast and conventional construction methods based on different areas such as cost, time and quality. Therefore, it is required to concentrate about the past comparative studies on precast and conventional methods of building construction industry all over the world. The study about “what should you are really measure if you want to compare prefabrication with traditional construction” [10] proposed the exact detractions to consider for the successful comparison between precast and conventional constructions base on the study in United Kingdom by considering Six main factors such as Cost, Time, Quality, Health and Safety, Sustainability and Site Issues. Those factors are interdepend and interested by different parties involve to the projects such as Client, Contractor and other project members.

The detail items which should considered under the above mention six main factors are categories as follow and it should be considered as a guideline for proper comparison between the prefabrication and conventional building construction under any of above said main categories.

- Factors to consider when measuring construction and maintenance cost
Material cost, Labour (with Supervision), Plant, Access, complex construction cost
- Factors to consider when measuring project cost
Site prelims, On-Site Logistical Cost, Overheads, Professional (Design, Plan and Mange), other and complex project Costs
- Factors to consider when measuring project life cycle cost
Capital Costs, Opportunity cost, Finance cost, Operation costs, Maintenance cost, Salvage and residual

- Factors to consider when measuring Time
Off site and preconst
Construction activities, On-site activities
- Factors to consider when measuring Quality
Construction/ Manufacturing Cost – Level of Quality, Defects and Damages, Customer requirements, Information Management and Flow
Life Cycle Cost – Performance and Functionality
- Factors to Consider when measuring health and safety benefits
Construction/ Manufacturing - Health and safety ratios, safety, health
Life cycle health and safety – Repair maintenance and replacement, Demolish and decommission
- Factors to consider when Measuring Sustainability
Ecological impact, Energy consumption, Water consumption, waste, Material, Transport, Physical pollution, community Pollution
- Factors to consider when measuring site benefits
Site space and storage, Multi-trade interfaces, skilled labour, Access to site, Live working condition, movement of units on site, restrictions

Construction performance comparison between conventional and industrial building systems in Malaysia [11] have done the comparative study about the conventional and IBS systems of Malaysia due to the failure of coping with the huge housing demand of Malaysia. According to the study conventional building construction consist with two major components such as structural system which includes in-situ cast Column, Beam and slab Frame. Other one is the nonstructural infill which is consist with brick and plastering infill. The structural frame constructed in four main operations named erection of timber formwork and scaffolding, erection of steel bar, pouring of fresh concrete in to formwork and dismantling of formwork and scaffoldings.

The IBS consist with three major categories which is considered for the comparison with conventional construction method such as cast in-situ formwork system (table or tunnel formwork), prefabricated system and composite system. Specifically the composite method, some elements of building casting in factory and some elements are cast on site. Therefore this method is more relevant to the considered slab system of this study. This study compared the following performance of the prefabrication and conventional systems based on the above said building methods.

- Actual labour productivity
- Structural Cost
- Crew Size
- Cycle Time

The results obtain form the study about the labour productivity of the building construction by using composite slab systems illustrated 7manhours/m² and 2manhours/m² in composite precast slab system with the percentage of 70% higher labour productivity than the conventional system. This results was in agreement with the previous studies such as 70% in Israel, 50% in Singapore and Japan. According to the result on structural cost comparison the cost was found to be insignificantly differ in Malaysia. The crew size comparison shows 22workers for conventional system and IBS shows 18works which was significantly difference of 18%.

When considered about the comparison of cycle time the conventional systems consumed 17days and Composite method precast system consumed 3.1 days which shows 76% cycle time saving in Malaysian context and this indicated the project construction time would also drastically reduced by the precast systems. The deduction of management overheads and other expenses incurred to the project with the accelerated construction will direct to the financial saving to the building construction.

The case study presented in the research paper by H.G.Vivek Prasad and H.N. Rajendra Prasad regarding the conventional and fast track construction technologies [12] has carried out a comparative analysis of precast slab systems, based on the building constructed for Police quarters at Masuru in India. This study compared the aspects such as quantities of material required, cost and time duration of the conventional, monolithic and precast building construction methods practiced in India.

The following results were obtain form the study and illustrates that the cost reduction of 37% in monolithic construction method and 53% in Precast construction compared to the conventional building construction methods as shown in Figure2.2 Further, it shows a 60% time saving with monolithic construction method and 82% time saving with the precast construction method compared to the conventional method. According to above results, the precast and monolithic methods has achieved greater advancement than the conventional method in time and cost which are most critical factors of the building construction.

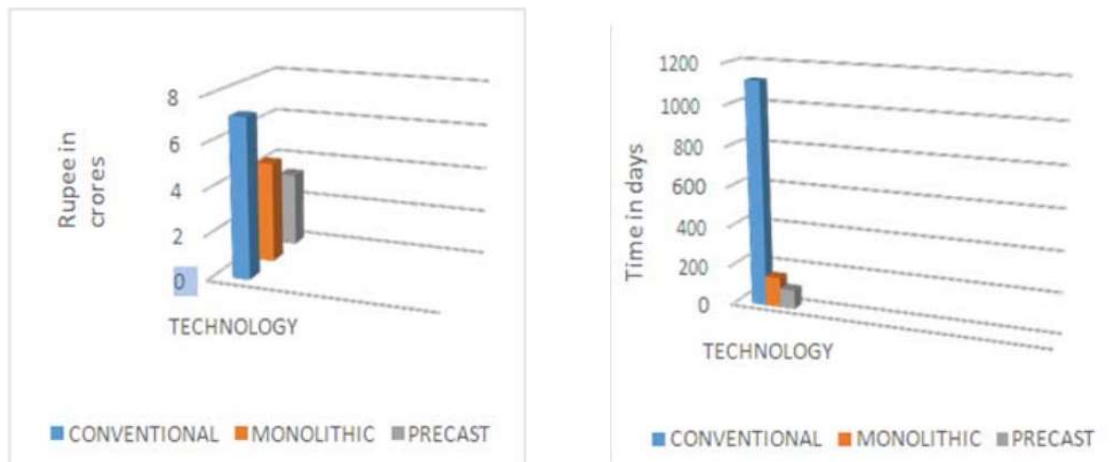


Figure 2.2: Estimated Cost and Time for Conventional, Monolithic and Precast Construction

Source: Research Paper conventional and fast track construction technologies [12]

Further, a considerable saving of materials which consumed valuable natural resources which lead the impact on material conservation and energy, have been determined with precast systems over conventional building systems. This also directed to the considerable waste reduction and environmental emission through the production, process and reduction of the material usage such as steel and concrete. According to the results of the paper, it has been illustrated that the monolithic and precast construction techniques has higher improvement with shortened construction time, economical construction and the improvement of building's sustainable performance. Further, it resulted in conservation of materials and lower energy consumption with compared to the conventional building construction methods.

The research paper, Comparative study on Prefabrication with cast in-situ construction of residential buildings by N. Dineshkumar and P. Kathirvel [13] has analyzed the precast and conventional building construction methods with the opportunity of adopting precast construction technology to residential building constructions in India. According to the study following benefits have been identified with precast slab systems applied for residential buildings.

- Precast concrete is comfortable -
Allowing temperature stability in cold and hot weather conditions and providing better acoustics insulation
- Precast concrete is safe -
It is significantly strong to resist impacts, blasts and natural effects like earthquakes and floods

- Precast concrete is versatile -
Factory production of precast elements allows wide range of surface finishes and offer an incredible variety of colours and visual effects
- Precast concrete is healthy -
The precast elements is stable throughout its lifecycle and it avoid the requirement of chemical treatments to protect from insects and improve the indoor air quality by eliminating emissions.
- Precast concrete is optimized
The advance technology used with precast improve the quality of construction by reducing tolerance and using thinner sections
- Precast concrete is durable
Effective design and detailing leads to lengthen the life of precast concrete

This study has mainly focused about the comparative analysis on project cost and project duration of two stories residential buildings in India which constructed with precast method and conventional method by the analysis of the construction stages such as sub structure, superstructure and finishing works.

According to the results of the study, the total time consumed for the selected residential building constructed with precast method shows significant advantage than the conventional method which is nearly two times faster construction. The sub structure construction method is similar for both types. For the super structure construction, 12 days have been consumed by precast method while 52 days have been consumed by conventional method. That leads to 40 days saving of construction time with the use of precast construction. In finishing works, it also consumed 31 days and 54 days respectively by precast method and the conventional method, which shows 22 days saving of time with the use of precast systems.

The analysis carried out in the said paper on project cost in different stages of the projects with precast and conventional methods has found that the cost of sub structure construction was similar due to the same conventional method use in each method and cost of finishing work is similar in both types due to the traditional methods used for the finishing in two stories residential buildings. But for the super structure, the cost for precast construction method is higher than the conventional method due to the use of both in-situ cast and precast methods for the prefabricated buildings when compared to the conventional method. When considered about the total cost 13% cost addition incurred to the precast method. Therefore, this study has

concluded that the conventional building methods are economical and comfortable for the two stories residential buildings in India.

The research paper by Vaishali Turai & Ashish Waghmare on cost comparison [14] has determined that the use of precast concrete technology for building construction is comparatively minimum in India than other countries due to the less awareness about this new technologies. Therefore, the said paper contribute to stipulate the cost effectiveness with the use of precast technology by considering following factors which directly and indirectly impact on project cost to solve the hesitations of Indian construction industry.

- Cost comparison
- Material wastage at site
- Labors policy, training, skill development
- Money required for safety at site
- Time required for completion of projects
- Heavy equipment cost, machinery cost
- Transportation cost
- Rework if required
- Money required achieving quality work
- Shuttering material manufacturing cost, maintenance cost, shuttering and deshuttering cost

As a results of said research, it has proven that the precast concrete systems are more economical than cast-in-place (conventional) concrete systems by considering all cost factors effected on project from start to end. But some restrictions are there in using precast systems such as long distances to transport precast concrete from manufacturing plants to assembling sites which incurred higher cost and high risk of damage to the edges of elements during the transportation.

The case study carried out by Raman Kumar, Manoj Patterson and Sandeep Jain on use of pre-cast technology for construction of high rise buildings [15] has presented the effectiveness of precast systems by considering the Indian scenario. The paper has described that the use of properly designed and specified precast concrete elements reduces and avoid many common utility problems and has following benefits.

- **Speed to Market**
Precast components are fabricated in controlled factory environment with minimum use of labor and possible to erect in any weather condition. This can be considered as a huge benefit over cast in-situ concrete works
- **Quality and Durability**
The controlled quality and long service life of precast elements are ensured with the strictly controlled factory environment and the commitments of dedicated experienced work force.
- **Enhance the safety**
Precast elements eliminate lot of hazards in construction sites by the offsite fabrication and improve the tidiness due to the lack of material usage and site work.
- **Sustainability**
Precast concrete methods reduce the overall life cycle impact on environment due to the construction and lower the destroyable wastes and increase the recyclable wastes.
- **Optimization and Flexibility**
Advance technical solutions on precast technology will optimize the resource utilization with the improvement of product quality and reducing the tolerance. Precast elements offer more flexibility in longer span selection and internal space arrangements of building construction.

The major precast elements use for building construction are columns, beams, slabs, canopies, wall panels and staircases. The lift core boundary wall elements are used for the common areas of the buildings. The case study specified in the said research paper is based on the Dream valley Project located in Delhi, India which consist with 47 high rise residential towers. According to the results following advantages of precast construction have been identified with compared to the conventional construction methods

- The 18 storied buildings have been completed within 18 month period and the slab cycle has been reduced up to 10-12 days for 7000 ft² area slab with the use of pre-cast slab systems.
- It has observed significant reduction of concrete and steel required for the square feet of buildup area.
- Site safety is improved with the adoption of precast elements and considerably reduces the waste, dust and noise by deducting ecological foot print of the project.

Therefore precast building construction technology could be identified as the smart way to achieve the sustainability objectives of green building construction. Further, the adoption of mix of cast in-situ and precast elements whenever required offer more time, cost and quality benefits.

2.5. Sri Lankan Approach

Prefabrication technology on building construction is not much popular in Sri Lanka with compared to the world and Asian trend. According to the studies of previous work, still Sri Lanka is in very far behind compared with other countries with the application of precast building technologies.

The National Engineering Research and Development Center (NERD) of Sri Lanka has invented a precast slab system for residential buildings of middle income families in Sri Lanka, in early 1987, with the guidance of late Dr. A.N. Kulasinghe. According to the study, Investigation on improvement of low cost NERD slab system [16], the NERD system consist with the 50mm thick in situ concrete layer on top of the trapezoidal shape Prestressed beams placed in 600mm intervals as illustrated in Figure 2.3.

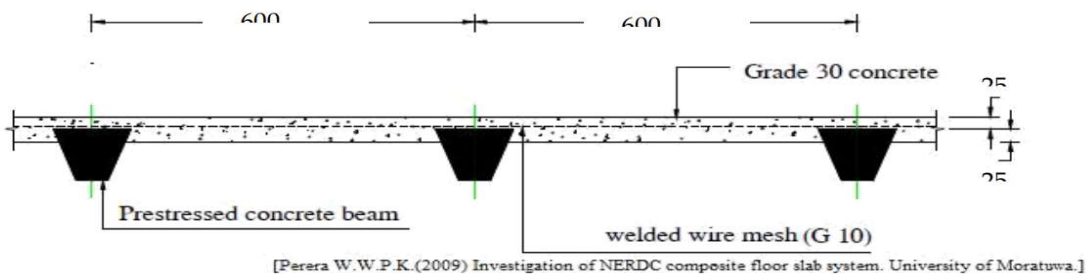


Figure 2.3: Cross section of NERD slab system

Source: Research paper Investigation on improvement of low cost NERD slab system [16]

This slab system is been widely used in building construction in Sri Lanka due to the significant advantages over the conventional slab systems such as primitive 30-40% cost effectiveness, considerable reduction of slab weight, elimination of propping during the casting and saving of material, labour and time consumed for the slab casting. Enabling workable bottom immediately after slab casting is the very important advantage to the clients and contractors. However, the exposed rafters in slab bottom keep away the people from adopting this cost effective method for their building construction in nowadays.

The “ICC (International Construction Consortium) Easy Slab System” is made up with four major components such as pre-stressed beams, concrete masonry soffit blocks, distribution reinforcement Galvanized Iron (GI) welded mesh (50x50sqrs) and structural concrete topping cast in site as shown in Figure 2.4.

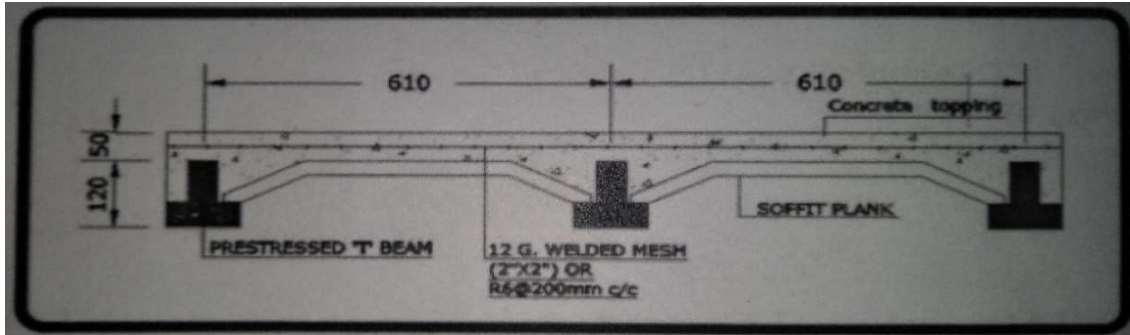


Figure 2.4: Cross section of ICC Easy Slabs

Source: ICC product Broacher Easy slabs system

According to the details given in ICC product brochures [17] 30% overall cost benefit is ensured with the use of ICC Easy Slab System and many other advantages like lack of skill labour requirement, elimination of formwork system, easy handling due to the light weight elements, quality surface finishing and the faster construction are identified in ICC slab systems. This slab system is mostly popular among commercial buildings and not much popular in residential and office building industry due to the exposed beams in slab soffit and the rough finish of concrete cement blocks which is affected negatively to the esthetic view of the slab soffits.

Another popular precast, pre-stressed solution on concrete slabs by the ICC is Suspended Beam Slab (SBS) which is much similar to the easy slab system [18] but improved slab soffit finishing by eliminating suspended beams and achieving the plain soffit finish with the use of hollow cement concrete blocks as shown in Figure 2.5.

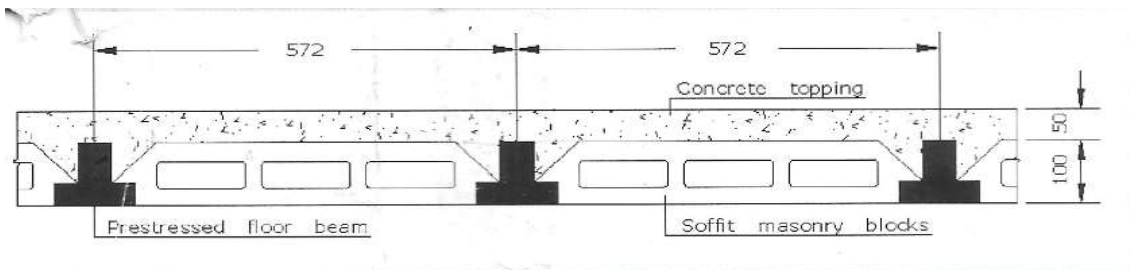


Figure 2.5: Cross Section of ICC SBS System

Source: ICC product Broacher SBS System

SBS system has comparative advantages over the conventional system such as considerable cost saving, saving of skill labour requirement, elimination of formwork, usability of the duct in the solid blocks for building services installation and the quick availability of slab bottom areas for future construction which lead fast track construction.

Further, several precast slab systems have been used for some particular projects in Sri Lanka and most of them have been not widely used due to the lack of knowledge sharing, poor industrial approach of the precast producers and the lack of detail research about those initiatives on building construction industry.

2.6. Summary of the Literature Survey

The literature review of this research covered a wide range of past studies related to the precast building construction practices such as research methodologies, the current status of precast building construction industry and the comparative analysis about precast concrete in different perspectives and approaches. The findings and results of past studies helped to demarcate the boundaries for this research study.

In Accordance with the findings of previous studies, it was observed that the precast construction has a positive effect on the environment by the reduction of material usage, lower energy consumption and a higher rate of waste reduction over the cast in-situ concrete technology in building construction. Therefore, the evolving of precast concrete technology was declared as an environmental friendly diversification of building construction practice.

Precast concrete technology was successfully adopted in most of the European countries long before. The use of repetitive building elements by developing standard designs and plans, is resulted in minimizing the initial capital investments on precast concrete plants. That leads to environmental friendly sustainable building construction by achieving the short term development targets through the fast construction progress. The Asian countries are rapidly diversifying to the precast technology due to the fast growing urbanization and residential building requirements by overcoming financial and technical disturbance on precast implementations.

There were vast range of past comparative analysis about the precast concrete practices and conventional construction practices base on case studies, questioner surveyors and the theoretical analysis which considering the different geological locations, building environments and various type of buildings. According to the findings of past studies, it's

clearly proven that adoption of precast technology will significantly save the time for construction and enhance the safe and environmental friendly construction. The cost factor of precast concrete is uncertain over the conventional concrete systems with the used purpose, environment and state rules and regulations. However, most of the studies illustrates that the cost on precast construction is much more similar or higher to the conventional method.

In Sri Lankan context, limited precast applications are recently practiced in building construction industry and limited precast building elements are used for the construction due to the lack of pre-planning and lack of awareness about the benefits of precast technology. Precast slabs with composite to in-situ cast concrete topping is the most familiar precast method used in Sri Lankan building construction industry and it shows benefits like significantly fast construction, cost saving, environmental friendliness and enhanced quality with compared to the conventional methods.

CHAPTER 03

RESEARCH METHODOLOGY

3.1. General

This chapter presents the research methodology, relevant data collection methods and data analysis methods used for this research study. The study was carried out mainly focusing on the analysis of resource optimization by use of specific precast plank slab system over the conventional methods.

Several international and local studies were read and referred in literature review of this research study. However, any of those studies have not been specifically focused on pre-cast slab systems and impossible to relate the results of those studies for Sri Lankan construction industry.

None of the comparative analyses were found nationally about advancement of resource utilization with the implementation of precast plank slab system. Hence, this research study was initiated with the purpose of analyzing resource optimization of slab construction in building constructions by the use of different technologies.

Therefore, the research analysis was proceeded based on the data from several actually constructed projects in Sri Lanka. The analysis was mainly focused on the resources optimization, direct cost and time optimization for the slab construction to produce statistics about those factors in selection of slab construction method in future projects

3.2. Research Approach

The research methodology followed for this study is a case study about the slab construction work of precast plank slab system comparing with conventional slab systems and a brief comparison with the existing ICC SBS system. The research study was proceeded according to the defined steps as illustrated in floor chart of Figure 3.1.

This case study was carried out based on a quantitative analysis of real building construction projects in different areas of Sri Lanka, which were executed with the application of each type of slab technologies

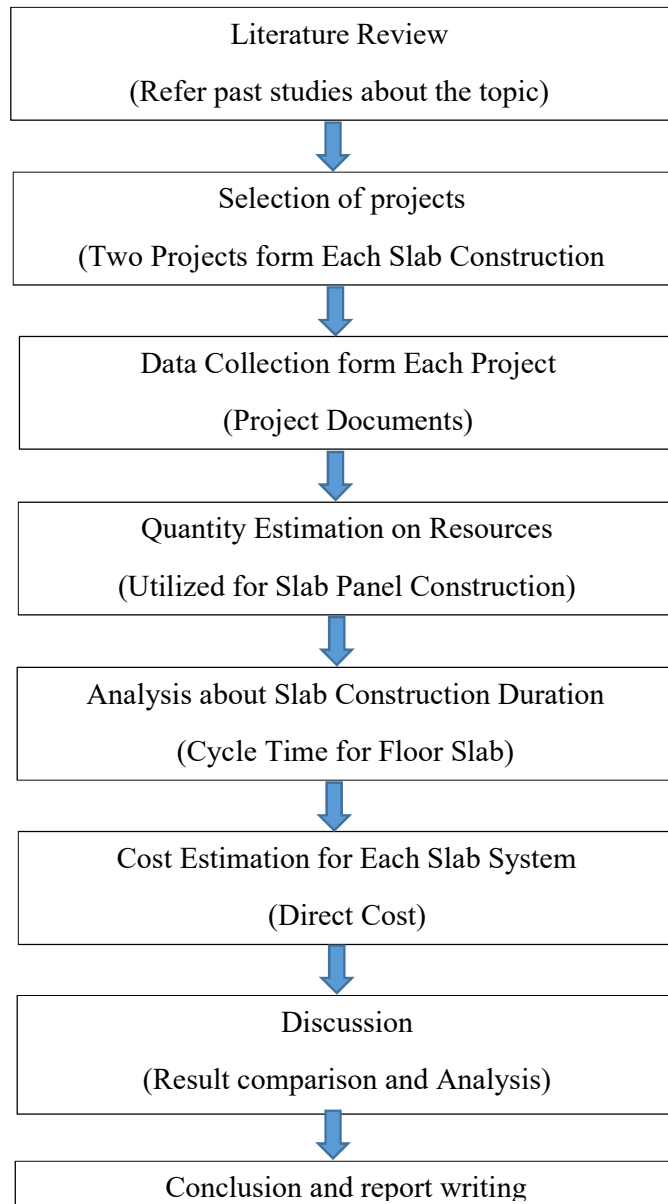


Figure 3.1: Flow Chart- Research Methodology

3.3 Selection of Projects

The sample projects were selected as two projects form each slab system namely conventional, precast plank and ICC SBS for enhancing the credibility of the study. The following factors were considered while selecting the projects to enhance the reliability of analysis on resource optimization on slab construction.

- Buildings constructed for a similar end purpose
- Buildings with three or more floors

- The considered construction period for the project selection was year 2010 to 2018 and prefer the projects which was initiated and completed within the period

Minimum two projects form each slab construction technology was considered for the study to enhance the reliability of the study.

The purpose of selecting the similar type of buildings which used for similar purpose is to analyses the resources, cost and time factors of slab construction based on equal structural platform to avoid the effect of structural factors on this comparative analysis.

In Sri Lanka, two major hospital buildings were constructed with precast plank slab technology during the considered time period. Therefore, another two hospital buildings constructed with conventional slab construction system were considered for the comparative analysis. However, similar type of buildings have not been constructed with the ICC SBS slab systems for collection of data. Hence, this comparative analysis was carried out among the precast plank slab system with the conventional slab system and further produced the brief analysis with the existing well known ICC SBS slab system.

The two buildings constructed with precast plank slab systems were selected from two District General Hospital Buildings. The selected buildings were with five to ten stories and project details are illustrated in Table 3.1 & Table 3.2

Table 3.1: New District General Hospital Building – Hamabntota (Project 01)

Client	Ministry of Health – Government of Sri Lanka
Main Sub Contractor	Central Engineering Consultancy Bureau (CECB)
Engineer	Design Advocacy (Pvt) Ltd.
Project Value	Rs.1,654,112,179.00
Project Period	10 th May 2013 – 18 th January 2015 (18 months)
Description	10 storied Hospital Building
	

Table 3.2: New District General Hospital Building - Nuwara Eliya (Project 02)

Client	Ministry of Health – Government of Sri Lanka
Main Sub Contractor	Orient Construction Co. (Pvt) Ltd.
Engineer	Design Advocacy (Pvt) Ltd.
Project Value	Rs.1,121.850.721.00
Project Period	1 st May 2013 – 1 st May 2015 (24 months)
Description	5 storied Hospital Building



Two buildings which were constructed using the conventional slab system was selected from the General Hospital (Teaching), Karapitiya as detailed in Table 3.3 & Table 3.4

Table 3.3: Nephrology Dialysis and Transplant (NDT) Unit, General Hospital, Karapitiya (Project 01)

Client	Ministry of Health – Government of Sri Lanka
Contractor Design & Build	Central Engineering Consultancy Bureau (CECB)
Project Value	Rs.739,516,377.00
Project Period	13 th August 2014 – 13 th August 2017 (36 months)
Description	10 storied Hospital Building



Table 3.4: Specialized Pediatric Unit, General Hospital, Karapitiya (Project 02)

Client	Ministry of Health – Government of Sri Lanka
Contractor Design & Build	Central Engineering Consultancy Bureau (CECB)
Project Value	Rs. 1,586,000,000.00
Project Period	10 th June 2017 – 10 th June 2020 (24 months)
Description	12 storied Hospital Building



ICC SBS system has not been used in any hospital building construction in Sri Lanka. Hence, two commercial buildings with 4 stories each were selected as per the details given in Table 3.5 & Table 3.6

Table 3.5: Commercial Building for Mr. L.I.S Perera, Nugegoda (Project 01)

Client	Mr. L.I.S. Perera
Slab Contractor	International Construction Consortium (ICC)
Description	Four stories commercial building

Table 3.6: Commercial Building for Welikala Holdings, Nawala (Project 02)

Client	Welikala Holdings, Nawala
Slab Contractor	International Construction Consortium (ICC)
Description	Four stories commercial building

The floor slabs of ward areas with similar imposed loads were selected for the analysis to avoid the effect of structural design differences throughout the research

3.4. Sources of Data Collection

The data for the comparative analysis was obtained through different methodologies from each considered project such as referring the project documents, interviews with project managers, visual inspections to the ongoing projects and refer the personal experience of my self which gained by working as a responsible Engineer of some specified projects.

Structural and general arrangement drawings, labour records, payment details, project progress reports and construction method statements of slab constructions were referred as the main sources of data collection. In addition to that the data about project execution with different type of slab construction methods and the impression about each slab system of professionals who are involved in building construction industry was obtained through the interviews with project managers of relevant selected projects and the plant managers who are fabricating precast slab elements.

The technical methods used for the installation and casting, machines and tools utilization, form work and false works systems used for each slab systems were observed through the site visits for each project.

The details of materials, labour and financial data about ICC SBS slab system was obtained from the visit to the ICC Precast plant at Madapatha and having a discussion with plant manager regarding the fabrication of precast elements and installation process at sites. Further, the data available in product brochures were considered for the analysis.

The data related for construction of one upper floor slab with rigid base for supports were considered for the analysis, excepting ground and first floor Slabs from each project to avoid the effect of different ground conditions on slab supporting systems.

CHAPTER 04

DATA ANALYSIS AND RESULTS

This chapter describes the comprehensive analysis of the data gathered from selected project of each slab construction technology and compared the results obtained with the other systems. The data was analyzed in different approaches such as quantity estimation of resource utilized, cost incurred to the slab construction and the time elapsed for the completion of the selected floor slab construction of each slab construction technology.

4.1. Precast Plank Slab Construction Technology (PPS)

The selected projects for precast slab systems were two hospital building projects in Hambantota and Nuwara Eliya. The design and installation details of precast slab panels and cross section of floor slab are similar for both projects except the method of casting the panels. Therefore, quantity estimations of both projects were carried out separately based on the available data as mentioned in chapter 3.

4.1.1. Design of precast plank slab

This floor slabs are basically consists with three layers as 60mm thick precast plank slab panel, 60mm thick prefabricated straw board (Fabricated by the use of faddy waist) and 60mm thick in-situ cast topping concrete layer. The cross sectional detail of typical slab panel is illustrated in Figure 4.11.

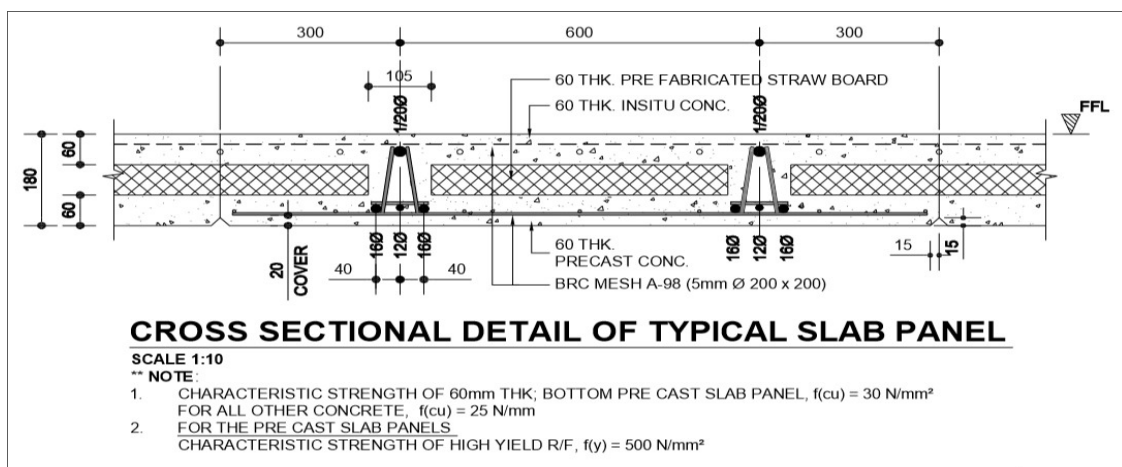


Figure 4.1: Cross sectional detail of precast plank slab

The standard precast plank slab panel is 1200mm wide, 5100mm long and 60mm thicker. The panel has been reinforced with the two triangulated lattice girders and 5mm thicker 200mm x 200mm BRC steel mesh. Grade 30 concrete is recommended for the slab panel concrete and underwater curing also prefers to avoid the thermal cracks on panels. The sections of precast plank slab panel is shown in Figure 4.24.2 and Figure 4.33

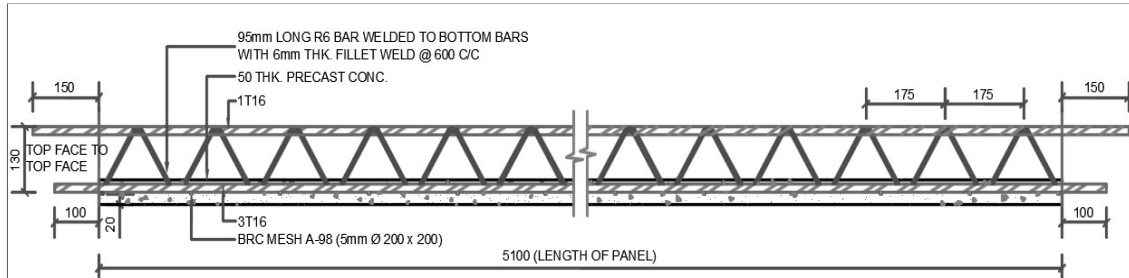


Figure 4.2: Longitudinal section of precast plank slab panel

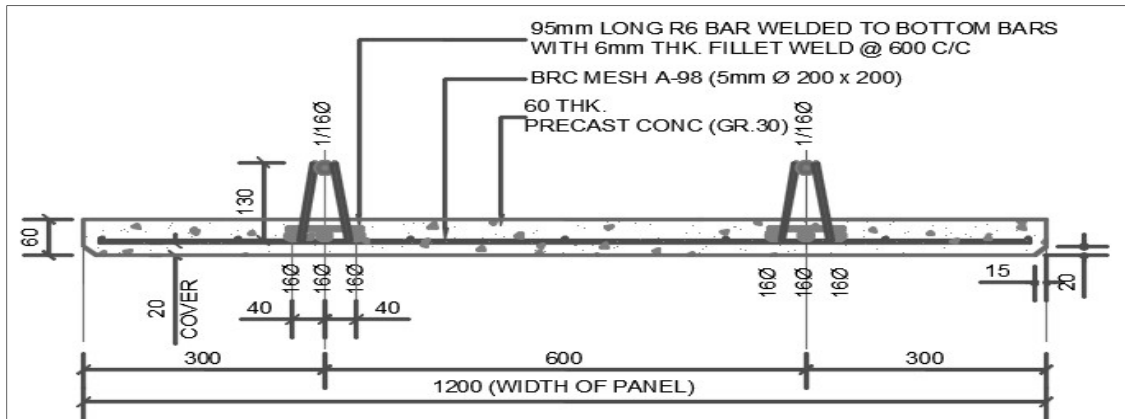


Figure 4.3: Cross section of precast plank slab panel

Three different size of precast slab panels are available with same length and different widths as 900mm, 600mm and 400mm for the flexible use in installation at site. Specifically, the 400mm width slab panel consist only with one lattice girder and all other sizes consist with 2 lattice girders as shown in Figure 4.4. The bottom and the top bars were extended 100mm and 150mm respectively from the edge of the precast panel to ensure the strong bond of slab panel with the beam.

The precast plank slab panel consists with two major resources as concrete and reinforcement steel. The material quantities for a standard precast slab panel is calculated and illustrated in following Table 4.1.

For Nuwara Eliya Hospital project, a precast plant was not available in nearby area and existed plants were situated very far from the project site. Fabrication of the slab panels in a precast plant for this project was impossible due to higher transportation cost, time and the risk of damages during the long distance transportation.

The contractor of Nuwara Eliya hospital project, Orient Construction Co. (Pvt.) Ltd. was decided to cast the precast slab panels by themselves in a nearby ground reserved from urban council as shown in Figure 4.6. In this process they build 7no's of 5.5m wide 30m long tanks with the height of one feet and casted the one set of precast panels by using 10 steel molds with two panel capacity and then fill the tank with water to allow normal curing procedure for 7days. Then they shift to the next tank and casting was done alternatively as illustrated in Figure 4.6. Therefore, time consumed for this practice was much higher than the factory production. Further, quality of the panels were comparatively low due to the constraints of uncontrolled environment.



Figure 4.6: Ground Reservation for panel casting and Mold used in Nuwara Eliya project within the tanks

According to the site records each mold set was used around 120 times in both projects and remains with good condition after the completion of projects. Hence, this molds can use many more times in future projects. Therefore, minimum 250 times usage of steel molds is assumed for the resources and cost analysis of this study.

4.1.3. Transportation and lifting

The precast slab panels casted in plant were transported to the site by using 40ft and 20ft long flat bed trucks by using specific stacking system by using timber spaces with rubber pads to avoid the damages during the transportation and storing as illustrated in Figure 4.7



Figure 4.7: Slab Panel Transport arrangement and Slab Panel Stacking System

The weight of the standard precast plank slab panel was around 900 kg and it was with 1200mm x 5100mm large area. Therefore, proper lifting mechanism is required to lift the panels to upper floors for avoiding damages to the panel edges. A special hanging device was used to hang the slab panel by keeping that horizontality during the lifting and placing as shown in Figure 4.8. Hence, precast planks slabs were lifted to installation on upper floors at site by using Tower cranes and Mobile Cranes. Mobile cranes has accessibility up to about 3rd floor level and from there onwards a tower crane was needed. The lifting of slab panels by tower crane is shown in Figure 4.8.



Figure 4.8: Slab Panel Hanging Device and Slab Panel Lifting by tower crane

4.1.4. Supports and installation

Both projects considered for this study has followed the same supporting and installation procedure under the instructions given by the design Engineer. The slab panels are placed on the two semi casted beams on both ends of the selected slab span and provide the support from one line of Acro jack supported GI pipe at the middle of each span. A 50mm strip of precast slab panel is placed on the beams in both sides and the supporting GI pipe is placed on the Acro jack supports in 900mm intervals at the middle of each span as shown in Figure 4.9. These supports were removed after 7days form the casting of topping concrete layer. Additional 100mm length of bottom reinforcement and 150mm of top reinforcement of lattice girders of

panel in both sides were allowed to embed the topping concrete to ensure the proper bonding to the beams as illustrated in Figure 4.9



Figure 4.9: Supporting system and placing method on main beams of precast plank slab panels

4.1.5. In-situ cast top layer

Precast plank slab construction is undergone on two major stages as off-Site construction and in-site construction as described in early chapters of this report.

The in-site construction stage mainly consists with two layers construction as 60mm thick prefabricate straw boards and 60mm thick in-situ cast concrete layer. The 60mm thick straw board layer designed as a filling layer of hollow section of these slab panels. The straw boards manufactured by ICC named “Durra Boards” were used for both projects with the purpose of environmental friendly construction by waste utilization. The standards board used for the filling was 495mm x 1200 mm and straw boards were available with different widths as 445mm, 395mm, 345mm and 295mm for the adjustments of filling at the edges of slab panels.

Figure 4.10



Figure 4.10: Straw Boards and Straw board laying on Precast Slab

The 600mm thick topping concrete layer consists with 6mm thicker, 200mm x 200mm BRC mesh and casted with the grade 25 concrete at site illustrated s Figure 4.11. The distribution reinforcement were put on the beams and additional reinforcements were provided for the areas which bear the weight of partition walls on floor slabs. The topping concrete was allowed to cure with wetted gunny bags for 7days period.



Figure 4.11: Preparation for topping concrete and Topping concrete pouring

4.1.6. Soffit surface finishing

The finished slab soffits are very smooth and surface preparation is not required before painting. Hence, two coats of skim coats is simply applied on the bottom surface of precast panels and apply two coats of emulsion paints for achieve the final finishing of slab soffit very easily. The bottom surface appearance of precast plank slab system and soffit finishing is shows in Figure 4.12.



Figure 4.12: Bottom surface appearance and finished slab soffit

4.1.7. Quality Testing

Precast slab construction system has been tested initially for the samples produced at ICC precast yard at Colombo and confirmed for the allowable deflection and compressive strength of the concrete. Deflection was the key factor tested for precast plank slab panel and maximum deflection which has been observed during the test is 23.55mm, the test results are within the allowable limits as per the test report given by ICC. The Testing Process is illustrated in Figure 4.13.



Figure 4.13: Load testing for sample slab

Precast slab panels casted for both projects were tested and confirmed the quality by the Engineer at the ELS factory in Hambantota and pre-casting yard at Nuwara Eliya as shown in following Figure 4.14.



Figure 4.14: Load testing for Precast Palnk Salb panel at site

4.1.8. Quantity Analysis of resources

Quantitative analysis of resources utilized for the floor slab construction with the use of precast plank slab technology is described in this section. The quantity estimation carried out based on the collected data are illustrated in following.

Quantity analysis of resources for precast plank slab was carried out by considering the selected floor slab area of both projects as illustrated in Figure 4.15 & Figure 4.16 extracted from the general arrangement drawings Appendix-B and Appendix-C. The calculated quantities for selected particular slab areas were tabulated for each project in Table 4.2.

Table 4.2: Quantities of resources utilized for precast plank slab

Ref. No	Resource Description	Unit	Recourse Quantity			
			Project 01 (Area 1070m ²)		Project 02 (Area 885.7m ²)	
01	Concrete					
	▪ Precast plank slabs (grade 30)	m ³	57.83		45.4	
	▪ Topping concrete (Grade 25)	m ³	64.26		52.26	
	▪ Main Beams	m ³	63.55		39.86	
02	Reinforcement					
	▪ Precast plank slab panels	kg	11662.32		9070.68	
	▪ Topping concrete layer (Distribution Rf)	kg	1883.80		1536.15	
	▪ Main Beams	kg	11,549.3		8550.7	
	▪ BRC Mesh (12ft x 7ft)	nos	309 (4944kg)		251(4016kg)	
03	Form Work					
	▪ Steel Molds with two panel capacity	nos	10		10	
	▪ Plywood for main beams	nos	133		97	
	▪ 2"x2" timber battens	m	756		672	
04	False Work (Support to installation)					
	▪ 2"x4" timber battens	m	261		182	
	▪ GI Pipes (Full lengths 5.7m)	nos	185		138	
	▪ Acro Jacks	nos	887		724	
05	Labour		SKL	USKL	SKL	USKL
	▪ Beam form work and false work	days	36	50	28	36
	▪ Beam reinforcement		30	50	24	38
	▪ Concreting		6	8	4	6
	▪ Green cut		-	4	-	3
	▪ Lattice Girder fabrication		32	8	24	6
	▪ Casting of Precast panels		16	16	14	14
	▪ Loading & Unloading		-	10	-	8
	▪ Providing supports		-	9	-	6
	▪ Precast panel laying		6	9	4	8
	▪ Preparation for topping concrete		20	30	14	24
	▪ Topping concrete casting		4	10	3	9
	▪ Support removing		-	4	-	3
Total Labour consumed			150	204	115	161



Figure 4.15: Selected Floor Slab are, Hambantota New District General Hospital (Project 01)

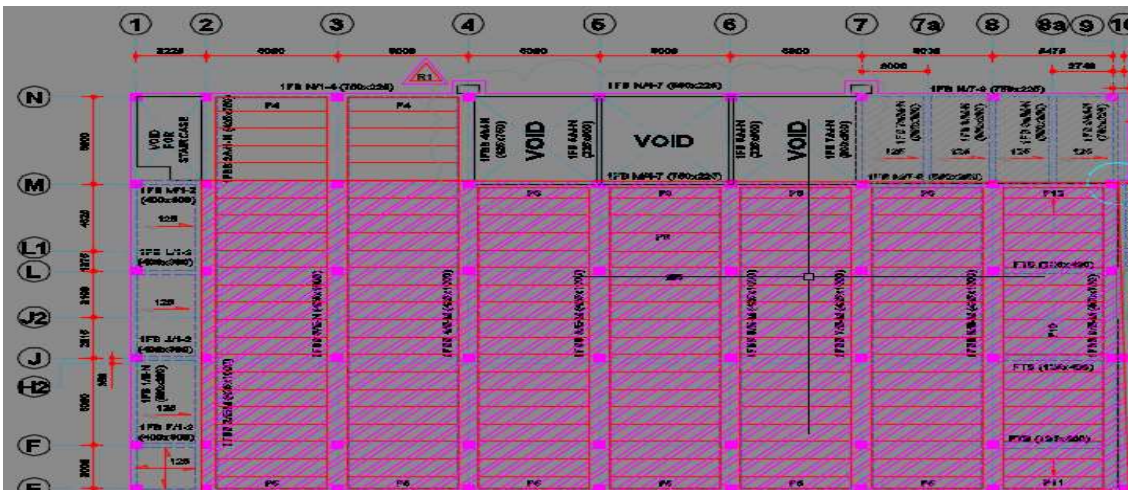


Figure 4.16: Selected Floor Slab, Nuwara Eliya New District General Hospital (Project 02)

4.2. Conventional In-Situ Cast Slab Technology (CS)

All the parties engage in the construction industry are well aware of the conventional slab construction method with the use of plywood boards and timber formwork. Therefore, the construction step of conventional slab systems is not deeply described in this report.

However, some modern form work systems are available which used for the in-situ cast slab construction in Sri Lankan high-rise building construction industry such as system form works. The system form works are designed for the specific project and cannot be used as it is for another project. The only gain is return value of the formwork from the supplier at the end of the project. The cost of those form work systems are much higher than the normal form work systems and this is used in very few occasions to overcome the issues with fast construction

and the lack of labour and resources availability for the tall buildings which are more than 20 floor heights.

Therefore, conventional slabs which are casted with system formworks are not considered for this study and precast plank slab system was compared with the most common slab casting method which use plywood sheets and timber formwork.

Two hospital building projects constructed with the use of conventional cast in-situ method were selected for this study. Both selected projects were constructed by same contractor and located in karapitya hospital premises. Same supporting system and formwork materials were used in those two projects and the same procedure was followed described below.

4.2.1. False work system

The false work of conventional slab system is the most important part of slab construction because total load of fresh slab concrete and reinforcement are bared by the false work support until the settlement of the concrete and achieves the expected compressive strength. Therefore 2”x4” timber battens support in 900mm intervals with the filling of GI pips in 450mm intervals supported on acro jacks with 900mm spacing in each sides were provided as a support to slab form work as illustrated in following Figure 4.17



Figure 4.17: Supporting System of Conventional Slab.

4.2.2. Form work

The form work for conventional slabs were prepared by using the 15mm thicker plywood boards laid on 2”x2” timber battens and GI pipes supported by 2”x4” timber battens on Steel jacks. Coated and non-coated plywood boards are available in the market. Non coated plywood sheets were used in both projects and joints were sealed by using the masking tapes as shows in Figure 4.18. Oil was applied on the plywood boards to prevent the bonding with concrete for the purpose of safe removing after the concreting and reused for next time. Normally,

plywood sheets were minimum 3times used as a form work for conventional slabs on both projects.

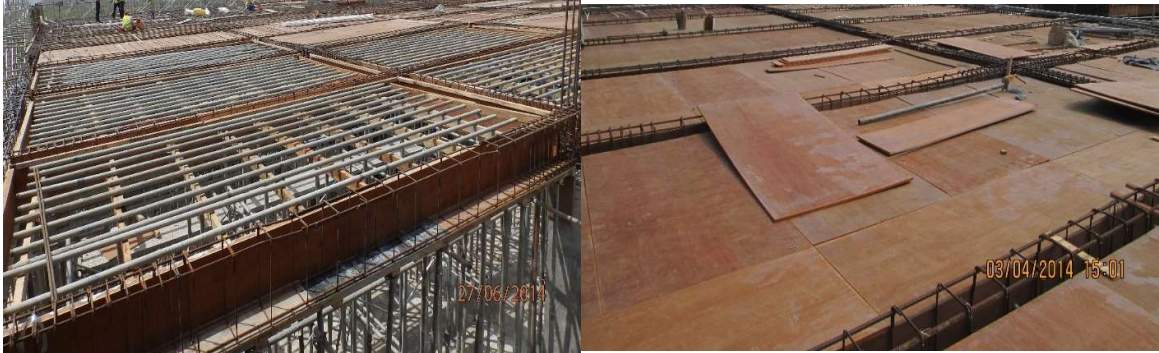


Figure 4.18: Form work of conventional slab.

4.2.3. Slab Reinforcement and concreting

Slab reinforcement of conventional method floor slab is mainly consist with two nets called Bottom net and top net. The slab reinforcement of both selected projects are basically design as a T10 bas in 225mm spacing shows as Figure 4.19, and slab thickness this projects are differ as 165mm thick in NDT building project and 140 mm thick in Pediatric building. Grade 25 Ready mixed concrete was used for both projects and poured to the upper floors by the use of concrete pump car as shown in Figure 4.19.



Figure 4.19: Reinforcement for conventional slab and Concrete pouring using pump car

4.2.4. Soffit surface Finishing

Soffits of the in-situ casted concrete slabs required surface smoothing with cutting of exposed concrete parts and filling of uneven locations to prepare the even surface before apply the skim coats and paints. There were uneven projections of slab soffits appear in the joints of Plywood sheets due to the grout leakage through the plywood board joints. Therefore slab soffit finishing was mainly depend on the quality of form work joint sealant and the quality of plywood sheet used for the form works. When plywood sheets used more than one times most

of the slab soffits were more defective due to the damaged edges of plywood sheets during the removing of early usage. Therefore, finishing effort of slab soffits will be increase with the reusing frequency of plywood sheets for formwork.

4.2.5. Quantity analysis of resources

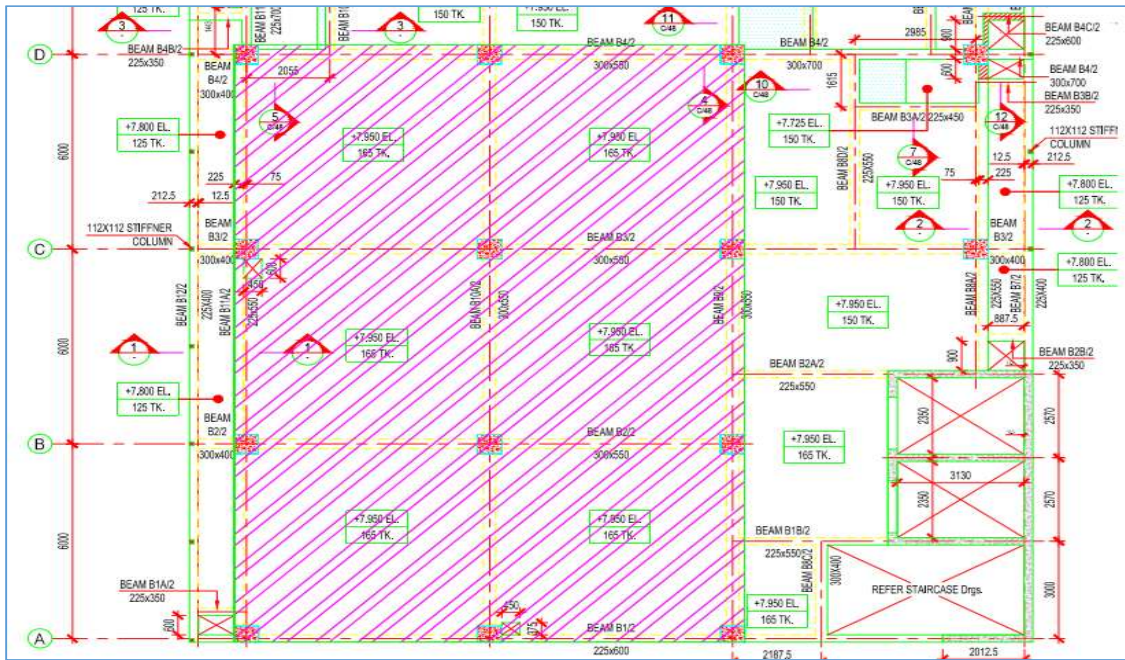


Figure 4.20: Selected Slab area of Nephrology dialysis center project (Project 01)

Quantitative analysis of resources utilized by the floor slab construction with the conventional in-situ cast technology was carried out under this study based on the selected hospital building projects and presented in Table 4.3 . Selected floor areas for quantity analysis is shown in Figure 4.20 & Figure 4.21.

The general arrangement drawings and structural drawings of floor slabs of nephrology dialysis center building and pediatric unit building were refer as a data source. Appendix-D and Appendix-E illustrated the Structural drawings of nephrology dialysis center project and Appendix-F & Appendix-G present the Structural drawing of pediatric building

The quantities of materials used for the conventional slabs were calculated based on the detail drawings and standard measurement guideline SLS573. Resources used for supporting system and formworks were measured through the site visits and construction method statements.

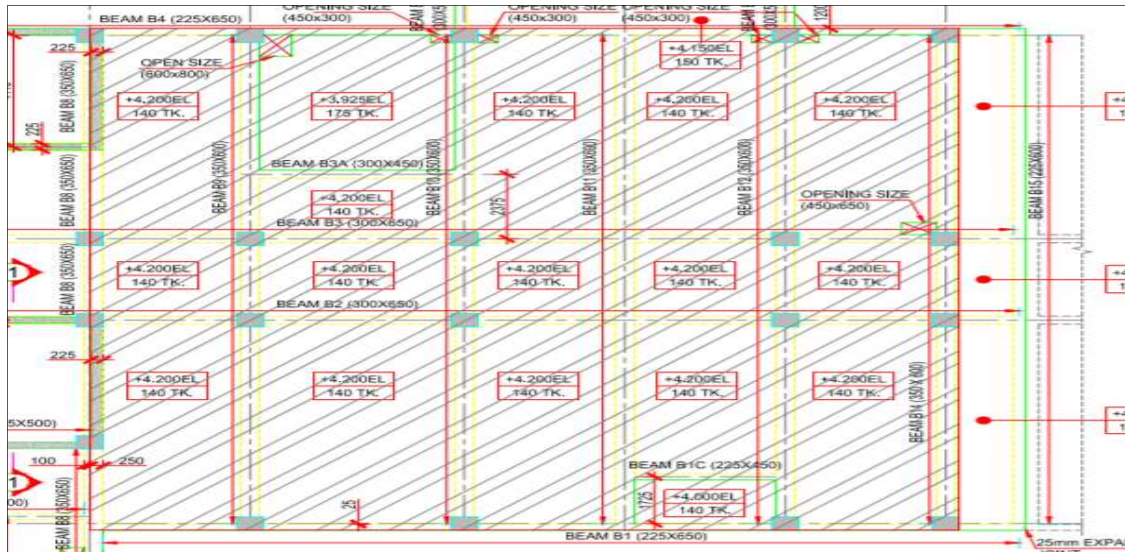


Figure 4.21: Selected Slab area of Pediatric Unit project (Project 01)

Table 4.3: Quantities of resources utilized for Conventional Slab

Ref. No	Resource Description	Unit	Recourse Quantity			
			Project 01 (Area 216m ²)		Project 02 (Area 288m ²)	
01	Slab Concrete (grade 25)	m ³	35.64		40.32	
	Beam concrete (G25)	m ³	11.26		26.2	
02	Reinforcement steel	kg	4310		6520	
03	Form Work <ul style="list-style-type: none"> ▪ 15mm thick Plywood sheets ▪ 2"x2" timber battens 	nos	110		172	
		m	579		916	
04	False work (Support to form work) <ul style="list-style-type: none"> ▪ 2"x4" timer battens ▪ 50mm Dia. GI Pipes ▪ Acro Jacks 	m	249		362	
		nos	166		267	
		nos	522		706	
05	Labour <ul style="list-style-type: none"> ▪ False work and formwork for slab ▪ False and Form work for beams ▪ Beam reinforcement ▪ Slab Reinforcement ▪ Concreting ▪ Cleaning ▪ False work and form work removing ▪ Curing Total labour consumption	days	SKL	USKL	SKL	USKL
			18	24	22	30
			12	16	24	30
			10	12	16	18
		6	8	6	10	
		4	6	6	8	
		-	4	-	6	
		-	8	-	10	
-	7	-	7			
50	85	74	119			

4.3. ICC Suspended Beam Slab System (SBS)

ICC SBS system mainly consist with three components as pre stress floor beams, soffit masonry hollow blocks and in-situ cast topping concrete. The T Beams and soffit masonry blocks were fabricated in ICC precast yard at madpatha and distributed all around the country for the projects. The Prestressed T beams were available with five different spans starting form 3mm and extended up to 5m with the 0.5m addition of lengths. The soffit masonry blocks are available in standard one size of 572mm x 185mm x 100mm. the soffit blocks are fabricated with the concrete masonry by using standard molds in precast yards.

4.3.1. Form Work System

Single T beams are used for the span up to 4m and two T beams used together for spans more than 4m and maximum up to 5m spans and beams casted with grade 40 concrete reinforced by prestressed tendons. The T beams are laid between support beams at 572mm intervals with 100mm end bearing and each and every beam are propped properly at center before pacing the soffit blocks as shown in Figure 4.22. The support props are removed after 7 days from casting the topping concrete.

The soffits blocks are placed on the T beams by unskilled labours. More than two workers to stand or walks on the T beams during the soffit block laying is never allowed even with the center props. Because, soffit blocks are not capable to bare any load in isolated situations as in Figure 4.22. The slab strength will gain together with topping concrete and t beams after setting of the topping layer.



Figure 4.22: T-Beam Installation at site and Cement Block Installation at site

4.3.2. Topping concrete

2'x2' GI welded mesh or 6mm mild steel net with 100mm centers were laid on the soffit block layer by keeping 20mm bottom covering as illustrated in Figure 4.23. Then 50mm thick grade 20 concrete layer is poured with well compacting and cure the in-situ cast concrete topping for 7 days as shown in Figure 4.23.



Figure 4.23: Arrangement for Topping concrete and pouring of 50mm thick concrete layer

4.3.3. Quantity analysis of resources

Two commercial buildings constructed with ICC SBS slab system selected for this study due to the difficulty of finding the similar type of buildings with other two types. Both buildings were four stories and constructed around the urban Colombo city area and owned by the private investors. Quantities were calculated by referring the shop drawing prepared by ICC (Appendix-H)

The ICC is the only manufacturer who carried out the slab construction part and they have only the data about slab construction activities. Hence, quantitative analysis about the ICC SBS system was based on the drawings produced by the ICC and details given by the ICC technical staff members during the visit to ICC precast yard at Madapatha, Piliyandala. The quantities calculated for resource utilized by ICC SBS system in selected projects are presented in following Table 4.4.

The T beams were placed on the main beam frame in above considered projects. Hence, resources utilized for the main beam construction also considered as a part of slab construction and calculate the quantities by considering the available details on the beams.

Table 4.4: Quantities of resources utilized for ICC SBS system

Ref. No	Resource Description	Unit	Recourse Quantity			
			Project 01 (Area 247.7m ²)		Project 02 (Area 168.2)	
01	Concrete					
	▪ T beams Length	m	444		342	
	▪ Topping concrete (Grade 25)	m ³	19		13	
	▪ Soffit Blocks	nos	1775		1595	
	▪ Main Beams	m ³	17.55		16.2	
02	Reinforcement					
	▪ Gauge 10 2"x2" GI mesh	nos	34		23	
	▪ Main Beams	kg	1008		939	
03	Form Work					
	▪ Steel Molds for beams	m	300		300	
	▪ Molds for soffit block	nos	2000		2000	
	▪ Plywood sheets	nos	60		55	
	▪ 2"x2" timber	m	520		480	
	▪ GI Pipes	nos	112		104	
04	False Work (Support to installation)					
	▪ 2"x4" timber battens	m	96		98	
	▪ Acro Jacks	nos	395		331	
05	Labour		SK	USK	SK	USK
	▪ Main beam casting	Days	25	35	21	30
	▪ T beam Fabrication		3	5	8	10
	▪ Soffit block fabrication		2	4	2	3
	▪ Loading & Unloading		-	2	-	2
	▪ T Beams & soffit block installation		12	20	8	12
	▪ Topping concrete preparation and casting		2	2	1	2
	▪ Support removing		-	4	-	3
	▪ Curing		-	5	-	4
	Total Labour consumed			44	79	40

4.4. Comparative Analysis on Resources

The comparative analysis about the resources utilization for slab construction with the use of precast slab system and conventional slab system is required for determine the advantage of precast plank slab construction over the conventional in-situ cast slab construction. Further, similar type of comparative analysis among the precast plank slab system and ICC SBS slab construction technology is required for the determination of advancement of precast plank slab system over the existing high commercialized precast slab system in Sri Lanka.

Table 4.5: Comparison of resource utilized for 100m² area of each slab system

Ref no	Construction Activity	Resources	Unit	Measured resources quantities for 100m ² slab area										% deviation With CS	
				Conventional Slab			Precast Plank slab System			ICC SBS system					
				Project 01	Project 02	Avg.	Project 01	Project 02	Avg.	Project 01	Project 02	Avg.	PPS	ICC SBS	
01	Slab Form Work	Plywood sheet	nos	51	60	55.5	13	11	12	23	33	28	-78.4	-49.5	
03		Timber battens (2"x2")	m	268	318	293	71	76	73.5	210	286	248	-74.9	-15.3	
06	Slab Supports (False work)	Timber battens (2"x4")	m	116	126	121	25	21	23	39	59	49	90.0	-59.50	
07		GI Pipes	nos	77	93	85	25	16	20.5	46	62	54	-64.5	-36.5	
08		Acro Jacks	nos	242	246	244	83	82	82.5	160	197	179	-66.2	-26.6	
10	Reinforcement Steel work	R/F steel	kg	1996	2264	2130	2346	2163	2254.5	407	559	483	27.3	-77.3	
		BRC mesh					462	454	458						
11	Concrete		m ³	21.7	23.10	22.4	17.35	15.53	16.4	16	18.74	17.37	-26.6	-22.4	
12	Labour	Skill Labour	days	24	25	24.5	14	13	13.5	18	24	20	-44.9	-18.4	
		Un skill Labour	days	40	42	41	19	18	18.5	32	36	34	-54.8	-17.1	
13	Steel Mesh		nos	-	-	-	29	29	29	14	14	14			

Therefore, all three types of slab construction methods are compared with the use of quantitative analysis of resource utilization by considering the quantities of each resource used in each project which considered for this analysis.

For a realistic comparative analysis among the different types of slab construction method by referring the data collected from different projects in different locations, there should be a common references of each projects to take all projects in to similar platform. The selected building sizes are totally differ from each other and slab areas of each project were different and quantified resources consumed for particular slabs were depend on the size of slab area. Hence, resource quantities measured for slab constructions of those projects were divert to 200m² specific floor area and recalculate the resources quantities for specified floor area proportionately to the original floor areas of each project. The resource utilization of each slab systems are compared by considering all projects together as illustrated in Table 4.5.

4.5. Cost Comparison

According to the quantitative analysis of resources utilized for each slab system, comparison is difficult between precast slab system and conventional slab methods due to the different material used and different construction methods applicable with different slab types.

Conventional slab construction is totally an in-site slab construction method and precast plank slab system and ICC SBS systems are partially in-site and partially off-site construction methods. Therefore, comparison of utilized resources quantities are not reliable for some resources used in different construction stages.

Therefore, the best way to compare the resource optimization of pre-cast slab systems over the conventional slabs is the financial analysis on resource utilized for each slab construction during the off-site and inside construction periods.

The cost of materials, tools and labour including transport and lifting expenses are calculated for Precast Plank Slab System, Conventional Slab System and ICC SBS System are illustrated in Table 4.6, Table 4.7 and Table 4.8 respectively.

Table 4.6: Cost calculation of 100m² area of Precast Plank Slab

Ref. No	Resource Description	Unit	Average Recourse Quantity	Rate Rs.	Cost Rs.
01	Concrete	m ³	16.4	14,500	237,800.00
02	Reinforcement	kg	2254.5	150	338,175.00
03	6mm BRC Mesh (200mmX200mm)	nos	29	3000	87,000.00
03	Form Work				
	▪ Steel Molds with two panel capacity (assume use all 10 molds in 250 times)	nos	16	(1,200,000.00/250)	76,800.00
	▪ Plywood sheets (3time Use)	nos	12	3300/3	13,200.00
	▪ 2"x2"timber battens(3time use)	m	73.5	65/3	1,593.00
04	False Work (Support to installation) Consider the cost of hire basis, 14 days				
	▪ 2"x4"Timber battens (10 times)	m	23	165/10	380.00
	▪ GI Pipes (Day Hire for 20 days)	nos	20.5 x 20	10	4100.00
	▪ Acro Jacks (Day Hire, 20days)	nos	83 x20	5.00	8300.00
05	Labour				
	▪ Skilled Labour	day	13.5	2,500	33,750.00
	▪ Un Skilled Labour	day	14	1,800	52,200.00
06	Transport cost				5,250.00
	Total Cost				858,548.00

Table 4.7: Cost calculation of 100m² area of Conventional Slab

Ref. No	Resource Description	Unit	Average Recourse Quantity	Rate Rs.	Cost Rs.
01	Concrete (Grade 25)	m ³	22.4	14,000	313,600.00
02	Reinforcement	kg	2130	150	319,500.00
03	Form Work				
	▪ Plywood Sheet (3time use)	nos	55.5	3300/3	61,050.00
	▪ 2"x2"timber battens (3time use)	m	293	65/3	6349.00
04	False Work (Support to installation) Consider the cost of hire basis, 24 days				
	▪ 2"x4" timber battens(10times)	m	121	165/10	1997.00
	▪ GI Pipes (Day Hire, 30 days)	nos	85 x 30	10	25,500.00
	▪ Acro Jacks (Day Hire, 30 days)	nos	244 x 30	5.00	36,600.00
05	Labour				
	▪ Skilled Labour	days	24.5	2,500	61,250.00
	▪ Un Skilled Labour	days	41	1,800	73,800.00
	Total Cost				899,646.00

Table 4.8: Cost calculation of 100m² area of ICC SBS

Ref. No	Resource Description	Unit	Average Recourse Quantity for 100m ²	Rate Rs.	Cost Rs.
01	Precast T beams	m	192	660	126,720.00
02	Soffit Blocks	nos	833	86.25	71,846.25
03	Concrete	m ³	7.7	14,000	107,800.00
04	2" x 2" GI Mesh	nos	14	4,000	56,000.00
05	Reinforcement steel	kg	483	150	72,450.00
06	Form Work				
	I. Plywood Sheet(3time use)	nos	28	3300/3	30,300.00
	II. 2"x2" timber battens	m	248	65/3	5,374.00
04	False Work (Support to installation)				
	I. 2"x4" timber battens(10times)	m	49	165/10	809.00
	II. GI Pipes (Day Hire, 20 day)	nos	54	10	10,800.00
	III. Acro Jacks (Day Hire, 20 day)	nos	179	5.00	17,900.00
05	Labour				
	I. Skilled Labour	days	20	2,500	50,000.00
	II. Un Skilled Labour	days	34	1,800	61,200.00
	Total Cost				611,199.00

4.6. Construction Time Comparison

The construction time of building projects are mainly depend on the time consumed for the preparation casting and strengthening of floor slabs. Therefore, time consumed for floor slab construction in site and waiting time for next construction activity is analyzed on each slab system to determine the comparative advantage on construction time of building projects with the use of conventional slab construction methods and precast plank slab systems. ICC SBS slab system also considered for the analysis to have a comparative analysis over the existing precast method and new precast plank system.

The time consumed for the construction projects were depend with the allocated labour force and working hours. Therefore total labour days consumed for each project was considered for the time calculation for the slab constructions with each type of slab systems. Following results in Table 4.9, were obtained from the analysis of selected building construction projects for this study from each type of referred slab construction technologies.

Table 4.9: Time consumed for construction of 100m² slab area of each slab system

Activity Description	Labour Days consumed for one floor slab construction (100m ²)		
	Conventional Slab	Precast plank Slab	ICC SBS system
Skill Labour days	24.5	13.5	20
Unskilled labour days	41	14	34
Waiting period for Strengthening	21	14	14
Total	86.5	41.5	68

The results about cost and time for slab construction with the use of precast plank slab system, Conventional method slab system and ICC SBS system can be illustrated as following Figure 4.24 & Figure 4.25 respectively to the easy comparison and understanding about the performance of each slab system.

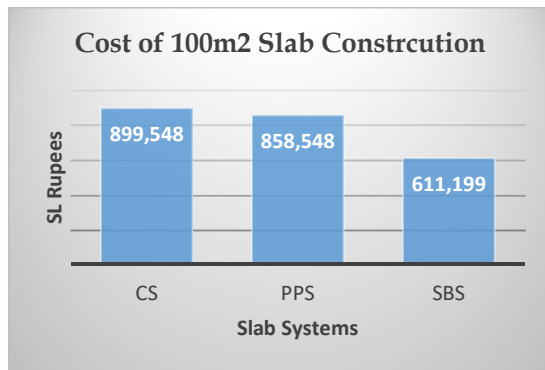


Figure 4.24: Cost of Slab Construction

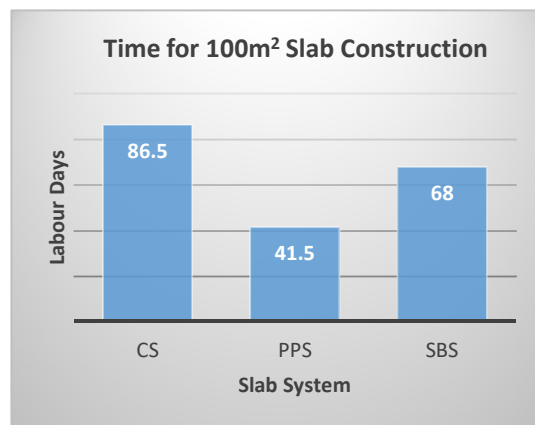


Figure 4.25: Time for Slab Construction

CHAPTER 05

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The study was conducted for producing comparative statistics of precast plank slab systems over conventional slab systems. The results obtained through the case study of this research verifies the usability of the application of precast plank slab system over the conventional slab system. The conclusions of the study is outlined as below.

- The use of materials for slab formwork (plywood sheets and timber battens) is reduced up to 75% with the use of precast plank slab system while the ICC SBS system shows around 50% saving over the conventional construction practices. This results the minimum use of timber which consumed for the fabrication of plywood sheets and timber battens for the construction and direct to the sustainability in building construction by saving natural resources for future generation.
- Fixed assets requirement for the slab construction (eg: supports, GI Pipes etc.) is reduced by 65% by the use of precast plank slab construction technique. That reduces the store capacity requirement and congestion of site while achieving higher cost and time performance than the existing precast methods.
- The concrete consumption is reduced by 25% with the precast plank slab system while drastically reduces the concrete wastage at site and save the valuable natural resources such as river sand, aggregate. Further energy consumed for manufacturing, transportation and pumping of concrete is reduced together with the deduction of concrete quantity.
- The reinforcement usage for plank slab system is considerably higher than the conventional method amounting 27% due to designed reinforcement of lattice girder for easy fabrication of precast panels in a factory environment as well as modified site locations. The ICC SBS system shows 75% saving of reinforcement over the conventional method due to the application of pre-stress technology in their well-established precast yard. However precast panels design for the higher spans and higher imposed loads compared to the ICC system. Therefore ultimate effect of reinforce steel may be further reduced with the comparison in equal conditions.

- 50% labour saving is the main advantage of the precast plank slab construction and it will be a better solution for the recent labour scarcity of the local construction industry. Further precast slab systems were considerably reduced the Skill labour requirement for slab construction as interesting solution for the lack of skill lbours problem in Sri Lanka. The Labour cost for ICC SBS system in this case study is slightly higher than the precast plank slabs due to the higher margins of labour rates in ICC.
- Optimized material usage of precast slab systems leads to minimizing the consumption of valuable natural resources which directly and indirectly impact the conservation of resources and energy. Further, a huge reduction of solid waste and emissions by this technology directed to the environmental friendly sustainable construction.
- The cost of the precast plank slab system is similar to the conventional method and it might vary with the availability and distance to the precast plant. However, ICC SBS system shows 30% cost saving over both systems as published in their commercial details. Cost equality with conventional method is the main drawback to the precast plank slabs to be popular within construction industry in the current scenario.
- Total labour days consumed for each slab system and the construction programs of selected projects shows that precast slab systems are two times faster the conventional method and it is slightly faster than the existing ICC SBS system. Therefore, this technology is a good solution for fast track construction projects arise with the fast grooving economy of the country.
- Reduction of resource usage and reduction of wastage may leads to enhancement of tidiness within the site premises which reduced the in-site accidents and resulted in improvement of health and safety of the workers while contributing to worker friendly construction environment.
- Strawboard layer used in precast plank slab systems reduces the thermal effects inside the buildings enhancing the occupant's comfort and energy saving. Therefore, this technology will be a good application in immerging green building concept in Sri Lanka.
- This technology reduces the destroyable wastage while improves the recyclable wastage over the conventional method leading for sustainability in building construction.

- The precast plank slab system shows an overall optimum resource utilization. Resource consumption can be further reduced in the use of reinforcement with the implementation of pre-stress technology for the fabrication of panels.

The precast plank slab system is an advance slab construction over the conventional in-situ cast slab construction method and it has resource optimization, time saving and similar cost performance. Therefore precast plank slab system will be feasible for the Sri Lankan building construction industry.

5.2. Recommendation

Conclusions outlined above finally recommends that the precast plank slab system is an advance technology compared to the conventional methods and a good solution for the high rise buildings with wide spaces. Considering analyzed facts and conditions, it is recommended that the precast plank slab system is an economical, feasible and time saving technology compared with conventional methods.

Large scale commercializes production of precast plank slab systems with the standardize buildings as a government policy decision will direct this system as an economical slab construction method for Sri Lanka. Adoption of pre stress technology for the precast plank slab fabrication is recommended as a further improvement of resource utilization while enhancing the quality and variety of product.

The deduction of cost of precast slab system through more commercialized production will help to construction practitioners to overcome their restriction to come out form the traditional construction practices. Therefore government should developed polices to support the precast construction industry with align to their sustainable goals.

Research and development regarding precast beams as an alternative for main beams of existing precast slab systems is recommended for future applications to further resource optimization of building construction and gain the faster building construction. Further studying on slab construction process by considering embodied lifecycle energy is recommended to find the optimal and sustainable prefabrication method over conventional slabs.

Further, the following recommendations are proposed for the improvements of the precast plank slab system with the practical experience gained through the execution of past projects.

- Beam formwork system of main beams should be improved with the use of a solid sideboard system and proposed to put the slab panels on the beam formwork and cast the beam concrete together with the topping concrete. This improvement will eliminate the difficulties in the cleaning of half casted beams and improve the structural performance of the beam. Further, time gaining and labour saving of this slab system can be improved
- Adoption of the pre stress technology for the precast main beam in this slab construction will further reduce the resource usage in the site and significantly reduce the time consumed. Therefore the use of improved technology on precast elements will be made more efficient in the precast plan slab system.
- The weight of the precast plank slabs can be reduced with the use of lightweight concrete solution available in the current construction industry to reduce the cost of handling and transportation

REFERENCES

- [1] A. Mire and R. Singh, "Study of Precast construction," *Mechanical And Production Engineering*, vol. 5, no. 11, pp. 101-103, 2017.
- [2] R. Athukorala and T. Cooray, "Casual relationship between construction activities and GDP growth," in *Annual reserch symposium, Faculty of Graduate Studies, University of Kelaniya, Kelaniya, Sri Lanka*, 2014.
- [3] T. G. Perez, "The Masterbuilder," 01 10 2013. [Online]. Available: <https://www.masterbuilder.co.in/precast-concrete-for-building-systems/>.
- [4] O. Pons and G. Wadel, "Environmental impacts of prefabricated school buildings in Catalonia," *Habitat International*, pp. 553-563, 05 03 2011.
- [5] A. Baldwin, C.-S. Poon, L.-Y. Shen, S. Austin and I. Wong, "Designing out waste in high-rise residential building: Analysis of Precasting methods and traditional construction," *Renewable Ennergy*, pp. 2067-2073, 08 02 2009.
- [6] Y. Luo, D. Riley , M. Horman and G. Kremer, "Reserchgate.net," 2008. [Online]. Available: https://www.researchgate.net/profile/John_Rooke/publication/40227013_Researching_decision_support_what_do_we_need_to_know/links/00b7d52b35415d4cff000000/Reserchgate.net/Researching-decision-support-what-do-we-need-to-know.pdf#page=377.
- [7] Y. Chen, G. E. Okuda and D. R. Riey, "Sustainable Performance Criteria for COnstruction method selection in concrete buildings," *Automation in Construction*, pp. 235-244, 04 10 2010.
- [8] L. Jaillon and C. Poon, "The evolution of prefabricated residential building systems in Hong Kong: A riview of the public and the private sector," *Automation in Construction*, vol. 18, pp. 239-248, 2009.
- [9] V. N. Nanyam, R. Basu, A. Sawhney, H. Vikram and G. Lodha, "Implementation of Precast Technology in India, Oppertunities and Challenges," *Procedia Engineering*, vol. 196, pp. 144-151, 2017.
- [10] C. Pasquire, A. Gibb and N. Blismas, "What should you realy measure if you want to compare prefabrication with traditional construction," in *13th Annual conferanceof the international group for lean construction*, Sydney, Australiya, 2005.
- [11] M. A. Kadir, W. Lee, M. Jaafar, S. Sapuna and A. Ali, "Construction Performance Comparision between conventional and industrialised building system in Malaysia," *Structural Survey*, vol. 24, no. 5, pp. 412-424, 2006.
- [12] H. V. Prasad and H. R. Prasad, "Case study on conventional and fast track construction techniques," *International Journal of Science, Engineering and Technology*, vol. 3, no. 5, pp. 1232-1235, 2015.

- [13] C. S. o. P. C. w. c. I.-S. C. o. R. Buildings, "Comparative study on Prefabrication construction with cast In-Situ Construction of Residential Building," *International Journal of innovative Science, Engineering & technology* , vol. 2, no. 4, pp. 527-532, 2015.
- [14] V. Thurai and Waghmare, "A Study of Cost comparision of precast concrete vs. Cast-in-Place," *International journal on recent and innovation trends in computing and communication*, vol. 3, no. 11, pp. 6235-6238, 2015.
- [15] R. Kumar , M. Patterson and S. Jain, "A case study on use of Precast technology for construction of High-Rise Buildings," in *NTPC Global Energy Technology Summit*, New Delhi, India, 2016.
- [16] B. Sanjaya, W. Srilal, W. Perera, H. Sooriyaarachchi and J. Appuhamy, "Investigation on improvement of Low Cost NERD Slab System," in *International Conferance on Structural Engineering and Construction Management*, Kandy, Sri Lanka, 2015.
- [17] I. C. C. (ICC), *ICC Easy Slabs - Product Broucher*, ICC , 2018.
- [18] ICC, *Product Broucher- ICC SBS*, International Construction Consourtium, 2019.

