APPLICATION OF COMPOSITE FIBRE REINFORCED PLASTIC (FRP) PLATE AS CONSTRUCTION FORMWORK

By

WAN SYIFAAK ZUHRI BT AHMAD ZOHRI

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

ABSTRACT

This paper entitled Application of Composite Fibre Reinforced Plastic (FRP) Plate as Construction Formwork, looks into the possibilities of implementing FRP as formwork. The main objective of this project is to study the prospects of using FRP plate as formwork for construction. FRP is high in strength, lightweight and durable. These characteristics are essentials for formwork to ensure good performance and long life span, as formworks are usually used many times. Traditional formwork materials such as timber and steel, usually suffer from disfigurement due to corrosion or humidity. Furthermore, difficulties have been experienced in the storage and handling of these traditional material formworks.

Currently, formworks made from FRP for concrete construction is rarely found due to novelty of FRP material. However, the application of FRP as a strengthening material and retrofitting for structure are quite commonly used. In this project, research is carried out to observe and study the characteristics and properties of FRP as material for formwork. For this study, the scope is narrowed down to the behaviour of FRP as permanent or stay-in formwork and the methodology for its development. Data gathering in this area was undertaken throughout this project period. The conclusion explains the possibilities of FRP for implementation as permanent formwork. Results of analytical calculations and related data analysis are provided in support of the conclusion. This report shall give an overview of the project and consists of five chapters; Chapter 1 is the Introduction, Chapter 2 mainly on Literature Review and Theory, Chapter 3 will include The Methodology and project work, Chapter 4 is the Results and discussion, and lastly Chapter 5 is the conclusion.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Concrete construction is the most popular type of construction compared to steel or wood structures. The concrete construction techniques are always being upgraded in order to optimise its usage. All concrete pours need to be contained, to hold the concrete in place until it hardens sufficiently to hold its own shape. Take a concrete slab for example, the freshly poured concrete may be retained by existing features, such as walls, kerbs, edgings etc, or some form of temporary shuttering, also known as 'Formwork' may be required. Since each structure is unique, the formwork must be designed and fabricated based on the specific requirement. On vertical concrete structures, the construction of the formwork can become quite complicated and is normally undertaken by specialist formwork erectors or formwork carpenters. Ground slabs are normally much less complicated and require only the simplest of formworks.

In all cases, the formwork must be sturdy and capable of bearing any forces created by wet concrete, plus the weight and force of any vibration equipment. The joints in the formwork are supposed to be taped or sufficiently tight to prevent wet concrete leaking out during vibration or curing process. Besides that, formwork for concrete structure also has a significant impact on the cost, time and quality of the completed project. For most structures, more time and cost is required to make, erect and remove formwork than the time and cost to place the concrete or reinforcing steel.

Generally, there are two main types of formwork, which have been widely used: steel rod and timber shuttering. Timber is the first material being used as formwork, as they are easily available. Steel rod form is quite popular amongst professional contractors nowadays for use on site, as it is sturdy and tough. Steel rod is capable to withstand the rough and tumble of a busy construction site and virtually unbreakable and also can be re-used time and time again. Further it requires little skill to set-up it is quite cheap relative to FRP.

However, both conventional formworks (steel and timber) have their own disadvantages as formworks. Both materials are susceptible to weathering environment. The performance of timber will be degraded if being exposed to weathering. Therefore, timber has its limitations in lifespan and reusability. It must be changed after being used only after a number of times. Steel formwork usually faced difficulties in storage and is also easily exposed to corrosion. Improper handling of the formwork may cause defect or blemish of the materials, rendering it to be unreusable. As a result, new formworks will have to be provided. Such will increase the construction cost as well as the construction period.

The use of the conventional concrete formwork also may be characterised as a labour-intensive and time-consuming operation. This is due to the situation that the forms are tailor-made manually on the site, and the concrete surface also requires man-hours for further finishing after stripping. The false work involving formwork is one of the activities causing major casualties at construction job sites and hence affecting workers' safety. Thus, the activity of formwork construction is often critical in a project, affecting it in terms of time, cost, quality, and safety.

The problems experienced by the commonly used formworks have lead to the experiments for usage of other material as formworks. Aluminium and Fibre Reinforced Plastic (FRP) are among the materials which are being studied and experimented to be used as formworks. This report focuses on the study of the possibilities of applying Fibre Reinforced Plastic (FRP) as permanent formworks. FRP is increasingly being used in construction due to its lightweight, ease of installation, low maintenance, tailor made properties, and corrosion resistance. FRP also has high tensile strength, moderate modulus of elasticity, non-magnetic and an elastic material up to rupture. Due to its special characteristics, FRP can be a good replacement for timber or steel rod formwork. However, more analysis and testing have to be done in order to enhance knowledge on the implementation of FRP as formwork material.

1.2 Problem Statement

1.2.1 Problem Identification

Normal formwork requires strong and durable material, as it will be used again and again. Conventional materials of formwork (timber and steel) are not durable enough, as they are sensitive to the effects of weathering. Besides, they are also difficult to handle and store. Due to some drawbacks faced by the conventional formworks, Fibre Reinforced Plastic (FRP) plate has been considered as a new material for replacement. The application of FRP in civil construction is still new but has gained more and more attention as a reinforcing option for concrete. Consequently, the possibilities in applying FRP plate, as a permanent formwork requires further study, testing and also analysis. This project will be focusing on the implementation of FRP plate as a permanent construction formwork.

1.2.2 Significance of the Project

FRP is a built up of unidirectional fibres arranged and manufactured in different ways and impregnated with resin. Its application is more as reinforcement in the form of bars, rods, cables, profiles and even as mould for the concrete, which the FRP is aimed to reinforce. In this project, the solution is to find out the characteristics of Fibre Reinforced Plastic (FRP) and to determine its strength. This is to analyse its ability to perform as concrete permanent formwork and to find out the needs and steps taken to construct the permanent formwork. This project shall also determine the advantages of using FRP against the conventional formwork with considering several factors such as cost, time consumption and ease of handling.

1.3 Objectives and Scope of the Study

The main objective of this project is to study the prospect of using Fibre Reinforced Plastic (FRP) panel as formwork for construction. FRP is a strong and durable material that can last longer when its usage as permanent formwork may give several advantages. In accomplishing this project, several stages of framework must be done. Therefore, to complete this project successfully, these objectives are to be achieved:

i) to understand the characteristics and behaviour of FRP reinforced concrete

ii) to study the application FRP as permanent formwork

The scope of this project takes into consideration the study of the FRP materials. This includes its characteristics, strength, behaviour and also its application in engineering. The main scope of the study is the application of FRP as a formwork in concrete construction. To be discrete and precise, this project will be discussing specifically on the usage of FRP as a permanent formwork. Additional studies on the characteristics of FRP as reinforcement also has been carried out to show FRP is actually suitable as reinforcement.

Design of concrete structures such as beams or slabs may be required for testing purposes. Nevertheless, the scope of this study is only limited to designing, calculating and observing analytically. It does not involve any mechanical testing or laboratory work due to expensive cost and lack of resources. However, based on the scopes stated in the introduction, this project has been developed in order to fulfil the requirements of the problem statement. Therefore, besides analytical calculation, several literature reviews also have been done. The data gathered was applied as additional information to support the study done for this project.

CHAPTER 2
LITERATURE AND THEORY

The literature review of this project is divided into two main parts, which are *Fibre Reinforced Plastic* and *Formwork*. Most of the literature review is geared towards identifying the current application use of FRP and formwork and their characteristics. Following is a brief summary of the literature review.

2.1 Fibre Reinforced Plastic

The Fibre Reinforced Plastic (FRP) materials are new for most civil engineers. Nevertheless, it had gained more and more attention as a reinforcing option for concrete. FRP reinforcement has high tensile strength, moderate modulus of elasticity, is corrosion resistant, non-magnetic and an elastic material up to rupture. There have been numerous studies and researches about the FRP, its characteristics and application. For example in Japan, the Japanese Society of Civil Engineers (JSCE) has written a code for FRP reinforced concrete structures. In USA, American Concrete Institute also has elaborated a proposal for design of concrete members reinforced with FRP rebars.

FRP is made of fibre materials such as carbon, aramid and glass that have tensile strength higher than that of steel and are elastic up to tensile failure without showing any yield. The fibres are impregnate or held together by using the resins. The resins, which are used, are epoxy, polyester, vinyl ester, polyamides, also modified urethane and polyethylene. Usually the properties of FRP are determined by looking at its mechanical properties such as:

i) *Basic mechanical properties of unidirectional composites*

- The main part of FRP rod is unidirectional (UD) composite. UD has very different moduli and strength values in fibre and transverse direction. The transverse modulus and strength of unidirectional composite mainly depend on resin properties.

ii) *Effects of loading direction on the tensile strength*

- Strength in inclined direction to the bar axis and against bending must be studied when FRP reinforcement is used as stirrups or prestressing tendons.

iii) *Thermal characteristics*

- The expansion coefficient for continuous fibre materials is governed by the thermal expansion of the resin. This coefficient of thermal expansion can be 5 to 8 times higher than the corresponding value for concrete.

iv) *Creep characteristics*

- The FRP materials have lower modulus of elasticity than steel reinforcements. The FRP with its lower modulus of elasticity is well designed for use as prestressing reinforcement, because creep of concrete will not affect the prestressing force as much.

v) *Long term strength*

- The long-term strength of FRP is influenced by aggressive environments and by stress corrosion.

vi) *Fatigue*

- Most FRP reveal excellent fatigue properties. The influence of moisture to fatigue resistance is essential and can reduce the fatigue limit significantly (up to 2 times).

2.1.1 ***Behaviour of FRP***

FRP has its own special characteristics, which has made it to become a special material to be used nowadays. It has high compressive, flexural and shear strength besides having good ductility. In considering the possible synergy of polymer composites with other materials, FRP has a mere distinction. FRP is simply a better replacement material with advantages such as corrosion resistance, low weight, high strength and true synergistic behaviour. It is also easy to handle and fabricate. FRP is often used in conjunction with other materials in building and no more remarkable than other familiar materials, such as timber, glass, metal and brick.

The manufacturing of concrete structural members such as columns, piers and piles also can be improved by incorporating fibre-reinforced-plastic (FRP) exterior shells and FRP interior sub members. Besides that, the exterior shell of FRP can act as a form of casting for concrete. Another behaviour of the FRP is it may prevent the intrusion of moisture that helps to retard the environmental degradation of concrete and corrosion of any steel that is embedded in the concrete [1]. These behaviours of FRP have made the concrete structural members become more durable and have greater strength.

It has been mentioned that FRP has been suggested as an alternative material to conventional steel for use in concrete structures primarily due to their corrosion resistance, as well as their strength-to-weight ratio. However, compared with steel reinforcement, FRP exhibits differences in mechanical properties, which naturally infer different design and construction approaches. Due to the relatively low stiffness of FRP materials compared to steel, concrete structures containing FRP have to be prestressed [2]. In this way, much of the FRP strain capacity is removed, leading to the achievement of similar strain levels between concrete and FRP under flexural conditions, so that both materials are used efficiently.

2.1.2 Usage / Application of FRP

The application of Fibre Reinforced Concrete sheet implemented with epoxy resin for RC structure strengthening or retrofitting has received considerable attentions due to its high strength, light-weight, quick and easily handled on site, high resistance against corrosion and fabrication ease.

Its application includes changing of usage, increasing safety requirement and improved deterioration of existing structure. The effective strengthening method of FRP has become widely used in America, Canada, Japan and Europe recently. [3] The method is done by applying the FRP sheets on the existing RC structure such as beams and column by wrapping the sheet around the structure due to the concrete confinement. The concept of confining has also been used for strengthening and retrofitting of concrete structure. The column retrofitted by wrapping FRP sheets may gain substantial enhancement in strength, ductility and shear performance.

Other usage of FRP materials include strengthening structures such as floors, bridges, silos, cooling towers and chimneys, has rapidly gained acceptance worldwide. It has also being used as direct replacements to conventional materials such as cladding for steel–framed buildings which is used to profile steel or timbers. Other direct replacement of timber by FRP includes ladders, scaffold boards, fascia boards, bridge decks, cabins, marine piles, doors and windows, utility poles and flag poles, concrete formwork and boats. [3]

For beams and bridges, generally, the strengthening technique involves bonding either unstressed or pre-stressed carbon fibre reinforced plastic plates to the underside (soffit) or bottom flange of the beam. The behaviour of FRP has made the concrete structural members become more durable and have greater strength. This may be the advantage in bridge or other similar construction in hurricane-prone coastal areas, earthquake zones, and regions where moist concrete is damaged during freeze/thaw cycles. [1]

FRP as Marine Structure

Fibre Reinforced Plastic (FRP) has been used for marine structures especially for marine retaining walls in applications such as beaches, causeways, docks, and harbours lakes, residential developments, rivers and streams. Besides that, FRP composite also has been installed as fender and structural piles for piers, docks, and wharves. The design of composite piles varies depending on the type of pile and the performance required. The FRP material is preferably used for marine structure as it gives defined, uniform and predictable strength and stiffness properties as well as good resistance to corrosion. In contrast, wood may experience large variation in properties due to cracking, splintering or other damage especially when expose to humidity.

Hybrid Column

Another application of FRP which is proposed nowadays is the hybrid column; FRP tube filled with concrete which can be for either pre-cast or cast in-place construction. The primary objective of hybrid column is to utilise the full section confinement of concrete by FRP with or without reinforcement to enhance load carrying capacity and durability of the column (Figure 1). The FRP tube acts as formwork, protective jacket, confinement and shear and flexural reinforcement.

Longitudinal and transverse stiffening ribs in the tube will act as shear connectors and load distribution mechanism. This may give benefits to the concrete as it is protected from the harsh environment effects and increase the column's strength by confining the concrete core [4]. Applying hybrid column is also cost effective as it reduces the cross-sectional area required for the same load. Moreover, the use of FRP form to pour concrete and retaining the FRP as part of the structural system would save labour cost and construction time. [5]

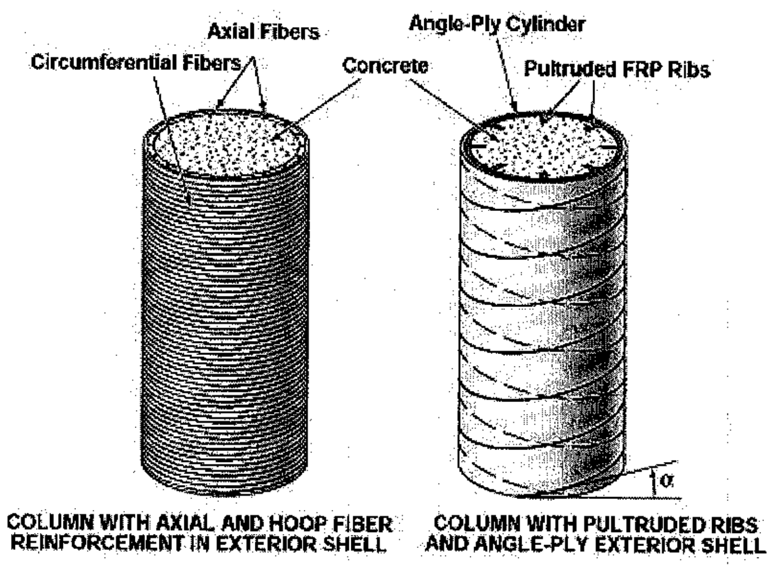


Figure 1 Hybrid column

FRP for Bridge Construction

Fibre Reinforced Plastic (FRP) composite has been considered for construction of bridges as it offers several advantages including superior strength-to-weight ratio and higher corrosion resistance. The composites tube is being used as replacement to conventional bridge substructure piles and pier columns [6]. Commonly bridge structures are made of steel or wood, as it is light and easier to construct compare to concrete. Nevertheless, corrosion of steel reinforcement in harsh environment usually causes problems to many steel bridges structures. Thus it has resulted in costly repairing and maintenance processes. Figure 2 shows the typical bridge substructure with a concrete-filled FRP tube support system. The tube acts as a structurally integrated pour form for the concrete and also acts as corrosion restraint for concrete core in harsh environments thereby increase the life span of the structure. Nevertheless, studies of FRP piles are very rare due mainly to their novelty.

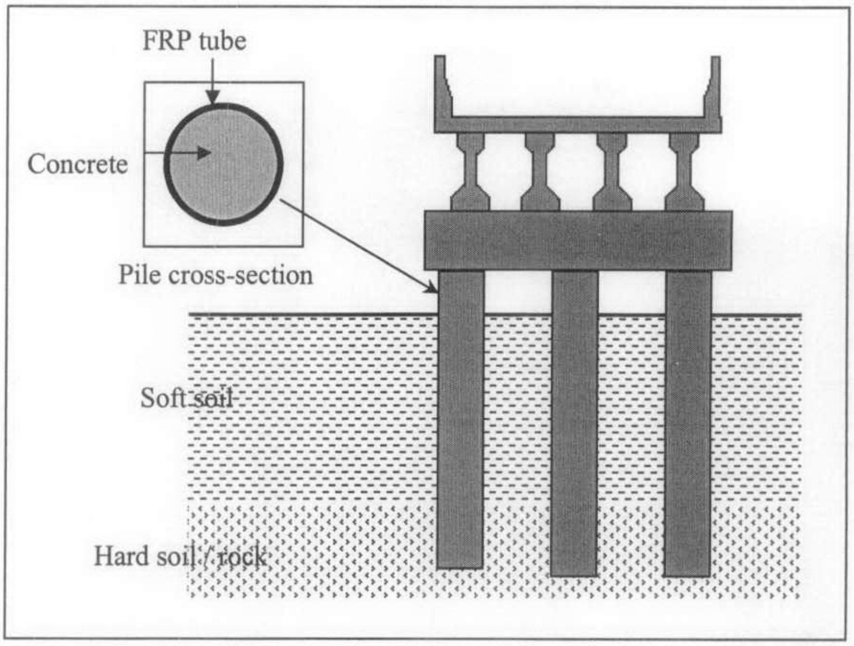


Figure 2 Typical bridge substructure with a concrete-filled FRP tube support system

Based on the analysis done by Ashford and Jakrapiyanum, they have concluded that FRP piles can reasonably attain equivalent design capacity of the conventional steel and concrete piles. However, FRP pile has low impedance that may limit the ultimate bearing capacity.

Besides, FRP also has been accepted to be applied as the bridge decks and also retrofitting existence bridges. A statistic has shown that most bridges are considered deficient or functionally obsolete due to poor physical condition of their respective decks. The poor deck condition is typically caused by exposure to weathering as well as rusting of internal reinforcing steel (the increase in steel bar diameter due to rusting introduces crack-inducing tensile stress within the concrete which may lead to deck spell). However, the recent investigation on FRP composites have revealed that FRP material is a better replacement for the bridge decks as it has higher strength, lighter in weight and more corrosion resistance. [7]

FRP as Aircraft Structure

Choosing the right material to improve flight performance is the most critical part in aerospace structures. The materials such as weight reduction, compliance to strength should satisfy several important factors, stiffness and stability requirements to conform the ability to withstand aerodynamic loads experienced by a structure in various flights conditions. Fibre reinforced composite materials have been found to have promising properties in this regard. Based on research done by Professor K.P. Rao, Carbon Fibre Reinforced Plastics (CFRP) are used extensively in aircraft structures as they give high stiffness and strength with lower weight. [8] Typical composite components of aircraft are wings, empennage and parts of fuselage. Cut-outs are introduced in these structures for lightening the component. Now, the FRP materials are being used broadly in the production of various aircraft components. This is due to the fact that it has a very high strength-to-weight ratio, higher damage tolerance, better manufacturability and lesser number of joints compared to conventional materials.

2.1.3 Advantages of Using FRP

FRP composites represent an alternative construction material without many of the performance disadvantages of conventional materials such as rot, rust, and spall. It also offers long-term and low-maintenance solutions. Thus, it is more economical when considering life-cycle cost.

The advantage of using FRP plates is it may reduce the dead load on the structure. This is due to the properties of FRP which has much higher tensile strength than steel but with much less weight. Other primary advantage of FRP components is the ability it to be prefabricated and tailor-made. There are numerous examples of applications where FRP offers a highly cost effective and practical alternative such as septic tanks, swimming pools and spa baths, water tanks, motorway sign gantries, pipe work and ducting.

Other benefits that FRP material can provide include:

- Corrosion resistance
- Ability to absorb the energy of vessel impact through recoverable deflection.
- Impervious to marine borers (long-term performance)

- Pre-engineered products and systems with predictable performance characteristics
- High-strength providing uniform properties
- Installation requires no specialised tooling or techniques.
- Lightweight for easy field installation
- Environmentally safe because there is no leaching of toxic preservatives or treatments
- Dimensionally stable for installation and long-term weather performance
- Custom colours available to blend into the surrounding environment
- Reduced installation time (one-piece construction)
- Low-maintenance (varies with installation and use)
- Nonmagnetic (facilities requiring low magnetic signatures)
- Non-conductive (facilities requiring low electrical conductivity)

*2.1.4 **FRP-to-Concrete Bonding***

In general, FRP is externally bonded to concrete by way of adhesives, and transfer of the interfacial stresses to the concrete is governed through bond. The ultimate load carrying capacity of the retrofitted members is directly influenced by bond, and for this reason the subject has received much attention. Research has been performed for determination of local bond behaviour in terms of the characteristic properties, factors affecting these properties, and the mechanism of bond failure. While the experimental approach taken by the investigators varies across the spectrum, in general, the specimens are designed to accommodate pull out of the FRP layer from the concrete substrate. [9]

The failure modes of reinforced concrete having externally applied FRP retrofit measures can be grouped into six distinct categories [Buyukozturk et al., 1998]: steel yield and FRP rupture, concrete compression failure, shear failure, failure of cover concrete along reinforcing steel layer (splitting), delaminating of FRP material and peeling of FRP material due to shear distortions and cracking. The delaminating and peeling modes are directly related to the properties of the bond between the FRP and concrete substrate. Since structural performance relies on the bond between FRP and concrete, the characteristics of the bond and methods to evaluate it are critical to understanding and evaluating FRP retrofitting techniques, their behaviour and failure mechanisms [Kurtz, 2000]. Methods previously used to investigate FRP bond to concrete include: uniaxial tension tests, peel tests, direct and torsion shear tests and many others. [10]

2.2 Formwork

2.2.1 General

Formwork is a significant aspect of concrete construction. It usually represents a greater cost than the concrete itself. Formwork for concrete typically has three attributes: quality, safety and economy [11]. The surface of formwork that acts as supports and forming is used to define the shape of concrete until it is self-supporting.

Formwork is a mould or a box which temporary offers support to pre-cast or insitu concrete structures. It holds the concrete and set it to the inner profile of the structure. So the inner profile must be fitted to the required shape and dimensions. The formwork should be supported until it cures sufficiently to become self-supporting. Formwork includes the actual material in contact with the concrete (form face) and all the necessary associated supporting structure. Formwork, which has the basic abilities of supporting new concrete, shaping and smoothing the surface, also influences the durability of the near surface concrete. Some factors such as formwork surfaces, concrete mixing and casting; and formwork set-up and joining points are important in relation to the formation of surface defects. [13]

Formwork that subjected to light loads requires a rational approach based on simplified assumptions and approximate beam formulas. However, a detailed structural design of formwork is required for extremely heavy loading, or where there is unusual danger to life or property. The formwork structure should be strong enough to hold the concrete in the desired size and shape until the concrete hardens and becomes self-supporting [12]. The design in the preliminary stages generally involves some guesswork backed by engineering judgement and experience.

2.2.2 Materials of Formwork

There are three main materials that are commonly used as formwork: metal or steel formwork, timber and plywood.

Timber Formwork

Timber is the most commonly used material for general formwork because it is easy to cut into shapes, fix and dismantle and cheap. Timber formwork is usually made from softwood that is free from excessive knots and other defects. Nevertheless, timber formwork may face a problem that is caused by the rapid absorption of the moisture from the concrete. Therefore timber should be wet before concrete is placed. Dry timber will absorb the moisture from the wet concrete that could weaken the resultant concrete member. Wetting the timber will prevent moisture to be absorbed too fast from the wet concrete. However if the timber is too wet, it will shrink and may cause open joints and leakage of grout.

Timber formwork is commonly used for the construction of cast-in-situ concrete structures because of its versatility and ease of handling. It contributes 35% to 60% of the construction cost. Therefore, the reuse of timber is required for substantial cost savings for the contractor. The ability to reuse the timber formwork may reduce the demand for timber that leads to reduction in logging and environmental degradation. [13]

During the initial stage of concreting, many uses of formwork can be obtained and a reasonable finish of the concrete can be achieved. However, observations of construction practice revealed that formwork sets are only reused after substantial alterations and maintenance are carried out. Therefore, it is important to identify and recognise the factors that influence the reusability of timber formwork. (Figure 3)

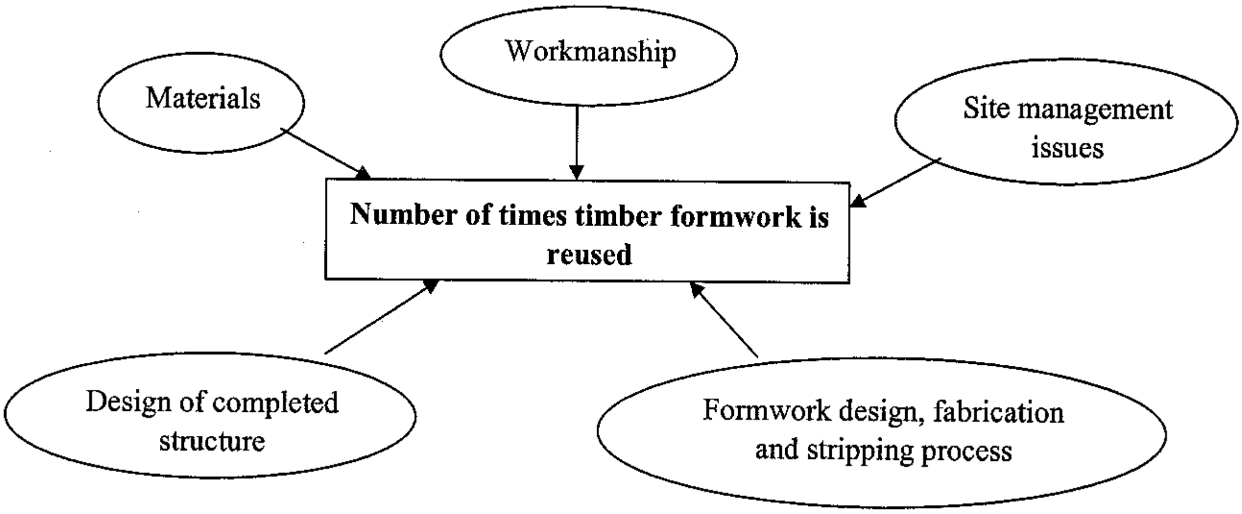


Figure 3 Factors affecting the reuse of timber formwork.

Traditional shuttering techniques for forming in-situ ground beams are increasingly being replaced by quicker and less labour intensive alternatives. A trend that is encouraged by the emphasis on fast track building programs and a shortage of skilled tradesmen. There have been some interesting trends and developments in the concrete construction industry concerning formwork over the last few decades. It has progressed from highly labour intensive traditional timber formwork, to sophisticated machinery and proprietary equipment that allows high output rates to be achieved. This has been achieved through developments in the technical knowledge and machinery that makes large quantities of concrete readily available at a consistent quality. [11] Consequently, equipment for lifting and handling the rapid placement of concrete was developed. This further led to the development in new forming materials such as aluminium, steel, plywood, plastics, glass-fibre and proprietary systems. This has taken the design of formwork further away from the foreman and carpenter on site, and brought in the temporary works designer and an improved engineering approach to design. [12]

Metal formwork

Metal formwork is more economical than timber where repetitive work is necessary. Metal formworks must be handled correctly where it must be cleaned thoroughly, oiled and maintained after each use. Such maintenance will continue to give smooth concrete finish. Metal formwork is made up of spatially made shallow rectangular pans of various sizes. They are clipped or bolted together to form the required shapes. The main disadvantage of using metal formwork is the formation of rusts under humid condition.

Plywood formwork

Thick plywood, which is smooth, fairly rigid and in large sizes is most suitable for formwork. The advantage of using plywood as formwork is that it gives a good surface finish. Thus there is no requirement for any further treatment. Plywood formwork can be used many times and easy to handle. However plywood sheets are very expensive. Curved formwork is most satisfactorily constructed by forming plywood to the required curve and fixing it to a rigid timber frame.

Aluminium Formwork

Nowadays, the Aluminium Formwork System for concreting has been said as the most versatile modern construction system. It is equally suited to both high and low raise constructions. Aluminium formwork is specifically designed to allow the rapid construction of multiple unit projects at optimum productivity. It can be used for a broad range of applications, from straightforward panels to more complicated structures involving bay windows, stairs and A/C hoods.

Compared to timber, the degree of pre engineering and inherent simplicity of the aluminium formwork enables unskilled foreign labour to be used. Furthermore, every component is light enough to be handled by one operative, minimising the need for heavy lifting equipment. The simplicity of aluminium formwork and the repetitive nature of the assembly process make it possible to accurately program construction sequences and thus cycle times well in advance. In addition this enables unskilled labour to work with the formwork therefore reducing the burden on skilled labour when this is in short supply. [14]

	Timber Formwork	Aluminium System Formwork
Material	Timber and Plywood	All Aluminium
Durability	20 times	120-150 times
Wastage	Yes	No
Quality	Subject to Workmanship	Good
Labour	Skilled	Unskilled
Flexibility	More	Less

Table 1 Comparison of Aluminium system and Timber Formwork

2.2.3 Removability and Striking of Formwork

Forms may have to remain undistributed until the concrete reaches a minimum strength until it is sufficiently cured, of the required colour or to protect it. Formworks must be struck slowly and must not be struck until the concrete is strong enough to be self-supporting because edges can be damaged. [15] The appropriate time, which it is safe to remove the formwork, depends on the type of element. Usually the minimum striking time varies from 1-28 days.

2.2.4 Maintenance and Storage of Formwork

Provision must be made for the removal and storage of large sections of formwork. A level storage area is required to store formwork after striking. They should be well cleaned before storing because the grout remaining on the forms become hard and stubborn. Then it is difficult to reuse. Metal panels need a light coating of oil before storage to prevent rust.

All forms need to be carefully stacked and stored. Panels of forms should be kept horizontal and face to face. The forms need to be carefully stacked and face to face. The forms and components should be clearly marked and kept together for easy identification on re-use. A tidy store reduces wastage, damage and losses.

2.2.5 *Permanent Formwork*

Permanent Formwork is an alternative for the traditional formwork, which finally has to be removed. Permanent formwork functions as the outer skin of a construction and is integrated into the concrete after the casting. Applying permanent formwork will save money because the removal and maintenance of traditional formwork can be left out.

In this project, the FRP is not applied to the existing structure but is being used as permanent formwork to the newly design concrete structure. There have been many researches and testing done on the application of FRP as concrete reinforcement. This is due to FRP characteristics, which are durable and strong. Therefore, it can be said that FRP also can be used as formwork to replace the conventional formwork. In order to apply this theory, research and testing must be done to make sure this idea is relatively beneficial either in terms of engineering or cost.

Permanent formwork is a structural element that is used to contain the placed concrete and mould it to the required dimensions. It will remain in place for the life of the structure. There are two types of permanent formwork being used, participating and non-participating formwork. Participating permanent formwork contributes to the ultimate strength and also serviceability of the structure. It also contributes to the durability of the structure. The use of participating formwork also can results in significant shift in emphasis during the design process from the basic requirement to form the concrete into a particular shape to the design and detailing of the composite sections.

In contrast, non-participating permanent formwork does not act compositely to the structure where there is no contribution to the strength of the structure. However, non-participating formwork may give alternative contribution to the structure such as increase the durability and give smooth finishing and also improve the insulation depending on materials used (R G Wrigley,2001). The durability can be increased by the thickness of the formwork where it gives additional and effective covering to the concrete reinforcement.

The normal erection and striking of conventional timber formwork and its associated false work is quite costly, time consuming, potentially hazardous and virtually impossible (in some locations). In contrast, permanent formwork will give more advantage due to its correct application. It may reduce cost of construction and also cost of maintenance. Thus applying permanent formwork also can reduce the construction time where it is not required to remove the formwork.

Permanent formwork may reduce costs and time by:

- eliminating or reducing the need of false work
- reducing the skill required on site
- increasing the potential of standardisation and repetition
- permitting prefabrication in factory conditions
- speeding erection time, particularly in building works
- eliminating the need to strike formwork and false work
- allowing early access for following or concurrent constructions
- eliminating programs limitations of re-use of formwork
- improving curing of concrete and reduce shrinkage cracking
- ensuring adequate cover to the reinforcement and providing associated benefits such as increase resistance to chloride ingress and carbonation
- improving durability of structure
- providing decorative finish required

Besides the above, appropriate usage of permanent formwork would also reduce hazards during construction as erection or striking of formwork especially at difficult location could be eliminated. For example, when doing bridge works where formwork has to be erected over the rail or water or at any confined space.

CHAPTER 3
METHODOLOGY / PROJECT WORK

3.1 Project Planning

This methodology will take a combination and variation of the existing methodologies and apply it to suit the time frame condition and the huge amount of research needed. Figure 4 shows the methodology that is used in the development of this project.

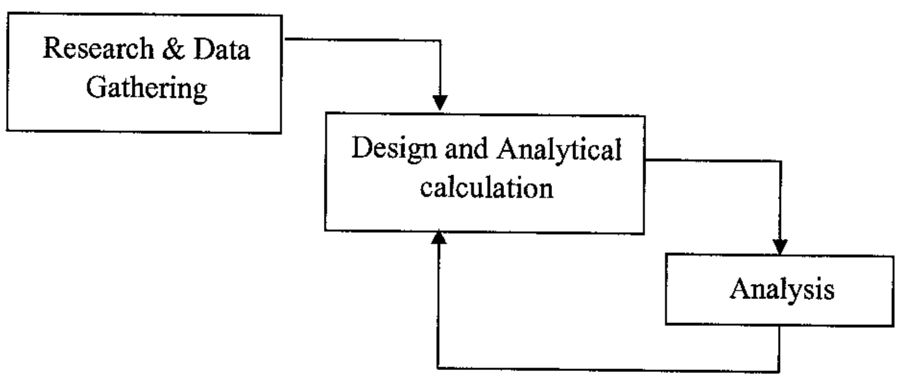


Figure 4 Methodology Used in this Project

The analysis of the information gathered and also the data collected from the testing is to be undertaken. Based on the analyses, new information can be extracted and conclusion of this project can be made.

3.2 Research and Data Gathering

From Figure 4, the first phase of the methodology is information gathering and facts finding that involve research on previous projects regarding the same area and fact-finding of Fibre Reinforced Plastic (FRP) and formwork. Sources such as textbooks, telecommunication and Reinforced Plastic magazines, articles and journals are used as resources of information. A preliminary and feasibility study on potential hardware, software and concept that will be used in this project is done during this phase.

3.3 Design and Analytical Calculation

After all the information has been gathered and researches have been done, the design phase will take place. In this phase, a concrete beam is designed to assist in the project to be carried out. Analytical calculation of the finite element is done to observe the behaviour of the concrete beam with FRP plate. The required area of FRP plate that can withstand the concrete load is obtained. The method of calculation used for this matter is similar with the one to calculate the area of the reinforced steel bar for concrete beam.

3.3.1 Beam Design

Firstly a beam is designed to obtain the required reinforcement area. Following formulas and steps are taken from the BS 8110 and being applied for calculation;

a) Design Load

Total design load, w = 1.4 Dead load (DL) + 1.6 Live load (LL)

Dead load, DL = Beam self weight + Finishing

b) Beam Shear , V = wL / 2

c) Bending moment, M = $wL^2 / 8$

d) Finding K and z value

$$K = \frac{M}{f_{cu} bd^2}$$

$$z = (0.5 + \sqrt{0.25 - K/0.9}\,)\,d$$

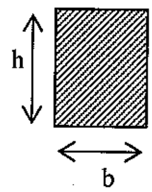
e) Area of reinforcement

$$As = \frac{M}{0.87 f_y z}$$

3.3.2 Moment of Inertia

The moment of inertia I_{xx} of the various cross sections is given by

a) Rectangular section



$$I_{xx} = (^1/_{12})(b)(h^3)$$

Value b is taken to be the side parallels to the reference axis and h the height of the section

b) Irregular sections

An irregular section is when the component parts which are not symmetrically distributed about the centroidal axis. To determine the moment of inertia of such a section is to find the moment of inertia of the component parts about their own centroidal axis and then apply the transfer formula. The transfer formula transfers the moment of inertia of a section or area from its own centroidal axis to another parallel axis.

$$I_x = I_c + (A)d^2$$

Where:

I_x = moment of inertia about axis x-x (in^4)

I_c = moment of inertia about the centroidal axis c-c parallel to x-x (in^4)

A = area of the section (in^2)

d = perpendicular distance between the parallel axes x-x and c-c (in)

3.3.3 *Deflection*

The allowable deflection of the beam is taken as L/360th of the span (L/360). The deflection of beam based on the distributed load is given by the formula:

$$\Delta = 5wL^4 / 384 EI$$

where, E = Modulus of Elasticity

I = Moment of Inertia

w = Total load

L = Length of beam

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Fibre Reinforced Plastic (FRP) – The Advance of Composite Material

Fibre Reinforced Plastic (FRP) material is a matrix of polymeric material reinforced by fibres or other reinforcement that has a discernible aspect ratio of length to thickness. That is, it is extremely thin, yet very strong. The reinforcement provides the oriented strength and the polymer matrix hold the reinforcement in its proper orientation to provide optimum properties. See Figure 5

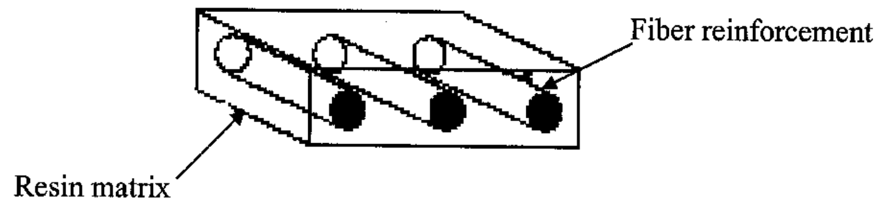


Figure 5 Composite System; Tow Sheet Cross Sections

Commercial applications of composite material began in the 1960s in the aircraft and aerospace industries. Utilising the basic composite characteristics of lightweight, thin, and high tensile strength, other industries adapted the use of the materials. Products ranging from bicycle frames, golf club shafts racecars and tennis rackets all embraced the benefits of composite materials.

The polymer resin systems can either be thermoset or thermoplastic in nature. Thermoset are typically used for construction applications and can be polyester, vinyl ester, phenolic or epoxy resin systems. The type and percentage of fibres selected depends on the performance criteria as established by the design engineer.

Advanced fibre reinforcement materials for construction are primarily:

- Carbon fibre (CFRP)
- Aramid, (AFRP)
- E-Glass, (GFRP)
- Hybrids

Below are the properties of FRP taken from different sources. The basic properties of glass, carbon and aramid FRP compared to steel are outlined in Table 2 while other typical properties are given in Table 3. There are various tables of properties of FRP material as the fabrication of FRP varies depending on the percentage of fibres used as well as their arrangement and lamination. See Appendix A.

Table 2 Basic Properties of Glass, Carbon and Aramid FRP Compared to Steel (American Concrete Institute)

PROPERTY	**GLASS FRP**	**CARBON FRP**	**ARAMID FRP**	**STEEL**
Tensile Strength (ksi)	200 – 250	240 – 350	170 – 300	200 - 270
Modulus of Elasticity (Gsi)	7 – 9	22 – 24	7 – 11	27 – 29
Elongation	0.003 – 0.45	0.01 – 0.015	0.02 – 0.026	0.04
Coefficient of Thermal Expansion (10° / °F	5.5	0	-0.5	6.5
Specific Gravity	2.4	1.6	1.25	7.9

(Source: An Overview of the Use of Composite Material for Structural Enhancement; G.J Martz Solis Ingo., Article)

Table 3 Typical Mechanical Properties of Glass. Carbon and Aramid FRP (Head 1996)

Unidirectional Advance FRP Materials	Fibre Content (% by weight)	Density (kg/m^3)	Longitudinal Tensile Modulus (GPa)	Tensile Strength (MPa)
Glass fibre/polyester GFRP laminate	50 – 80	1600 – 2000	20 – 55	400 – 1800
Carbon/epoxy CFRP laminate	65 – 75	1600 – 1900	120 – 250	1200 – 2250
Aramid/epoxy AFRP laminate	60 – 70	1050 – 1250	40 – 125	1000 – 1800

(Source: FRP Strengthened RC Structure, John Wiley & Sons Ltd. Text Book)

The inherent advantages of the composite materials when compared to conventional materials include:

- Corrosion resistance
- Light weight
- High strength
- Design flexibility
- Low maintenance
- Durability

The use of Fibre Reinforced Plastic (FRP) composite materials for infrastructure rehabilitation and retrofit applications has been widely studied. The advantages of FRP composite materials are that they have high specific stiffness and specific strength ratios, outstanding fatigue behaviour, corrosion resistance, and are light and easy to handle.

The structural benefits of a composite system include an increase in strength, stiffness and toughness yet this high performing technology saves 25% to 50 % in labour costs due to ease of installation.

4.2 Applying FRP as Permanent Formwork

The main focus of this project is to apply the FRP as permanent formwork. The permanent formwork will also act as the concrete reinforcement. In such situation the concrete structure is will not require the normal steel bar reinforcement. Although FRP is more expensive than the traditional formwork materials, there can be net savings in cost from the elimination of the cost of steel bars. This permanent FRP formwork will then provide the reinforcement to the concrete structure, in place of steel bars.

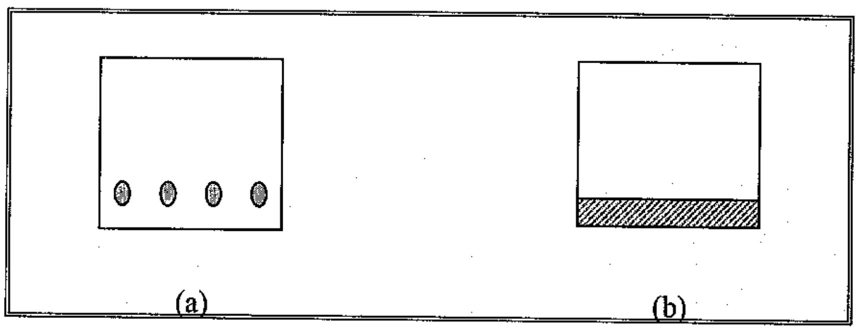


Figure 6 Cross-section of (a) normal reinforced beam and (b) beam with FRP permanent formwork.

4.3 FRP Plate for Concrete Reinforcement

As the FRP plate formwork will also act as the reinforcement, its strength must be sufficient enough to avoid the concrete bending or failure. Therefore, the appropriate size of FRP plate must be calculated. The method of calculation used for this matter is similar with method to calculate the area for the reinforced steel bar for concrete beam.

4.3.1 Concrete beam design, reinforced with steel bar.

The first step in obtaining the required area is to design the beam. The area of reinforce steel bar is also calculated for comparison. The calculation to design the beam and obtain the required area is presented below.

Concrete Beam Design

A simply supported beam of 1-meter (1000-mm) length is considered. The cross section of the beam is taken as 150 mm x 150 mm. The beam is assumed to carry a uniform live load of 3.0 kN/ m^2 (Figure 2). (The 3.0 kN/ m^2 uniform distributed live load is for lecture room; taken from BS 6399 Part 1 and CP3: Chapter V: Part2.)

Take concrete grade, f_{cu} is taken as 25 N/mm^2 and the Modulus of Elasticity for concrete, E is taken as 28 kN/ mm2. High yield steel is used where the steel grade, f_y is 460 N/mm^2.

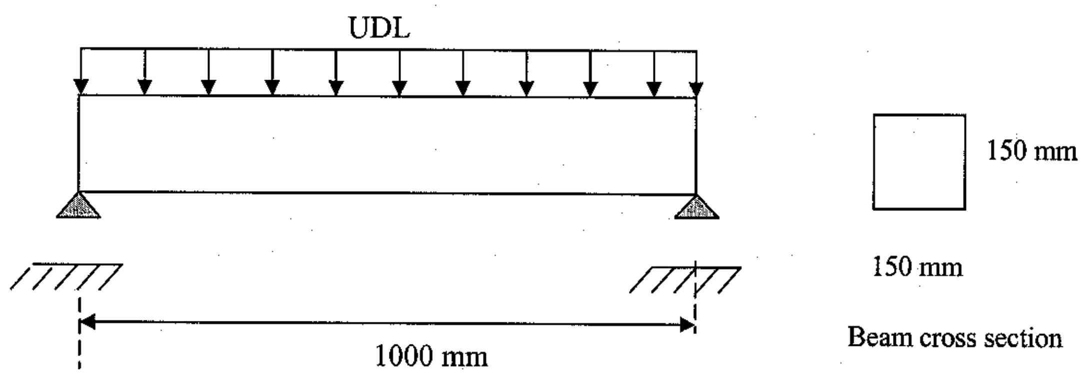


Figure 7 1000 mm concrete beam with Uniformly Distributed Load

f) Design Load

Dead load (beam self weight) + Finishing, DL

= (ρ x b x h) + 1

= (24 kN/m^3 x 0.15m x 0.15m) + 1 kN/m

= <u>1.54 kN/m</u>

Live load, LL = 3.0 kN/m^2 x 0.15m

= <u>0.45 kN/m</u>

Total design load, w = 1.4 (DL) + 1.6 (LL)

= (1.4 x 1.54) + (1.6 x 0.45)

= <u>2.876 kN/m</u>

g) Beam Shear, V $= wL / 2$

$= (2.876\ kN/m \times 1m) / 2$

$= \underline{1.438\ kN}$

h) Bending moment, M $= wL^2 / 8$

$= (2.876\ kN/m \times 1m^2) / 8$

$= \underline{0.36\ kNm}$

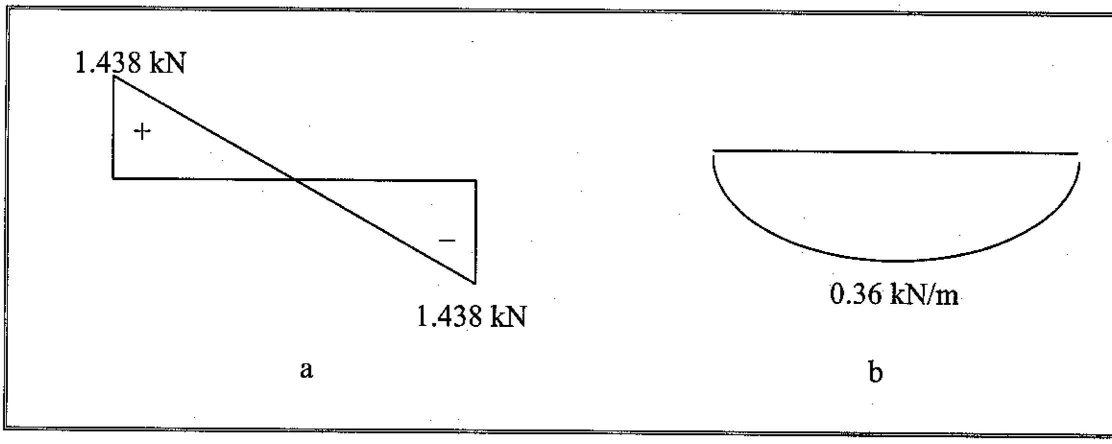


Figure 8 (a) Beam shear diagram and (b) Beam bending moment diagram

i) Designing beam (using BS 8110)

$$K = \frac{M}{f_{cu} b d^2} = \frac{0.36 x E^6}{25 \times 150 \times 125^2}$$

$= \underline{0.006\ \text{Beam is singly reinforced}}$

$$z = (0.5 + \sqrt{0.25 - K/0.9}\ ) d$$

$$= (0.5 + \sqrt{0.25 - 0.006}\ / 0.9\ ) d$$

$= \underline{0.994d}$

Area of reinforcement steel bar

$$As = \frac{M}{0.87 f_y z} = \frac{0.36 \times E^6}{0.87 \times 460 \times (0.994 \times 125)}$$

$$= \underline{7.24 \text{ mm}^2}$$

* Use 1 T6 reinforcement bar ($As = 28.3 \text{ mm}^2$)

Based on the calculations made, the area of reinforcement steel bar for 1 meter concrete length is 7.24 mm^2. This area is too small where it can be neglected which means that the concrete beam is not required to be reinforced.

4.3.2 Concrete beam design, reinforced with FRP plate.

Referring on the calculation of concrete beam made previously, the area required for the FRP plate can be obtained. The FRP to be used is the Glass FRP, where the tensile strength, f_{frp} is taken as = 1100 MPa or 1100 N/mm^2 (The tensile strength is taken as the average value from the range of tensile strengths for Glass FRP from FRP properties in Table 3). The same formula used for obtaining steel area is applied to calculate the FRP plate required area.

Area of FRP plate

$$As = \frac{M}{0.87 f_y z} = \frac{0.36 \times E^6}{0.87 \times 1100 \times (0.994 \times 125)}$$

$$= \underline{3.027 \text{ mm}^2}$$

The area required for the FRP plate is 3.027 mm^2. This means cross-section of the plate can be taken as 150 mm x 0.02 mm. It is obtained from the calculation, where the required area divided with the beam width.

$$3.027 \text{ mm}^2 / 150 \text{ mm} = 0.02 \text{ mm}$$

The 0.02 mm thickness of FRP plate is too small. It is quite impossible to fabricate a plate with that thickness. Based on research done, the minimum thickness of FRP plate to be applied in construction and as can be fabricated by the manufacturer, is 3 mm.

Beam Deflection Check (FRP thickness = 3mm)

The allowable deflection of the beam is taken as L/360th of the span (L/360). The deflection of beam based on the distributed load is given by the formula:

$$\Delta = 5wL^4 / 384 EI$$

where, E = Modulus of Elasticity

I = Moment of Inertia

w = Total load

L = Length of beam

Modulus of Elasticity, E for the Glass FRP is taken as 38 GPa or 38000 N/mm^2. (This value is taken as the average value of the Modulus of Elasticity range value for Glass FRP. Refer Table 3).

Value for Moment of Inertia I, $= bh^3 / 12$

$= (150 \times 3^3) / 12$

$= \underline{112.5 \text{ mm}^4}$

The beam deflection, Δ

$$\Delta = 5wL^4 / 384 EI$$

$$= (5 \times 2.876 \times 1000^4) / (384 \times 38000 \times 112.5)$$

$$= \underline{8760 \text{ mm}}$$

The allowable deflection,

$$L / 360 = 1000 / 360$$

$$= \underline{2.8 \text{ mm}}$$

* Beam deflection is greater that allowable deflection

$\underline{8760 \text{ mm} < 8.3 \text{ mm}}$, Beam will deflect.

The above design calculation has indicated that the FRP plate with 3mm thick may deflect due to concrete load. This may be occurring due to insufficient Moment of Inertia from the cross-section of the FRP plate. For that reason, other design of FRP plate is done in order to come out with greater Moment of Inertia that can withstand the concrete load to be poured and will not deflect. Therefore, further calculation is made to come out with sufficient FRP plate section to be applied as the permanent formwork. Besides having flat regular formwork, the I section is also being considered as it may give greater cross-section area as well as greater Moment of Inertia, and it is assumed that that type of plate may help to reduce the deflection. Applying 2 mm, 3 mm and 5 mm thickness of FRP plate to see the differences does the calculation. Table 5 shows the result of Moment of Inertia of the FRP plate with different cross-section area. (Figure 9)

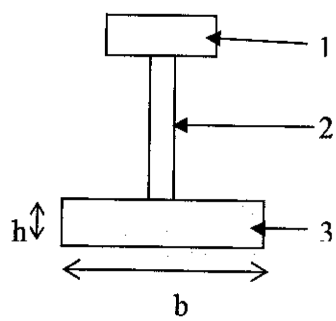


Figure 9 Cross-section of I plate

Appendix C shows the variation of cross-section of I plate and the value of the Moment of Inertia for each cross-section. From the Moment of Inertia values obtained, the deflection at mid-span is calculated (Appendix D). This is to observe whether that section of I plate can withstand the fresh concrete load. From the analyses of the results in Table 4, the FRP plate with greater thickness will be appropriate to be applied as the permanent formwork as it gives less deflection due to fresh concrete to be poured.

Beam Sample	Section 1		Section 2		Section 3		Total Area (mm^2)	Moment of Inertia, I (mm^4)	Deflection, Δ (mm)
	b	h	b	h	b	h			
P	20	2	2	30	150	2	400	48389	20.4
Q	20	3	3	40	150	3	630	140530	7.0
R	25	5	5	40	150	5	1075	287501	3.4
S	25	2	2	30	150	2	410	55192	17.9
T	25	3	3	40	150	3	645	158294	6.2
U	25	5	5	50	150	5	1125	453038	2.2
V	30	2	2	30	150	2	420	61671	16.0
W	30	3	3	40	150	3	660	175251	5.6
X	30	5	5	50	150	5	1150	497844	2.0

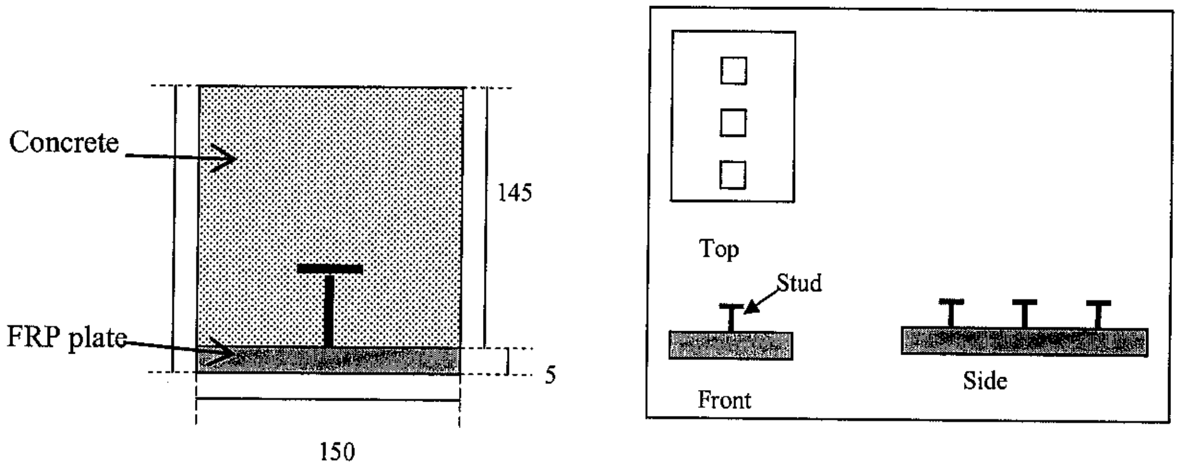
Table 4 Modulus of Elasticity and Deflection of various cross-section of I Plate

4.4 FRP Plate as Permanent Formwork

To be applied as the permanent formwork, the plate is designed differently from the one designed previously. This is because the FRP plate will not only being applied as permanent formwork, but will also act as the reinforcement to the concrete. Subsequently, there will be three schemes provided for the formwork design. The schemes are designed in such a way so that the formwork can carry the load and will not deflect or buckle as well as can reinforce the concrete. The purpose of having this different type of FRP scheme is to increase the cross-section area in order to increase the Moment of Inertia of the FRP plate. By doing this, the beam deflection can be decreased. Besides that, it is also to determine implication of the various behaviours, to the beam performance.

The three schemes are as shown below (Figure 10, Figure 11 and Figure 12). Basically all three schemes are different from the normal rectangular beam formwork as they have the additional of T shape section area. For Scheme 1 and Scheme 3 additional studs are placed on the FRP plate while for Scheme 2, the plate itself is in the I shape.

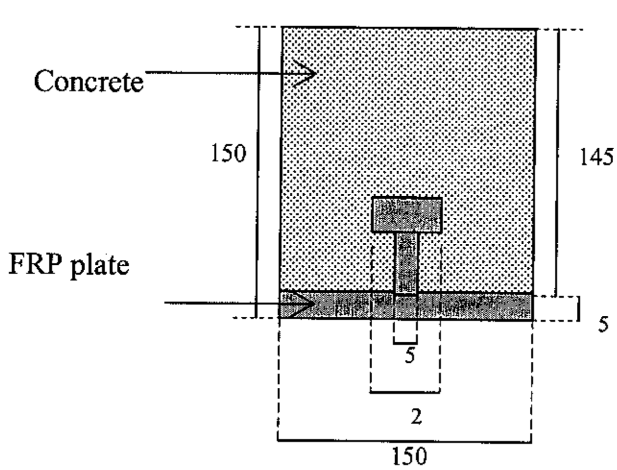
Scheme 1 is the basic design of FRP plate where it comprises of rectangular FRP plate as the base and there are studs on top of the plate (Figure 4). The studs, which are placed repeatedly at the same distance between each other, will act only as the bond material to avoid the concrete slip.



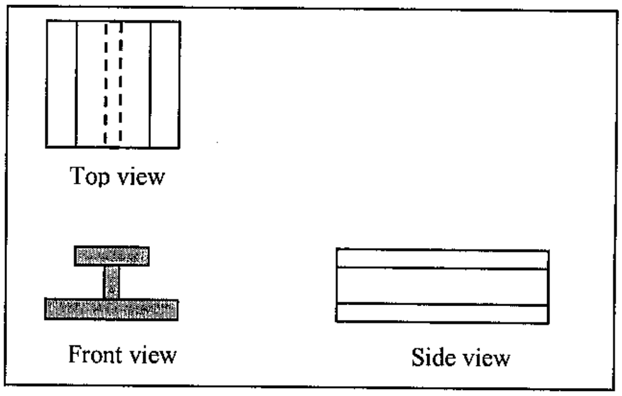
a) FRP-concrete beam b) Detail section of FRP plate

Figure 10 Scheme 1

For *Scheme 2*, the FRP plate is designed to have I shape cross-section. However, the width of T flange section above the bottom plate is smaller that the bottom plate width. As shown in Figure 5, the T section is continuous along the plate length.



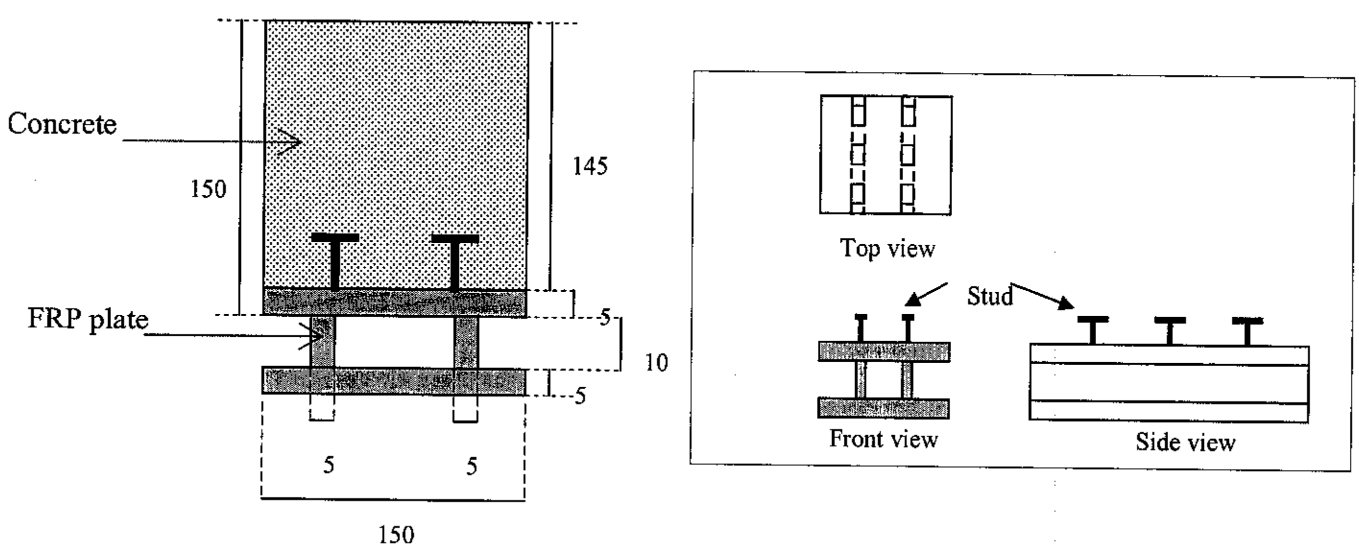
a) FRP-concrete beam



b) Detail section of FRP plate

Figure 11 Scheme 2

Scheme 3 has two layers of horizontal FRP plate that is connected with Vertical FRP plates. There are additional studs placed on the top layer plate. This design is made to overcome the bending and deflection of the concrete beam. The thickness of the two plates and the width of the vertical plate are suggested to be in the same length. By having two layers of FRP plate, it would increase the strength of the plate to perform as permanent formwork.



a) FRP-concrete beam

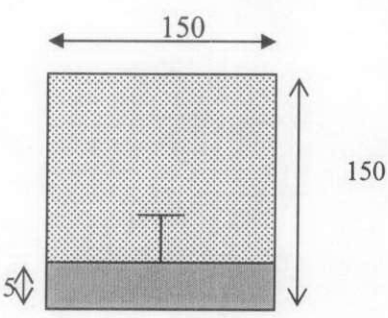
b) Detail section of FRP plate

Figure 12 Scheme 3

The idea to have studs or T section in the design is to make it function as the reinforcement for the concrete. Besides that, it also will be functioning as bonding material between the concrete and FPR plate. The vertical studs can help in preventing concrete from concrete sliding horizontally whereas the T flange can prevent concrete from sliding vertically.

4.4.1 ***Behaviour of FRP-concrete composite beam.***

The behaviour of the composite beam is observed by evaluating the stress and strain of the beam and the forces acting on it. The strain of FRP is taken as the control parameter. The strain of concrete can be determined from the strain diagram as the neutral axis of the beam is known. Later the stress of the FRP and concrete is obtained by referring to the stress-strain graph (Appendix D and E) for each material.



Information required:

Concrete Compressive strength f_{cu} = 25 N/mm^2

FRP Compressive strength, f_{rp} = 1100 N/mm^2

FRP Modulus of Elasticity, E_{frp} = 38 kN/mm^2

Modular ratio Modulus of Elasticity, n

$$n = \frac{E_{frp}}{E_c} = \frac{38 \text{ kN/mm}^2}{30 \text{ kN/mm}^2} = 1.27$$

	Area, A, mm^2	yi, m	yiA, mm^3	I self (bh^3/12) mm^4	yi – y, m	I transform (A (yi - y)^2) mm^4
Concrete	22500	75	1687500	42187500	0.65	9506.25
FRP	202.5	147.5	29869	1562.5	71.85	1045390.56
Σ	22702.5		1717369	42189062.5		

Table 5 Moment of Inertia of the Composite beam

Neutral centroid, y

$$y = \frac{\Sigma yiA}{\Sigma A}$$

$$= 75.7 \text{ mm}$$

Moment of Inertia for ideal beam (no crack) , I

$$I_n = I_{self} + I_{transform}$$

$$= 43243959 \text{ mm}^4$$

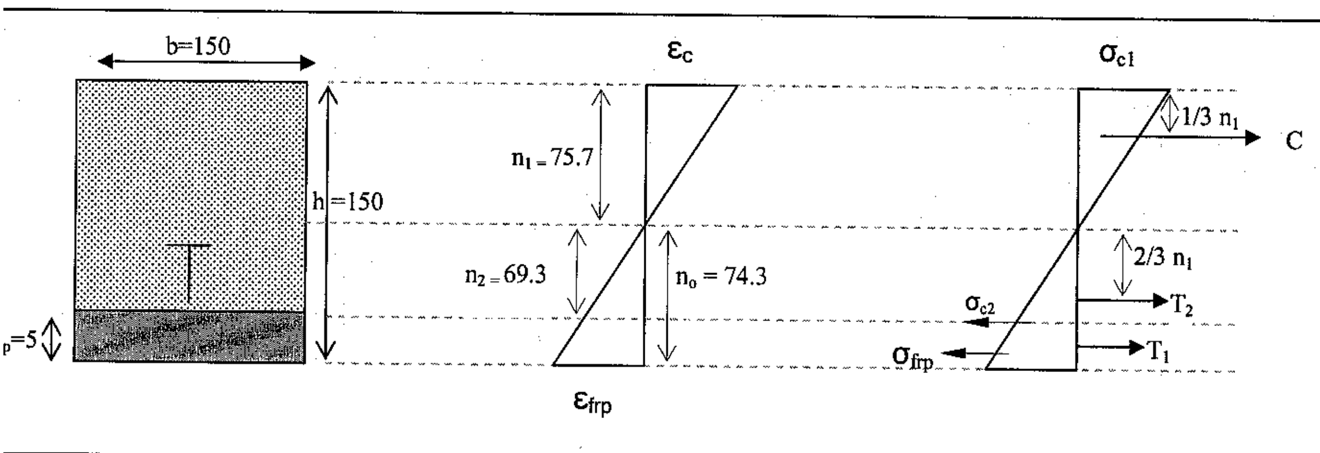


Figure 13 Strain – Stress block diagram

Data that can be obtained from the stress-strain block diagram:

i) Concrete Stress, f_c

$$f_c \text{ or } \varepsilon_c = f_{c''}\left[\frac{2\,\varepsilon_c}{\varepsilon_o} - \left|\frac{\varepsilon_c}{\varepsilon_o}\right|^2\right]$$

where $\varepsilon_o = 2 f_{c''} / E_c$

$E_c = 4730 \sqrt{f_{c''}}$ N/mm², given $f_{c'} = 25$ N/mm²

$= 23650$ N/mm²

ii) Tension Force,

$$T_1 = A_{frp} \,.\, \sigma_{frp}$$

$$T_2 = \tfrac{1}{2}\, \sigma_{c2} \,.\, n_2 \,.\, b$$

$$T = T_1 + T_2$$

iii) Compression Force,

$$C = \tfrac{1}{2}\, \sigma_{c1} \,.\, n_1 \,.\, b$$

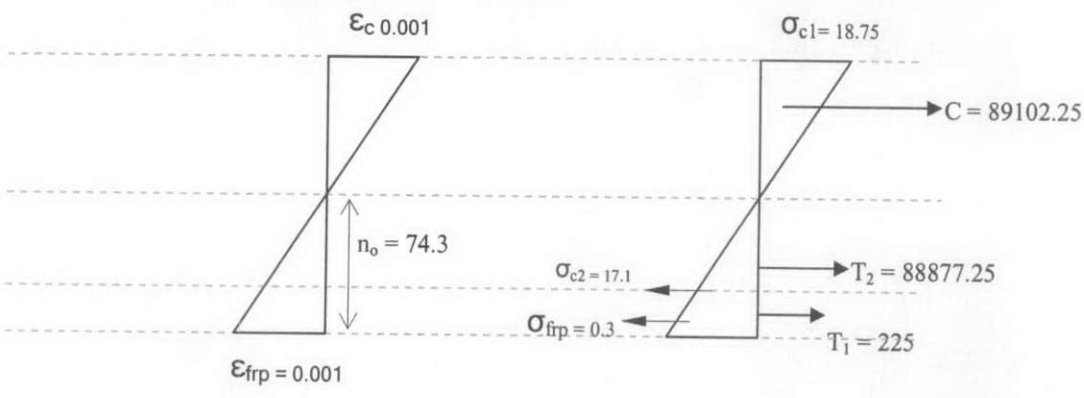
iv) Bending Moment,

$$M = C \,.\, 2/3\, n_1 + T\,(n_2 + t_{frp}/2)$$

FRP				Concrete		T (N)		C (N)	M (Nm)
strain	stress (N/mm2)		Area (mm2)	Strain	Stress (N/mm2)				
0.001	σ_{frp}	0.3	750	0.001	18.75	T_1	225	89102.25	10894.2
	σ_{c2}	17.1	200			T_2	88877.25		
0.002	σ_{frp}	0.6	750	0.002	25	T_1	450	119992.5	26844.3
	σ_{c2}	23	200			T_2	119542.5		
0.003	σ_{frp}	0.9	750	0.003	18.75	T_1	675	89552.25	20034.3
	σ_{c2}	17.1	200			T_2	88877.25		

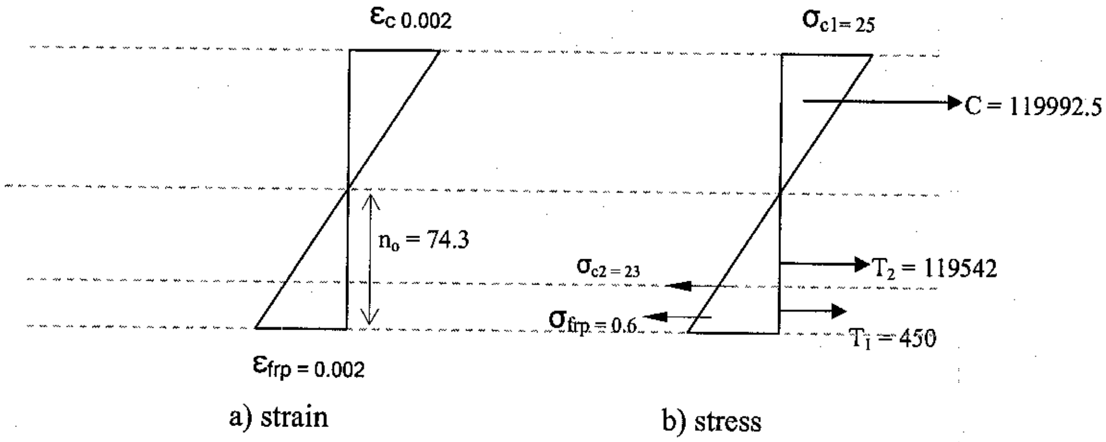
Table 6 Results obtained for the Strain – Stress block diagram of the FRP-Concrete composite beam

Case 1: Strain, ε_{frp} of FRP equals to 0.001

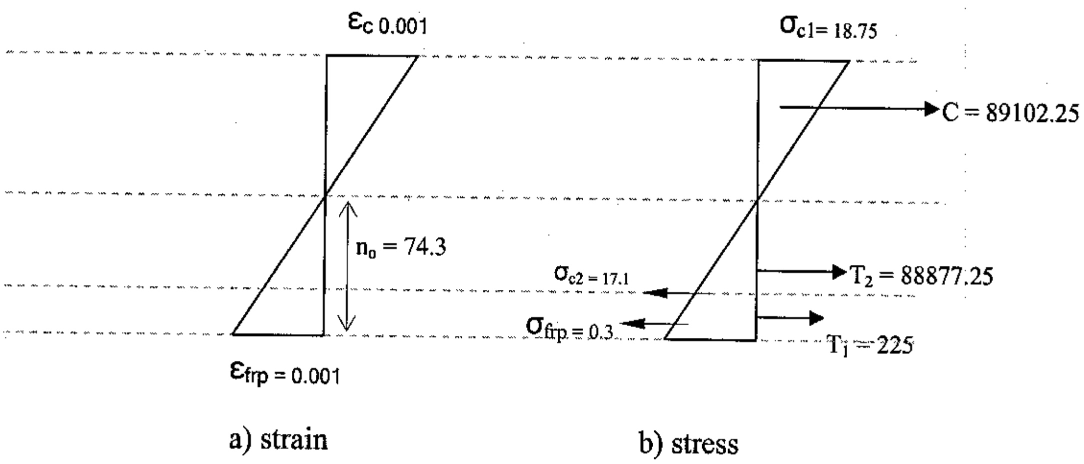


a) Strain b) Stress

Case 2: Strain, ε_{frp} of FRP equals to 0.002



Case 3 : Strain, ε_{frp} of FRP equals to 0.003



From diagram blocks that have been obtained, a graph of stress versus strain of the composite beam according to the different cases is plotted (Figure 14). By evaluating the graphs, further understanding of the beam behaviour can be achieved. It can be seen that the concrete will fail when at the strain of 0.002 while FRP plate is not. The beam experience failure at the compressive region. In this case, therefore the control parameter for this composite beam design is supposed to be the concrete strain instead of FRP strain. This is because the beam will be fail whenever the concrete fails regardless of the formwork behaviour

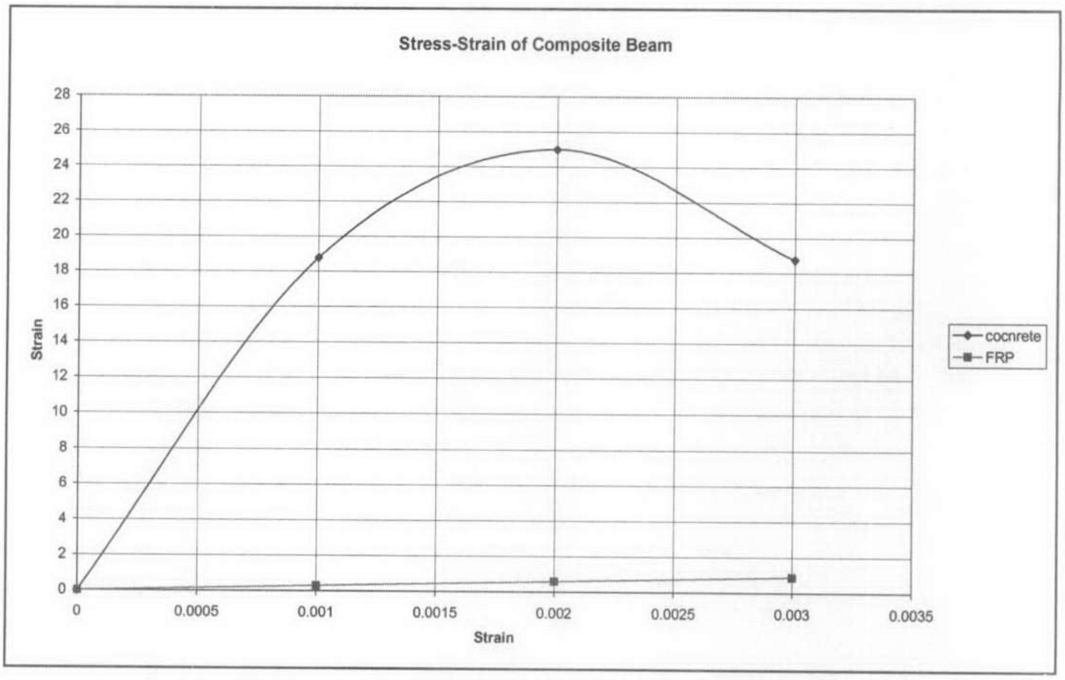


Figure 14 Stress-strain graph of the composite beam

Besides that, by having the value of bending moment of the beam, the load applied that can cause that bending can be calculated. Assuming the load applied on the beam is the uniformly distributed load, the bending moment is given by;

$$M = PL^2 / 8$$

Therefore, the value of the applied load can be obtained by rearranging the formula;

$$P = 8M / L^2$$

The deflection at mid span of the beam then can be calculated as the value of bending moment and applied load is had. The maximum deflection at mid span is given by,

$$\Delta = 5wL^4 / 384 EI$$

FRP strain	Moment (N.mm)	Load (N/mm)	Deflection (mm)
0.001	10894200	87.5	1.1
0.002	26844300	214.8	2.73
0.003	20034.3	87.6	1.1

Table 7 Values for the applied load and deflection.

Table 7 shows the values of the applied load that cause the bending moment at the composite beam. The tale also shows the value of deflection of the beam caused by the applied load. The values obtained are differing for different values of FRP strain that has been used as the control parameter. As we can see, the deflection of the beam with FRP strain of 0.003 and the beam with FRP strain of 0.001 is the same. This occurs because of the concrete failure at beam with strain of 0.003. The strain limit of concrete is usually 0.003.

4.5 Discussion

Overall, based on the calculation and the analytical observation, the FRP plate acting as the permanent formwork shows positive behaviour. By referring to the stress – strain graph of the composite beam (Figure 14), it can be seen clearly that the limit of failure for FRP is far different from that of concrete. It can be supposed that, by applying controlling strain mode, the flexural stiffness of the beam will be half of the initial flexural determined by the applied loading. The FRP will act like tension reinforcement and takes the tensile force. In this case, we can see that the beam fail due to concrete compressive failure. This is because the FRP stress-strain behaviour is said to be linear elastic up to final brittle rupture when subject to tension. Although the concrete has failed, the FRP has not yet reach its limit. Since the concrete stress has not reached its maximum strength, the rectangular stress block needs to be modified according to the stress level. The concrete strain can be used to control the beam behaviour.

In selection the type of fibre to be used for an application, there are few things to be considered. Glass FRP and Aramid FRP are known to be excellent for seismic upgrades where the seismic loads only temporarily engaged the FRP. Carbon FRP is much more suitable for cases where stresses are sustained in the FRP as compared to Glass and Aramid FRP, and is therefore most durable. However, when comparing based on price, Carbon FRP are at the higher price levels. Therefore, in most application, either Glass or Aramid FRP is regularly used as they are lower in cost. The availability of FRP product with low-weight, flexibility, high tensile stress and high durability has solved many problems concerned in formwork application. However, in order to obtain the best performance of FRP plate as material for permanent formwork, several parameters should be considered such as the thickness, length, shape and cross-section area, surface preparation and etceteras. The combination of these factors is very important key-factor in the design. For example, a specific reduction of mid-span deflection at service load can be obtained from several variations in FRP thickness and/or the length of the plate. But the ultimate load could be very different due to the fact that the failure mechanism of FRP-concrete beam may change from one more ductile to other more brittle.

4.6 Recommendations

FRP have been suggested as an alternative material to conventional steel for use in concrete structures. These materials have been selected primarily due to their corrosion resistance, as well as their strength-to-weight ratio. However, compared with steel reinforcement, they exhibit differences in mechanical properties, which naturally infer different design and construction approaches.

In that case, other factors that should be determined in applying FRP as permanent formwork is delaminating or debonding and prestressed behaviour. The delaminating and peeling modes are directly related to the properties of the bond between the FRP and concrete substrate. Due to the relatively low stiffness of FRP material compared with steel, concrete structures containing FRP ought to be prestressed. In this way, much of the FRP's strain capacity is removed, leading to the achievement of similar strain levels between concrete and FRP under flexural conditions, so that both materials are used efficiently. So that it can order to induce ductility, deformability and a modest additional capacity. To achieve this, sufficient laboratory testing or experiment shall be carried out.

Other than that, the studies of application of FRP can also be enhanced by doing the cost analysis. It shall be done to compare the economic benefits that can be acquired by applying FRP plate as permanent formwork over other materials.

CHAPTER 5
CONCLUSION

As the conclusion, the objectives of this project which are to understand the characteristics and behaviour of FRP reinforced concrete and to study the application FRP as permanent formwork have been achieved. Combining fibre reinforce plastic materials with concrete appears to be a feasible way to produce efficient and cost effective materials. In concrete structures, FRP members pose many desirable mechanical behaviour characteristics such as pseudoductility, high strength and stiffness as well as maintaining low weight. FRP will not only increase and enhance the concrete structure behaviour but also reduce or eliminate the retrofitting works due to reinforcement failure. Reinforced concrete structures can be strengthened using FRP composites. The most common application is bonding FRP composites to a beam soffit to increase its bending capacity. This method has proved to be able to increase the flexural capacity of RC beams up to 72%

Yet, in conjunction with the objective of this project and based on the research done, it can be said that FRP plate can be applied as formwork. This is due to its high strength and other performance and behaviour that are better compared to the conventional formwork. Based on the analytical calculation done, this study has concluded that the use of FRP plate as the permanent formwork can be applied. The beam theory applied is able to predict the full composite action of beams with FRP permanent formwork. Overall, the simply supported FRP-concrete beam of this study poses good results and characteristics in applying the FRP plate as permanent formwork.

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APPENDIX A

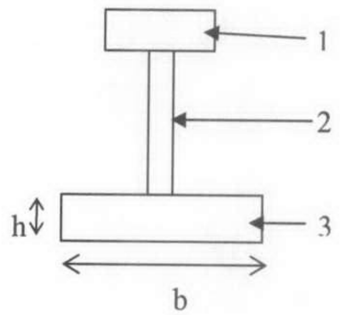
TYPICAL FIBRE REINFORCED PLASTIC PROPERTIES

	E-Glass	S-Glass	Aramid (Kevlar 49)	High Strength Carbon	High Modulus Carbon	Polyeth-Ylene (Dyneema Sk65)	Steel (Grade S275)
Tensile Strength (MPa)	2400	3100	3600	3300-6370	2600-4700	3000	275 Yield 430 Ultimate
Tensile Modulus (GPa)	70	86	130	230-300	345-590	95	205
Failure Strain (%)	3.5	4.0	2.5	1.5-2.2	0.6-1.4	3.6	20
Density (Kg/m^3)	2560	2490	1440	1800	1900	970	7900
Coefficient of Thermal Exp (10^{-6}/¡C)	5.0	5.6	-2L + 59 T	-1L +17T	-1L	-12L	12
Fibre Cost (£/kg)	1.25	7	15	10-15	~60	20-30	0.4
Fabric Cost (£/kg)	2-3	10-15	20-25	15-35	~100	30-50	0.4
Specific Fabric Cost (£/m^3 x 10^{-3})	5-8	25-37	29-36	27-63	~190	29-49	3
L = Longitudinal T = Transverse							
TYPICAL E-GLASS/POLYESTER LAMINATE PROPERTIES							

	CSM	WR/CSM COMBI	WOVEN ROVING (WR)	UD	STEEL (Grade S275)	CONCRETE
Tensile Strength (MPa)	100	180	250	650	275 Yield 430 Ultimate	2-5
Compressive Strength (MPa)	140	180	210	550	275 Yield 430 Ultimate	25-60
Tensile Modulus (GPa)	7.5	12	14	30	205	25-36
Tensile Failure Strain (%)	2	2	2	2	20	0.01
Density (Kg/m3)	1500	1600	1700	1700	7900	2400
Coefficient of Thermal Exp (10^{-6}/¡C)	30	-	14	10	12	7-12
UD - Unidirectional Laminate, Vf = 40%, properties in longitudinal direction.						

APPENDIX B

VARIOUS CROSS-SECTION OF I PLATE AND ITS MOMENT OF INERTIA



A= area

y = centroid

y' = neutral axis

I = moment of inertia

y" = y' – y

I_{xx} = moment of inertia at neutral axis

Beam Sample	Area 1								
	b	h	A	y	Ay	I	y"	Ay"^2	Ixx
P	20	2	40	33	1320	13	-26	27878	27892
Q	20	3	60	44.5	2670	45	-35	72702	72747
R	25	5	125	47.5	5937.5	260	-36	158254	158515
S	25	2	50	33	1650	17	-26	33169	33185
T	25	3	75	44.5	3337.5	56	-34	86700	86756
U	25	5	125	57.5	7187.5	260	-43	228742	229003
V	30	2	60	33	1980	20	-25	37930	37950
W	30	3	90	44.5	4005	68	-33	99365	99432
X	30	5	150	57.5	8625	313	-42	262686	262999

Beam Sample	Area 2								
	b	h	A	y	Ay	I	y"	Ay"^2	Ixx
P	2	30	60	17	1020	4,500	-10.40	6490	10,990
Q	3	40	120	23	2760	16,000	-13.31	21257	37,257
R	5	40	200	25	5000	26,667	-13.08	34225	60,891
S	2	30	60	17	1020	4,500	-9.76	5711	10,211
T	3	40	120	23	2760	16,000	-12.50	18750	34,750
U	5	50	250	30	7500	52,083	-15.28	58353	110,436
V	2	30	60	17	1020	4,500	-9.14	5016	9,516
W	3	40	120	23	2760	16,000	-11.73	16503	32,503
X	5	50	250	30	7500	52,083	-14.35	51465	103,548

Beam Sample	Area 3								
	b	h	A	y	Ay	I	y"	Ay"^2	Ixx
P	150	2	300	1	300	100	5.60	9408	9508
Q	150	3	450	1.5	675	337.5	8.19	30187.76	30525
R	150	5	750	2.5	1875	1562.5	9.42	66532.59	68095
S	150	2	300	1	300	100	6.24	11695.9	11796
T	150	3	450	1.5	675	337.5	9.00	36450	36788
U	150	5	750	2.5	1875	1562.5	12.22	112037	113600
V	150	2	300	1	300	100	6.86	14106.12	14206
W	150	3	450	1.5	675	337.5	9.77	42977.79	43315
X	150	5	750	2.5	1875	1562.5	13.15	129734.8	131297

Beam Sample	Total A	Total Ay	y'	Total h	Total I (mm^4)
P	400	2640	6.60	34	48389
Q	630	6105	9.69	46	140530
R	1075	12812.5	11.92	50	287501
S	410	2970	7.24	34	55192
T	645	6772.5	10.50	46	158294
U	1125	16562.5	14.72	60	453038
V	420	3300	7.86	34	61671
W	660	7440	11.27	46	175251
X	1150	18000	15.65	60	497844

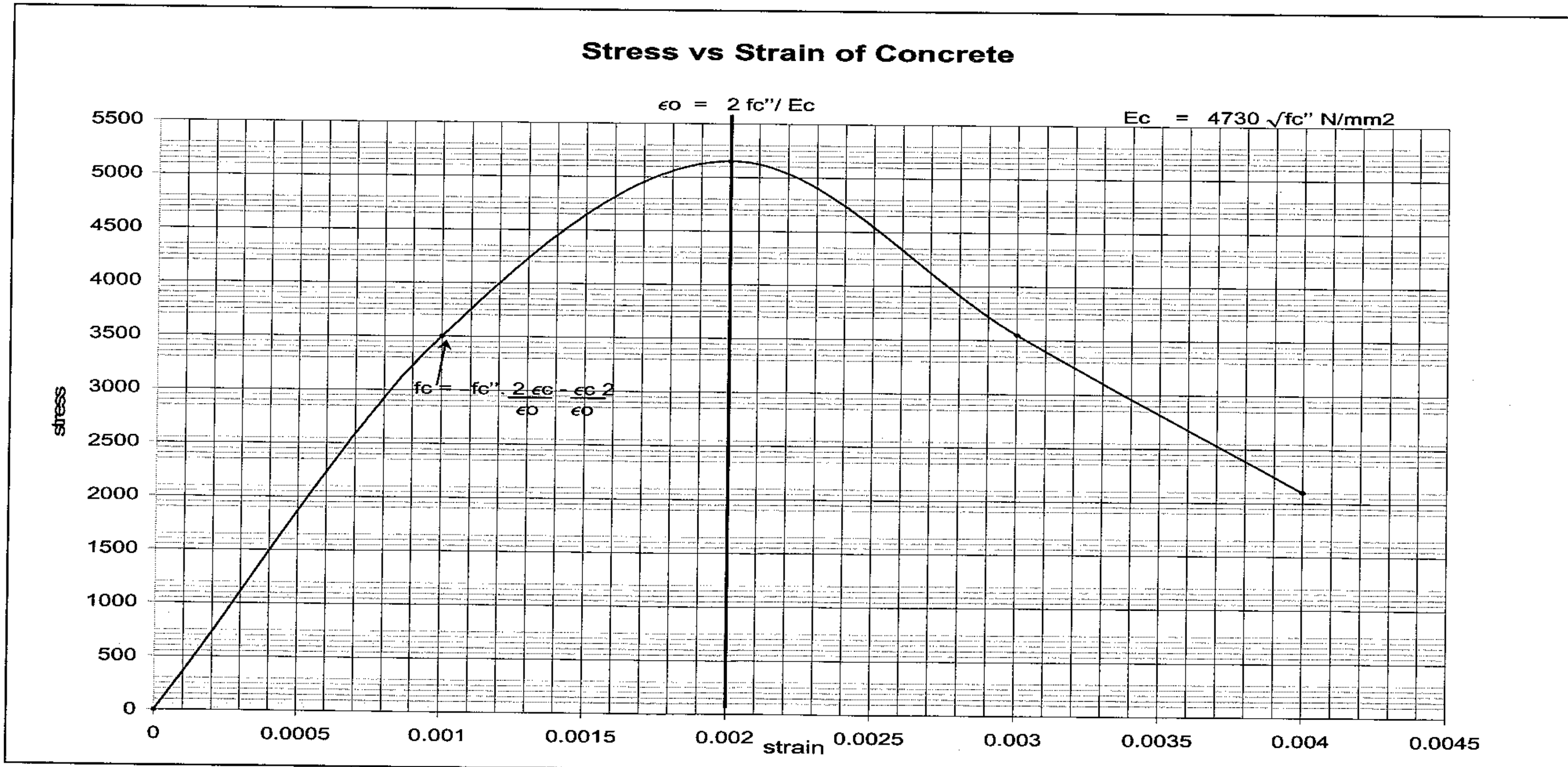
APPENDIX C

I DEFLECTION WITH DIFFERENT MODULUS OF ELASTICITY,E

			E=38000	E=42000	E=45000	E=50000	E=55000
Beam Sample	Beam Length, l (mm)	Load,w (kN/m)	Deflection, Δ (mm)	Deflection, Δ (mm)	Deflection, Δ (mm)	Deflection, Δ (mm)	Deflection, Δ (mm)
P	1000	2.876	20.4	18.4	17.2	15.5	14.1
Q	1000	2.876	7.0	6.3	5.9	5.3	4.8
R	1000	2.876	3.4	3.1	2.9	2.6	2.4
S	1000	2.876	17.9	16.2	15.1	13.6	12.3
T	1000	2.876	6.2	5.6	5.3	4.7	4.3
U	1000	2.876	2.2	2.0	1.8	1.7	1.5
V	1000	2.876	16.0	14.5	13.5	12.1	11.0
W	1000	2.876	5.6	5.1	4.7	4.3	3.9
X	1000	2.876	2.0	1.8	1.7	1.5	1.4

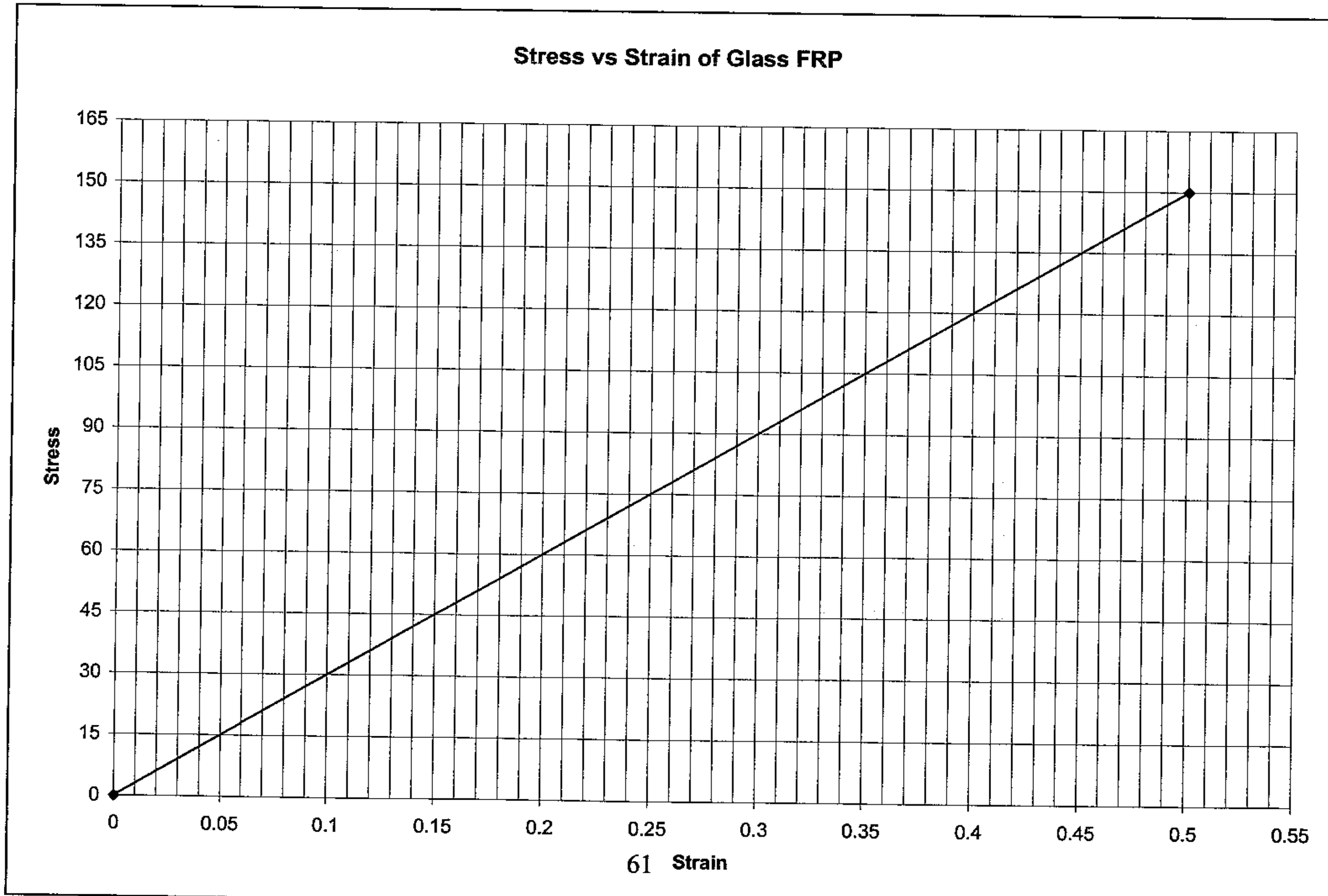
APPENDIX D

STRESS – STRAIN CONCRETE



APPENDIX E

STRESS- STRAIN GRAPH FOR GLASS FRP



APPENDIX F

STRESS-STRAIN GRAPH OF THE COMPOSITE