University of Stellenbosch
Department of Civil Engineering

AN INVESTIGATION INTO THE FEASIBILITY OF HYBRID CONCRETE CONSTRUCTION IN SOUTH AFRICA

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Study Leader:

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature: ______________________ Date: **12/03/2008**

SYNOPSIS

Introduction

South Africa is currently experiencing a significant increase in infrastructure investment. Forecasts by BMI-BRSCU have shown that the building and construction industry is expected to grow considerably to 2010, before languishing slightly to 2015. This growth will be driven in particular by investment in non-residential building (41% growth) and construction (73% growth) activities. Even beyond 2015 however, the demand will still be high on the construction industry to provide infrastructure for South Africa's growing population.

South Africa is also facing a serious shortage of engineers, technicians and other skilled workers in the construction industry. This places high demands on designers and contractors to provide services and to realise projects in ever-reducing time periods and at less cost. These conditions have made it increasingly difficult to maintain the required quality of construction in an industry where mistakes can lead to disastrous consequences.

Recent advances in structural materials, structural systems and the way in which projects are handled, now enables a new look at the possibilities of combining pre-fabrication with on site work. This method, known as Hybrid Concrete Construction (HCC), has the potential to revolutionize the South African construction industry if applied correctly. Local research into this technique is however required and it is the aim of this thesis to draw attention to this subject.

Key Findings

Hybrid Concrete Construction (HCC) can be applied to any structural project, it will however not necessarily be successful. A structure needs to be adapted from the very start to suit a particular construction method. This ensures that all the advantages of the selected construction method may be achieved. Adapting a structure to a different construction method requires a mutual understanding and commitment from all project participants, including the architect, engineer, contractor and client. HCC also requires a certain degree of repetition in a project to be financially viable.

A theoretical cost exercise was performed where only the material and erection costs were considered. In this exercise, HCC was found to be slightly less expensive than other construction methods for the Office Building of more than 10 storeys. HCC was also found to be significantly faster than other construction methods for the Office Building of more than 3 storeys. The time calculation was however based on the simplified time estimates from one source.

Because of HCC's shorter estimated construction period, the client can expect to earn revenue from a much earlier date. This decreases the relative cost of a HCC project. This advantage, however, needs to be quantified for chosen South African projects.

On-site safety is still an important issue with HCC projects. Labourers are not accustomed to this construction method and it may be necessary to alter current skill development programs to include a crane safety course. The training of qualified riggers and crane operators should receive priority if HCC is to develop in South Africa.

This preliminary investigation has shown that Hybrid Concrete Construction (HCC) can be feasible for the South African market. Further investigation is however required to determine the parameters for which HCC would be the preferred construction method.

Recommendations

Based on the findings and conclusions of this investigation, the following recommendations are made.

The following actions should be undertaken by individual South African companies:

- Develop relationships with external project partners
- Train competent riggers and crane operators

The South African concrete industry should invest in the following actions:

- Invest in mass-producing precast concrete facilities
- Develop a central database of South African projects with information on time, costs, project concepts and layouts to be used as a guideline for decision making
- Develop local guidelines for the production and application of self compacting concrete
- Compile guidelines for the design and construction of HCC and precast concrete construction in South Africa
- Develop a local hidden corbel type connection to its full potential

OPSOMMING

Inleiding

Suid-Afrika ondervind tans 'n merkwaardige toename in infrastruktuur ontwikkeling. BMI-BRSCU voorspel dat die konstruksie bedryf aansienlik sal groei tot en met 2010, voordat dit effens sal terug sak tot en met 2015. Groei word veral verwag in die nie-residensiële gebou (41%) en konstruksie (73%) sektore. Daar word egter verwag dat die aanvraag na infrastruktuur selfs na 2015 hoog sal bly as gevolg van Suid-Afrika se groeiende populasie.

Suid-Afrika staar ook tans 'n reuse tekort aan vaardighede in die gesig. Dit plaas al hoe meer druk op ontwerpers en kontrakteurs om projekte teen laer pryse en so vinnig as moontlik te voltooi. Hierdie kondisies maak dit moeilik om die nodige kwaliteitsvlakke te handhaaf in 'n bedryf waar foute tot groot ongelukke kan lei.

Onlangse vordering met strukturele materiale en die manier waarop projekte bedryf word, lei nou tot nuwe moontlikhede vir die gebruik van Hibriede Beton Konstruksie (HBK). Hierdie konstruksie metode kan die Suid-Afrikaanse bedryf heeltemal omvorm. Verdere ondersoek word egter benodig en dit is die doel van hierdie tesis om aandag op hierdie nuwe konstruksie metode te fokus.

Hoof Bevindings

Hibriede Beton Konstruksie (HBK) kan op enige konstruksie projek toegepas word. 'n Struktuur moet egter van die begin af aangepas word om die voordele van voorafvervaardigde beton elemente te kan benut. Sulke veranderings verg 'n toegewyde projekspan. Hierdie span bestaan tipies uit 'n argitek, ingenieur, verskeie kontrakteurs en die kliënt. HBK verlang egter 'n sekere mate van repitisie om suksesvol te kan wees.

In 'n teoretiese gevallestudie is gevind dat HBK goedkoper is as ander konstruksie metodes vir 'n kantoor gebou van meer as 10 verdiepings. HBK was ook merkwaardig vinniger as die ander konstruksie metodes vir 'n kantoor gebou van meer as 3 verdiepings. Hierdie tydsberkeninge was egter gebasseer op die skattings van slegs een kontrakteur en een voorafvervaardigende kontrakteur. Meer gevalle asook meer deelnemers word benodig vir 'n meer volledige indruk.

As gevolg van HBK se korter konstruksie tydperk, kan die kliënt verwag om vroeër 'n inkomste te verdien. Dit verlaag dus die lewenssiklus koste van 'n HBK projek. Hierdie voordeel moet egter nog ten volle gekwantifiseer word vir Suid-Afrikaanse projekte.

Terrein veiligheid is nog steeds 'n probleem by HBK projekte. Werkers is nie gewoond aan hierdie nuwe konstruksie metode nie. Huidige vaardigheid kursusse moet dalk verander word om 'n kraan veiligheidskursus in te sluit. Die opleiding van hoë kwaliteit oprigters en kraan operateurs behoort voorkeur te geniet as HBK werklik in Suid-Afrika wil posvat.

Hibriede Beton Konstruksie word dus as uitvoerbaar in die Suid-Afrikaanse konstruksie bedryf beskou. Verdere ondersoek word egter benodig om vas te stel vir watter tipe projekte dit die verkose konstruksie metode is.

Aanbevelings

Gebasseer op die bevindings en gevolgtrekkings van hierdie ondersoek, word die volgende aanbevelings gemaak.

Suid-Afrikaanse maatskappye moet die volgende aksies neem:

- Ontwikkel verhoudings met eksterne project vennote
- Lei hoë kwaliteit oprigters en kraan operateurs op

Die Suid-Afrikaanse beton bedryf moet die volgende aksies neem:

- Belê in massa-produksie, vooraafvervaardigde beton fabrieke
- Ontwikkel ‘n sentrale databasis van Suid-Afrikaanse konstruksie projekte met inligting oor konstruksietyd, -kostes, projek konsepte en uitlegte wat as riglyne in die besluitnemingsproses gebruik kan word
- Ontwikkel Suid-Afrikaanse riglyne vir die vervaardiging en toepassing van Self-kompakterende beton
- Ontwikkel riglyne vir die gebruik van Hibriede beton konstruksie in Suid-Afrika
- Ontwikkel ‘n Suid-Afrikaanse versteekte korbel konneksie tot sy volle potensiaal

ACKNOWLEDGEMENTS

Several individuals and institutions have contributed to the research reported in this thesis. With these acknowledgements I would like to express my sincere gratitude to everyone who, by their support, encouragement, help or remarks has contributed to this work.

Firstly I would like to thank my study leader and mentor, Prof. Jan Wium. His assistance, motivation and enthusiasm for structural concrete inspired me to study structural engineering, which led to the formation of this thesis.

I would also like to thank Christo van der Merwe (Infraset) for his assistance throughout this investigation. Without his help, this investigation would not have been a success.

The following people contributed greatly to the outcome of this investigation. Thank you for your various inputs:

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- Johan Troskie (ex Grinaker LTA)
- Keith Muller (Group 5)
- Marius van der Merwe (Grinaker LTA)
- Richard Brown (RBD construction)
- Steven Brown (RBD construction)
- Steven Chambers (NMC)

A special word of thanks to my family for all their support during this research period. Thank you for always encouraging me to do better, but also for supporting me during the difficult times.

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

Bonded and Un-bonded tendons
Un-bonded tendons for post-tensioned members have ducts which are permanently un-grouted. This allows the tendons to move within the ducts. Bonded tendons, however, are grouted after the post-tensioning force has been applied.

Consulting engineers
A civil or structural engineer working at a consulting practice and is generally involved in regular design work.

Contracting engineers
A civil or structural engineer working for a contracting firm and has thorough design knowledge, but is generally not involved in regular design work.

Performance based design method
Performance based design refers to the methodology in which structural design criteria are expressed in terms of achieving a set of performance objectives. The performance objectives may be a level of stress not to be exceeded, a load, a displacement, a limit state or a target damage state. This method is particularly useful in seismic engineering.

Precast concrete structures
Precast concrete structures are characterized by structural concrete elements manufactured elsewhere than in the final position in the structure. In the structure, concrete elements are connected to ensure the required structural integrity.

Prestress
The process of prestressing consists in applying forces to the concrete structure by stressing tendons relative to the concrete member. “Prestress” is used globally to name all the permanent effects of the prestressing process, which comprise internal forces in the sections and deformations of the structure. Prestressing can be applied before (pre-tensioning) or after (post-tensioning) concrete casting.

Pre-tensioning
In this process, the tendons are prestressed in a mould without any concrete. Concrete is then added and allowed to cure before the prestressed tendons are released, and the element removed from the mould.

Post-tensioning
Post-tensioning can be either bonded or un-bonded. Bonded tendons are placed in ducts before the concrete is poured into the mould. After the concrete has cured, the element is removed from the mould. The tendons are then tensioned to the required stress and then grouted. Un-bonded tendons are greased and placed in sheathes before the concrete is poured. After the concrete has cured, the required tensioning force is applied to the tendons which are then anchored into the concrete to maintain this force.

LIST OF ABBREVIATIONS

BMI-BRSCU	Business and Marketing Intelligence - Building Research Strategy Consulting Unit
CRC	Compact Reinforced Composite
FEM	Finite Elements Method
HBK	Hibriede Beton Konstruksie
GFCF	Gross Fixed Capital Formation
HCC	Hybrid Concrete Construction
RC	Reinforced Concrete
RCC	Reinforced Concrete Council, United Kingdom
SCC	Self Compacting Concrete
VWSA	Volkswagen of South Africa

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Subject

This thesis describes an investigation into the feasibility of Hybrid Concrete Construction (HCC) in the South African construction industry.

1.2 Background

South Africa is currently experiencing a significant increase in infrastructure investment. Forecasts by BMI-BRSCU (figure 1.1, 2007) have shown that the building and construction industry is expected to grow considerably to 2010, before languishing slightly towards 2015.

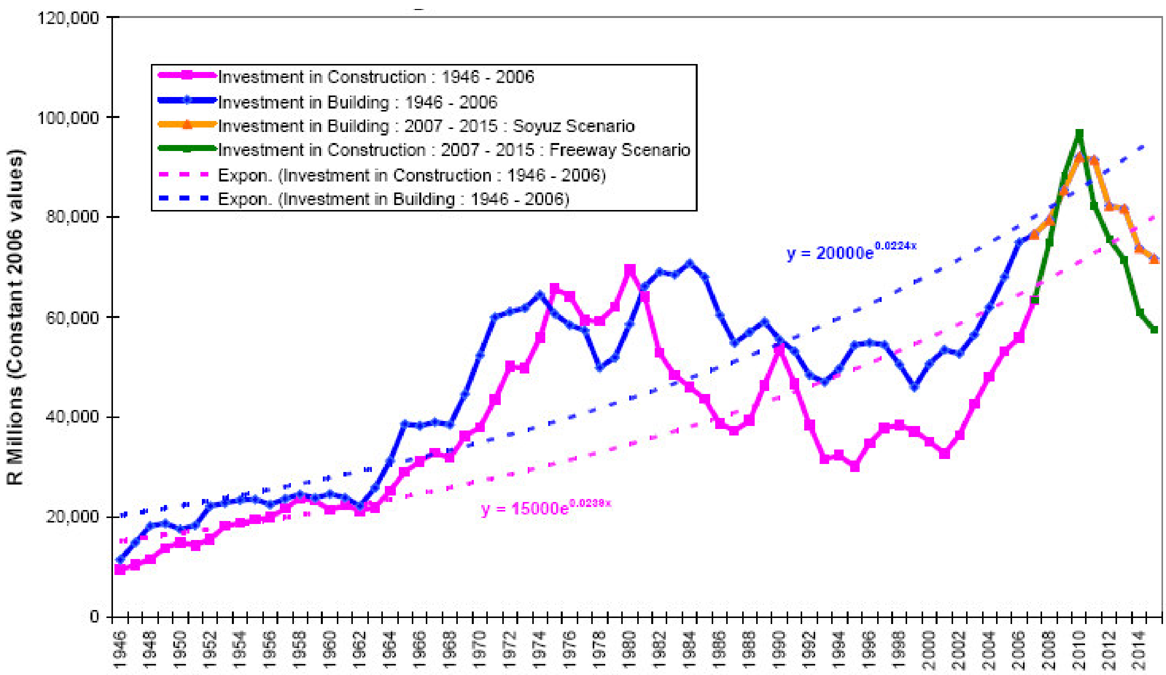

Figure 1.1 The expected investment in South Africa's Building and Construction industries (BMI-BRSCU, 2007).

According to the BMI-BRSCU (2007) report, this growth will be driven in particular by investment in non-residential building (41% growth) and construction (73% growth) activities. Even beyond 2015 however, the demand will still be high on the construction industry to provide infrastructure for South Africa's growing population (Botha, 2007).

South Africa is also facing a serious shortage of engineers, technicians and other skilled workers in the construction industry. Research by Lawless (2005) found that the number of professionals will have to be increased dramatically if the country is to tackle the service delivery problems in all forms, including legal, financial and infrastructure. Unfortunately, Lawless (2005) also found that the number of professionals in South Africa is slowly declining.

The shortage of skills in the construction industry clearly places high demands on designers and contractors to provide services and to realise projects in ever-reducing time periods and at less cost. These conditions, in a growing economy, augmented by the shortage of labour, make it increasingly difficult to maintain quality of construction in an industry where mistakes can lead to disastrous consequences.

A well-recognised need therefore exists to seek and identify ways and means by which the image of the South African construction industry can be improved. This will entail devising means to deliver construction projects on time, within budget, at a high quality and using techniques and methods of a high technological level (Wium, 2005).

South Africa is not the first or the only country to experience these challenges. Similar conditions have forced the United Kingdom and other countries to address these problems, and we can take some lessons from their experience. Having recognized these and other problems specific to their conditions, the United Kingdom has investigated the concept of Hybrid Concrete Construction and released several best practice guidelines for Hybrid Concrete Construction (Goodchild, 2004).

This investigation into the concept of Hybrid Concrete Construction to improve the South African project delivery rate is therefore justified. This thesis presents a study into the suitability of Hybrid Concrete Construction for the South African market.

1.3 Objectives

The ultimate goal of Hybrid Concrete Construction (HCC) is to reduce the overall project cost and time of construction, whilst improving construction quality. Therefore, the objectives of this study are to:

- Identify any obstacles that may prevent the widespread use of HCC in the South African construction industry
- Apply local and international knowledge to a South African case study and report the findings
- Evaluate the HCC, in-situ construction and flat slab construction methods in terms of their respective cost and construction time requirements for a specific project
- Draw conclusions and make recommendations about the feasibility of HCC in South Africa
- Make recommendations about a course of action to extend this study through continued research into the use of precast and Hybrid Concrete Construction methods in South Africa

1.4 Scope and Limitations

According to the SANS 10160, some regions in South Africa are classified as moderately active seismic areas. The international literature study (*Chapter 2*) and the Precast connections (*Chapter 4*) were therefore restricted to moderately active seismic countries with a successful precast concrete construction industry. Designing seismic precast structures are more complex than designing non-seismic precast structures. Therefore, if HCC is proven to be feasible for South Africa's moderately active seismic zones, it is reasonable to believe that it will be feasible for the entire South Africa.

When evaluating the South African design codes and guides against their international equivalents, the SANS 10100-1 was only evaluated against the EN 1992-1. The EN 1992-1 is the newest international code and employs the latest evaluation methods. It also covers a very broad region and the theory behind its calculation is well defined. Although the EN 1992-1 covers precast concrete design, the "Seismic Design of Precast Concrete Building Structures" (fib, 2003) and the "Planning and Design Handbook on Precast Building Structures" (fib, 2004) were also investigated. These guidelines provide valuable information about the design, management and construction practices of a precast concrete project.

Personal interviews were conducted with representatives from some of the biggest South African contractors (*Chapter 3*). The precast questionnaire survey was then restricted to a sample of South African consulting and contracting firms. Only senior engineers at these firms were asked to answer the survey.

The selected case study was designed according to the SANS 10100-1 and SANS 10160 codes. It was however, not deemed necessary to design the Office project (*Chapters 6 & 7*) in the smallest possible detail. Only the determining cases of the conceptual design were evaluated. The costs and scheduling of the foundations, services and non-structural finishes were assumed to be similar for all three project types. These costs were therefore ignored in the cost evaluation.

1.5 Research Methodology

This thesis is based on the results of the three main components of this study, namely a comprehensive literature study, a survey of the South African construction industry and the evaluation of two South African case studies.

The information on which this thesis is based was gathered from:

1. Statistics South Africa
2. A literature study of local and international construction industries
3. Evaluating the South African design codes against their international equivalents
4. Interviews with the following representatives (*Appendix G*) from contracting companies:

    a. Christo van der Merwe (Infraset)
    b. Dave Hickson-Smith (Echo Prestress)
    c. Eric Ettish (Murray & Roberts)
    d. Johan Troskie (ex Grinaker LTA)
    e. Keith Muller (Group 5)
    f. Marius van der Merwe (Grinaker LTA)
    g. Richard Brown (RBD construction)
    h. Steven Brown (RBD construction)
    i. Steven Chambers (NMC)

5. A questionnaire survey completed by consultants and contractors from across South Africa
6. An evaluation of existing moment-resisting precast connection designs
7. Presentations by:

    a. D. Botha (SAICE Presidential address, Stellenbosch University, 2007)
    b. A. Dazio (Seismic engineering course, Stellenbosch University, 2006)
    c. B. Engstrom (Design of Precast connections, Cape Town University, 2007)
    d. A. Van Acker (Design of Precast concrete building structures, Cape Town University, 2007)
    e. J.C. Walraven (Prefabricated concrete construction course, Stellenbosch University, 2007)
    f. J.A. Wium (Seismic design of building structures. Stellenbosch University, 2006)

8. A site visit to Volkswagen of South Africa’s paint shop in Uitenhage

1.6 Plan of Development

This study can be divided into several phases (figure 1.2), which are identified and described in the following sections.

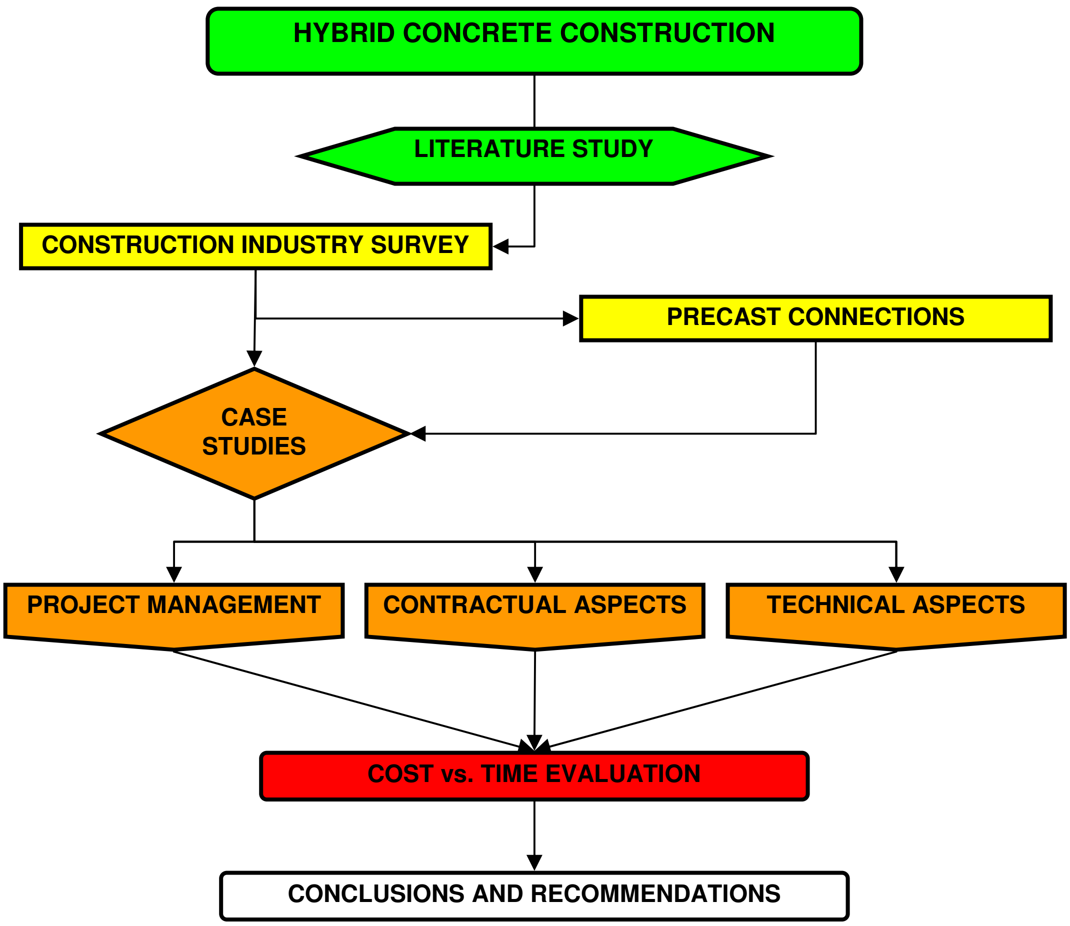

Figure 1.2 A Flow diagram illustrating the breakdown of this research study.

1.6.1 Phase I: Literature study

A literature study was performed to evaluate the current state of the South African Precast concrete industry against its international equivalents.

Data from Statistics South Africa was used in a survey of the South African construction industry based on the Rand value of construction work done.

This section then focused on the precast construction experience of other moderately active seismic countries to determine the extent to which precast construction is being used on an international level. It is believed that if HCC is proven to be feasible for the moderately active seismic regions in South Africa, it will be feasible for the entire South Africa.

Furthermore, a comparison was made between the precast concrete construction sub-clauses of the SANS 10100-1 and the EN 1992-1. The “Planning and Design Handbook on Precast Building Structures” (fib, 2004) was also evaluated as a starting point for the development of South African Precast construction guidelines.

1.6.2 Phase II: Construction industry survey

The literature study (*Chapter 2*) determined that many of the countries with a successful precast concrete industry have their own precast concrete guidelines. It was therefore decided to perform a survey of the South African construction industry to determine if local designers have access to similar information. The extent to which Hybrid Concrete Construction (HCC) is being implemented in South Africa was also investigated.

This survey consisted of interviews with representatives from several large contractors as well as a questionnaire survey of consultants and contractors from across South Africa.

1.6.3 Phase III: Precast connections

It was determined during the construction industry survey (*Chapter 3*), that local information is required for the design of aesthetic precast connections.

Designing the connections is one of the most essential parts of a precast project. These connections must meet a wide variety of design and performance criteria. Their principle function is to transfer forces across construction joints so that interaction between precast units is obtained. Other aspects such as the water tightness, fire protection, durability, aesthetics and the manufacture, transportation and erection practices (tolerances etc.) of the chosen design should also be taken into consideration.

This investigation included reviewing the SANS 10100-1, the EN 1992-1, the “Planning and Design Handbook on Precast Building Structures” (fib, 2004), the “Seismic Design of Precast Concrete Building Structures” (fib, 2003) and several publicised results of experimental connections. This investigation also aimed to determine if South African designers have access to sufficient, readily available information to correctly design precast connections.

1.6.4 Phase IV: Case studies and their respective aspects

The construction industry survey (*Chapter 3*) also determined that local examples of precast projects are required to prove the advantages of using HCC methods. Two case studies were selected for this investigation.

The first case study (*Chapter 5*) consisted of a site visit to Volkswagen of South Africa’s (VWSA) new paint shop in the Eastern Cape. The project consisted of the construction of an R750million automotive paint shop. The paint shop has a surface area of 45 000 m^2, employs 530 people and doubled the Uitenhage plant’s capacity to 1200 vehicles a day. Through the extensive use of precast elements, this project was completed in just over a year (VWSA, 2006). The case study included a detailed discussion with the project’s construction management team.

The second case study (*Chapter 6*) consisted of a double storey office building. The original building consists of a total floor area of 1800m^2. This building was chosen because of its square and relatively modular arrangement (figure 6.1). The effect of project size on the suitability of Hybrid Concrete Construction (HCC) can also be studied by increasing the number of floors as required. For the purpose of the case study, the building was preliminary designed, priced and scheduled according to the in-situ, HCC and flat slab construction methods.

After evaluation of the Best Practice Guidelines for Hybrid Concrete Construction (Goodchild, 2004) and Rationalizing Reinforced Concrete Construction for Economy and Quality (Wium, 2005), the research was classified into three subsections. These subsections can be identified from the investigations by Goodchild (2004) as performed for the market in the United Kingdom.

The three subsections, that are to be investigated for the South African construction environment, are as follows:

- Project Management challenges specific to HCC
- Technical properties of structural details and construction methods
- Contractual aspects of HCC projects

1.6.5 Phase V: Cost vs. Time comparative study

A desk top study was undertaken, with the help of a design engineer, quantity surveyor, precast contractor and an in-situ contactor, to compare the cost and erection time of the In-situ, HCC and Flat slab designs for the Office Building. The influence of the project's size on the cost and erection time was also investigated for each construction method.

It was determined that the cost of the materials for the three versions of the Office project is very similar. Furthermore, determining the theoretical scheduling process and the cost of the tendering process was found to be problematic. Conclusions were therefore drawn and recommendations made about the components that would require further investigation in a complete costing study of several different South African projects.

1.6.6 Phase VI: Conclusions and Recommendations

Based on the findings of this investigation, conclusions are drawn and recommendations are made about the feasibility of Hybrid Concrete Construction in South Africa. Furthermore, recommendations are made about a course of action to extend this study through continued research into the use of Precast and Hybrid Concrete Construction methods in South Africa.

2. LITERATURE STUDY

A literature study was performed to determine what work others have done in the same research field. It is an important part of any research project and prevents the researcher from "re-inventing the wheel."

The objectives of this literature study were to:

- Determine the current state of the South African construction industry
- Study the precast concrete construction experience of other countries
- Correctly define Hybrid Concrete Construction
- Evaluate the South African design codes against their international equivalents
- Justify the validity of this research project

2.1 State of the South African construction industry

Using the data from the "Selected building statistics of the private sector as reported by local government institutions" (Statistics South Africa, 2006), a complete survey was conducted of the South African construction industry based on the Rand value of construction work done. The complete outcome of this survey can be found in *Appendix A*.

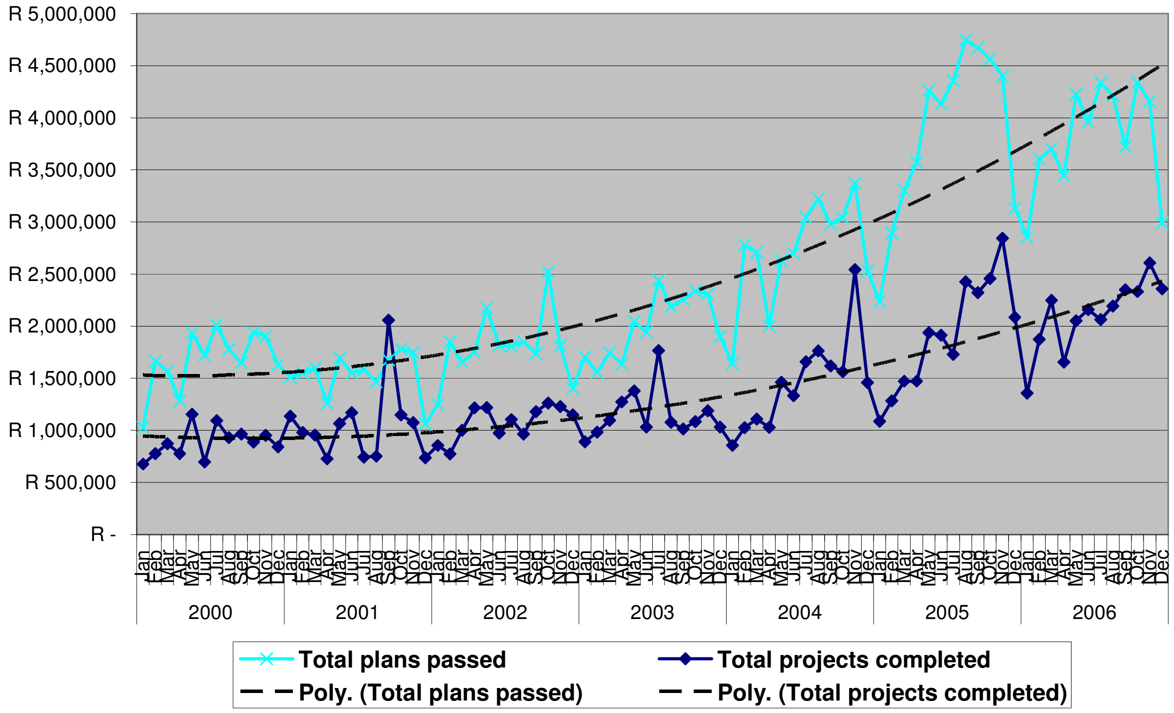

Figure 2.1 The value of all the plans passed compared to the value of all the projects reported as complete in South Africa at constant 2000 prices, (Statistics South Africa, 2006).

Second order polynomial trend lines were used to show that the difference between the value of the projects planned and projects completed has been widening steadily from as early as the beginning of 2001 (figure 2.1). This proves that even though the construction industry has shown considerable growth, it has become unable to keep up with the required rate of development. Although several factors may be the reason for this, it is also considered that a new strategy for project implementation may be needed.

It is postulated that one of the reasons for the industry's delay may be the slow and labour intensive practices that are currently employed in the South African construction industry. Attention is thus drawn to the South African precast industry. Precast construction is well known for delivering projects at greater speed while requiring less labour. It may therefore be argued that employment numbers will be reduced by increasing precast activities, it can however be argued that more workers become available for other projects, thereby increasing the capacity of the industry.

Recent advances in structural materials, structural systems and the way in which projects are handled (Walrafen, 2007), now enables a new look at the possibilities of combining pre-fabrication with on site work. This method, known as Hybrid Concrete Construction (HCC), has the potential to revolutionize the South African construction industry if applied correctly. Local research into this technique is however required and it is the aim of this thesis to draw attention to this subject.

2.2 State of the International Precast Industry

South Africa is mostly non-seismic, but several regions are classified as moderately active seismic zones (SANS 10160).

Designing precast structures to effectively withstand earthquake loads is more complex than designing regular precast structures. If HCC is proven to be viable for seismic designs it is reasonable to believe that HCC will be viable for the entire South Africa. Therefore this section also includes the precast construction experience of other moderately seismic countries.

Information about the international use and market share of precast concrete in composite construction (table B.2) as well as the common building types that are constructed with composite construction (table B.1) may be found in *Appendix B*.

The following sections give a brief overview of the extent to which precast is being used on an international level and was referenced from the "Seismic design of precast concrete building structures" (fib, 2003).

2.2.1 Canada

The Canadian Prestressed Concrete Institute published a Design handbook in 1964. This led to the construction of several multi-storey precast beam and column systems. After the invention of the hollow core manufacturing system in 1962, the construction of shear wall residential buildings with hollow core flooring also became common practice.

Precast concrete construction for parking garages are now mostly used because of their excellent durability. Constructing water tanks by post-tensioning precast wall panels together is also common practice.

2.2.2 Italy

The introduction of prestressing, escalating labour costs and the high demand for industrial buildings in the 1950's led to the development of Italy's precast concrete construction industry.

Today, all types of buildings are built using precast elements. These include commercial buildings, industrial buildings, social and office buildings, car parks and even dwellings. Composite (or Hybrid) construction has also been very successful.

Slabs and beams are usually precast onto in-situ columns. The reasons being that horizontal elements require expensive propping solutions and post-tensioning systems require highly skilled labour.

2.2.3 Japan

The use of precast reinforced concrete construction in low to medium rise buildings started in the 1970's and rapidly spread through the industry. This forced the Architectural Institute of Japan to publish a design guide entitled "Design and Construction of Precast Reinforced Concrete buildings" (1986). Many high-rise buildings are still being constructed based on the structural and materials research contained in this document. Performance based design methods were, however, adopted under the Building Standard Law in 1999.

After the Ministry of Construction circulated their Notification No. 1320 (1983) precast prestressed concrete construction rapidly spread in Japan. This notification was based on the Building Standard Law and not only covered monolithic construction but also precast prestressed concrete construction. Nowadays almost all prestressed concrete buildings are constructed by joining precast elements through post-tensioning.

2.2.4 United States of America

The use of precast prestressed concrete has grown steadily in the United States since the introduction of 7-wire strands and high strength concrete in the 1950s. The precast industry is currently focussing on the development of seismic-force-resisting systems for use in the higher seismic regions of America.

Various floor products and piles are currently manufactured in large volumes and in standardized unit sizes. Standard connection solutions are readily available and this not only improves constructability but also keeps down unit costs.

2.3 The United Kingdom and Hybrid Concrete Construction

The Rethinking Construction task force's report (Egan, 1998) stated that the United Kingdom's construction industry required a radical change in its approach to the delivery of construction projects if it were to improve.

Research conducted by Goodchild (2001) identified an enthusiasm for Hybrid Concrete Construction (HCC) within the United Kingdom's construction industry. HCC was found to be broadly cost neutral, offered equal or better construction times and had many other potential benefits such as reduced whole-life costs. Its acceptance and widespread use was however hindered by a general lack of experience or guidance.

With this in mind, the Reinforced Concrete Council (RCC) carried out a research project entitled "Best Practice Guidance for Hybrid Concrete Construction." The research was finally completed under the RCC's successor, The Concrete Centre and published in September 2004.

2.3.1 What is Hybrid Concrete Construction?

The Concrete Centre (2005) defines Hybrid Concrete Construction (HCC), also known as composite construction, as "a method of construction which integrates precast concrete and cast in-situ concrete to take best advantage of their different inherent qualities. The accuracy, speed and high-quality finish of pre-cast components can be combined with the economy and flexibility of cast in-situ concrete."

Furthermore, hybrid construction is unique in that it explores the extent to which use can be made of pre-fabrication for each individual project. This allows the project team to optimise the project's cost and schedule, whilst maintaining high levels of quality, safety and architectural aesthetics.

2.3.2 Why Hybrid Concrete Construction?

Hybrid concrete technology aims to deliver fast and cost effective construction projects. This is achieved by removing time-consuming operations on-site and replacing them with industrialized production in precasting yards and factories. HCC does however require a high level of cooperation from all parties during all stages of the design and construction process. HCC should be considered at the beginning of the design process because it becomes progressively more difficult to influence the design and reduce costs as the design proceeds.

The other advantages of HCC, as identified by the United Kingdom's construction industry, are discussed below. This section is referenced from "Hybrid Concrete Construction" (The Concrete Centre, 2005).

1. Cost Cost is a significant influential factor in the choice of frame material. Although the building's structure represents typically only 10% of the construction cost, the choice of frame material has a dramatic effect on the cost of other elements such as external cladding, services and the internal planning. It also affects the useable floor area. Selecting the correct structural framing material is therefore vital to a project's success.

In-situ concrete is viewed as the most economic option, while precast concrete promotes speed and high quality. Efficiently combining the two can deliver projects at greater speed, quality and overall project economy.

For instance, use of a hybrid concrete frame instead of a composite steel frame on a shell-and-core office project in central London led to savings of 29% and a 13% increase of net usable floor area from 33,700 m^2 to 38,200 m^2 (Goodchild, 1995).

It is important to evaluate a HCC project in terms of its whole-life cost and not only the construction cost. HCC excels in terms of energy demands (Thermal mass), which relates to a structure's operating cost, and also in terms of comfort and aesthetics which can lead to productivity gains.

A project's cost is also linked to construction speed as a faster programme means an earlier return on investment, lower interest charges, reduced construction preliminaries and optimal development cost.

2. Speed Encouraging the speed of construction through buildability should be a fundamental objective of the design process. It may require more design effort and contractual flexibility, but it leads to satisfied clients, designers, contractors and end-users.

As stated, Hybrid Concrete Construction (HCC) moves work away from site and into the factory. This reduces the duration of disruptive on-site operations and construction should progress quickly. The precasting operation is unaffected by site conditions and can thus continue independently of on-site operations. The construction process should thus never have to wait for precast elements. Using HCC techniques that reduce the need for follow-on trades such as ceilings and finishes enables even faster construction times, but requires greater care in handling the precast elements.

3. Building In the United Kingdom, formwork can account for up to 40% of the in-situ frame cost. The erection and removal of formwork, especially at higher levels, is a time-consuming process. HCC meets the industry's demands for faster construction, better quality, more prefabrication and reduced site activity (Goodchild, 2004).

4. Safety HCC reduces the potential for accidents. This is achieved by providing working platforms on a less cluttered site. A higher proportion of the work is also carried out in the safer and more controlled environment of the precast factory by more experienced personnel.

However, later in this research paper (*Chapter 5*) it was found that some HCC projects experience similar levels of risk as in-situ projects. South African labourers are not accustomed to this construction method and it may be necessary to alter current skill development programs to include a crane safety course.

5. Others If correctly designed concrete buildings are stable, robust, fire resistant and adaptable, as well as solid, quiet and essentially vibration free. The thermal properties of concrete have been successfully exploited in several naturally ventilated low-energy buildings (The Concrete Centre, 2005).

Long spans are possible by using large units or by pre-stressing or post-tensioning. The development of very high strength concrete, which allows full tension laps between reinforcing bars to be achieved in only 6 diameters (Aarup, 2002), has also simplified the detailing of precast connections. Although the application of concrete which allows such short lapping distances may not be used in the South African industry soon, it demonstrates the progress that is being made in addressing such issues.

2.3.3 Best Practice Guidance for Hybrid Concrete Construction

A research study was undertaken by Dr. Glass (2002) to produce procurement process maps and discuss relevant issues. It consisted primarily of interviews with a range of industry professionals in the United Kingdom. These procurement maps were refined through successive interviews and were finally tested against events that occurred on actual HCC projects to determine their validity.

Knowledge capture workshops were held by reconvening each HCC project's original team. These teams consisted of the client, architect, project manager, engineer, main contractor and other appropriate stakeholders. These workshops were then used to discuss the key events and lessons learned from previous HCC projects.

Several Key Performance Indicators were also developed, under the Construction Best Practice Programme (2007), to provide the industry with an unified method of measuring a project's performance.

Imperial College evaluated the structural design process of HCC projects. It was found that the general principles of in-situ and precast concrete construction were mostly sufficient. Precast products are usually covered by their respective manufacturers' literature. However, because many designers were less familiar with the concept of composite construction, Imperial College released several additional design notes.

As previously stated, The Concrete Centre finally published the results of all the above-mentioned research in the "Best Practice Guidance for Hybrid Concrete Construction" (Goodchild, 2004). These guidelines do however not provide the user with sufficient information about precast design principles. This was later identified during the industry survey (*Chapter 3*) as one of the obstacles that are preventing the widespread use of HCC in South Africa.

2.4 South African design codes versus their International equivalents

This section compares the precast concrete construction sub-clauses of the SANS 10100-1 to those of the EN 1992-1. The "Planning and Design Handbook on Precast Building Structures" (fib, 2004) was also evaluated. This is not a code, but a design guideline and is intended to be used in conjunction with one of several design codes.

2.4.1 Design Handbook on Precast Building Structures

Inexperienced designers often try to obtain a final precast design that is as close as possible to an in-situ structure. From the Design Handbook it follows very clearly that this is incorrect. It is very important for the structure to be designed according to the specific rules of precast construction from the outset of the project.

Unfortunately there is very little local information available to help South African engineers and architects to achieve a complete understanding of the concepts of precast concrete designs. Many international publications exist, that provide sufficient precast design information. Most South African engineers are however not aware of such sources. Unfortunately, many South African engineers also lack the interest to search for extra sources of information, preferring to use only the industry's standard publications and design codes.

The Design Handbook aims to provide such information and to promote the use precast concrete construction. It may therefore be necessary to adopt such a design guide in local tertiary education programs.

The Planning and Design Handbook on Precast Building Structures (fib, 2004) supplies the user with the following important information:

- Suitability of precast construction for various project types
- Preliminary design considerations
- Examples of precast buildings
- General design principles for connections and other elements
- Designing frame and skeletal structures
- Designing precast floors
- Designing bearing walls
- Designing architectural concrete claddings

This book can be a good starting point in the process to develop a South African design guide for Hybrid Concrete Construction (HCC). This guide is also used on a tertiary education level as a text book for precast design courses (Van Acker, 2007).

2.4.2 SANS 10100-1 and the EN 1992-1

The SANS 10100 is based on the British BS 8110, but has been adapted to the South African environment. The EN 1992-1 also partly evolved from the BS 8110. It was found that the clauses relating to precast construction in the SANS 10100-1 and the EN 1992-1 are very similar. Both clauses state that a precast design should firstly satisfy the general design requirements. The codes then continue to state several considerations that should be incorporated into the precast design of the structure.

As can be seen in Table 2.1, the topics that are treated in the SANS 10100-1 and the EN 1992-1 are very similar. The presentation, layout and explanation of the design concepts are however very different.

Table 2.1 Comparing the precast sub-clauses of the SANS 10100-1 and the EN 1992-1

Description	SANS 10100	EN 1992
Glossary of precast construction terms		X
General rules for manufacturing and transient situations	X	X
Effect of heat curing on concrete strength development		X
Effect of heat curing on creep and shrinkage		X
Effect of heat curing on prestressing force		X
Structural analysis includes the structure's behaviour during all stages of construction	X	X
Structural analysis includes the actual and theoretical behaviour of connections	X	X
Structural analysis includes alignment deviations during construction	X	X
Consider effect of horizontal movement on structural integrity		X
Restraining moments in precast slab topping	X	X
Restraining moments in hollowcore slab by placing reinforcement in open cores		X
Wall to floor connection reinforcement design	X	X
Obtaining shear transfer between precast floor elements	X	X
Considerations for achieving diaphragm action in a precast floor		X
Tying systems	X	X
Placement of transverse reinforcement in slabs	X	X
General rules for connections transmitting compressive forces	X	X
General rules for connections transmitting shear forces	X	X
General rules for connections transmitting bending moments or tensile forces	X	X
General rules for connections with structural steel inserts	X	
General rules for shear in interfaces	X	X
General rules for half joints and detailing	X	X
General rules for reinforcement at supports	X	X
Designing bearings	X	X
Designing pocket foundations		X
Designing corbels	X	X
Specific design of vertical elements to prevent progressive collapse	X	

The EN 1992-1 was found to be more up to date with current international precast design practices. The design of precast floors differs significantly between these codes. The EN 1992-1 focuses on the overall design of hollow core slabs for effective diaphragm action. The SANS 10100-1 neither covers hollowcore units nor the design of diaphragm action in a floor without a structural topping. The EN 1992-1 also has several highly detailed sketches to aid the user in understanding certain concepts.

The SANS 10100-1 clearly states that the engineer should design the overall structure to prevent progressive collapse if a vertical support (i.e. a column) fails. The EN 1992-1 merely states that the structure should be “robust.”

It may therefore be necessary to upgrade the SANS 10100-1 if HCC is to achieve its full potential in South Africa. It is found that suitable design guides are available in other countries where precast construction is successfully used. Therefore, a decent design guide for HCC and precast construction will be required to stimulate growth in the South African HCC industry.

2.5 Conclusions

Even though the South African construction industry has shown significant growth in recent years, it would appear as if it is unable to meet the required rate of development. One factor would be to address the rate of development and attention is thus drawn to the precast industry to help deliver projects at greater speed.

Similar circumstances in the United Kingdom led to the development and widespread acceptance of Hybrid Concrete Construction (HCC). HCC is a construction method that combines the accuracy, speed and high-quality finish of precast components with the economy and flexibility of in-situ concrete. The correct application of HCC can lead to significant time and whole life cycle cost savings on various types of projects. It does however require more design effort and co-ordination. Construction costs may also be slightly higher.

Many other countries have been very successfully using precast construction techniques for a very long time. Several of them developed their own standardised precast units and connections. This rapidly led to the widespread use of precast methods in these respective countries. Standard product sizes not only helped the constructability but also lowered the cost of precast projects.

Even though the SANS 10100-1 and the EN 1992-1 cover similar precast design topics, the newer EN 1992-1 is preferred. It is more aligned with current precast practices and better explains the key concepts of designing for precast construction. Therefore, it may be necessary to upgrade the SANS 10100-1.

It was shown that the use of precast construction grew rapidly in Canada, Japan, the United States, the United Kingdom and in the most parts of Europe after these countries published precast design guides. A similar design guide may be required to stimulate growth in the South African HCC industry.

3. SOUTH AFRICAN CONSTRUCTION INDUSTRY SURVEY

The use of new materials and techniques, together with precasting, are shown to be widely used in several of the European construction markets (Van Acker, 2007) (Bruck, 2007). It was therefore decided to perform a brief survey of the South African construction industry to determine the extent to which Hybrid Concrete Construction (HCC) was being implemented, if at all.

This chapter presents the results of the above-mentioned survey. The survey consisted of interviews with representatives from several large contractors as well as a questionnaire survey of consultants and contractors from across South Africa.

3.1 Personal Correspondence and Interviews

Through personal interviews, data was collected from representatives of Grinaker-LTA, Group 5, Infraset, Murray & Roberts, NMC and RBD Construction (*Appendix G*).

The objectives of these interviews were to:

- Identify any obstacles that are preventing the widespread use of Hybrid Concrete Construction (HCC) in South Africa
- Discuss these obstacles to obtain possible solutions
- Use the knowledge gained to develop a national questionnaire survey

The following paragraphs provide an overview of the information obtained from the personal interviews. The following items are discussed in more detail:

- Cooperation within the project team
- Communication within the project team
- Specific skill requirements for HCC projects
- The availability and use of precast elements in the South African market
- The application of Self Compacting Concrete (SCC) in precast construction
- Tendering for HCC projects
- The Design-build procurement system

3.1.1 Project Management Aspects

In many cases, current projects undertaken in South Africa lack the team approach that Hybrid Concrete Construction (HCC) projects require. Project participants (client, contractor, designers and managers) need to work as a unit from the start of a project to finalize the project's design at an early stage (Goodchild, 2004). This ensures that construction can progress quickly and without timely delays. Appropriately trained and experienced project managers are required to provide effective leadership to the project team (Goodchild, 2004). This approach towards project management is not currently widely experienced in South Africa, but most of the interviewees agreed that it is important and requires greater attention.

Communication between the project team participants is vital to the success of a HCC project. All participants need to be kept up to date with any design changes to prevent costly construction changes. The interviewees confirmed the information from the studies by Goodchild (2004).

HCC projects require specific skills that are currently in extremely short supply, these include experienced project managers, design engineers with experience in HCC projects and high quality crane operators and riggers. Several individuals do exist that possess great amounts of experience and knowledge about the advantages of using more prefabrication in projects (Table 3.1 & 3.2). Unfortunately, these individuals are forced to use their own initiative when suggesting changes to a project and their input is often lost in the busy construction environment.

It is concluded from the above information that to achieve these goals it may be required that the tertiary education programs for engineering students and project managers be altered. Individual companies may also need to invest in the development of the required skills as the governmental programs cannot meet the required demand.

3.1.2 Technical Aspects

It is found that South Africa's precasting industry is capable of producing similar types of products as their European counterparts (e.g. Echo Group, South Africa (2006), SEAC, France, (2003)), but local widespread knowledge and experience about the advantages of Hybrid Concrete Construction (HCC) is lacking.

The use of precast elements on a project should not be restricted to products available in the market. Precast moulds are however expensive and a large number of elements need to be produced to lower the cost per unit. It is therefore important to discuss with the contractor, before construction commences, where the best application of precast elements will be (Goodchild, 2004). Some of the interviewees confirmed that this problem could be eliminated by constructing several similar buildings such as schools, hospitals or parking garages.

Most of the contractors confirmed that in-situ columns delay the entire construction process. They agree that a multi-storey continuous precast column could lead to significant on-site construction time savings, but that the difficulty of the associated connection is preventing the widespread use of this system. This was the motivation for an investigation into the available precast connections and led to the preliminary development of a Hidden Corbel Connection (*Chapter 6*).

Richard Brown (RBD Construction) mentioned that the current cost and limited availability of Self Compacting Concrete (SCC) are preventing the widespread use of SCC in the South African industry. It was found that SCC costs 5% - 10% more than normal concrete in Europe (Bennenk, 2007). However, SCC costs 20% - 30% more than normal concrete in South Africa (Lafarge, 2007). Even at the increased material price, several South African examples exist (Lafarge, 2007) that already indicate the overall cost savings associated with using SCC. These savings usually result from the decreased labour cost associated with constructing such SCC slabs.

Self Compacting Concrete (SCC) is very useful in the precasting industry. Research by Geel *et al.* (2007) found that SCC offers the following main advantages:

- Faster construction times
- More intricate shapes can be cast
- Better surface finishes
- No vibration is required, therefore precast moulds last longer
- Construction noise is significantly reduced

Geel *et al.* (2007) concluded that a local set of guidelines for the production and application of Self Compacting Concrete (SCC) is required to promote the widespread use of this relatively new material. Recent developments show that Readymix producers are now starting to market SCC (Geel *et al.*, 2007) and this should lead to increased usage and understanding of this material. Furthermore, Geel *et al.* (2007) also found that precast operators are in the best position to reap the maximum rewards offered by SCC, even though most precast operators were not willing to make the required changes to their factories.

The development of affordable Self Compacting Concrete (SCC) requires further investigation and the Netherlands may be used as an example. They experienced similar circumstances and their entire ready-mix concrete industry cooperated in the development and testing of affordable SCC (Bennenk, 2007).

3.1.3 Contractual Aspects

Hybrid Concrete Construction (HCC) requires that the Project team work together from the start of a project, and that more time is spent planning the conceptual design. The interviewees commented that this significantly increases the costs and the time required for tendering. Ideally, the contractual format and/or tender procedure should allow for such collaboration between different parties. It was confirmed by the majority of the interviewees that such procedures normally do not exist, and that initiatives for collaboration are often initiated by individual companies or persons on the project teams.

It was found that contractors often prefer the Design-build procurement system. In this system, they usually take control of the project and play a bigger role in the preliminary design of the building. The contractor now becomes the client and the design team has to work under their coordination and not under the coordination of an architect. This also leads to greater cooperation in the project team from the beginning of the project, an essential requirement to achieving success in a HCC project (Goodchild, 2004).

The Design-build delivery method is shown to be increasingly used in the United States of America (El Wardani *et al.*, 2006) for all construction project types. It offers significant project time and cost savings and on average, delivers the best project performance (Konchar and Sandivo, 1998).

Unfortunately, the Design-build delivery method is not used very often in South Africa. According to research conducted by Michell *et al.* (2007), only 9% of South African projects employ the Design-build delivery method. Better informed South African clients, who wish to remain involved in the entire construction process, may be responsible for the above-mentioned statistic.

It may therefore be advantageous to promote the use of this delivery method within the South African in-situ and precast construction industries. Suitable South African guidelines are however required.

3.1.4 Conclusions

Most of the current South African projects lack the team approach that Hybrid Concrete Construction (HCC) projects require. Effective communication within the project team is vital. The project's team needs to discuss the final design and the optimum use of precast elements if cost-savings are to be achieved. It may therefore be necessary to alter the tertiary education programs for engineering students and project managers to promote such partnerships.

HCC projects require specific skills that are currently in extremely short supply and individual companies may need to invest in the development of these skills, as the governmental programs cannot meet the required demand.

More information is required about South African precast suppliers, the availability of their products and the precast market potential. A complete literature study and possibly an industry survey is required to determine the above-mentioned facts, as well as to compare the South African precast suppliers' market to its European counterparts. Such a study, however, was deemed fall outside the scope of this thesis and is therefore recommended for further investigation.

An effective multi-storey continuous precast column system, that is easy to manufacture and erect, could lead to significant on-site construction time savings. Further investigation into the development of such a system would be a worthwhile endeavour.

The development of affordable Self Compacting Concrete (SCC) in South Africa is very important as SCC allows the use of cheaper moulds and provides a better surface finish to precast elements. This could give precasting another important advantage over in-situ concrete construction. Geel *et al.* (2007) also found that a local set of guidelines for the production and application of SCC is required. Further investigation into this field is highly recommended.

It may be advantageous to promote the use of the Design-build delivery method within the South African in-situ and precast construction industries. Suitable South African guidelines are however required and such guidelines should include the following items:

- The advantages of using the Design-build method in the South African construction industry
- The experience and skills required by all parties involved to guarantee the success of such an undertaking
- Local case studies of successful Design-build projects along with the lessons learned by the project team
- The type and size of projects for which this delivery method is considered to be feasible

3.2 Precast Design Questionnaire Survey

A national questionnaire survey was undertaken to determine the state of HCC in the South African market. The Precast Design Questionnaire evolved from the knowledge gained during the personal interviews. It was decided to focus on some of the well-known engineering practices in South Africa. A complete survey of all South African engineering practices would be an immense under-taking. Escalating the survey into the main focus of this thesis was not deemed to be within the objectives of this thesis and smaller practices were therefore ignored.

Only the more experienced engineers were selected for this survey. This was done to obtain a broader historic evaluation of the building systems that are regularly used in South Africa.

The objectives of this questionnaire survey were to determine:

- How often precast systems are used in the South African industry
- If South African designers are comfortable with using precast systems
- If there is sufficient information available to evaluate precast versus in-situ systems during the conceptual design phase of a project
- Why precast structural systems aren't used more often in South Africa
- If precast construction is considered to have a future in the South African market

Twelve contracting engineers, including three from precast element manufacturers, and fifteen consulting engineers from various South African firms were selected for this survey. After obtaining their permission, an e-mail with five elementary questions were sent to the participants. Eight (66.7%) of the contracting engineers and twelve (80%) of the consulting engineers finally responded and their individual feedback forms can be found in *Appendix C*.

The following sections describe the results obtained from the consultants and contractors in the questionnaire survey.

3.2.1 Survey Results - Consultants

Table 3.1 contains the statistical results of the Precast Design Questionnaire for consultants. It was found that 67% of the consultants have never or do not often become involved in the design of precast concrete systems, even though 75% of them are confident in designing such systems.

75% of the consultants believe that precast construction has a successful future in the South African market. Most however added that there is a significant amount of work required if the South African precast industry is to catch up on its European counterparts. The following comments were made:

- A South African example project is required and every step of the project's progress has to be documented
- Investment is required into more and proper precast manufacturing plants
- Precasting requires a major marketing effort to promote its advantages
- The current skill shortages and time limitations are ideal circumstances for promoting the development of precast construction in South Africa

Table 3.1 Statistical results of the Precast Design Questionnaire for consultants

CONSULTANTS	***12***		
How often do you become involved in the design of precast concrete systems?			
Never	1	8.33	%
Not often	7	58.33	%
Often	3	25.00	%
Very often	1	8.33	%
Do you feel adequately equipped to perform designs on precast systems (connections etc.) with a high level of confidence?			
Yes	9	75.00	%
No	3	25.00	%
Do you have sufficient information to weigh options of precast vs. in-situ casting against one another during the pre-design phase of a project?			
Yes	3	25.00	%
No	9	75.00	%
Do you think precasting has a future within the South African construction industry?			
Yes	9	75.00	%
No	1	8.33	%
Maybe	2	16.67	%

Interestingly, the survey found that 75% of the consultants do not have sufficient information to weigh options of precast versus in-situ systems during the conceptual design phase of a project. This may be one of the biggest reasons why precast systems are not used more often in South Africa. One respondent stated that the prices of precast elements are not freely available, as they are in Europe, and that further investigation is required on the preliminary pricing of precast and Hybrid Concrete Construction (HCC) projects.

The time available to evaluate alternatives in the tender process is also very limited. It may therefore be required to alter the current tender process or to promote the use of alternate procurement systems and delivery methods. Once again, the Design-build procurement method was suggested.

In summary:

- Precasting is considered to have a successful future in South Africa
- The prices of precast elements and their erection costs are not freely available
- There is a lack of information to weigh options of precast versus in-situ systems during the conceptual design phase of a project
- It may be necessary to alter current tender processes to promote alternative delivery methods
- The Design-build delivery method was suggested as it can lead to significant time and cost savings

3.2.2 Survey Results - Contractors

Table 3.2 contains the statistical results of the Precast Design Questionnaire for contractors. Contractors indicated that constructing in-situ concrete or precast concrete systems are very similar and that precast construction does not present any significant challenges. Contractors were therefore also evaluated on the design of precast systems. Similar to the consultants, it was found that 75% of contracting engineers have never or do not often become involved in the design of precast concrete systems. 75% also believe that precasting has a successful future in the South African construction industry and similar comments were received as those from the consulting engineers.

However, in this case 75% of the contractors are not confident in designing precast systems. Respondents noted that they prefer to leave the design work to the consulting engineers and usually only give input about the ease of manufacturing and erecting of a specified precast design. Another similarity to the consulting respondents' results was that 62.5% of the contractors do not have sufficient information to weigh precast versus in-situ systems during the conceptual design phase of a project.

Table 3.2 Statistical results of the Precast Design Questionnaire for contractors

CONTRACTORS	***8***		
How often do you become involved in the design of precast concrete systems?			
Never	2	25.00	%
Not often	4	50.00	%
Often	1	12.50	%
Very often	1	12.50	%
Do you feel adequately equipped to perform designs on precast systems (connections etc.) with a high level of confidence?			
Yes	2	25.00	%
No	6	75.00	%
Do you have sufficient information to weigh options of precast vs. in-situ casting against one another during the pre-design phase of a project?			
Yes	3	37.50	%
No	5	62.50	%
Do you think precasting has a future within the South African construction industry?			
Yes	6	75.00	%
No	0	0.00	%
Maybe	2	25.00	%

This not only shows that more research is required into this field, but highlights the current lack of collaboration between members of the project team from the beginning of project. In the literature study (*Chapter 2*), this cooperation was shown to be vitally important to the success of a Hybrid Concrete Construction project. It may therefore be required to promote long-term partnerships between contracting, consulting and architectural firms who regularly work together in the South African industry. This could significantly reduce the time and cost of tendering for projects.

In summary:

- Precasting is considered to have a successful future in South Africa
- There is a lack of information to weigh options of precast versus in-situ systems during the conceptual design phase of a project
- It may be necessary to promote long-term partnerships between contracting, consulting and architectural firms who regularly work together

3.2.3 Limitations to the use of Precast Construction

The participants of the questionnaire survey were asked why they thought that precast construction methods are not used more often in South Africa. Their complete responses may be viewed in *Appendix C*, but the following responses are highlighted.

- Project teams do not have time to develop and evaluate new alternatives in their busy construction schedules
- Most consultants and contractors currently lack sufficient technical experience in precast construction
- Not enough South African precast projects have been documented sufficiently to be used as case studies by the industry
- There is a lack of understanding of the cost and time savings and the perceived expensive costs of rigging equipment versus the cost of in-situ methods exists
- South African designers and constructors are used to working with in-situ concrete systems and it may be difficult to alter their perceptions
- The current project delivery method is not conducive to the use of precast construction as the design is not completely finished before construction begins
- There is a severe shortage of skills in all activities associated with precast concrete construction
- There are currently no mass production precast manufacturers of structural elements (except for hollowcore slabs) and no standardized product ranges in the South African precast industry
- Better information and education is required on the design, management and use of precast construction in South Africa

The skill shortages, lack of information about the advantages of precast methods and the limited availability of experienced precast designers and constructers were identified as the biggest obstacles that are preventing the widespread use of Hybrid Concrete Construction (HCC) in South Africa.

3.2.4 Conclusions

Most of the respondents have never or do not often become involved in the design of precast systems. They do however consider that precasting has a future in the South African industry. Most of the consulting engineers feel confident in designing such systems, while most of the contractors do not. 75% of consultants and 62.5% of contractors do not have sufficient information to weigh precast options versus in-situ systems during the preliminary phases of a project. This may be one of the obstacles that is preventing the widespread use of Hybrid Concrete Construction (HCC) in South Africa.

Respondents indicated that the biggest obstacles that are preventing the widespread use of HCC in South Africa are the severe skill shortages, the lack of information about the advantages of precast methods and the limited availability of experienced precast designers and contractors.

It was again found that it may be advantageous to promote the use the Design-Build delivery method within the South African construction industry. It may also be necessary to promote long-term partnerships between contracting, consulting and architectural firms who regularly work together in the South African industry. These steps could significantly reduce the time and cost of tendering for projects.

Further investigation is recommended into the development of suitable guidelines for HCC and precast construction in South Africa. Such guidelines should include:

- Advice on the proper design of precast systems
- Cost evaluations of precast versus in-situ systems during the preliminary design phase of a project
- Detailed South African case studies of successful HCC projects

Investigation is also needed into the required training programs for the development of scarce skills in South Africa.

4. PRECAST CONNECTION DESIGN

Designing the connections is one of the most essential parts of a precast project. These connections must meet a wide variety of design and performance criteria. Their principle function is to transfer forces across construction joints so that proper interaction between precast units is obtained. Other criteria such as the water tightness, fire protection, durability, aesthetics and the manufacture, transportation and erection practices (tolerances etc.) of the chosen design should also be taken into consideration.

The literature survey identified that much information is available internationally on precast connection design. However, limited information could only be found for the South African market.

Therefore, the objectives of this section were to:

- Identify the basic types of precast connections that are being used by the international industry
- Briefly discuss their inherent properties
- Evaluate the current information that is available to South African designers

This investigation included reviewing the SANS 10100-1, the EN 1992-1, the Planning and Design Handbook on Precast Building Structures (fib, 2004), the Seismic Design of Precast Concrete Building Structures (fib, 2003) and several publicised results of experimental connections.

South Africa is mostly non-seismic, but several regions are classified as moderate active seismic zones (SANS 10160). The investigation was therefore limited to Moment carrying precast connections as these connections have the added benefit of being useful in seismic designs. The example connections in the "Seismic Design of Precast Concrete Building Structures" (fib, 2003) were found to be useful for the South African market and some extracts are presented below.

4.1 Forces within the Connection Area

The interaction of forces found within a typical connection area can be very complex. The design of a precast connection is even more critical as the number of variables to consider increases. The space available to ensure proper anchorage of the necessary reinforcement is also very limited, further complicating the design process.

Figure 4.1 shows a typical Beam-column precast connection (*Chapter 4.1.1*) as well as a layout of the forces that are present within the connection area.

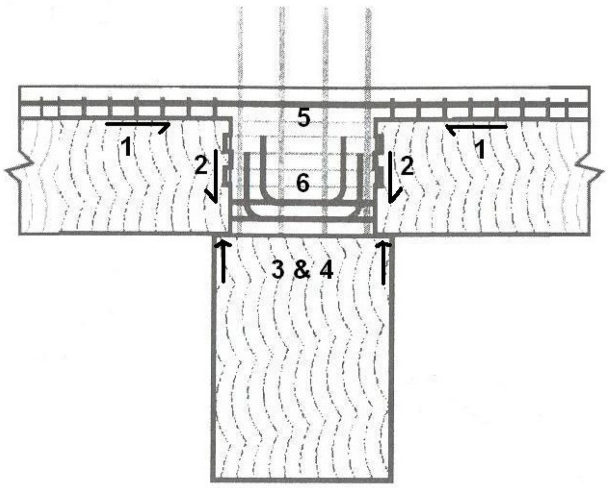

Figure 4.1 A typical Beam-column connection and the forces acting within the joint area.

The following forces (figure 4.1) usually act within a typical precast connection area:

1. Interface shear and bond stresses (SANS 10100-1 6.4.4)
2. Vertical shear or Shear friction concept (SANS 10100-1 6.2.5.3.4)
3. Bearing forces (SANS 10100-1 6.2.4)
4. Temporary bearing forces if no propping is provided (SANS 10100-1 6.2.4)
5. Tension force in Top reinforcement
6. Compression force in Bottom concrete

To properly design a precast connection, the engineer has to be aware of all the forces that are present within the connection during all stages of construction. The connection has to withstand all of the above-mentioned forces as well as any combination of them.

Interface shear and bond stresses, as well as their understanding, is a specialized and highly scientific field of study. Many international and local publications exist on the topic and continuous research work is being done in this field at the University of Stellenbosch (Stander, 2007).

Chapter 6.2 of the EN 1992-1 gives a thorough explanation of the entire shear concept. The application of the Strut-and-Tie model of analysis to any shear problem is also explained with detailed sketches. The Strut-and-Tie model is a useful method to address many of the design aspects in reinforced concrete and it may be necessary to update the SANS 10100-1 code to match such modern techniques.

4.2 Beam-Column Connections

The design of a Beam-Column connection requires careful attention and a well defined load path needs to be identified. These connections have to transmit moments, tensile forces and shear forces. Most of the following examples strive to ensure the continuity of the longitudinal reinforcement. The joint's core is often heavily congested and relatively high construction tolerances are required. It is also recommended that the precast concrete surfaces be roughened and cleaned before casting the in-situ concrete. Alternatively, mechanical shear keys may be cast into the units to improve shear transfer (fib, 2003).

Beam-Column connections are categorised into several groups. Within the group there are many alternatives, but the group's concept remains similar. These concepts are discussed in the following sections.

4.2.1 Precast beam units between columns

In this arrangement precast reinforced or precast prestressed members form the lower part of the beams (figure 4.2). The precast beam elements are placed between columns and seated on the cover concrete of an in-situ or precast column using adjacent props. Hollowcore floor elements are typically placed to span between these beam elements. Reinforcement is then added to the top of the beams, over the precast floor and into the joint. The topping slab over the floor and the joint is then cast before the next in-situ or precast column is placed via a Column-Column connection.

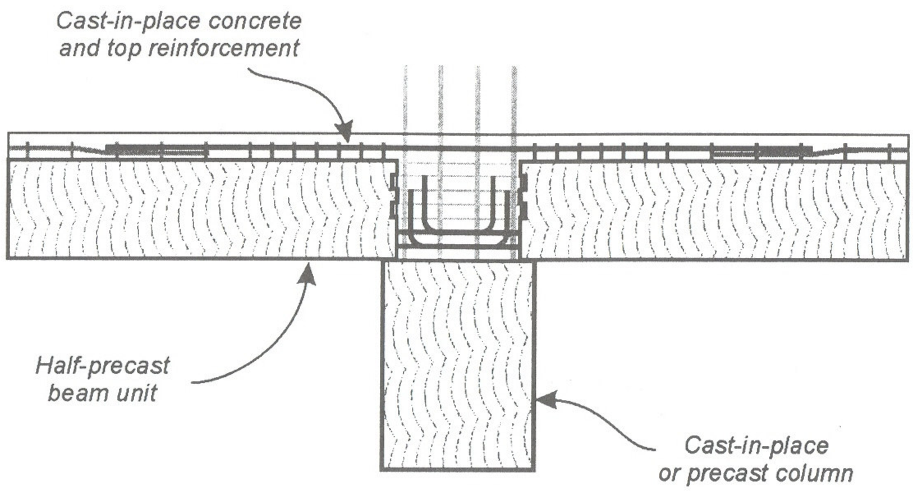

Figure 4.2 A Beam-Column connection using hooked bar anchorages (fib, 2003).

The joint core can however become very congested and the columns need to be reasonably large to allow enough space for the required anchorage lengths. The effective anchorage of bars is required for the transfer of shear forces through the shear friction concept (SANS 10100-1).

4.2.2 Precast beam units through columns

This system (figure 4.3) makes more use of precasting than the above-mentioned system and doesn't require the placing of in-situ concrete in the congested joint core. It does however require tighter than normal tolerances to be successful. The columns can be either in-situ reinforced concrete or precast reinforced concrete. The precast beam extends from near midspan to near midspan and the complex reinforcement in the joint core is manufactured at the precast factory. The precast beam is then placed on the column and propped for stability. The column's protruding longitudinal reinforcement passes through steel ducts in the precast beam and extends above the top of the beam. The steel sleeves are then filled with grout from below to avoid air-locks. The beams are connected at midspan using one of the Beam-Beam connections before a floor system similar to *Section 4.2.1* is put in place.

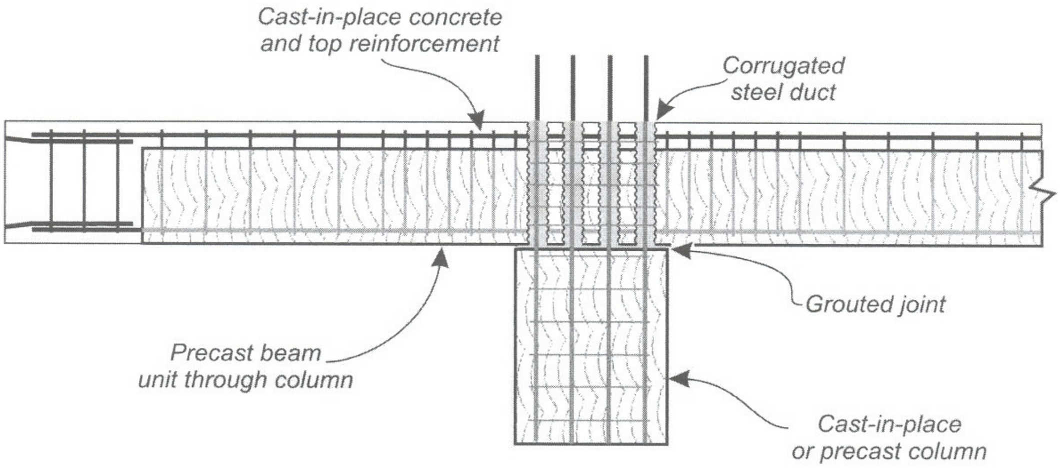

Figure 4.3 A Precast beam through the column connection (fib, 2003).

Unless individual contractors devise systems to easily place such beams, the difficulty which South African contractors may experience in placing such beams with the column reinforcement already in place, may make this connection unsuitable for the South African market.

4.2.3 Precast beam units post-tensioned between columns

The main advantages of post-tensioned systems are their deflection recovery and immediate occupancy characteristics. The arrangement in figure 4.4 uses precast beams and columns. This system works very well with multi-storey continuous columns. The precast beams are placed on temporary supports, the gaps between the beam and column are grouted, and then the system is post-tensioned and the tendons grouted. The grouted tendons are necessary to allow energy dissipation through the yielding tendons. It is recommended to anchor the post-tensioning tendons in an end block outside of the column so as to remove the bursting stresses from the critical joint area (fib, 2003).

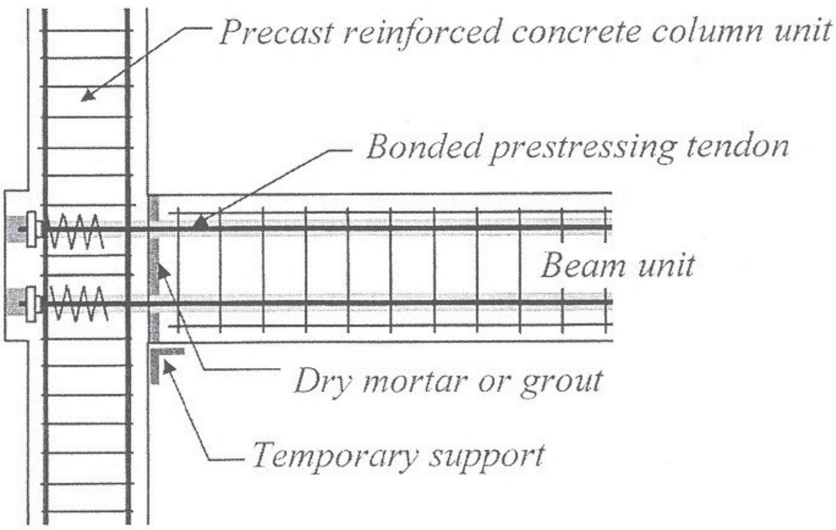

Figure 4.4 General reinforcing details of an equivalent monolithic post-tensioned system (fib, 2003).

Another variation of this system involves corbels to replace the temporary props. This system is only suitable for elastic responses as the corbel complicates the response mechanism of this system. Large shear forces are expected to develop in the beams when loaded beyond their elastic limit.

In seismic regions, a hybrid frame connection (figure 4.5) uses un-bonded post-tensioning tendons to connect precast beams to multi-storey columns. Mild steel reinforcement is placed into corrugated ducts at the top and bottom of the beam before being grouted into place. These bars provide the required energy dissipation through yielding. The amount of mild steel reinforcement and post-tensioning steel is balanced. This allows the frame to self-center after a major seismic event.

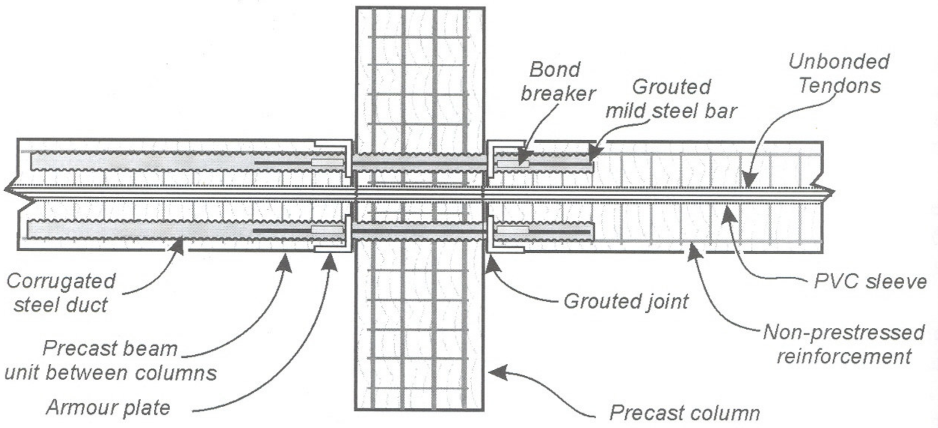

Figure 4.5 The Beam-Column assemblage of a hybrid frame system (fib, 2003).

Since large rotations can occur, the beam ends need to be protected against premature crushing. This is achieved by armouring the beam ends or adequately confining the concrete with spiral reinforcement (fib, 2003).

The moderately active seismic regions in South Africa may however not justify the use of this type of connection. Further investigation will be required to determine if this type of connection is needed in the South African market.

4.2.4 Hidden corbel connections

The classic corbel connection provides a simply supported joint that offers very little moment transfer between the beam and column. This connection is simple to design, manufacture and erect, but is not very suited to earthquake applications. This connection has several other disadvantages including its low aesthetic value.

Hidden corbel connections such as the Beam, Column and Freely-supported (BCF, figure 4.6) connection are gaining popularity across the world. This connection has several advantages but is more expensive than its classic corbel counterpart.

According to Vamberski *et al.* (2005), the BCF corbel has the following advantages:

- Simple formwork
- Fast erection time
- No screws or nuts
- The corbel is completely hidden
- Provides direct stability against transverse loads
- Good fire resistance
- For the dimensions considered by Vamberski, it is a standardised detail with a bearing capacity of up to 350kN in the serviceability limit state

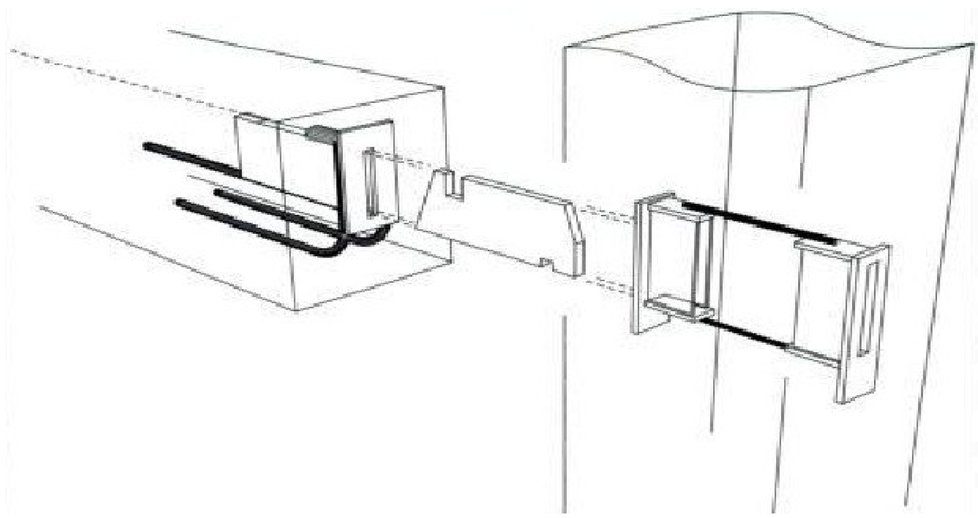

Figure 4.6 The BCF hidden steel corbel connection (Vamberski *et al.*, 2005).

This connection was developed and patented by the Norwegian firm Ostspenn and is not currently available in South Africa. Several other designs have been tested and developed, but usually the engineer has to devise his/her own design for a specific project. This is often a challenging task for engineers that are not used to designing precast connections.

4.3 Beam-Beam Connections

Beam-Beam connections strive to ensure the continuity of the longitudinal reinforcement. This does however lead to the formation of a stiffer section in the area of overlapping bars. Therefore, in seismic regions, these connections need to be placed outside of any potential plastic hinge areas. It is also recommended that the precast concrete surfaces be roughened and cleaned before casting the in-situ concrete. Alternatively, mechanical shear keys may be cast into the units to improve shear transfer (fib, 2003). Design information on a variety of beam-beam connections are freely available (Restrepo *et al.*, 1995).

Non-contact straight bar laps are often used to connect beams with short aspect ratios. In such cases the longitudinal reinforcement is offset to minimize a potential clash that might occur during erection. If the span between columns is long enough, a double-straight bar lap (figure 4.7) provides a simple way of connecting the precast beams.

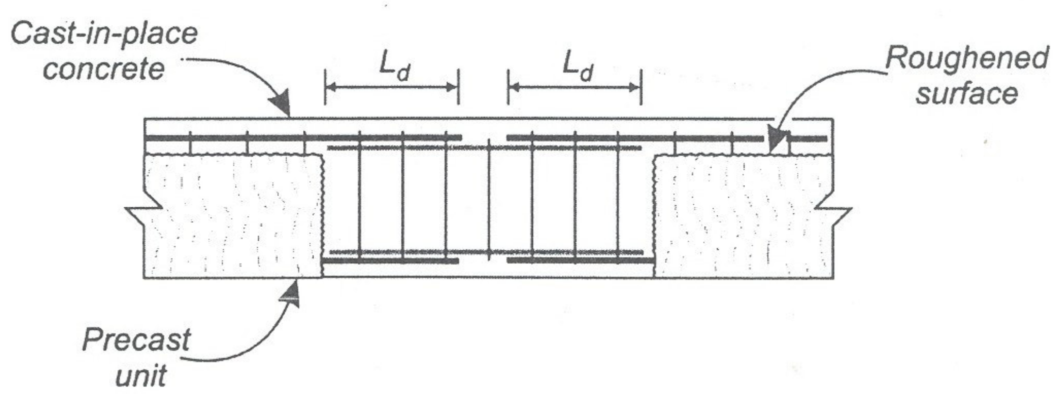

Figure 4.7 A Beam-Beam connection using double-straight bar laps (fib, 2003).

Alternatively, drop-in double hooked bars (figure 4.8) can be used. This connection is very simple to erect and is suitable for connections located away from the supports. It is also recommended that these joints be located at 1/3 points along the span. This ensures that bending moments in the connections are minimized. Transverse rods of the same diameter as the hooked bars are required to prevent splitting of the concrete due to the large radial forces developed in the bend (fib, 2003).

No guidance is available in SANS 10100-1 for this type of connection, while EN 1992-1 provides some information. South African designers may therefore be reluctant to use this type of connection unless some test results on similar joints are made available.

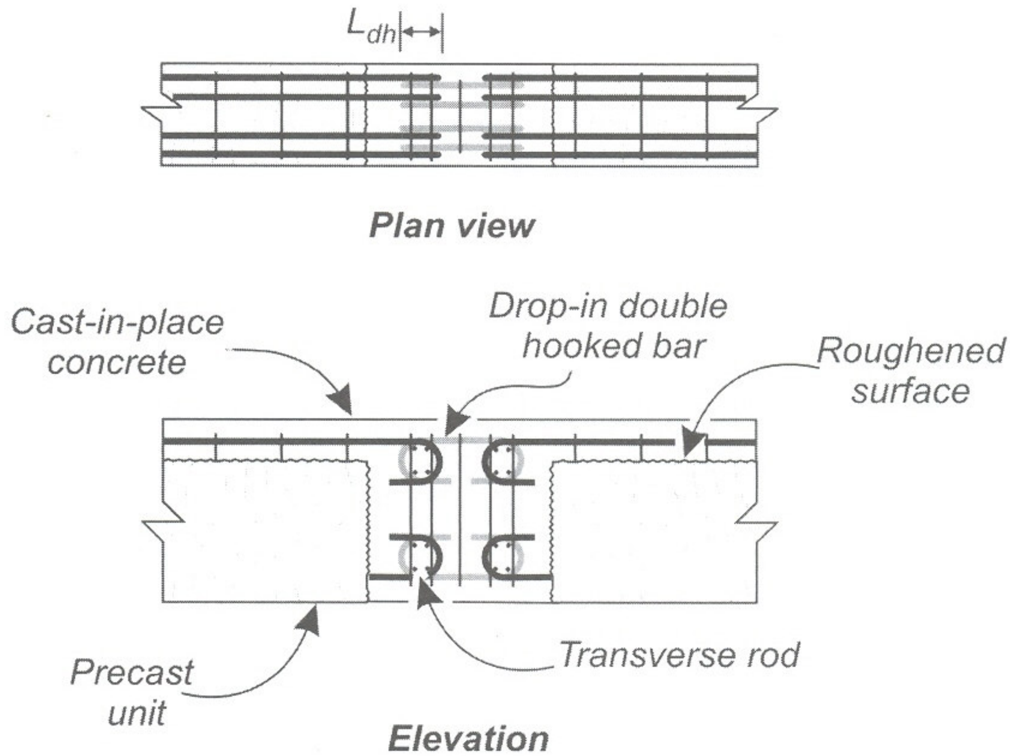

Figure 4.8 A Beam-Beam connection using drop-in double hooked bars (fib, 2003).

A beam-beam connection can also be made by welding or mechanically coupling (figure 4.9) the longitudinal reinforcement from the precast beam elements. This produces a very neat joint but requires strict construction tolerances and on-site quality assurance procedures. The use of welded joints is however not considered feasible for the South African market due to the associated quality control difficulties.

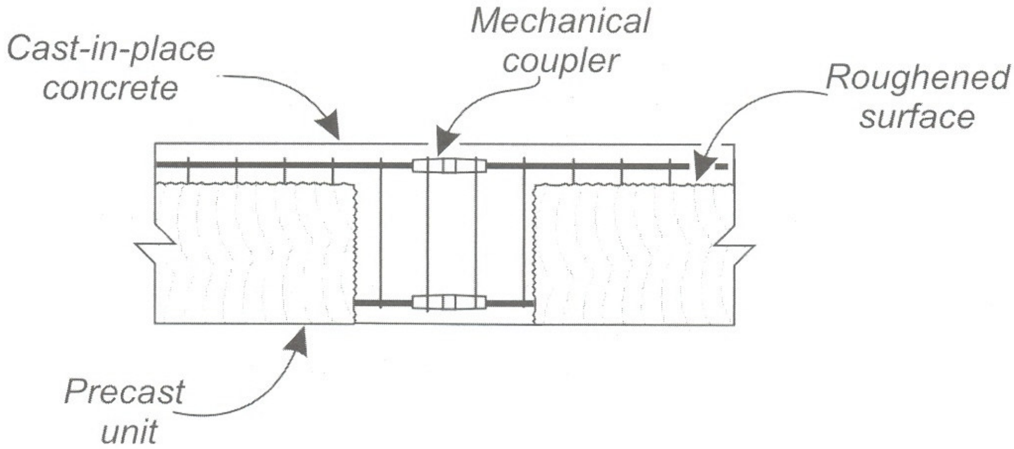

Figure 4.9 A Beam-Beam connection through mechanical couplers (fib, 2003).

4.4 Column-Column Connections

Although South African practice rarely makes use of precasting and joining columns, this practice is fairly common internationally. Furthermore, the Industry survey (*Chapter 3*) identified that the use of precast columns could greatly improve the rate at which projects are delivered. The following Column-Column connections are therefore important for the South African industry.

Precast concrete columns are usually connected either at the bottom end above a beam or at mid-height between floors. Connections at the column ends should only be used if the development of a plastic hinge there is excluded through proper design. These connections transmit mostly compression forces but should also be capable of transmitting bending moments.

There are two main approaches for connecting columns. In both cases a gap is left between the jointing surfaces. These surfaces must be roughened and clean before the connection is made.

The first method uses grouted steel sleeves (figure 4.10) to align the longitudinal reinforcement before they are grouted together. Because the steel sleeves are oversized, the reinforcement has to be placed closer to the column's center to maintain a specific concrete cover. It is not necessary to overlap the reinforcement as sufficient anchorage for each bar is provided within the steel sleeve.

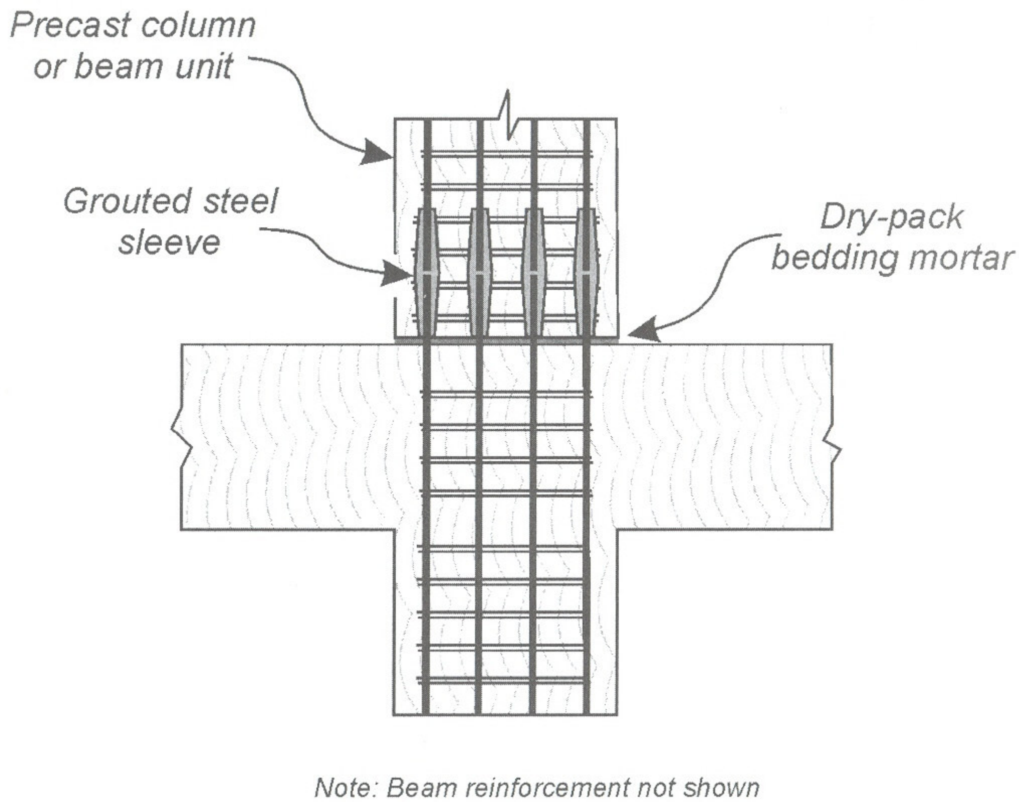

Figure 4.10 A Column-Column connection through grouted steel sleeves (fib, 2003).

Another approach is to connect the longitudinal bars through non-contact splices (figure 4.11a). The protruding bars from the bottom column (Bars "G") are grouted into corrugated steel ducts in the top column. Two smaller bars (Bars "L") are then placed to overlap the steel ducts and the "G" bars from the next level. Bars "G" have to be lap-spliced more than the development length of Bars "L" (figure 4.11b).

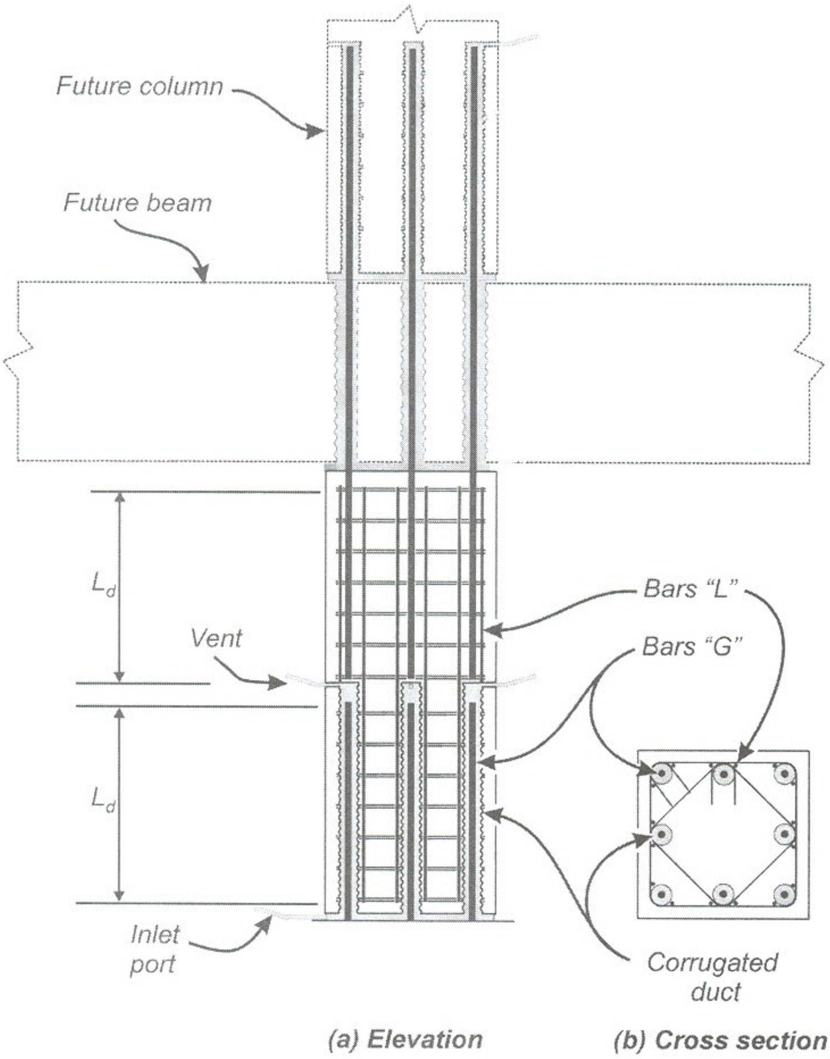

Figure 4.11 A Column-Column connection through non-contact lap splices (fib, 2003).

4.5 Precast Slab Connections

Floor systems play a very important role in the lateral resistance of a building structure. By providing diaphragm action, they transfer lateral loads to the internal load resisting elements (e.g. shear walls). Diaphragm action also unites the individual lateral load resisting elements into a single system.

It is, however, generally accepted that the current design guidelines for precast concrete diaphragms in seismic regions require further improvement after their poor performance in recent earthquakes (Ghosh, 1999).

In low to moderate seismic zones, such as South Africa, un-topped precast concrete slabs (figure 4.12) are sufficient (fib, 2003). In these systems, the chord forces are carried by reinforcement bars within the edge pour strips. These chord forces ensure that the precast slab elements are pulled together to enable the effective transfer of shear forces from adjacent elements through their interlocking shear keys. However, most current South African projects use topped precast concrete slab systems (figure 4.13) as the design of un-topped floor systems for diaphragm action is not covered by the SANS 10100-1. This information is however provided in the EN 1992-1. The following precast floor systems are regularly used and may be used in the topped or un-topped floor configurations.

4.5.1 Hollowcore slabs

Hollowcore slabs have become very popular in construction activities the world over. Their high quality finish and long span capabilities make them ideal for almost any construction project. The units are placed on the cover concrete of an in-situ reinforced or precast reinforced or prestressed half-beam (figure 4.12 & 4.13). Reinforcement is then added to the top of the beams, over the precast floor and into the joint. The "Paper clip" bars are placed into the opened cores of the hollowcore unit. The topping over the floor, shear keys and the joint is then cast. In the case of un-topped systems, only the shear keys and the joint area is filled. This creates a solid T-flange section to carry the bending forces in the beam. The interface shear force in the longitudinal direction of the beam should however be checked (fib, 2003).

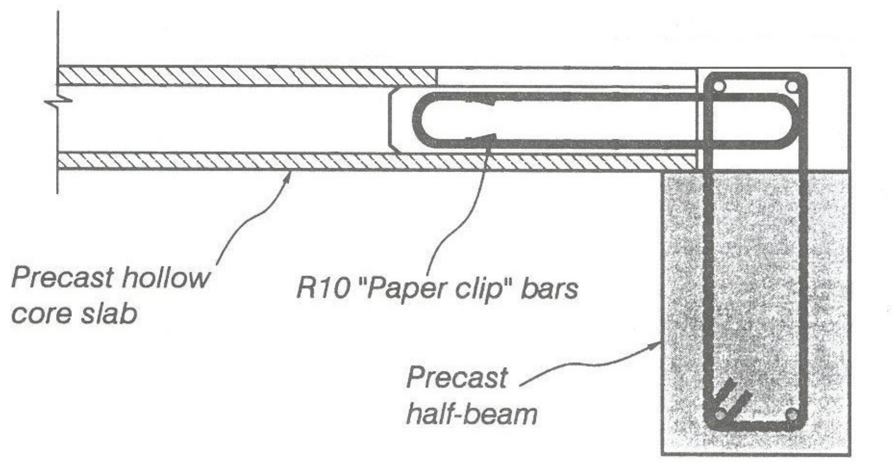

Figure 4.12 A detailed Beam-Hollowcore un-topped precast floor connection (fib, 2003).

No guidance about the design of hollowcore systems is provided in the SANS 10100-1. Recommendations about the design of such systems are published by the individual South African hollowcore manufacturers (Echo, 2006). It may however be required to update the SANS 10100-1 to include this topic.

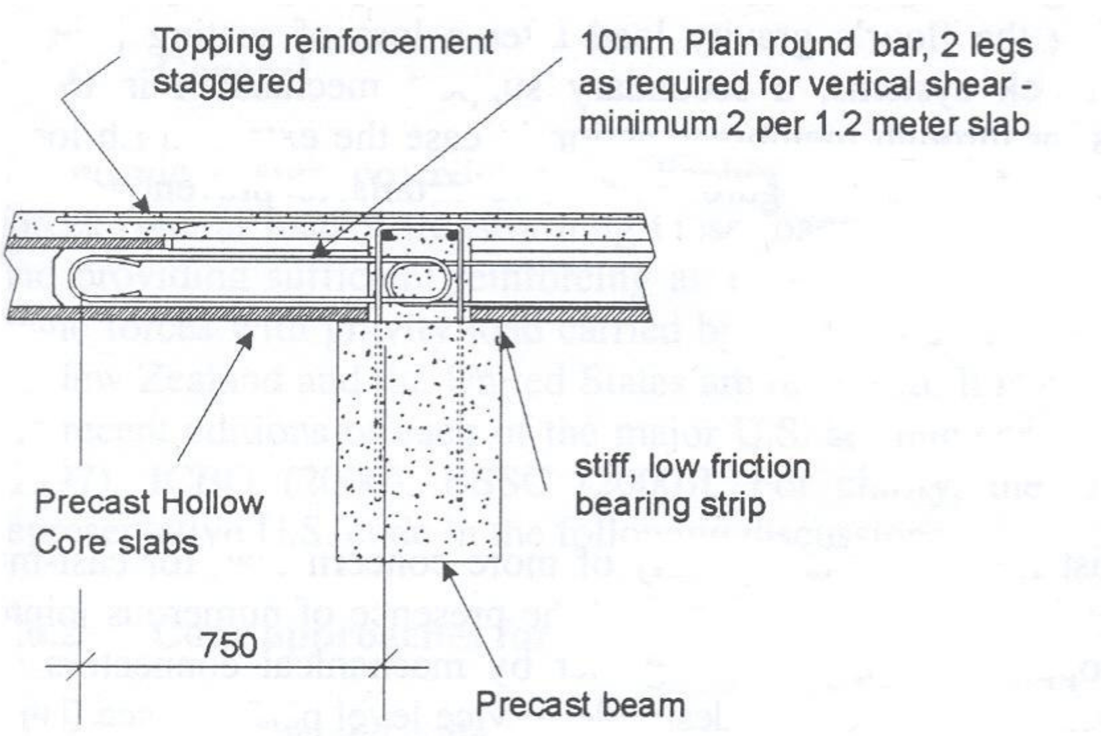

Figure 4.13 A detailed Beam-Hollowcore topped precast floor connection (fib, 2003).

4.5.2 Other precast floor systems

Solid planks, with roughened top surfaces, Beam-and-Block systems and Double or Single tee systems may also be used for diaphragm action and have very similar connections to the hollowcore slab system.

The design and use of the above-mentioned precast floor systems are very well documented. No further information is therefore given here.

4.6 Development of a Hidden Corbel Connection

Examples are limited for the design of hidden corbels that are both simple to design and easy to manufacture. Currently, the most successful hidden corbels in the international market are standardised units. These are bought from the manufacturer and are rated at a maximum capacity. Unfortunately, such products are not readily available in South Africa.

Another promising option was the Ductile Connector for beams and columns (Englekirk, 1995). It was however found to be too expensive for widespread use. The Ductile Connector also lacks the ability to connect beams that are spanning in different directions to a single column.

For the purpose of this study it was decided to conceptually investigate the feasibility of a standardised hidden corbel for the South African market.

The objectives of this investigation were developed through discussions held with several contractors and a precast manufacturer (*Appendix G*). Contractors were questioned about the performance characteristics that they would like in a precast Beam-column connection. A concept connection was then devised (*Chapter 4.6.1*). The concept connection's ease of manufacturing and erection were discussed with the precast manufacturer before the final design alterations were made. Figure 4.14 shows the conceptual proposal for the Hidden Corbel Connection. Further drawings may be found in *Appendix E.*

The main objective of this section was to develop a concept connection that is:

- Simple to design
- Economical to manufacture
- Compatible with multi-storey continuous columns
- Requires no on-site grouting

The constraints of this investigation meant that a bolted connection was required. Inspiration was drawn from several steel connection and foot-plate designs to develop the concept connection.

4.6.1 The Hidden Corbel Connection

It was finally decided to focus on a connection consisting of a steel corbel (figure 4.14) that will be cast into the precast beam's end. The Hidden Corbel will be bolted through a multi-storey continuous precast column to another Hidden Corbel and beam, or a steel plate at external columns.

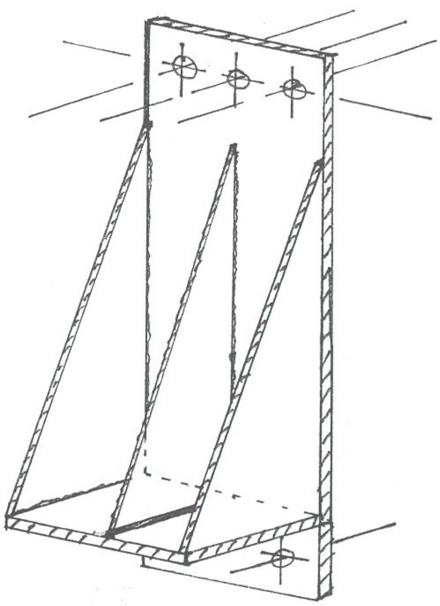

Figure 4.14 The Hidden Corbel Connection that is to be cast into a precast beam.

Thin metal shims will be used to close the gap between the beam and the column face. The bolt holes have to be oversized to allow for slight construction inaccuracies. The central web was found to be necessary to limit bending moments in the horizontal bearing plate. The use of High Strength Friction Grip bolts is recommended as they perform very well under combined tension and shear force loads.

Sleeves will be cast into the precast column with very tight tolerances. The accurate placement of the column is vital and the column bases have to be adjustable. Once the columns have been erected, the beam elements will be lifted into position and fastened by trained riggers. The hollowcore slabs can then be placed as usual (figure 4.15).

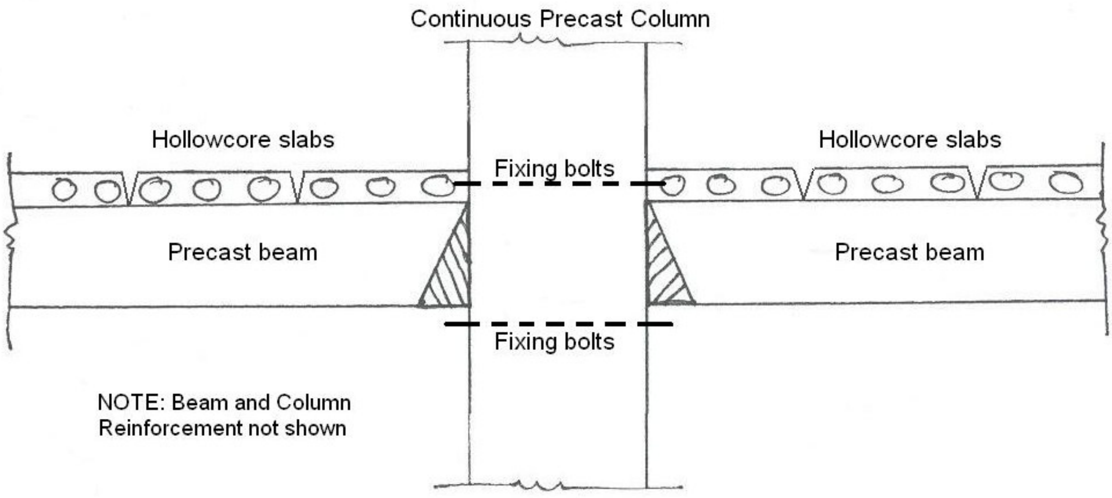

Figure 4.15 The Hidden Corbel Connection showing the continuous precast column, the precast beams, the hollowcore slabs and the Hidden Corbel.

The Hidden Corbel Connection potentially has the following advantages:

- It can be developed into a standardized detail
- It is easy to design and economical to manufacture
- Complicated formwork is not required
- Completed elements are easy to store and transport
- It is aesthetically pleasing
- No on-site grouting or propping is required
- It is compatible with multi-storey continuous columns

4.6.2 The Feasibility of the Hidden Corbel Connection

Preliminary calculations according to the SANS 10100-1 and SANS 10160, were used to determine the feasibility of the element's dimensions. Similar to the BCF hidden corbel (figure 4.6), the preliminary calculations were performed for a shear force of up to 350kN. It was found that the steel shoe could resist the mentioned forces with 16-25mm plates. The proposed connection was then discussed with representatives from several large South African contracting firms (*Appendix G*).

The following conclusions were drawn:

- The Hidden Corbel Connection's fire and corrosion resistance require special attention on the exposed bottom surface and bolts
- The construction tolerances have to be very high. The connection's adaptability requires further investigation
- The Hidden Corbel Connection can be developed to perform as a simply supported joint or moment carrying joint. This can be achieved by anchoring the reinforcement past the center of the support or by welding the reinforcement to the plate under controlled, factory conditions
- The interaction between the bending, tensile, shear and prying forces acting on the connection requires further investigation
- The cost of the connection versus the cost of the propping and the extra construction time of other precast connections require further investigation
- The Hidden Corbel Connection is believed to be feasible and further investigation would be a worthwhile endeavour

Several important questions did however arise during the preliminary design stage. These are:

- The requirements for longitudinal reinforcement anchorage, with regards to the simplified rules in SANS 10100-1, are to be investigated.
- Can the tensile reinforcement in the slab be used both for the transfer of shear (through shear friction) and for the bending moment?
- What friction coefficients can be relied upon and is this a redundant approach in the design of precast to in-situ concrete interfaces?

The above mentioned questions require a scientific investigation. It is therefore recommended that a complete study be launched on the development of a similar Hidden Corbel Connection.

4.7 Conclusions

Connections are a critical part of any precast project. These connections must meet a wide variety of design, performance and other criteria. It was shown that there are many examples of connections that have proven themselves over the years. These examples and their design principles are however not found in the South African design codes. Once again the need is emphasized for a proper precast design guide for the South African market. It has however been shown in this Chapter that SANS 10100-1 provides adequate information for the design of standard connections. Information which is lacking includes the strut-and-tie design method, as well as the effect of transverse bars on bar anchorage to prevent concrete tensile splitting. This information can however be found in other codes.

It was determined that the Hidden Corbel concept is feasible and that further investigation is required to develop the connection to its full potential. There are however several important questions that remain un-answered and a complete research study is required.

Such a research study would have to include:

- Detailed calculations about the element's dimensions for selected loading categories (e.g. 150kN, 300kN, 450kN)
- A detailed FEM model analysis (2-D initially, then full 3-D)
- Thorough laboratory testing of scale model setups of common connections and sub-frames
- Determining the serviceability limitations of the connection (fatigue loadings under regular and earthquake conditions)
- Evaluating the connection's cost against the gained construction time (including the time value of money and the follow-up time of secondary services)
- Experimental testing to investigate any tolerance issues

5. VWSA PAINT SHOP

As stated in the Plan of Development (*Chapter 1.6*), the case study presented in this chapter consisted of a site visit to Volkswagen of South Africa's (VWSA) new paint shop in the Eastern Cape. The case study included a detailed discussion with the project's construction management team.

The objectives were to:

- Verify the results of the Industry survey
- Identify the challenges that the project team faced and
- Determine how they overcame these challenges

5.1 Project description

The project consisted of the construction of an R750million automotive paint shop. The paint shop has a surface area of 45 000 m^2, employs 530 people and doubled the Uitenhage plant's capacity to 1200 vehicles a day. Through the extensive use of precast elements, this project was completed in just over a year (VWSA, 2006).

The German clients proposed a precast layout for this particular project. They are used to working with similar precast concrete factories and had already completed their financial feasibility study before appointing the main contractor (Grinaker LTA). The contractor evaluated the proposed project plan and determined that although an in-situ concrete system would have been cheaper, the expected project deadline could not be met. The contractor relayed this information to the client, who opted for the faster, but more expensive Hybrid Concrete Construction project.

The structural frame of the facility consists of precast foundations, in-situ cast columns and precast beams (figure 5.1). The floors were constructed using precast planks as permanent formwork and then casting an in-situ slab on top of them. The building's cladding was specified by the client and had to be imported. The connections between beams and columns consisted of corbels and half-joints with simple rubber bearings.

Some of the elements were up to 26m in span, weighing up to 35t and had to be placed as high as 18m above ground level (figure 5.2). Handling and fixing such heavy elements at these heights posed a significant safety risk. Most of the elements were post-tensioned and cast using 35MPa concrete, unless the construction schedule required an earlier tensioning strength.

The project was a design-build venture with Grinaker LTA as the main contractor and ARQ consulting engineers as a specialist consultant (ARQ, 2007). The contract included a re-measurement clause and a Bill of Quantities was used for the tendering process. The client carried all the risks posed by weather related construction delays.

Figure 5.1 The structural frame of the new VWSA paint shop.

Figure 5.2 Placing a 26m precast beam, 18m above ground.

5.2 Problems encountered

This section highlights the project management, technical and contractual problems that the project team encountered. The data was obtained during the VWSA site visit and through the discussion held with the construction management team.

5.2.1 Project Management Aspects

The contractor experienced the following difficulties concerning the project's managerial aspects.

- Severe on-site drainage problems hampered the initial construction process
- The project team did not finalize all aspects of the design before construction began. Due to later design alterations, over 400 different precast beam configurations were required, which complicated the precasting operation and restricted on-site management
- The precasting yard was found to be a critical element in the construction process and delays here put the entire project's schedule under pressure
- Inadequate communication between the design team, precasting yard and construction manager with regards to the latest design alterations, led to confusion and unnecessary rework issues

5.2.2 Technical Aspects

The contractor experienced the following difficulties concerning the project's technical aspects.

- The contractor had to train shutter hands as riggers and had difficulty due to the workers not being used to this type of construction method, which led to on-site safety concerns
- The crane operators were not experienced in high precision work and struggled to place the first elements
- The use of heavily prestressed, precast beams caused some construction problems. The pre-camber of the beams were so large that it caused the formation of a discontinuous joint where two slabs spanning in different directions met (similar to figure 5.3). This required the structural topping depth to be increased in some instances

5.2.3 Contractual Aspects

The contractor experienced the following difficulties concerning the project's contractual aspects.

- The contractor used their in-house designers for the preliminary design. It is believed that the tendering process would have been difficult to manage if they had to outsource the architect and the design team

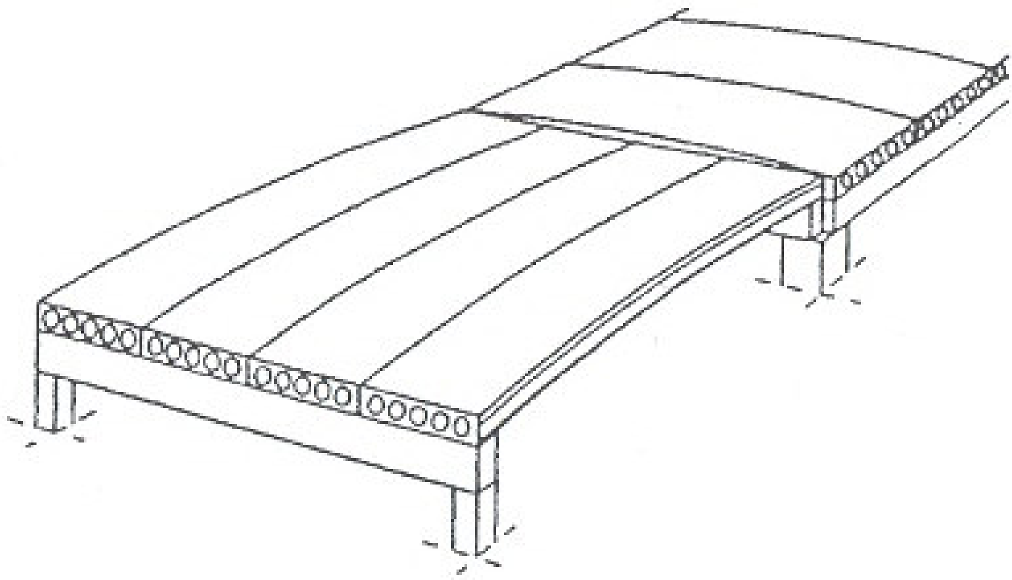

Figure 5.3 The effect of pre-camber on the joint between two slabs spanning in different directions (Vambersky *et al.*, 2005).

5.3 Lessons learned

This section highlights the solutions that the project team developed to overcome the above-mentioned problems. The data was obtained during the VWSA site visit and through the discussion held with the construction management team. The data is once again grouped into the project management, technical and contractual aspects.

5.3.1 Project Management Aspects

The contractor learned the following lessons about the project's managerial aspects.

- Effective communication between the client, architect, design team and the construction team is vital to the overall success of a precast project
- It is important that the entire project team agrees and commits to the concept of pre-casting. This will reduce and minimize eventual changes and will also ensure that critical conceptual matters are resolved at an early stage
- It is imperative that the project design be finalized at an early stage of the project as this can lead to significant cost and time savings. This requires input from the entire project team and shouldn't be limited to the design engineer
- Much attention should be paid to the location and operating logistics of the precasting yard as this has a significant impact on the rest of the project
- In hind sight, the contractor suggested using a separate design manager, or checking engineer. This person needs to coordinate between the design team, precasting yard and the construction manager to ensure that the work is optimised and coordinated. The design manager will have to anticipate problems in the construction process and has to notify the design team of any necessary changes before construction reaches that point

5.3.2 Technical Aspects

The contractor learned the following lessons about the project's technical aspects.

- High strength concrete (45-65 MPa) and pre-stressed elements are needed to create slender beams and columns. These can easily be created under the controlled conditions of the precasting process. The Construction team agreed that this might be HCC's biggest advantage
- Sub-contractors recommended the use of multi-storey continuous precast columns, as in-situ columns can cause delays in a project's schedule. The column has to be cast as a single unit to bring down the cost of the mould and the construction time. This also leads to fewer joints
- The corbel connection that this project used is not very aesthetically pleasing and would not be suitable for an office or residential structure. It was however suitable for this industrial application
- On-site safety concerns were in sharp contrast to the results published by Goodchild (2004). This required further investigation (*see Chapter 5.4*)

5.3.3 Contractual Aspects

The contractor learned the following lessons about the project's contractual aspects.

- Frequently working together and establishing a solid relationship with external partners (contractors, designers, architects and quantity surveyors) is very useful in the tendering process of an HCC project. This method could be very useful in the South African market where the time available to tender for a project partner is limited
- The Design-build delivery method was worked well for this particular project. Internationally, the Design-build delivery method is gaining recognition due to the numerous advantages it offers (Wardani *et al.*, 2006). This method works well with HCC projects, but is unfortunately only used in 9% of South Africa's projects (Michell *et al.*, 2007)

5.4 Crane safety on-site

In *Chapter 2,* Goodchild (2004) stated that HCC projects reduce the potential for on-site accidents. The construction manager for the VWSA project however experienced that HCC projects have similar safety risks as in-situ projects, albeit from different sources. This is especially true if the labourers are not used to working with cranes and the related overhead travelling dangers. Further investigation into the on-site safety of using cranes in construction was therefore required.

The objective of this investigation was to determine if other projects experienced similar safety risks as the VWSA site.

Moore *et al.* (2006) investigated 125 case files, involving 126 crane and 127 fatalities, from the United States Occupational Safety and Health Administration's (OSHA) case files from 1997-2003. These case files only cover the Federal Program States (approximately half the states of the United States of America) and represented 57% of the 2004 US construction industry's workforce (US Department of Labour, 2004).

They found that crane-related fatalities represented at least 8% of all fatal construction activities. More importantly, 107 (90%) of the victims were riggers, labourers, ironworkers, carpenters etc. The writers concluded that there is a lack of training for those who regularly work in close proximity to crane operations.

Moore *et al.* (2006) made the following recommendations:

- Assign a diligent competent person to manage the overall crane operations
- Employ a qualified crane operator
- A qualified rigger must be in charge of all rigging activities
- All of the above people must have the authorization to stop any unsafe crane or rigging operations once observed
- Everyone working around the crane operation must have crane safety training

This could be very important in the South African context, as the industry is currently facing a shortage of skilled labourers. The majority of the industry is also not used to constructing large precast projects, which may further hamper the adaptation of the work force. It may therefore be necessary to alter the current skill development programs to include an awareness of basic crane operations.

5.5 Conclusions

Precast projects are faster to construct, but require more planning and design coordination to ensure success. The design concept and layout must be finalized before construction commences, to enable the effective planning of precasting yard logistics and construction site operations. It is therefore important that the entire project team agrees and commits to the concept of pre-casting. This will reduce and minimize eventual changes and will also ensure that critical conceptual matters are resolved at an early stage. Sub-contractors also need to be present for coordinating aspects such as the placement of air conditioning systems, electrical ducts, water and sewage mains and fire-fighting systems.

Developing relationships with external project partners for future co-operation is highly recommended for HCC projects. This could lead to shorter tendering times and lower overall project costs. The Design-build delivery method was found to work well with HCC projects and internationally this delivery method is gaining popularity due to its inherent advantages. It is once again found that it may be necessary to promote its use in the South African construction industry.

On-site safety is still a very important issue with HCC projects. South African labourers are not accustomed to this construction method and it may be necessary to alter current skill development programs to include a crane safety course. The training of competent riggers and crane operators should receive priority if HCC is to develop in South Africa.

Although relevant for industrial environments, the simple corbel connection is deemed to be unsuitable for commercial or residential buildings because of its unsightly joints. The development of a simple, cost-effective and aesthetic Beam-to-Column connection that would allow the use of multi-storey continuous columns can greatly improve the current rate of construction as well as the public's image of the precasting industry. The results of a preliminary investigation into such a connection can be found in *Chapter 6*.

6. THEORETICAL OFFICE BUILDING

The second case study consisted of a theoretical exercise to conceptually design, price and schedule a suitable project. In this theoretical exercise, Prof J. Wium, Mr. C. Van der Merwe, Mr. S. Brown and Mr. C Jurgens acted as the project's design team. For documentation purposes, it was decided to present the conceptual design calculations here and the conceptual costing and scheduling exercises in *Chapter 7*.

Either an office project or a high-rise residential project was required as most South African industrial buildings are constructed with steel frames. On the other hand, low-rise South African residential buildings are usually built with load-bearing masonry. Furthermore, a modular layout was required to simplify the design process and the application of Hybrid Concrete Construction (HCC) and In-situ flat slab construction methods.

This theoretical case study finally consisted of an architect's drawing for a new Office building. The Office building was designed according to the In-situ beam and slab, HCC and In-situ flat slab construction methods. All designs were based on the SANS 10100-1 concrete design and the SANS 10160 loading codes. More detail may be found in *Appendix D*.

The objectives of this case study were to:

- Apply the knowledge gained from the literature study, industry survey and the VWSA paint shop to a case study
- Determine if HCC could be used without making major changes to the architect's original drawing (figure 6.1)
- Identify any unforeseen managerial, technical or contractual problems that require further investigation for the HCC case
- Use the Office project's design to compare the In-situ beam and slab, HCC and In-situ flat slab methods in terms of their cost and construction time
- Identify other matters about the use of precast which could only be determined by actually performing a precast design

6.1 Project description

An office building was identified to be considered in this case study. The building consists of a total floor area of 900m^2. This building was chosen because of its square and relatively modular arrangement (figure 6.1). The effect of project size on the suitability of Hybrid Concrete Construction (HCC) can also be studied by increasing the number of floors as required. The building was conceptually designed, priced and scheduled according to the In-situ beam and slab, HCC and In-situ flat slab construction methods. The original architect designs for the Office Building may be viewed in *Appendix D*.

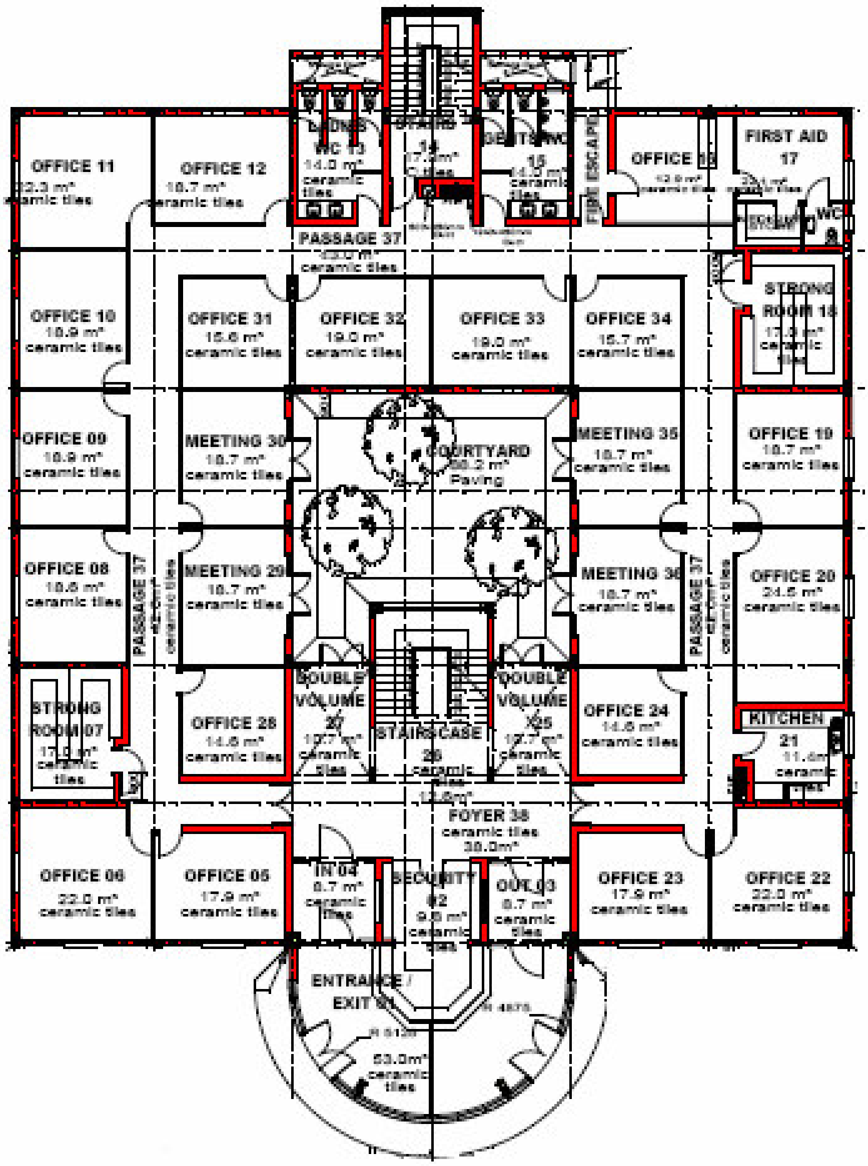

Figure 6.1 A plan view of the Office Building.

This study aims to evaluate the feasibility of HCC for the South African construction industry. As such, it was only deemed necessary to consider the conceptual design aspects. The element sizes and their reinforcement requirements were only tested for the determining cases. These elements were then evaluated using the SANS 10100-1 and SANS 10160 code specifications. This includes criteria such as the minimum spacing between bars etc. This was done to determine if HCC could be successfully applied to this project.

Furthermore, element sizes were not optimised as far as material usage is concerned, but were chosen for constructability (e.g. choosing slab and beam depths in multiples of the brick height). These element sizes, together with an average reinforcement amount, were then used to cost and schedule the three project versions (*Chapter 7*). The foundations and all non-structural elements were assumed to be similar for all three cases and were thus ignored as they would not significantly influence the cost evaluation.

The project's design specifications were chosen as follows:

- 30 MPa concrete (28 day strength) for the In-situ concrete (beam and slab; and the flat slab) cases
- 50 MPa concrete (28 day strength) for the precast elements and the in-situ concrete joints of the HCC case
- General office loading (2.5 kPa) and a partition load (1.5 kPa)
- Cantilever balcony load according to SANS 10160 (4.0 kPa)
- 1.2 kPa allowance for screed and tiles
- 0.1 kPa allowance for services
- Western Cape indoor exposure conditions

6.2 In-situ Beam and Slab Construction

The In-situ beam and slab concrete version of the Office building was designed according to the architect's original layout. The project consisted of reinforced concrete (RC) slabs, beams, columns and foundations.

The final design consisted of:

- 200mm thick RC slabs spanning 5m
- 40mm levelling screed
- 10m RC flange beams of total depth 680mm (400mm web)
- 5m RC L-shaped perimeter beams of total depth 680mm (400mm web)
- Column sizes were calculated for 3, 6, 9 and 12 storey versions of the Office project

These element sizes were used in *Chapter 7* for the *Theoretical Cost vs. Time Evaluation of the Office Building*. The In-situ beam and slab project's design calculations may be viewed in *Appendix D*.

6.3 Hybrid Concrete Construction

The Hybrid Concrete Construction (HCC) version of the Office building was designed to closely resemble the architect's original specifications. The project consisted of precast reinforced concrete beams and columns with In-situ beam and slab concrete foundations and hollowcore slabs.

Prestressed elements were not used as the facilities to mass produce such elements do not currently exist everywhere in South Africa. Precast reinforced concrete elements have the added benefits of cheaper moulds and can be constructed on-site, reducing transportation costs. Prestressed elements are however very useful for building elegant, slender structures.

The final design (figure 6.2) consisted of:

- 250mm thick Echo (2006) slabs with J+4 prestressing, spanning 10m. The cores of these slabs are opened up at the beam support and filled with cast in-situ concrete to create a solid T-beam section in bending with a flange width of 1800mm (according to SANS 10100).
- 40mm structural topping to precast slabs
- 5m precast beams of depth 430mm (400mm web)
- 5m precast perimeter beams of depth 430mm (400mm web)
- For positive bending, a solid T-section with d = 630mm was used (*Appendix D*)
- For negative bending, a rectangular section with d = 430mm was used (*Appendix D*). The 430m had to be used as all the necessary reinforcement could not be placed in the space between the ends of the hollowcore slabs.
- Column sizes were calculated for 3, 6, 9 and 12 storey versions of the Office project

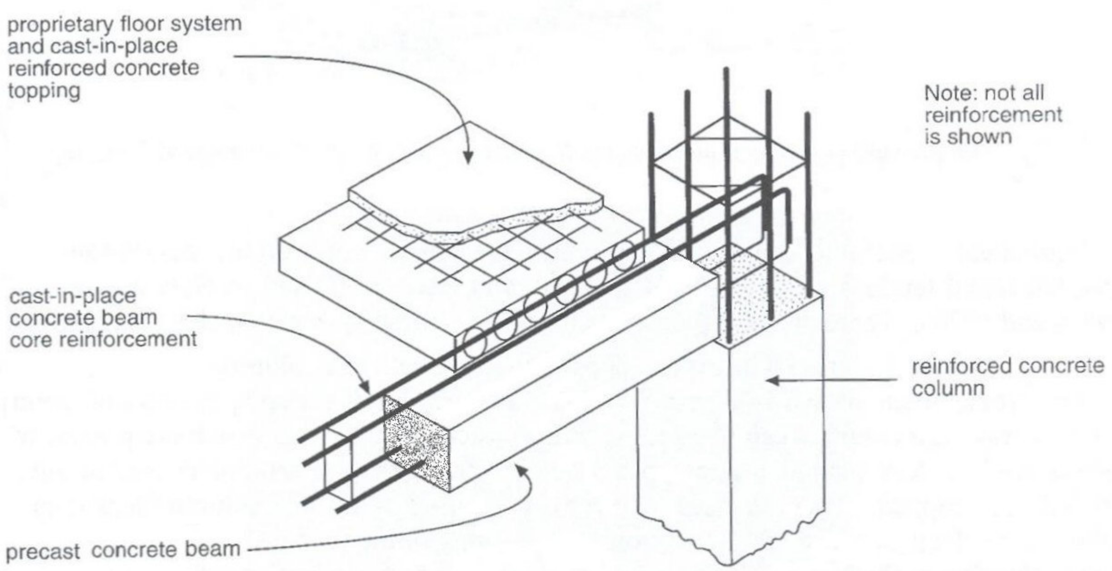

Figure 6.2 A typical hollowcore floor connection (fib, 2003).

These element sizes were used in *Chapter 7* for the *Theoretical Cost vs. Time Evaluation of the Office Building.* The project's HCC design calculations may be viewed in *Appendix D*.

The following sections highlight the project management, technical and contractual aspects that the theoretical project team encountered. The data was obtained during the design process of the Office building and through discussions held with Prof. J.A. Wium and Mr. C. van der Merwe.

6.3.1 Project Management Aspects

The theoretical project team experienced the following difficulties concerning this project's managerial aspects.

It is evident that a structure needs to be adopted to suit an option where precasting can be used extensively and effectively. This requires a mutual understanding and commitment from all participants, including the architect, engineer, contractor and client. The layout of structural elements for the building was originally based on the In-situ beam and slab construction method. It quickly became very clear that the layout needed slight alterations to successfully accommodate the precast approach.

These types of changes need to be discussed between the architect, engineer, contractor and client. A building can therefore not be changed from one construction type to another without involvement from the entire project team. It is therefore important to take this into account from the start of the project. If the precast option is only considered once a contractor has been appointed, the process becomes ineffective and counter productive.

6.3.2 Technical Aspects

The theoretical project team experienced the following difficulties concerning this project's technical aspects.

Although connection designs can be successfully based on the current South African design codes, it is clear that there is a lack of information to assist South African designers to achieve architecturally acceptable precast connections. Guidelines are needed for the design of typical aesthetically pleasing connections between the precast elements and in-situ concrete work. These guidelines should also explain the flow of forces within the connection area as this will help designers to understand and effectively dimension the connection.

After consulting with a precast contractor, it became apparent that the architect's design had to be altered for the HCC case. The aim of these alterations were to reduce the number of different elements. This would greatly simplify the precasting operation. Changes included adding several columns. This made it possible to design the entire structure with three different beams, one column design (per floor) and one precast floor panel type. Column sizes were optimized for every 3 storeys of the 3, 6, 9 and 12 storey versions of the Hybrid Office project. Shear walls, the foyer's semi-circular beam and the smaller staircase beams will be built with in-situ concrete.

The precast contractor agreed that it would be faster and more economical to use multi-storey continuous columns, as in a corbel framed structure. The architect would not accept any visible joints and therefore it was decided to use an invisible corbel connection. Current South African design codes (SANS 10100-1) are however not explicit in the use of bending reinforcement as a component when designing for shear friction. Refer to *Chapter 4* for more information about this connection investigation.

6.3.3 Contractual Aspects

The theoretical project team experienced the following difficulties concerning this project's contractual aspects.

Based on the lessons learned from *Chapter 5*, it was decided to use the Design-build procurement system for this project. This procurement system requires that a high level of cooperation within the design team has to be maintained from the start of the project. Regular communication is also required to ensure that the entire project team is up to date with the latest design changes. The appointment of an engineering manager to direct and coordinate the design will therefore be an essential part of the project team.

Determining the preliminary cost and schedule requirements was not a clear-cut exercise. The estimated construction time proved to be especially problematic and was based on a rough estimate. This aspect is discussed in more detail in *Chapter 7*.

6.4 In-situ Flat Slab Construction

Longer spanning In-situ flat slab structures (7m+ spans) are often post-tensioned in South Africa. This option was however not considered. This was done to draw an accurate comparison between the three versions of the Office project for regular reinforced concrete construction methods.

The final design consisted of:

- 255mm thick RC slabs spanning 5m x 5m panels
- 40mm levelling screed
- Column sizes were calculated for 3, 6, 9 and 12 storey versions of the Office project
- No column heads were required

These element sizes were then used in *Chapter 7* for the *Theoretical Cost vs. Time Evaluation of the Office Building*. The final In-situ flat slab design calculations may be viewed in *Appendix D*.

6.5 Conclusions

The Hybrid Concrete Construction (HCC) method can be applied to any structural project, it will however not necessarily be successful. A structure needs to be adapted to suit a particular construction method. This ensures that all the advantages of the selected construction method may be achieved. Adapting a structure to a different construction method requires a mutual understanding and commitment from all project participants, including the architect, engineer, contractor and client. HCC also requires a certain degree of repetition in a project to be financially viable.

The facilities to mass produce prestressed elements do not currently exist everywhere in South Africa. Prestressed elements are very useful for building elegant, slender structures. Significant investments into this industry are required.

Connection designs can be successfully based on the current South African design codes. It is once again found that there is a lack of information to assist South African designers to achieve architecturally pleasing precast connections. This emphasizes the need for local guidelines that also explain the flow of forces within the connection area.

It was agreed that multi-storey continuous columns would be faster and more economical to use, but invisible corbel connections were required to satisfy the project's aesthetic specifications.

It is believed that the Design-build procurement system would work well for this project, but regular communication would be required to ensure that the entire project team is up to date with the latest design changes.

Determining the preliminary cost and schedule requirements was not a clear-cut exercise. The estimated construction time proved to be problematic and was based on a rough estimate.

7. THEORETICAL COST vs. TIME EVALUATION OF THE OFFICE BUILDING

The two case studies are described in Chapters 5 and 6. This Chapter continues with the evaluation of the second case study (the Office Building) by presenting the theoretical costing and scheduling exercises. In this theoretical exercise, Prof J. Wium, Mr. C. Van der Merwe, Mr. S. Brown and Mr. C Jurgens acted as the project's design team.

A desk top study was undertaken to compare the cost and erection time of the In-situ Beam and slab, Hybrid Concrete Construction (HCC) and In-situ Flat slab designs for the Office Building. The influence of the project's size on the cost and erection time was also investigated for each construction method.

The objectives of this evaluation were to:

- Determine how the cost and construction time of a HCC project compares to that of an In-situ Beam and slab and a In-situ Flat slab project
- Evaluate the influence of project size on the above-mentioned relationship
- Identify the components that would require investigation in a complete costing study of several different South African projects
- Identify the components that would require investigation in a complete scheduling study of several different South African projects

The following assumptions were made during the costing and scheduling exercises:

- The tendering costs could not accurately be determined without executing a detailed tendering process and was estimated to be constant for all three project versions
- It was estimated that the In-situ Beam and slab project would require 7 more start-up days than the In-situ Flat slab project to prepare the additional formwork.
- Furthermore, it was estimated that the HCC project would require 28 more start-up days than the In-situ Flat slab project to complete the project's design and prepare the production processes
- The foundations and all non-structural elements were excluded from the construction costs. These were assumed to be similar for all three cases and were thus ignored as they would not influence the cost evaluation
- Element sizes were not optimised as far as material usage is concerned but chosen for constructability (e.g. choosing slab and beam depths in multiples of the brick height)
- The element sizes, together with an average reinforcement density, were used to cost the three project versions. The assumptions with regards to the average reinforcement density used may be found in *Appendix F.1*
- The estimated construction time per floor may be found in *Appendix F.1*

Prefabricated construction is not always faster than in-situ construction methods. As far as the client is concerned, the total building time is the stage between commission and delivery. A prefabricated project's total building is negatively influenced by a long lead-in time. As mentioned above, the additional lead-in time is usually used for the completion of the project's design and for the preparation of the production processes.

An additional benefit of HCC is the shorter period over which the bulk of the project funds is required. Assuming that the total building time for a HCC project equals an in-situ project's total building time, the financial advantage of HCC is the smaller amount of money spent on interest payments. Figure 7.1 gives a graphical explanation of the period over which the major sum of the project investment is required.

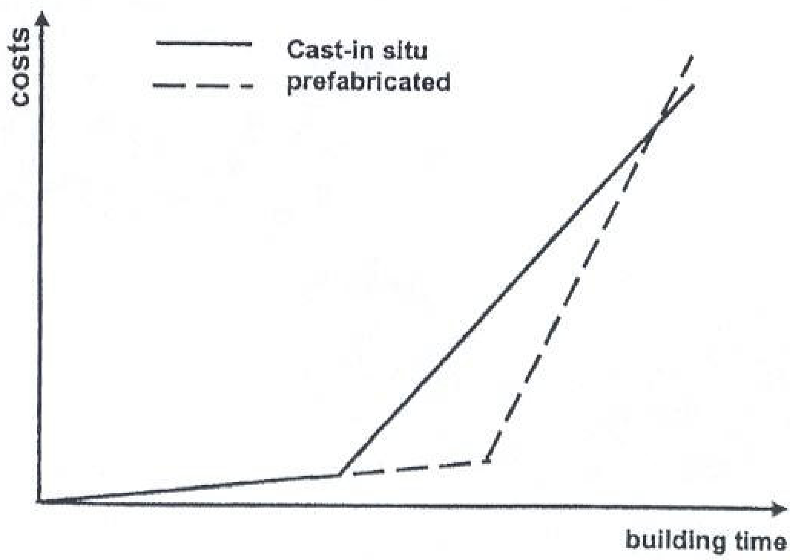

Figure 7.1 The total cost vs. the building time for a cast in-situ and prefabricated project of equal length (Vambersky *et al.*, 2005).

7.1 Cost

This section discusses the results of the costing exercise for the In-situ Beam and slab, Hybrid Concrete Construction (HCC) and In-situ Flat slab versions of the Office Building. The costing exercise presented here is based on material and erection costs only. The effect of construction period and other time related costs are not included. The calculations may be viewed in Appendix F.2.

Determining the project's preliminary cost proved to be rather difficult. The cost of the tendering process could not accurately be determined in this theoretical exercise.

The element sizes from *Chapter 6* were used to determine the required material quantities (*Appendix F.1*) for the costing exercise. Costing data (including labour) were received from both the precast and in-situ contractors. Each project version's construction cost could then be calculated (*Appendix F.2*).

The same floor layout (figure 6.1) was used to determine the effect of project size in the comparison between HCC and the other construction methods. The project's size was increased by increasing the number of storeys.

Figure 7.2 gives a summary of the final construction costs for each project. As can be seen, the cost of construction for the three versions of the Office project is very similar.

In-situ Beam and slab construction was found to be slightly less expensive than In-situ Flat slab construction for all the different number of storeys. It has to be stated that the In-situ Flat slab cost would have been significantly lower if the slab thickness had been optimised. This would however have meant that the column length had to be adjusted, raising the floor-to-floor height slightly.

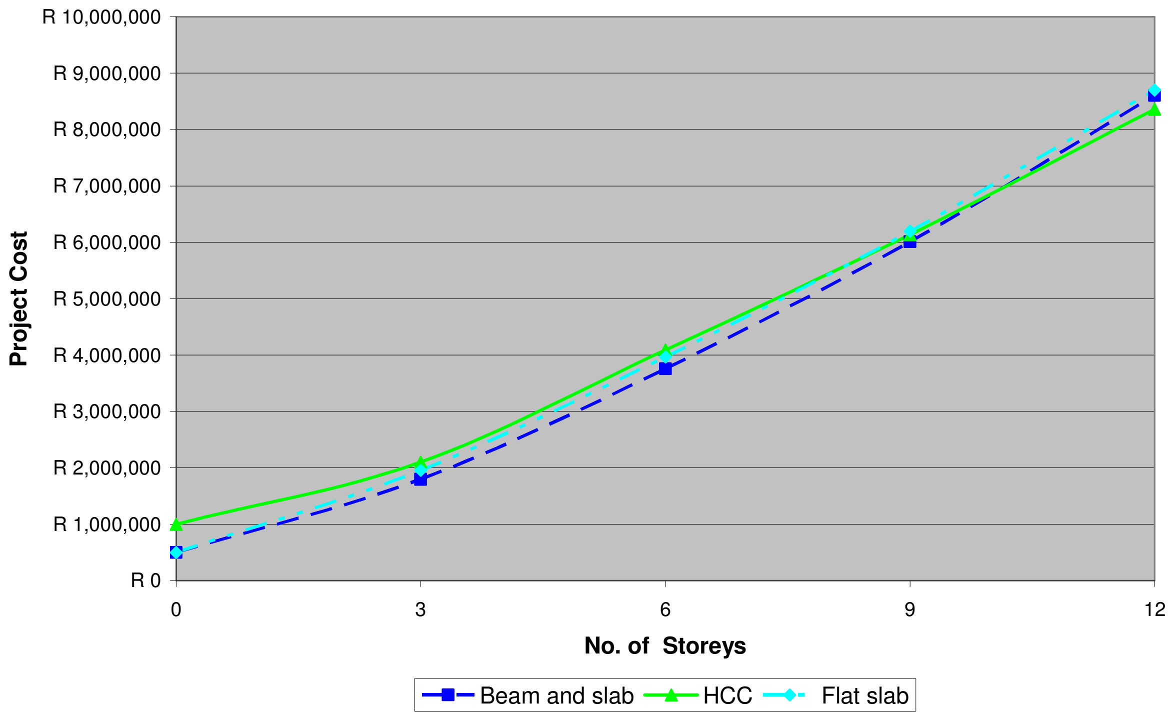

Figure 7.2 Construction cost vs. the number of storeys for the three versions of the Office Building.

The In-situ Beam and slab project was found to be slightly less expensive than the HCC project for 10 storeys (9000m^2 of floor area) or less. This is to be expected as the increasing number of repetitions for large projects favour prefabricated construction methods. The re-usability of initially expensive steel moulds helps to keep the construction cost of bigger projects relatively low.

A complete Cost comparison of several South African projects is however required to determine HCC's break-even point with greater accuracy. Such an investigation should also examine other types of buildings (e.g. schools, reservoirs, industrial and residential buildings). More detail about a proposal for such an investigation may be found in *Chapter 7.3*.

7.2 Time

This section discusses the results of the scheduling exercise for the In-situ Beam and slab, Hybrid Concrete Construction (HCC) and In-situ Flat slab versions of the Office Building. As previously stated, the estimated construction time may be viewed in *Appendix F.1*.

Through discussions held with the in-situ and precast contractors, an estimated construction time per floor was determined. This time frame is however not fixed and is significantly influenced by the number of construction teams and cranes working simultaneously. This, of course, significantly influences the cost of construction as labour costs are a large part of a project's overall cost. It is also believed that labour costs would increase in the future, thereby playing an ever increasing role on the final costs.

Furthermore, the cost of using extra cranes can also significantly influence the project's overall cost. The effect of scaffolding and props on the installation schedule of follow-up services (tiles, furniture etc.) could also not be determined.

The same floor layout (figure 6.1) was used to determine the effect of project size in the comparison between HCC and the other construction methods. The project's size was increased by increasing the number of storeys.

The current exercise therefore identified the important parameters to be included and considered when performing a comprehensive scheduling evaluation. Such an evaluation is required of several South African projects to determine the types of projects for which Hybrid Concrete Construction (HCC) may be the preferred construction method. Following this current investigation, it was decided to make recommendations about the parameters that would require investigation. These recommendations may be found in *Chapter 7.3*.

Figure 7.3 gives a summary of the final construction time (in days) required for each project version. As can be seen, the construction time for the In-situ Beam and slab and In-situ Flat slab versions of the Office project is very similar. This is because they have the same estimated construction time per floor. A detailed cost vs. time investigation is once again required to exactly distinguish between these two construction methods. The purpose of this investigation is rather to compare HCC with the other two construction methods.

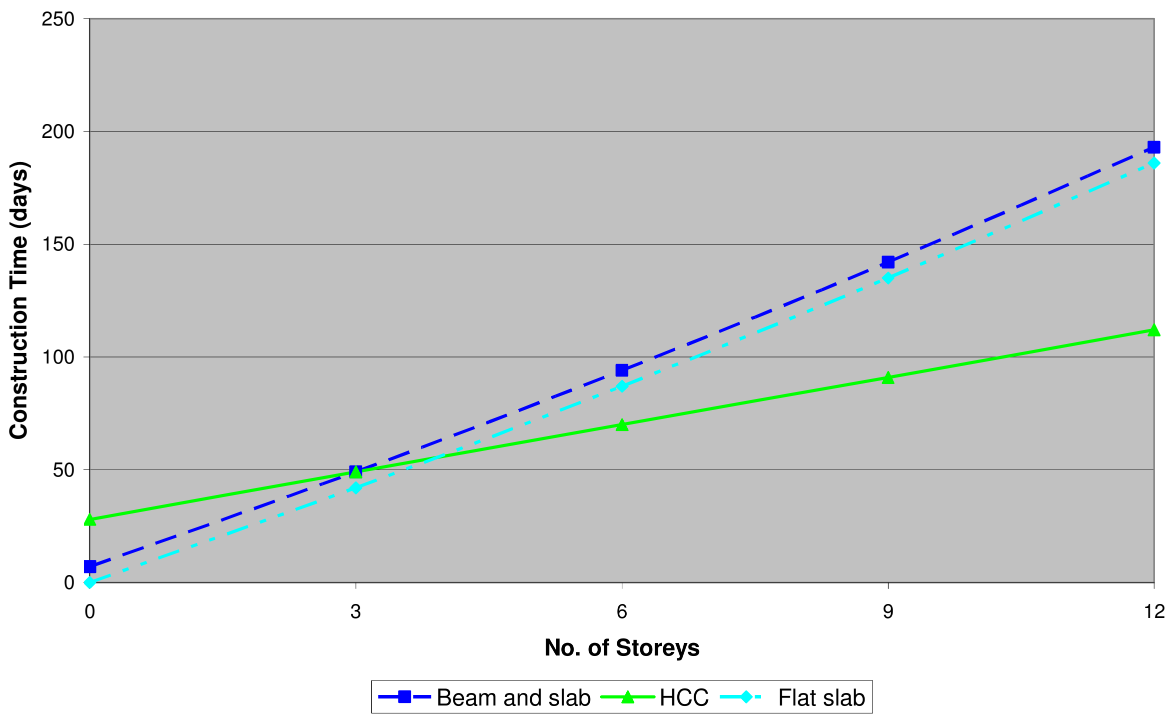

Figure 7.3 Construction time vs. the number of storeys for the three versions of the Office Building.

It was found that the HCC method is significantly faster than the other construction methods for more than 3 storeys (2700m^2 of floor area). This could severely influence the cost evaluation. Because of HCC's shorter construction period (almost half for 12 storeys), the client can expect to earn revenue from a much earlier date. This, in essence, decreases the relative cost of the HCC project. A detailed cost vs. time evaluation would be required to exactly determine the position of such a break-even point, as well as its effect on the final project cost to the client.

7.3 Recommendations for a Complete Cost vs. Time Evaluation

During the cost and scheduling exercises it was determined that a complete Cost vs. Time evaluation, of several South African projects, is required. Such an investigation should also examine other types of buildings (e.g. schools, clinics, reservoirs, industrial and residential buildings etc.). This would allow any user to easily determine HCC's break-even point for both the cost and time benefits with greater accuracy for various project types.

Such an investigation could also answer the industry's call (*Chapter 3*) for more information about the selection of Hybrid Concrete Construction (HCC) during the conceptual design phase of a project. This will determine the parameters for which HCC would be the preferred method of construction.

A complete research study into this field is recommended and the main objective of this section is therefore to introduce such a study. It should however be noted that a dedicated and experienced design engineer and an enthusiastic contractor would be required to thoroughly design, price and schedule the selected projects.

7.3.1 Complete Time Evaluation

A complete Time evaluation of the South African market would have to include the following items:

- The additional time required for completing the HCC project's design during the tendering stage of the project
- The additional time needed for site and precasting yard preparations
- The project's detailed construction schedule requirements
- The time gained on high-rise buildings by all casting work being done on ground level
- The effect on the construction schedule if more or fewer moulds and cranes are used, i.e. determining the optimum number of moulds and cranes
- The time gained for the installation of secondary services because fewer temporary supports and formwork makes earlier access to the building possible
- The time required for disassembling the temporary precasting yard
- The time required to train the required skills for a particular project

7.3.2 Complete Cost Evaluation

A complete Cost evaluation of the South African market would have to include the following items:

- The additional cost of tendering for a HCC project or suggesting alternatives (if any...)
- The additional site and precasting yard preparation costs
- The project's detailed construction cost
- The cost of transporting elements vs. the advantages of using pre-tensioned precast elements
- The financial advantages to high-rise buildings of all casting work being done on ground level. This includes the financial saving with regards to multi-level formwork
- The cost of interest on borrowed money and its effect on the "Return of Investment" period
- The cost of precast moulds and the effect on the construction schedule if more or fewer moulds are used, i.e. determining the optimum number of moulds
- The cost of various crane sizes and determining the optimum number of cranes for a specific project
- The cost of hiring temporary supports and formwork vs. designing precast elements that don't require any propping
- The feasibility of building several similar buildings (like clinics or schools) with one set of moulds, in effect, lowering the cost per precast unit
- The cost of disassembling the temporary precasting yard
- The costs involved with training the required skills for a particular project

7.3.3 Central Database of South African Projects

A central database with data about South African projects could greatly simplify the process of obtaining valuable project information. This information could then be used in the development of local Hybrid Concrete Construction (HCC) guidelines that are required to help make decisions about the practicality of prefabricated construction methods for various project types.

It is also proposed that that database of information be compiled from South African in-situ projects where information is readily available. Information from a small number of studies on identified HCC alternatives should be used to complete the database. With the help of the projects' quantity surveyor, such a database should include the following parameters:

- Project cost including finishes
- Project duration including finishes
- Total floor area
- Number of floors
- Cost of structural frame
- Construction time of structural frame
- Construction method selected and why
- Procurement method selected and why

The following optional information could be useful if it is available:

- Tender process cost and duration
- Project safety statistics
- The project team's comments about the successfulness of the completed project
- How the project team would approach the project if they had to do it again

Once sufficient information has been gathered, a theoretical project team would be required to select several projects from the database. It is assumed that most of the projects will be cast in-situ projects. These projects would therefore have to be re-designed for the HCC method and compared to their original projects. Such a theoretical project team would have to include a contractor, design engineer, architect and a quantity surveyor. All the members of such a theoretical project team should be dedicated to the development of HCC in South Africa.

Initially, the project team could only evaluate the structural system of the projects as it was shown in *Chapter 2* that the structural frame has a significant impact on a project's final cost. A dedicated researcher is also required to coordinate between the theoretical project team members and to combine their individual findings in a suitable report.

The development of a central database is therefore recommended as it could greatly assist South African designers, further awareness about the advantages of HCC and lead to the widespread use of the HCC method.

7.4 Conclusions

Hybrid Concrete Construction (HCC) was found to be slightly less expensive than other construction methods for the Office Building of more than 10 storeys. The costs considered only included the material and erection costs. HCC was also found to be significantly faster than other construction methods for the Office Building of more than 3 storeys. This time calculation was however based on the in-situ and precast contractors' time frame estimates.

Because of HCC's shorter estimated construction period, the client can expect to earn revenue from a much earlier date. This decreases the relative cost of a HCC project. Quantitave values of these advantages are however required for chosen South African projects and further investigation is therefore recommended.

A central database with data about selected South African projects is required to simplify the process of obtaining valuable project information. This information could then be used in the development of HCC guidelines that could help South African designers to make decisions about the practicality of prefabricated construction methods for various project types. The development of such a central database is therefore recommended. Such a database would also be invaluable for any further investigations into the development of HCC methods in South Africa.

It was determined that a complete Cost versus Time evaluation, of several South African projects, is required. Using data from a central database, as suggested above, such an investigation should also examine other types of buildings (e.g. schools, reservoirs, industrial and residential buildings). This would allow the user to determine HCC's break-even point for cost and time with greater accuracy for various project types. Such an investigation could also determine the parameters for which HCC would be the preferred method of construction. It could also assist South African designers, further awareness about the advantages of HCC and lead to the widespread use of the HCC method. A complete research study into this field is therefore recommended. A dedicated and experienced design engineer and an enthusiastic contractor are however required to thoroughly design, price and schedule several selected projects.

8. CONCLUSIONS

Based on the findings of this investigation, concluding remarks were drawn at the end of each chapter. This section therefore serves as a summary of the main findings. The main conclusions of this study are therefore presented in the following paragraphs.

8.1 The Feasibility of Hybrid Concrete Construction in South Africa

Hybrid Concrete Construction (HCC) can be applied to any structural project, it will however not necessarily be successful. A structure needs to be adapted from the very start to suit a particular construction method. This ensures that all the advantages of the selected construction method may be achieved. Adapting a structure to a different construction method requires a mutual understanding and commitment from all project participants, including the architect, engineer, contractor and client. HCC also requires a certain degree of repetition in a project to be financially viable.

A theoretical cost exercise was performed where only the material and erection costs were considered. In this exercise, HCC was found to be slightly less expensive than other construction methods for the Office Building of more than 10 storeys. HCC was also found to be significantly faster than other construction methods for the Office Building of more than 3 storeys. The time calculation was however based on the simplified time estimates from one source.

Because of HCC’s shorter estimated construction period, the client can expect to earn revenue from a much earlier date. This decreases the relative cost of a HCC project. This advantage, however, needs to be quantified for chosen South African projects.

On-site safety is an important issue with HCC projects. Labourers are not accustomed to this construction method and it may be necessary to alter current skill development programs to include a crane safety course. The training of qualified riggers and crane operators should receive priority if HCC is to develop in South Africa.

This preliminary investigation has shown that Hybrid Concrete Construction (HCC) can be feasible for the South African market. Further investigation is however required to determine the parameters for which HCC would be the preferred construction method.

8.2 The South African Precast Industry vs. its International Equivalents

Hybrid Concrete Construction (HCC) projects require specific skills that are currently in extremely short supply and individual companies may need to start investing in the development of these skills, as the governmental programs cannot meet the required demand.

The development of affordable Self Compacting Concrete (SCC) in South Africa is very important as SCC allows the use of cheaper moulds and provides a better surface finish to precast elements. This could give precasting another important advantage over in-situ concrete construction. Geel *et al.* (2007) also found that a local set of guidelines for the production and application of SCC is required.

A national questionnaire survey was undertaken to determine the state of HCC in the South African market. Eight (66.7%) of the selected contracting engineers and twelve (80%) of the selected consulting engineers finally responded and their individual feedback forms can be found in *Appendix C*. Most of the respondents consider that precasting has a future in the South African industry. The preliminary findings from this study support this response. More definitive information is however required to guide the way forward. Respondents also indicated that the biggest obstacles that are preventing the widespread use of HCC in South Africa are the severe skill shortages, the lack of information about the advantages of precast methods and the limited availability of experienced precast designers and constructers.

8.3 South African Design Codes, Guidelines and Courses

Even though the SANS 10100-1 and the EN 1992-1 cover similar precast design topics, the newer EN 1992-1 is preferred. The EN 1992-1 gives more guidance on some aspects such as the strut-and-tie design method, and diaphragm action of precast floors without topping. Therefore, it will be beneficial to upgrade the SANS 10100-1.

It was shown that the use of precast construction grew rapidly in Canada, Japan, the United States, the United Kingdom and in the most parts of Europe after these countries published precast design guidelines. Similar design guidelines will assist to stimulate growth in the South African HCC industry.

Connections are a critical part of any precast project. These connections must meet a wide variety of design, performance and other criteria. It was shown that there are many examples of connections that have proven themselves over the years. Not all design principles are however found in the South African design codes. Once again the need is emphasized for a proper precast design guide for the South African market.

It is also proposed that a central database of information be compiled from South African in-situ projects where information is readily available. Information from a small number of studies on identified HCC alternatives should be used to complete the database.

This information could then be used in the development of HCC guidelines that could help South African designers to make decisions about the practicality of prefabricated construction methods for various project types. The development of such a central database is therefore recommended. Such a database would also be invaluable for any further investigations into the development of HCC methods in South Africa.

8.4 The Feasibility of the Hidden Corbel Connection

The simple corbel connection is deemed to be unsuitable for commercial or residential buildings because of its unsightly joints. The development of a simple, cost-effective and aesthetic Beam-to-Column connection that would allow the use of multi-storey continuous columns can greatly improve the current rate of construction as well as the public’s image of the precasting industry. The proposed Hidden Corbel Connection is believed to be a viable option and further investigation into its development is needed.

8.5 South African Managerial Processes

Most of the current South African projects lack the team approach that Hybrid Concrete Construction (HCC) projects require. Effective communication within the project team is vital. The project's team needs to discuss the final design and the optimum use of precast elements if cost-savings are to be achieved. It may therefore be necessary to alter the tertiary education programs for engineering students and project managers to promote such partnerships.

The appointment in a project team of a dedicated engineering manager to direct the coordination and design of the HCC project also needs to be considered for each project where HCC is used.

8.6 South African Contractual Processes

The Design-build delivery method was shown to offer significant project time and cost savings and on average, delivers the best project performance for all construction types. It is believed that it could work well for HCC projects as this procurement system promotes cooperation within the project team. Investigation into the parameters which determine when this contractual process will be successful is however required.

8.7 Cost vs. Time Evaluation

It was determined that a complete Cost versus Time evaluation, of several South African projects, is required. Using data from a central database, as previously suggested, such an investigation should also examine other types of buildings (e.g. schools, reservoirs, industrial and residential buildings). This would allow the user to determine HCC's break-even point for cost and time with greater accuracy for various project types. Such an investigation could also determine the parameters for which HCC would be the preferred method of construction. It could also assist South African designers, create further awareness about the advantages of HCC and lead to the widespread use of the HCC method. A complete research study into this field is therefore recommended.

9. RECOMMENDATIONS

This study investigated the feasibility of Hybrid Concrete Construction in the South African construction industry. Based on the findings and conclusions of this investigation, the following recommendations are made.

9.1 Recommendations for the South African Industry

The following recommendations are made for the South African construction industry.

9.1.1 Develop relationships with external project partners

Developing relationships with external project partners for future co-operation is recommended for Hybrid Concrete Construction (HCC) projects. This could lead to shorter tendering times and lower overall project costs. The Design-build delivery method also works well with HCC projects and internationally this delivery method is gaining popularity due to its inherent advantages. It therefore recommended to promote the use of this procurement method. It will also be necessary to define the type and range of projects for which this type of contractual arrangement is considered to be feasible.

9.1.2 Train competent riggers and crane operators

On-site safety is still a very important issue with HCC projects. Labourers are not accustomed to this construction method and it may be necessary to alter current skill development programs to include a crane safety course. The training of competent riggers and crane operators should receive priority if HCC is to develop in South Africa.

9.1.3 Invest in mass-producing precast facilities

The facilities to mass produce prestressed structural elements do not currently exist everywhere in South Africa. Prestressed elements are very useful for building elegant, slender structures. Significant investments into this industry are required.

9.1.4 Develop a central database of South African projects

A central database with data about South African projects could greatly simplify the process of obtaining valuable project information. This information could then be used in the development of local Hybrid Concrete Construction (HCC) guidelines that are required to help make decisions about the practicality of prefabricated construction methods for various project types.

It is also proposed that the database of information be compiled from South African in-situ projects where information is readily available. Information from a small number of studies on identified HCC alternatives should be used to complete the database. With the help of the projects' quantity surveyor, such a database should include the following parameters:

- Project cost including finishes
- Project duration including finishes
- Total floor area
- Number of floors
- Cost of structural frame
- Construction time of structural frame
- Construction method selected and why
- Procurement method selected and why

The information contained in this database could then be used for further investigations (*Chapter 9.2.4*) into the development and widespread use of HCC in South Africa.

9.2 Recommendations for Further Investigation

The following recommendations are made about a course of action to extend this study through continued research into the use of Precast and Hybrid Concrete Construction methods in South Africa.

9.2.1 Develop local guidelines for the production and application of SCC

The development of affordable Self Compacting Concrete (SCC) in South Africa is very important as SCC allows the use of cheaper moulds and provides a better surface finish to precast elements. This could give precasting another important advantage over in-situ concrete construction. Geel *et al.* (2007) also found that a local set of guidelines for the production and application of SCC is required.

9.2.2 Develop guidelines for HCC and precast construction in South Africa

Further investigation is recommended into the development of suitable guidelines for HCC and precast construction in South Africa. Such guidelines should include:

- Advice on the appropiate design of precast systems
- Cost evaluations of precast versus in-situ systems during the preliminary design phase of a project (see *Chapter 9.2.4*)
- Detailed South African case studies of successful HCC projects

It is also recommended that the South African design codes be updated to match their international equivalents.

More information is also required about South African precast suppliers, the availability of their products and the precast market potential. A complete literature study and possibly an industry survey are required to determine the above-mentioned facts, as well as to compare the South African precast suppliers' market to its European counterparts. Such a study is therefore recommended for further investigation.

9.2.3 Develop the Hidden Corbel Connection to its full potential

It was determined that the proposed Hidden Corbel Connection is feasible and that further investigation is required to develop the connection to its full potential. There are however several important questions that remain un-answered. A complete research study is therefore required.

Such a research study would have to include:

- Detailed calculations about the element's dimensions for selected loading categories (e.g. 150kN, 300kN, 450kN)
- A detailed FEM model analysis (2-D initially, then full 3-D)
- Thorough laboratory testing of scale model setups of common connections and sub-frames
- Determining the serviceability limitations of the connection (fatigue loadings under regular and earthquake conditions)
- Evaluating the connection's cost against the gained construction time (including the time value of money and the follow-up time of secondary services)
- Experimental testing to investigate any tolerance issues

9.2.4 Perform a Cost vs. Time evaluation of several South African projects

It was determined that a complete Cost versus Time evaluation, of several South African projects, is required. Such an investigation should also examine other types of buildings (e.g. schools, reservoirs, industrial and residential buildings). This would allow the user to determine HCC's break-even point for cost and time with greater accuracy for various project types.

Such an investigation could answer the industry's call for more information about the selection of Hybrid Concrete Construction (HCC) during the conceptual design phase of a project. Such an investigation could also determine the parameters for which HCC would be the preferred method of construction. A complete research study into this field is therefore recommended.

Using the Central Database of South African Projects (*Chapter 9.1.4*), a theoretical project team would select several projects from the database. It is assumed that most of the projects will be cast in-situ projects. These projects would therefore be re-designed for the HCC method and compared to their original projects. Such a theoretical project team would have to include a contractor, design engineer, architect and a quantity surveyor. All the members of such a theoretical project team should be dedicated to the development of HCC in South Africa. A dedicated researcher is also required to coordinate with the theoretical project team and to combine their findings in a suitable report.

A complete Time evaluation of the selected projects from the above-mentioned database would have to include the following additional items:

- The additional time required for completing the HCC project’s design during the tendering stage of the project
- The additional time needed for site and precasting yard preparations
- The project’s detailed construction schedule requirements
- The time gained on high-rise buildings by all casting work being done on ground level
- The effect on the construction schedule if more or fewer moulds and cranes are used, i.e. determining the optimum number of moulds and cranes
- The time gained for the installation of secondary services because fewer temporary supports and formwork makes earlier access to the building possible
- The time required for disassembling the temporary precasting yard
- The time required to train the required skills for a particular project

A complete Cost evaluation of the selected projects from the above-mentioned database would have to include the following additional items:

- The additional cost of tendering for a HCC project or suggesting alternatives (if any...)
- The additional site and precasting yard preparation costs
- The project’s detailed construction cost
- The cost of transporting elements vs. the advantages of using pre-tensioned precast elements
- The financial advantages to high-rise buildings of all casting work being done on ground level. This includes the financial saving with regards to multi-level formwork
- The cost of interest on borrowed money and its effect on the “Return of Investment” period
- The cost of precast moulds and the effect on the construction schedule if more or fewer moulds are used, i.e. determining the optimum number of moulds
- The cost of various crane sizes and determining the optimum number of cranes for a specific project
- The cost of hiring temporary supports and formwork vs. designing precast elements that don’t require any propping
- The feasibility of building several similar buildings (like clinics or schools) with one set of moulds, in effect, lowering the cost per precast unit
- The cost of disassembling the temporary precasting yard
- The costs involved with training the required skills for a particular project

9.2.5 Develop guidelines to promote the Design-build method in South Africa

The Design-build delivery method was shown to offer significant project time and cost savings and on average, delivers the best project performance for all construction types. It is believed that it could work well for HCC projects as this procurement system promotes cooperation within the project team. Investigation into the parameters which determine when this contractual process will be successful is however required.

It may therefore be advantageous to promote the use of this delivery method within the South African in-situ and precast construction industries. Suitable South African guidelines are however required. Such guidelines should include the following items:

- The advantages of using the Design-build method in the South African construction industry
- The experience and skills required by all parties involved to guarantee the success of such an undertaking
- Local case studies of successful Design-build projects along with the lessons learned by the project team
- The type and size of projects for which this delivery method is considered to be feasible

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APPENDIX A:
SOUTH AFRICAN BUILDING STATISTICS

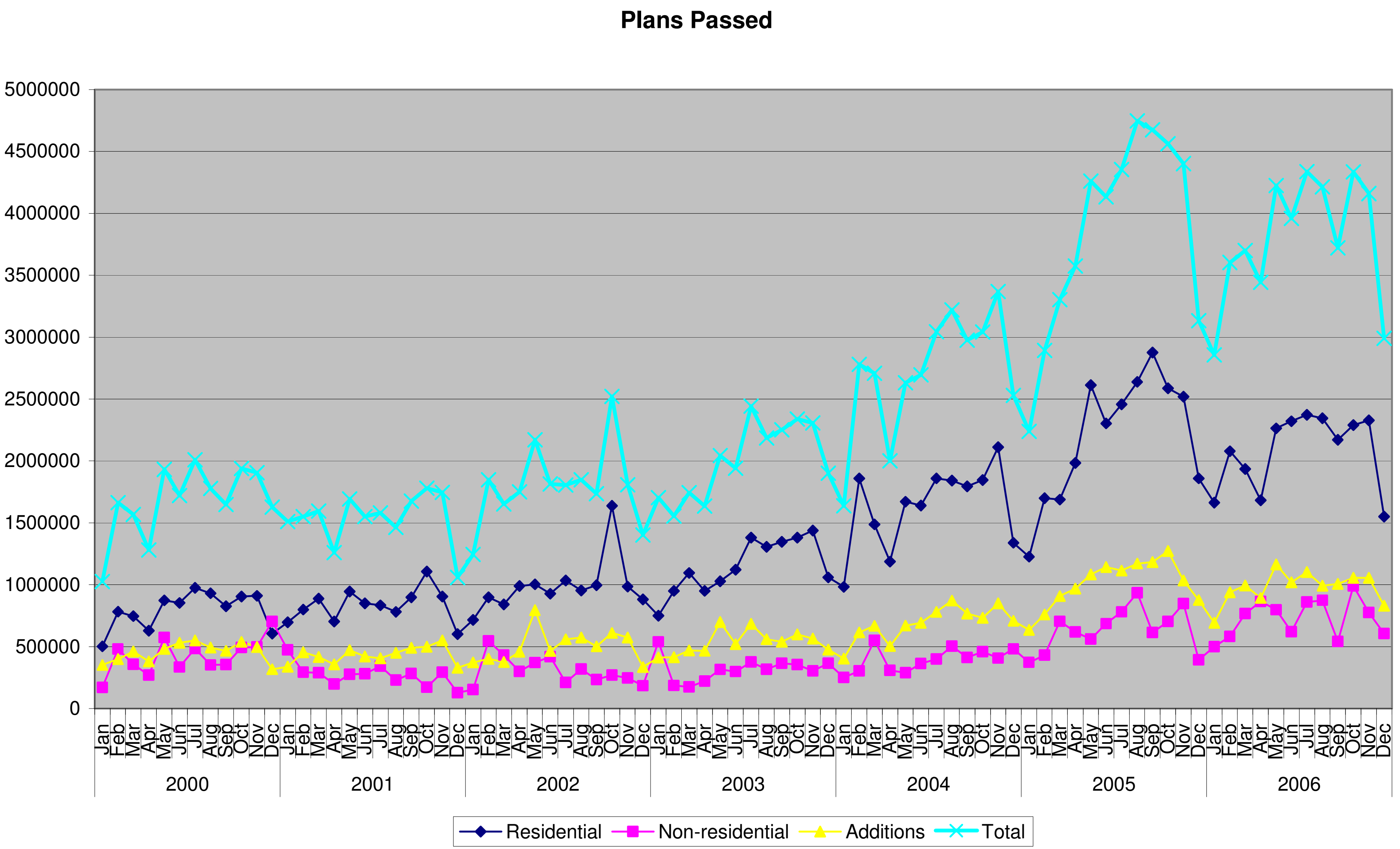


Figure A.1 The monetary value of plans passed (Statistics South Africa, 2006).

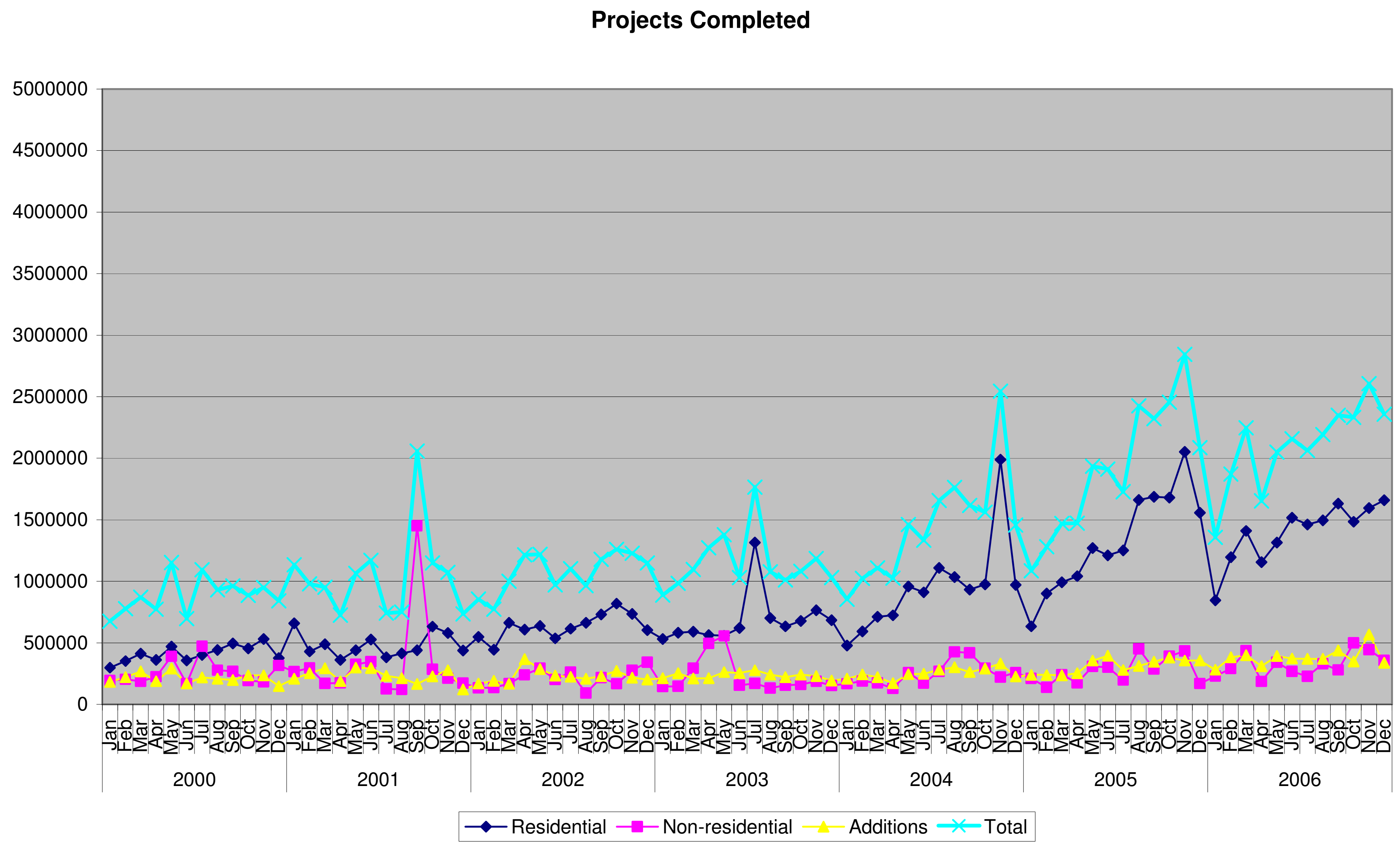


Figure A.2 The monetary value of projects completed (Statistics South Africa, 2006).

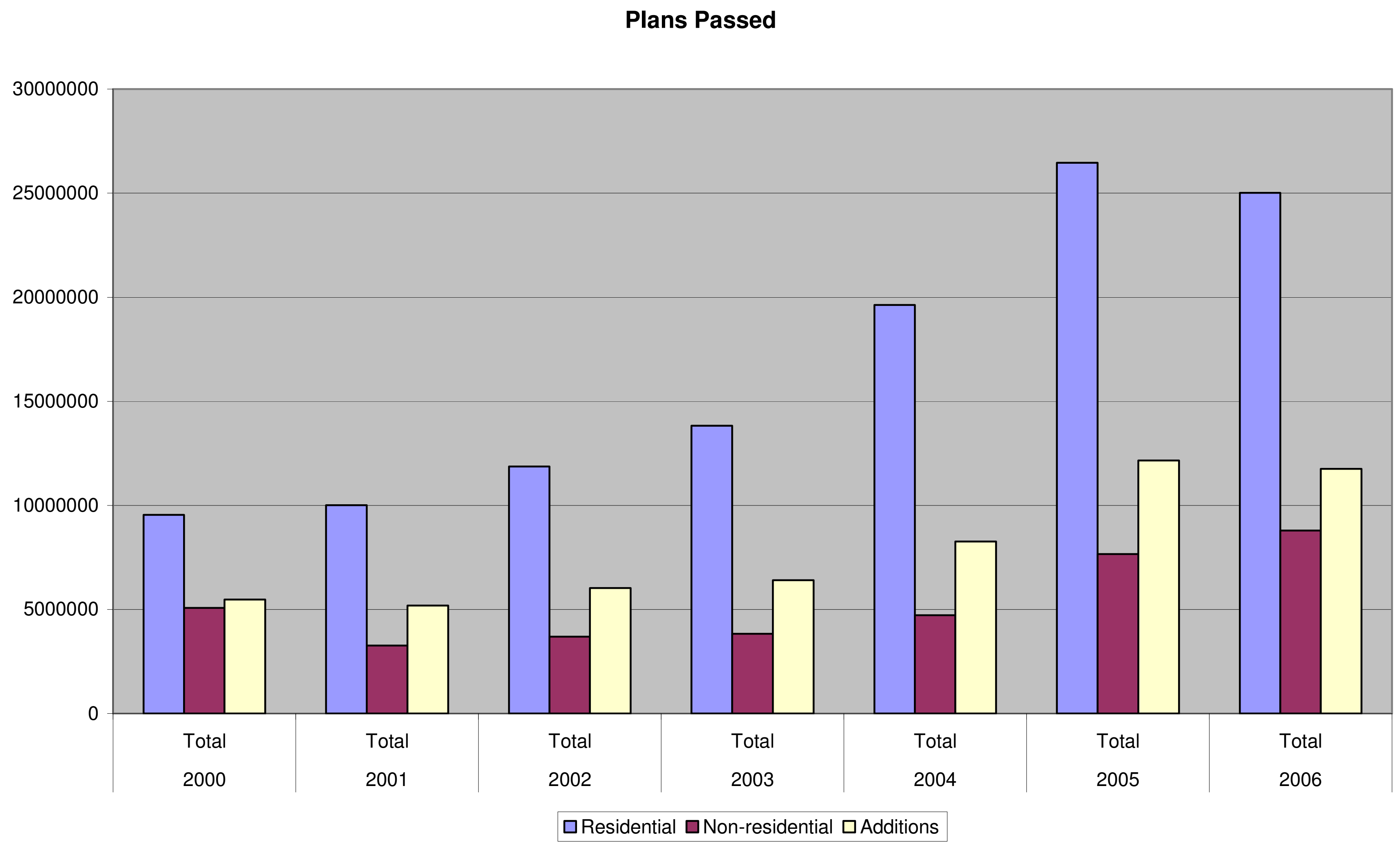


Figure A.3 The monetary value of plans passed by category (Statistics South Africa, 2006).

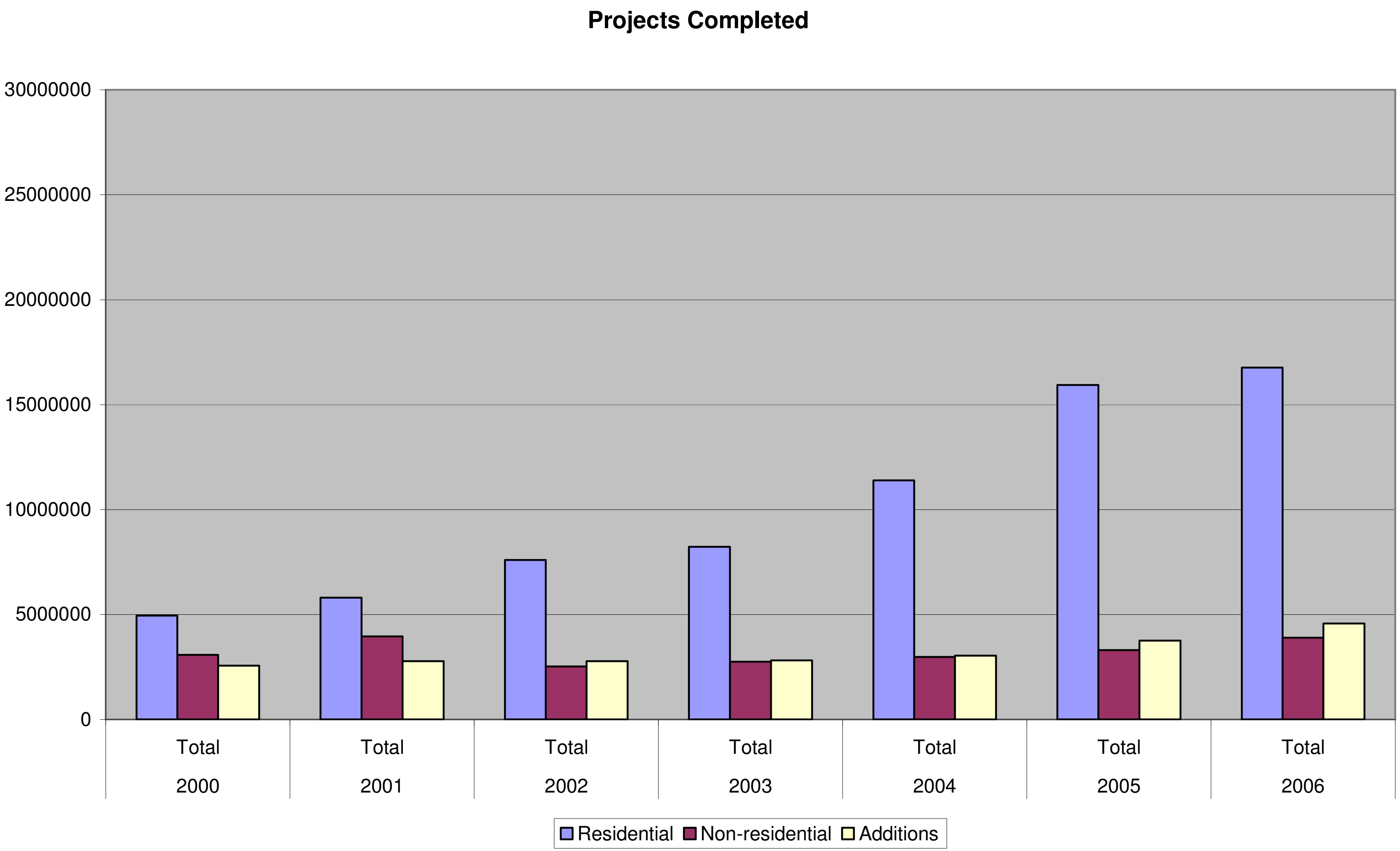


Figure A.4 The monetary value of projects completed by category (Statistics South Africa, 2006).

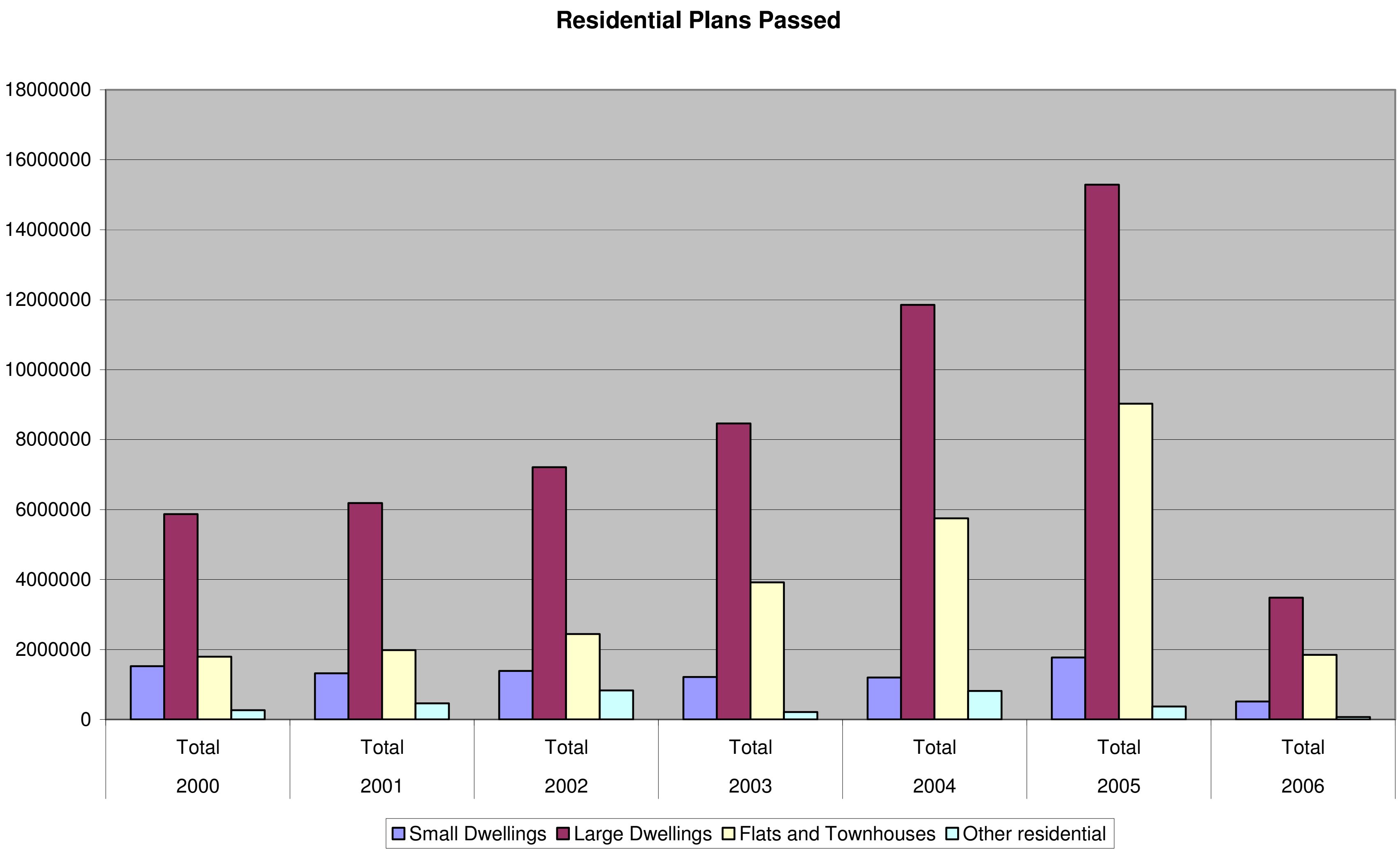


Figure A.5 The monetary value of residential plans passed (Statistics South Africa, 2006).

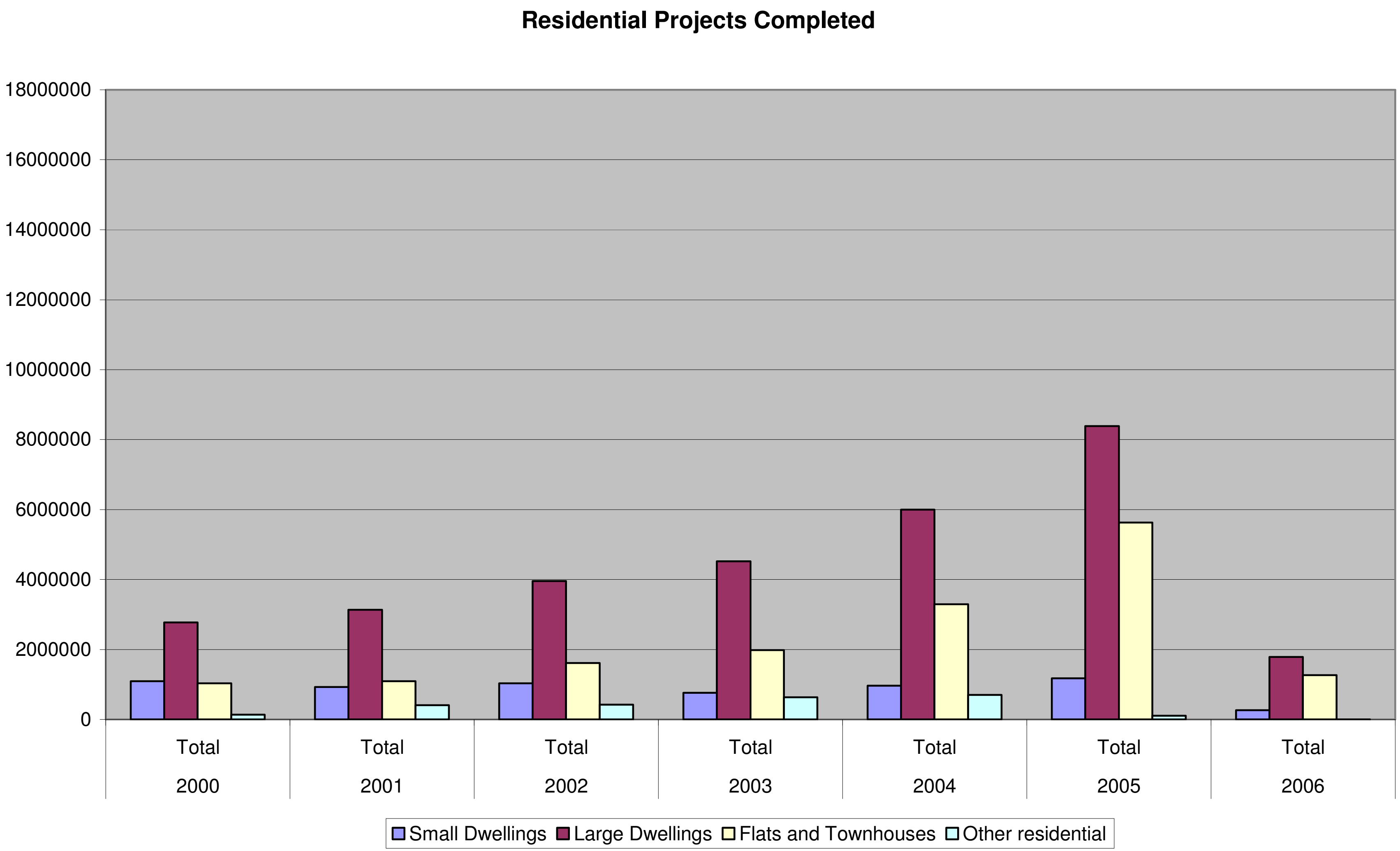


Figure A.6 The monetary value of residential projects completed (Statistics South Africa, 2006).

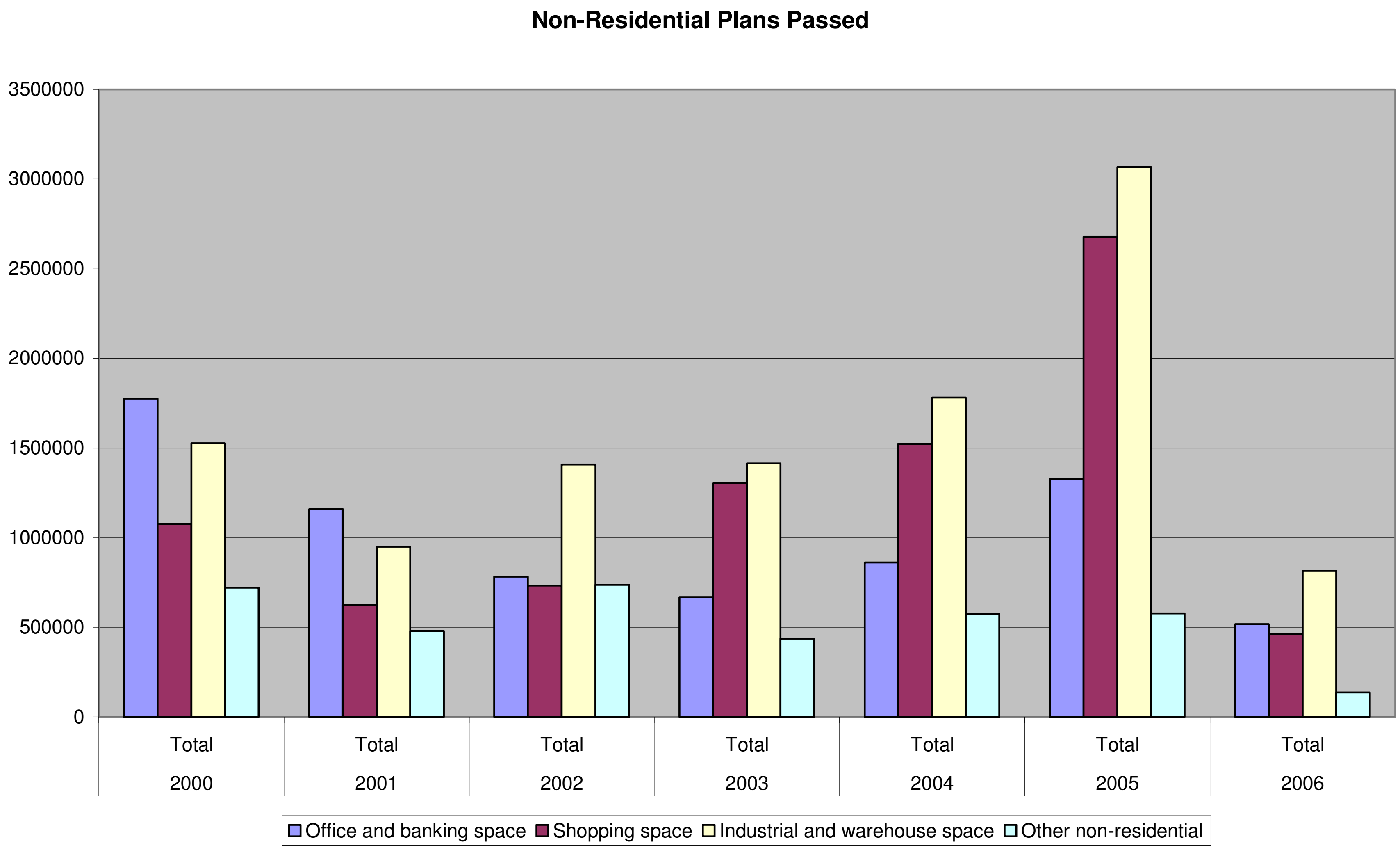


Figure A.7 The monetary value of non-residential plans passed (Statistics South Africa, 2006).

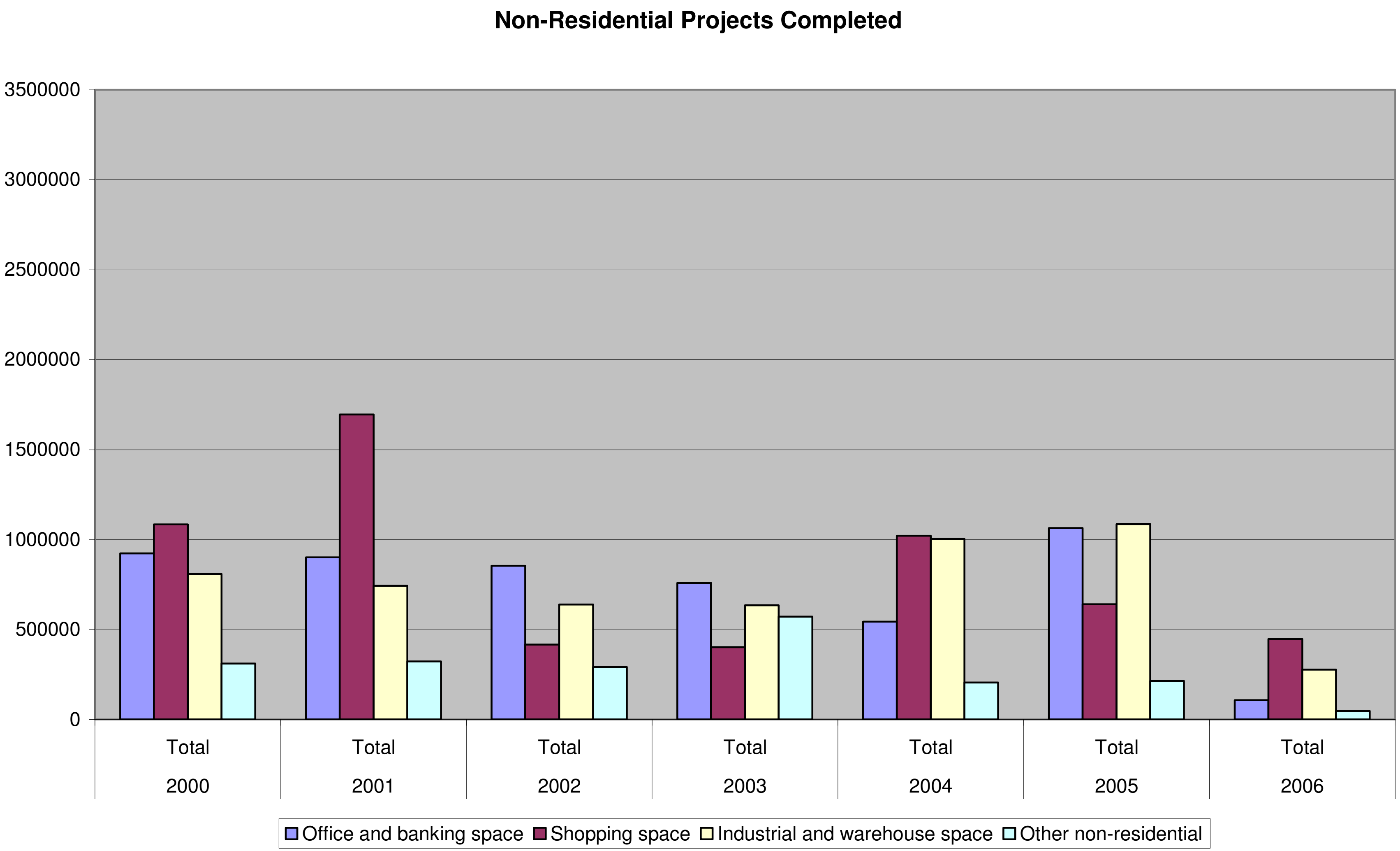


Figure A.8 The monetary value of non-residential projects completed (Statistics South Africa, 2006).

APPENDIX B:
THE INTERNATIONAL USE OF COMPOSITE CONSTRUCTION METHODS

Table B1 Building types using Mixed Precast Construction (fib, 2002)

Building type	Mixed precast construction methods	Comments
Commercial offices	In-situ concrete frame with precast flooring and facades. Steelwork frame with precast shear walls, flooring and facades. Precast frame with steel raker ('Mansard' type) or steel roof truss. Precast frame with pitched timber truss.	All combinations possible with in-situ concrete under-ground or ground floor podium.
Retail and shopping	In-situ concrete or steel frame with preast flooring and facades. Precast load bearing wall with cast in-situ floors. Masonry load bearing walls with precast floors.	Ditto
Educational buildings	Steel frame with precast floor, with steel or timber roof. Load bearing masonry with precast floors.	Maximum clear spans to allow for changes in use.
Parking Garages	In-situ concrete or steelwork frame with precast flooring and cast in-situ topping. Precast frame with glue laminated timber or steel roof.	Long span double tee floors up to 20m.
Industrial and warehouses	Steel frame with long span precast wall units. Precast columns with steel roof truss. Steel frame with precast floors (office areas).	Hollowcored or sandwich walls give thermal insulation. Long span lightweight roof.
High rise Residential	Precast load bearing walls with cast in-situ floors. Masonry load bearing walls with precast floors.	Composite floor plank often used because of complex floor plan layout.
Domestic, low-medium density	Masonry load bearing walls with precast floors. Precast walls with timber floors.	Beam-and-block precast and hollowcore dominates.
Stadia	Steel frame including raker beams, with precast terraces. Cast in-situ frames with precast terraces. Precast columns with steel raker beams and precast terraces.	All combinations possible with steel or pretensioned precast roof.

Table B2 Mixed Precast Construction Worldwide (fib, 2002)

Region	Mono Construction	Mixed Construction	Domestic	Commercial & Residential	No. of storeys	Percentage of market	Precast share in a project
Northern Europe	CC, S, PC, M	S+PC CC+PC M+PC PC+S PC+CC PC+M PC+T	NO NO YES NO NO NO YES	YES YES YES YES YES YES YES	>2 >2 2-5 1-20 2-20 2-10 1-10	HIGH MEDIUM HIGH MEDIUM LOW LOW LOW	MEDIUM LOW MEDIUM HIGH HIGH HIGH HIGH
Southern Europe	PC, CC, M, S, T	CC+PC M+PC S+PC PC+CC PC+T	YES YES NO NO NO	YES NO YES YES YES	2-10 2-5 2-10 2-10 <5	HIGH LOW LOW MEDIUM LOW	LOW MEDIUM LOW HIGH HIGH
Scandinavia, incl. Finland	PC, T, CC, M, S	S+PC CC+PC PC+S PC+CC PC+M PC+T	NO YES NO YES NO YES	YES YES YES YES YES YES	2-5 >2 1-20 2-20 2-3 2-5	MEDIUM MEDIUM HIGH MEDIUM LOW LOW	HIGH LOW HIGH HIGH HIGH HIGH
Middle East	CC	CC+PC S+PC M+PC	YES NO YES	YES YES NO	2-20 2-40 2-5	HIGH LOW LOW	HIGH MEDIUM MEDIUM
Russia	PC, CC	CC+PC PC+CC	YES YES	YES YES	2-20 2-20	LOW HIGH	HIGH HIGH
Far East	CC, PC	CC+PC PC+CC	YES YES	YES YES	2-20 2-10	LOW LOW	LOW MEDIUM
China	CC, S, PC, M	S+PC CC+PC M+PC PC+S	NO YES YES NO	YES YES NO YES	<3 <5 2-3 1-5	MEDIUM LOW HIGH LOW	MEDIUM MEDIUM MEDIUM HIGH
Japan	PC, CC, S	CC+PC S+PC	YES YES	YES YES	2-10 2-5	LOW LOW	LOW LOW
Australasia	CC, S, PC	CC+PC S+PC M+PC PC+CC	NO NO YES YES	YES YES YES YES	2-20 2-20 <5 2-12	VARIES IN DIFFERENT AREAS	LOW MEDIUM MEDIUM HIGH
North America	CC, PC, S, M, T	CC+PC S+PC M+PC PC+CC PC+S PC+M PC+T	YES YES YES YES YES YES YES	YES YES NO YES YES YES NO	2-40 2-15 <7 2-30 1-10 2-20 2-4	VARIES WIDELY IN DIFFERENT AREAS	MEDIUM LOW LOW LOW LOW MEDIUM LOW
South America (Brazil only)	CC, PC	CC+PC PC+CC	NO YES	YES YES	2-10 2-20	LOW HIGH	MEDIUM MEDIUM
Southern Africa	CC, S, PC, M	CC+PC S+PC M+PC	NO NO YES	YES YES YES	>2 2-4 2-4	LOW LOW LOW	LOW LOW MEDIUM

CC = in-situ concrete, PC = precast concrete, S = structural steelwork, T = timber, M = masonry

APPENDIX C:
PRECAST DESIGN QUESTIONNAIRE

C.1 Consultants

Consultant 1:

Name: **Alten Hulme**
Company: **Hulme & Associates**
Expertise: **BSc.Eng, Practicing Consulting Engineer for 17 years**

1. How often do you become involved in the design of pre-cast concrete systems?
Not very often. And then it's mostly with precast slabs

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
No, but I am aware that there is a substantial body of knowledge around precast connections and have looked at some literature

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
No

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
To choose a pre-cast system requires the Contractor to "buy into" the idea and to look to assist in solving problems rather than using problem areas as a reason for claims.

5. Do you think pre-casting has a future within the South African construction industry?
If a construction company could "lead the way" by offering a turnkey solution, the initial cost of documenting all the junction details could be paid for by the time/cost gain of the project rather than the consultant on their own.

Consultant 2:

Name: **Bennie Zietsman**
Company: **Element Consulting Engineers**
Expertise: **Structural Engineer**

1. How often do you become involved in the design of pre-cast concrete systems?
Very often, say one in four in-situ concrete projects.

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
Fairly well, always room for improvement.

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
Yes.

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
Economy of scale (vs. Europe for example) as well as severe skills shortage at all levels (artisan, design, quality control etc.)

5. Do you think pre-casting has a future within the South African construction industry?
Yes.

Consultant 3:

Name: **Colin Koen**
Company: **SUTHERLAND**
Expertise: **10 years**

1. How often do you become involved in the design of pre-cast concrete systems?
Residential properties of up to 3 storeys-
Always look into precast slab systems (not always selected as final design solution, but it is kept open as option during pretender design)

Multi storey buildings where large amount of elements are the same-
Stairs- always look at pre-casting (on/of site) options (not always selected as final design solution, but it is kept open as option during prelim design-pending contractor).

Ring/Eaves Beams of various structures (provided enough repetition)-
Always looked at on site casting as standard pre-casting elements (not always selected as final design solution, but it is kept open as option during prelim design-pending contractor).

Structures with large similar faces of brickwork (like warehouses and shopping centres)-
Tilt-up is considered (not always selected as final design solution, but it is kept open as option during prelim design-pending contractor).

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
For the above we use external literature and company experience, with most connections kept to standard in-situ connections, hence some part of elements require in-situ casting to allow for fixing. Lifting and handling is obviously taken into account during design.

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
We tend to leave the options open till negotiations with a contractor starts (excluding pre-cast floors), as in most cases it will depend on the contractor as crane capacity and availability and program are together with cost the main decision making factors.

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
Labour is inexpensive compared to the cost of equipments (such as cranes and transport) and material. A higher skill of labour is also required, which is in shortage.

Precast also needs to compete with steel, which is considered the traditional way for industrial structures, and the fast (but expensive) alternative to concrete.

5. Do you think pre-casting has a future within the South African construction industry?
Yes, but more so to compete with steel (in the case industrial type buildings) than with in-situ concrete due to the high cost of steel, and that the erection of precast and steel are at similar (apart from precast floors and floor planks).

Consultant 4:

Name: **Dudley de Klerk**
Company: **ARQ (Pty) Ltd**
Expertise: **Structural Engineer**

1. How often do you become involved in the design of pre-cast concrete systems?
Rarely (Two in approx 8 years, total of 4 not counting precast hollow core slab systems - Echo and the like)

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
Yes.

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
Depends on the project - when we do work on turnkey projects the contractor who considers precast would have the technical as well as financial and management skills to handle pre-cast. They then provide the information for the proper evaluation or often do it themselves. Other projects that are run along the traditional lines of design and tender are more difficult to evaluate.

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
The construction system is pre-determined by the client or design team based on the limited experience with precast systems. Experience is better in the pre-cast cladding field, but that is expensive and you often get better aesthetic value for less money with in-situ finishes. In addition the number of capable contractors are small, skills are not available, transport and or handling costs are high even if pre-cast is done on site, etc. Another major factor is that the designer does not want to waste time on developing and evaluating alternatives because he's not getting paid for it.

5. Do you think pre-casting has a future within the South African construction industry?
No. It will require a huge marketing drive to change and it needs to make economical sense.

Consultant 5:

Name: **E van Brouwershaven**
Company: **EVN AFRICA CONSULTING SERVICES**
Expertise: **Water supply, water purification, structural**

1. How often do you become involved in the design of pre-cast concrete systems?
Seldom, limited to pre-cast floor slabs

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
No. Rely on third party engineers. (Supplier's engineers)

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
No.

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
Lack of information regarding available systems, existing successful projects, cost comparisons

5. Do you think pre-casting has a future within the South African construction industry?
Yes.

Consultant 6:

Name: **F M Riedemann, Technical Director**
Company: **Bergstan South Africa**
Expertise: **Structural Engineering Design**

1. How often do you become involved in the design of pre-cast concrete systems?
Evaluated fairly frequently, implemented rather infrequently.

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
Yes

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
Generally, yes, but feasibility of pre-cast concrete systems is often dictated by project specific constraints/needs and specific contractor's preferences and available plant and equipment.

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
Lack or scarcity of appropriately skilled artisans. Lack of local availability of proprietary cast-in joint connector assemblies, etc. Quite often not cost competitive. Joint complications associated with the provision of seismic resistant structures in the Western Cape.

5. Do you think pre-casting has a future within the South African construction industry?
Yes.

Consultant 7:

Name: **Gerrit Bastiaanse**
Company: **BKS**
Expertise: **Pr. Eng. - Structures**

1. How often do you become involved in the design of pre-cast concrete systems?
Not so much the design, more specifying existing products

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
Probably 80%

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
No, mostly a discussion between contractor and engineer

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
Purely because it will be something new and we don't have time to play around with new ideas. Construction programs do not allow at this stage for investigating alternatives.

5. Do you think pre-casting has a future within the South African construction industry?
Yes, especially with the labour skills deteriorating. The more work you can do off site the better.

Consultant 8:

Name: **Hennie Niehaus**
Company: **Ninham Shand Consulting Services**
Expertise:

1. How often do you become involved in the design of pre-cast concrete systems?
We become involved in pre-cast concrete components reasonably often. I am not sure however that this can be described as pre-cast concrete systems as they are only components of mainly cast in situ systems. The components that we quite often are involved in is the following:

- Pre-cast beams for bridge decks
- Permanent shutters to be used with the pre-cast beams for the in situ deck slabs
- Pre-cast parapet units on bridge decks
- Pre-cast suspended slabs for buildings (not very often and only to evaluate design-and-supply alternatives)

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
Yes. We have sent some of our designers on pre-cast concrete courses in this regard.

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
No, since a lot of the advantages are in time and ease of construction that is not easy for a consultant to quantify.

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
Until recently, labour has been readily available and affordable in South Africa. The quantity of construction and the distance between major centres is also not conducive to large centrally located pre-casting yards. This requires the contractors to provide a one off casting yard for every project and thereby negating a number of advantages of pre-cast concrete.

5. Do you think pre-casting has a future within the South African construction industry?
Yes. Skilled labour is very scarce and time limits become tighter for every project. This situation is ideal for pre-cast construction.

Consultant 9:

Name: **Ig de Villiers**
Company: **Vennootskap de Villiers**
Expertise: **Strukture 30 jr in RSA**

1. How often do you become involved in the design of pre-cast concrete systems?
Never in RSA

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
Yes

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
No because prices are not commonly available in RSA as they are in Europe. Only once an established fabricator has been established (big bucks) will there be a norm.

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
There are no suppliers/fabricators with mass production capabilities as in Europe.

5. Do you think pre-casting has a future within the South African construction industry?
Yes, but somenone with a brave heart and lots of money will need to invest in a proper plant.

Consultant 10:

Name: **Lucas Bosch**
Company: **Kwezi V3 engineers**
Expertise: **Technical Director-Structures Division**

1. How often do you become involved in the design of pre-cast concrete systems?
Specify it from time to time as a design and supply item (specific reference to pre-cast decking systems)

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
Yes

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
Consider myself experienced enough to make an early recommendation without prejudice.

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
Because of the poor quality and service encountered in the market

5. Do you think pre-casting has a future within the South African construction industry?
In specific applications - Yes

Consultant 11:

Name: **Patrick Hut**
Company: **Kantey & Templer**
Expertise: **Consulting Stuctural Engineers**

1. How often do you become involved in the design of pre-cast concrete systems?
Precast concrete floors are usually dealt with by the supplier (design and supply) in the jobs that I have been involved with (mainly houses)

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
See above

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
Often client & cost driven. Very much depends on the type of project.

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
Perhaps SA is just in the habit of using in-situ concrete. The US, UK & Australia use a lot of precast, composite, and steel frame structures. It generates a lot of details, but I never worked out why they are so extensively used there and not here.

5. Do you think pre-casting has a future within the South African construction industry?
If it becomes more marketed and available. Perhaps more people in the industry (in all facets) need more info and education on the topic?

Consultant 12:

Name: **Wahl Hugo**
Company: **Africon**
Expertise: **Structural Engineer**

1. How often do you become involved in the design of pre-cast concrete systems?
Not often say 10%

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
Yes

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
Yes

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
Contractors more familiar with in-situ option and probably more expensive (we did try to propose that as an alt for the parking garage at the airport) In situ option more flexible to suit design changes

5. Do you think pre-casting has a future within the South African construction industry?
Yes, programme benefits and also with is an alt taking into account skills shortages

C.2 Contractors

Contractor 1:

Name: C J Van Der Merwe
Company: Infraset
Expertise: Precasting

1. How often do you become involved in the construction of pre-cast concrete systems?
Only Manufacturing

2. Do you feel adequately equipped to build pre-cast systems (connections etc.) with a high level of confidence?
Only Manufacturing

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
We need to give input to the design of elements

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
Mind set need to change

5. Do you think pre-casting has a future within the South African construction industry?
Yes

Contractor 2:

Name: **Eric Ettisch**
Company: **Murray & Roberts Construction**
Expertise: **Principal Contractor for major projects**

1. How often do you become involved in the construction of pre-cast concrete systems?
The main involvement would be at design/concept stage where the contractor's expertise can influence the design team in changing to a more efficient system giving a more build-able & time efficiency benefits to the project

2. Do you feel adequately equipped to build pre-cast systems (connections etc.) with a high level of confidence?
All changes in design is & must be discussed/workshopped with the contracting team in order that the designer can understand the limitations of the practicalities the contractor faces in the constructability during the build stage. The Construction Regulations governs the designers & contractors to understand the Health & Safety risks before putting the works in hand to enable the design to be altered to mitigate any shortfalls during the temporary works stage

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
As Principal Contractors we are often not consulted early enough in the project to influence the choice of methodology & often the structural designer will choose a method based on his comfort level of expertise, this can be as a result of insufficient knowledge or not having the design team back-up/know how to develop details to overcome challenges

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
In Spain & the Western European countries the design is driven by pre-cast design & manufacturers yard being by far more sophisticated than in SA & hence the principal of design & build projects there being the order of the day.

We still want to reinvent the wheel on every project with the design team in isolation to the contracting ability. Pre-cast systems in a Industry where skilled resources is at a premium this option should be pursued as it does have a major saving on time & reduces on site resources.

5. Do you think pre-casting has a future within the South African construction industry?
Yes, the Industry Designers needs to be educated in the possibilities as there is major advantageous in the use of precast for most applications in the industry time saving on inner city high rise will be a huge benefit as it cuts out formwork, rebar & concrete resources (labour & material) improving logistics in having the finished article deliver as well as being manufactured controlled environment guaranteeing quality, lessening the down time & dependency on labour, material & suppliers of key resource.

If the industry is to equate to European standards this will require huge investment of capital plant/factories as well the need some of the plant for lifting on site will to be changed.

Contractor 3:

Name: **GRANT ROBERTSON**
Company: **J. VAN DER SLUYS (PTY) LTD**
Expertise: **CONSTRUCTION CONTRACT MANAGER**

1. How often do you become involved in the design of pre-cast concrete systems?
Very rarely. Over the last ten years' experience, I have probably only been involved 4x times.

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
No. I am not versed in such structural designs

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
Each project may be different and requires different and specific information

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
The professional teams, in particular the architects and designers, need to be either better educated or informed regarding the options that precast can offer.

5. Do you think pre-casting has a future within the South African construction industry?
Definitely

Contractor 4:

Name: **J.Cane**
Company: **Ruthcon**
Expertise: **General Civils & Slipform Construction**

1. How often do you become involved in the design of pre-cast concrete systems?
Never

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
No

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
Yes

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
It depends on the Construction Methods rather than Original designs as well as construction expertise!!

5. Do you think pre-casting has a future within the South African construction industry?
Limited

Contractor 5:

Name: **Stephen Chambers**
Company: **NMC**
Expertise: **Project Director**

1. How often do you become involved in the design of pre-cast concrete systems?
We use precast concrete beams (eaves, down stand and ground beams) quite often. Probably on more than 10 projects per year. The design of it is always in consultation with the structural engineer. The placement of the beams in position will therefore play a significant role in the design of the beams. We have also been involved in tilt-up construction methods. In this application full on external walls are cast flat on concrete floors and after curing is lifted into final position. We have not done this for the past 3 years though.

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
The design responsibility is always in conjunction with the structural engineer. Our years of experience though gives us the confidence to say that we know what we are doing.

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
Yes. We understand fully the cost implications to both. With precast beams precast will be more cost effective roughly 90% of the time.

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
Lack of practical appreciation by consulting engineers
Lack of technical experience by consultants and contractors
Lack of understanding of cost savings
Lack of experience by contractors placement teams
Non availability of full designs up front to give team opportunity to find best solution
Perceived expensive costs of rigging equipment
Lack of skills in coordinating all activities associated with precast
Lack of understanding of time savings

5. Do you think pre-casting has a future within the South African construction industry?
Yes

Contractor 6:

Name: **Werner Jerling**
Company: **Stefanutti & Bressan Civils (Pty) Ltd**
Expertise: **General Manager Construction Company. Pr Eng, Pr CPM. 18 Years Construction Experience, 2 Years Exp in design office**

1. How often do you become involved in the design of pre-cast concrete systems?
On design and construct schemes. Only scheme and concept development and method studies + application studies worldwide.

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
No

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
Partial. Not enough scientific work has been done and the market changes so quickly that it is difficult to keep up with changing construction costs. In the past there has been a severe downturn in the construction market which has been hampering the possibility of doing alternatives and doing studies into various cost alternatives.

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
The construction market has come through a terrible downturn during which there was plenty supply of construction services. The pressure is really coming on innovation and quicker construction during the past year or so.
We are also now really feeling the pinch of shortages in skills and now need less skill intensive construction methods putting our best skills in manufacturing and using lower skills in assembly.

5. Do you think pre-casting has a future within the South African construction industry?
Yes, refer to some of my comments under the previous question.
We need to study and evaluate the use thereof on current projects such as the stadia in detail to enable this info to be used in future.
Studies into connections and the education of designers on precast design and particularly the design of connections are required.
During the late 1970's and early 80's a lot of precast buildings were erected by companies such as CONFORM, an old LTA firm. These have all gone under now. At the time a stigma was created with precast buildings following a collapse of an apartment building in the UK that used precasting extensively. This event still sits in the mind of some of the older structural design engineers.

Contractor 7:

Name: **Steven Brown**
Company: **RBD Construction**
Expertise: **Construction (Civil & Structural)**

1. How often do you become involved in the design of pre-cast concrete systems?
Ongoing

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
Up to this point have always received design from engineering

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
No

4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
Insitu design more efficient at present but lack of precast development

5. Do you think pre-casting has a future within the South African construction industry?
It needs to be properly analyzed (cost engineering)

Contractor 8:

Name: **Keith Miller**
Company: **Group Five Construction**
Expertise: **PrEng, BSc Civ Eng**

1. How often do you become involved in the design of pre-cast concrete systems?
Almost never

2. Do you feel adequately equipped to perform designs on pre-cast systems (connections etc.) with a high level of confidence?
Personally yes, but generally within the company, no.

3. Do you have sufficient information to weigh options of pre-cast vs. in-situ casting against one another during the pre-design phase of a project?
Would doubt it

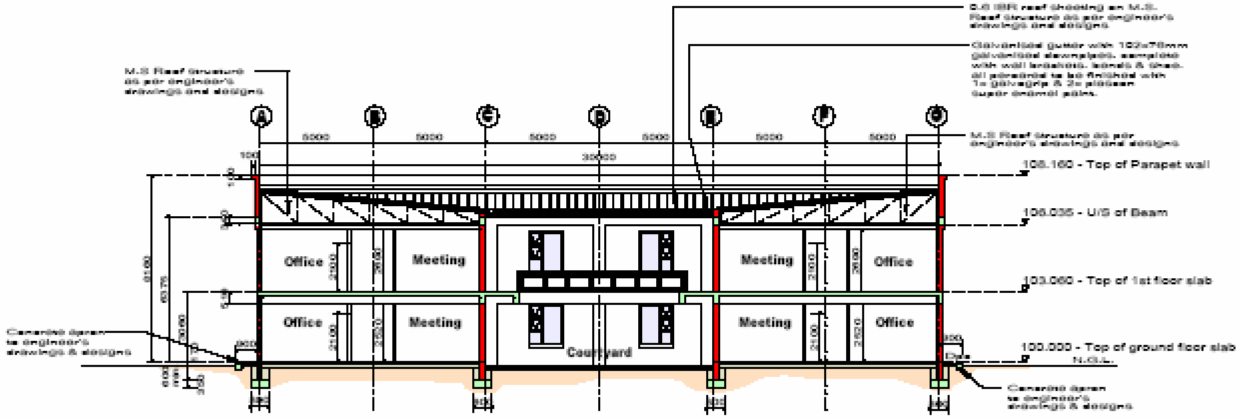
4. Why, in your own opinion, do you believe that pre-cast structural systems aren't used more frequently in South Africa?
Mind set of clients/engineers

5. Do you think pre-casting has a future within the South African construction industry?
Absolutely

APPENDIX D:
OFFICE BUILDING CALCULATIONS

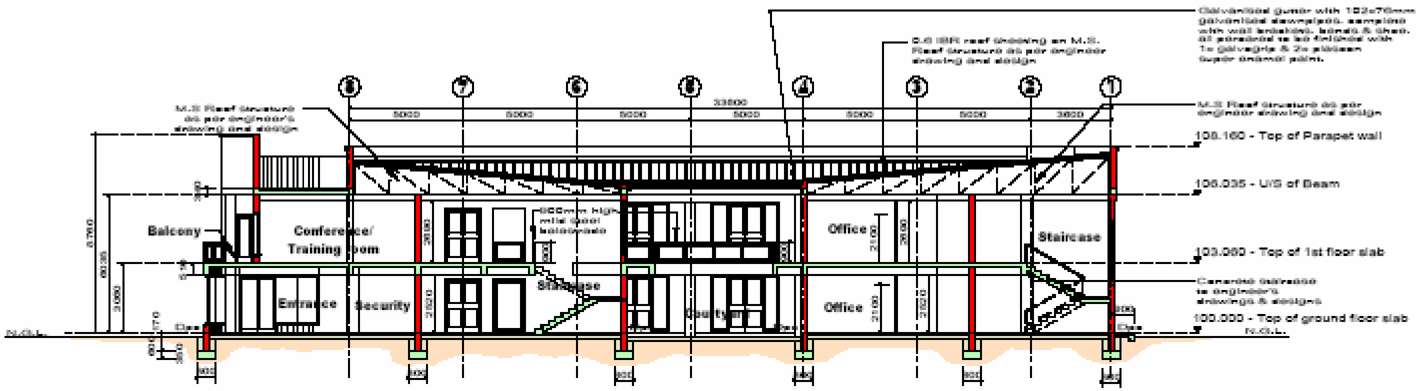
This Appendix contains the following information:

- The architect's original drawings of the Office building
- The modified conceptual layout drawings for the In-situ Beam and Slab, HCC and Flat slab versions of the Office Building
- Excel spreadsheets with the In-situ Beam and slab Office building's calculations
- Excel spreadsheets with the HCC Office building's calculations
- Excel spreadsheets with the In-situ Flat slab Office building's calculations



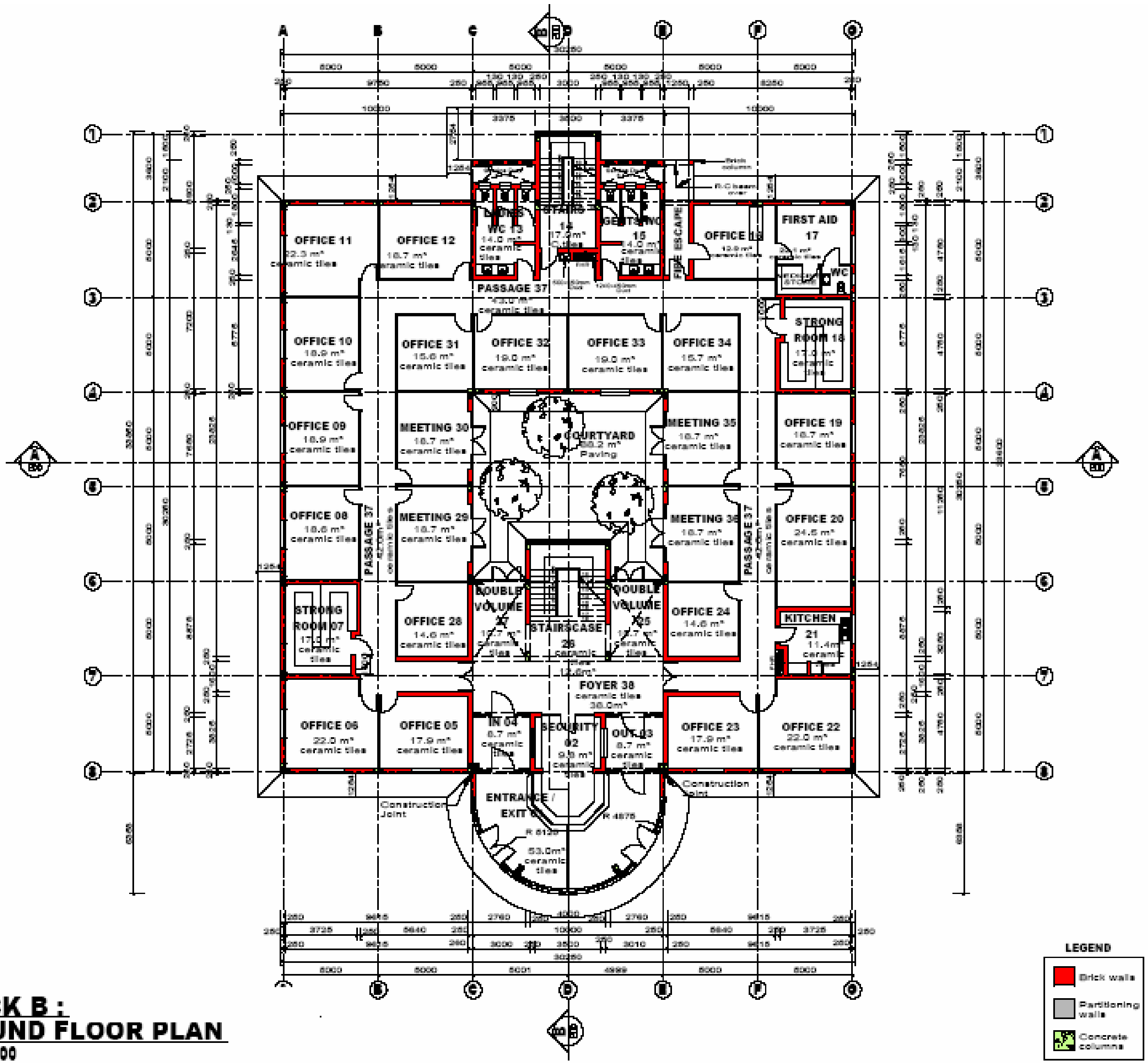
NOTE:
R.C concrete slabs, beams, staircase, apron & foundations to Engineer's details & specifications.

BLOCK B :
1 SECTION A - A
Scale 1:200



NOTE:
R.C concrete slabs, beams, staircase, apron & foundations to Engineer's details & specifications.

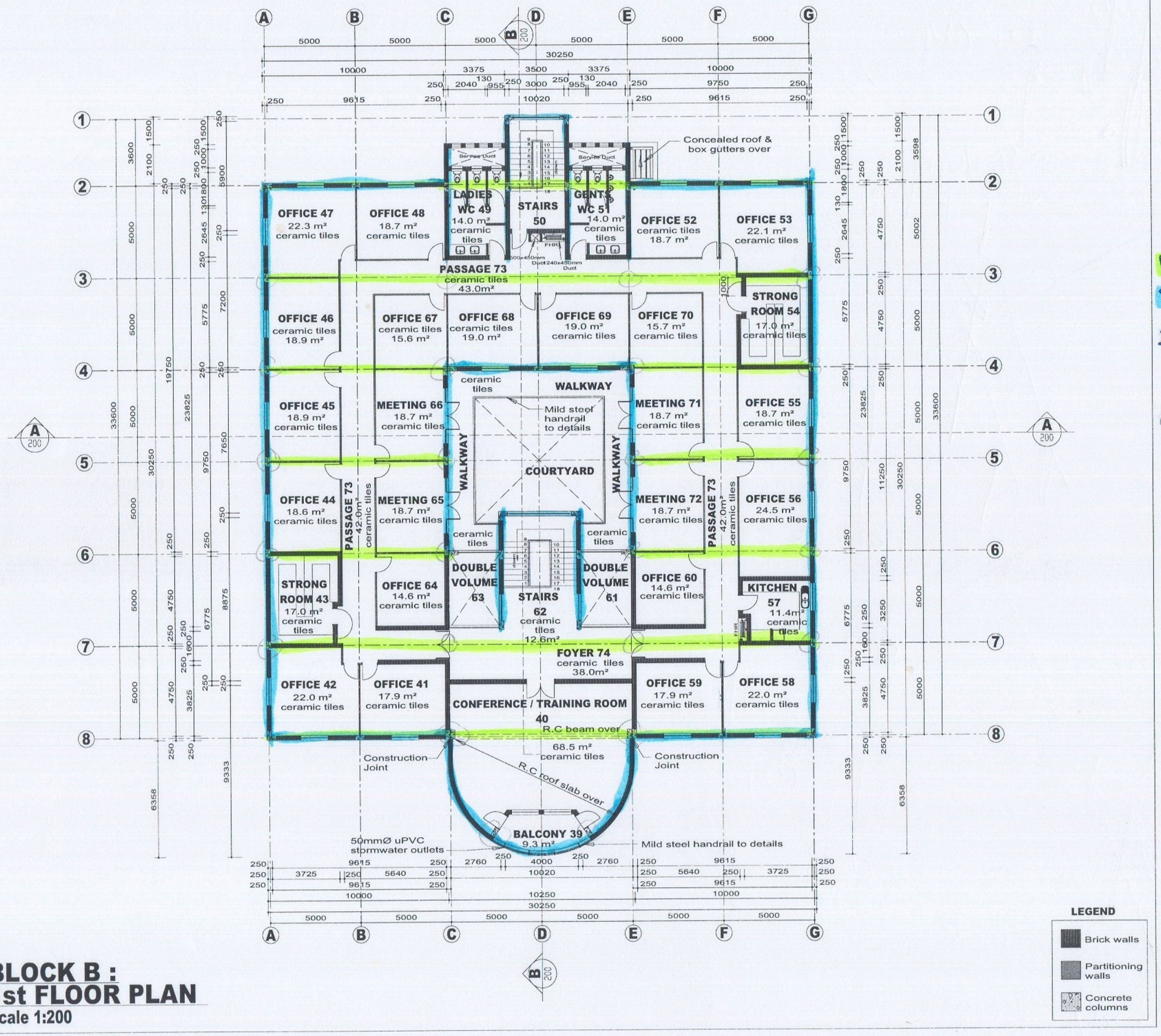
BLOCK B :
2 SECTION B - B
Scale 1:200



1 BLOCK B : GROUND FLOOR PLAN

Scale 1:200

In-Situ Beam-and-Slab:



1 **BLOCK B : 1st FLOOR PLAN**
Scale 1:200

GENERAL NOTES:

AREAS:

GROUND FLOOR AREA	907.50m²
FIRST FLOOR AREA	907.50m²
TOTAL FLOOR AREA	1817.0m²

Main Beams
Secondary Beams
200mm in-situ slab
680mm total beam depth

HCC:

ALL DRAWINGS AND DIMENSIONS MUST BE CORRELATED BEFORE ANY MATERIALS ARE ORDERED OR BUILDING WORK COMMENCES. ANY DIFFERENCES MUST BE BROUGHT UNDER THE ATTENTION OF THE ARCHITECT IMMEDIATELY.

GENERAL NOTES:

AREAS:

GROUND FLOOR AREA	907.50m²
FIRST FLOOR AREA	907.50m²
TOTAL FLOOR AREA	1817.0m²

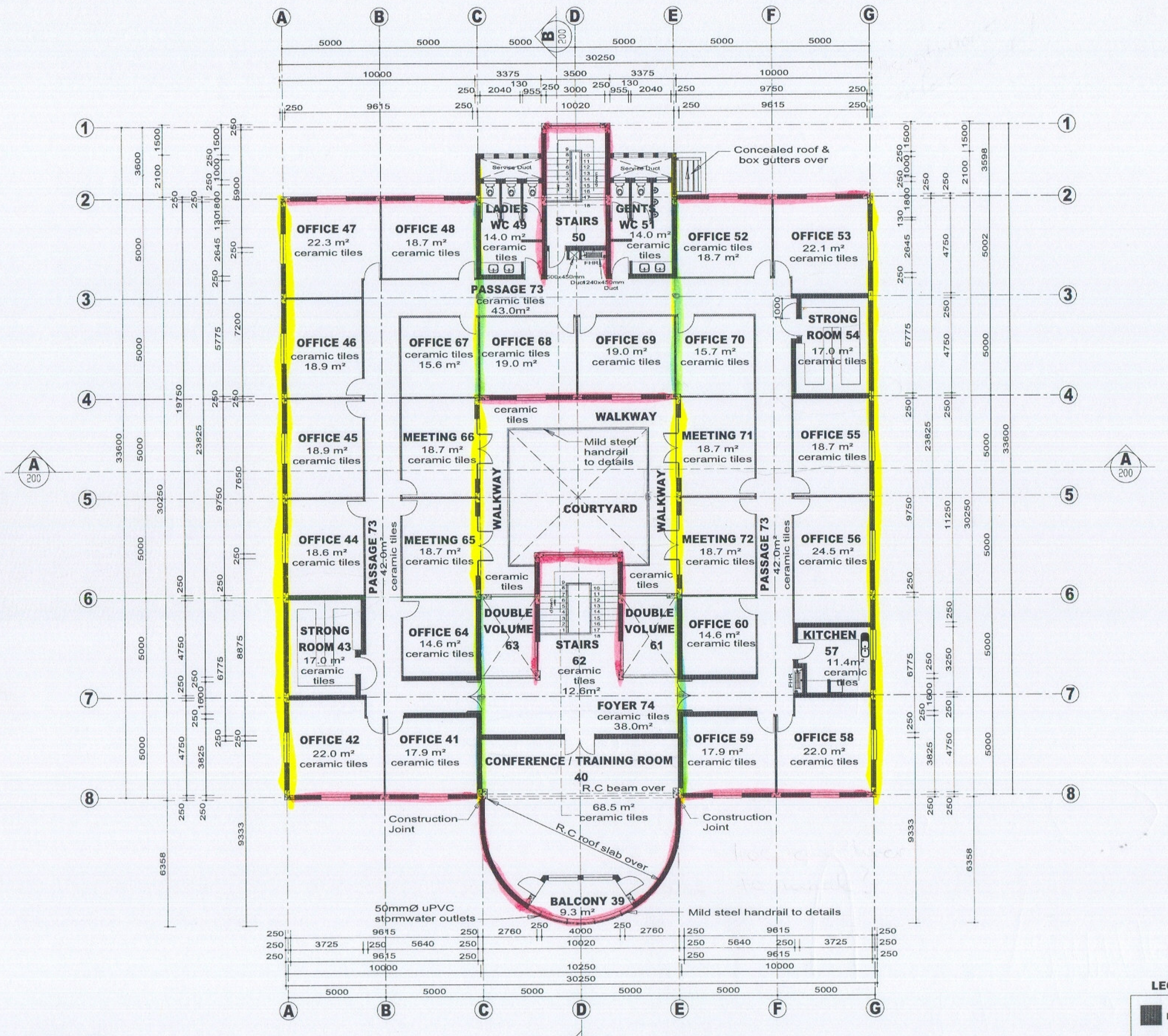
Single Span beam

Main beams

Secondary Beams

250mm echo HC slabs

680mm total beam depth



BLOCK B :

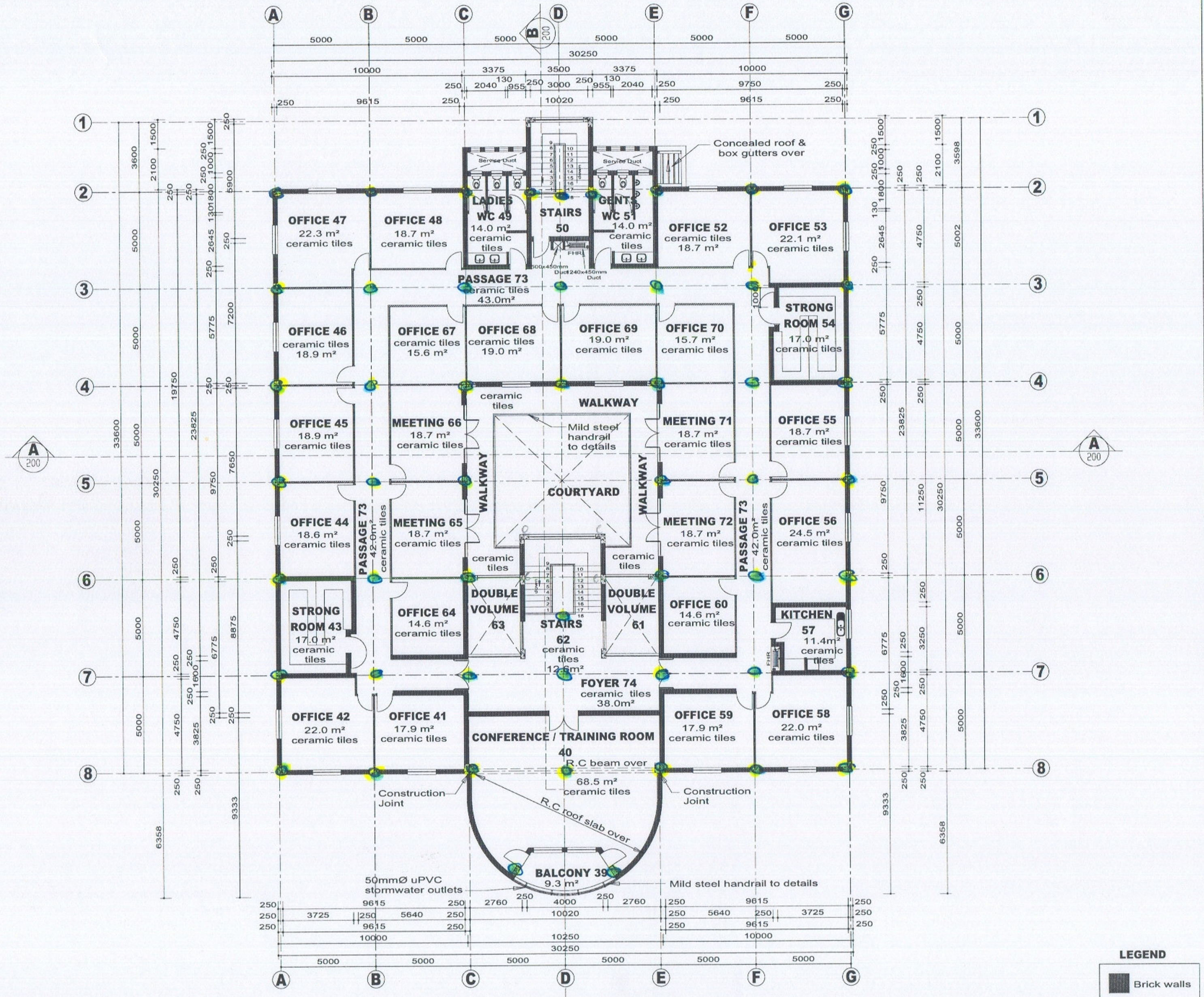
1 1st FLOOR PLAN

Scale 1:200

LEGEND

- Brick walls
- Partitioning walls
- Concrete columns

In-Situ Flat slab:



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GENERAL NOTES:

AREAS:	
GROUND FLOOR AREA	907.50m²
FIRST FLOOR AREA	907.50m²
TOTAL FLOOR AREA	1817.0m²

255mm flat slab

No column heads

5m x 5m panels

Column placement

BLOCK B :

1 1st FLOOR PLAN

Scale 1:200

In-situ Beam and Slab Office Building

200mm RC slab, Top reinforcement design

Reactions					Design	
SABS	M+ max	=	29.5	kNm	**29.5**	**kNm**
	M- max	=	-29.5	kNm	**29.5**	**kNm**
	V max	=	41.2	kN	**41.2**	**kN**

Flexural Design:

Section	L	=	5000	mm
	h	=	200	mm
	bw	=	1000	mm
	bf	=	1000	mm
	hf	=	200	mm
	d	=	155	mm
	d'	=	45	mm
	fcu	=	30	Mpa
	fy	=	450	Mpa

K'	=	0.132		20% redistribution			
K	=	0.041					
K < K'	**Yes**			**No Compression reinforcement required**			
z	=	147.3	mm	also z < 0.95d			
						0.13% <As<	
As	=	512	mm^2		260	4%	8000
Y12 @ 200	=	566	mm^2			OK	
As'min	=	260	mm^2				

Y10 @ 300	=	262	mm^2		OK		
x	=	11.3	mm				
Mr	=	29.8	kNm		**OK**		
K > K'	**No**			**Compression reinforcement required**			

Shear Reinforcement:

v	=	0.27	Mpa		**OK**		
vc	=	0.52	Mpa	vc max		4.11	Mpa
Stirrups required	**Asv min**						
sv	=	150	mm				
fyv	=	450	Mpa				
Asv min	=	153	mm^2				
Asv	=	-96	mm^2				
2Y10	=	157	mm^2				

In-situ Beam and Slab Office Building

200mm RC slab, Bottom reinforcement design

Reactions					**Design**	
SABS	M+ max	=	29.5	kNm	**29.5**	**kNm**
	M- max	=	-29.5	kNm	**29.5**	**kNm**
	V max	=	41.2	kN	**41.2**	**kN**

Flexural Design:								
Section	L	=	5000	mm				
	h	=	200	mm				
	bw	=	1000	mm				
	bf	=	1000	mm				
	hf	=	200	mm				
	d	=	155	mm				
	d'	=	45	mm				
	fcu	=	30	Mpa				
	fy	=	450	Mpa				
	x	=	17	mm	M =		**30.44**	**kNm**
	Is x < 1.11hf?		**Yes**					
	K'	=	0.132		20% redistribution			
	K	=	0.041					
	K < K'		**Yes**		**No Compression reinforcement required**			
	z	=	147.3	mm	also z < 0.95d			
	As	=	512	mm^2	260	0.13% <As< 4%	8000	
	Y12 @ 150	=	754	mm^2		OK		

As'min	=	260	mm^2	
Y10 @ 300	=	262	mm^2	OK
x	=	17.3	mm	OK
Mr	=	40.3	kNm	**OK**

K > K' **No** **Compression reinforcement required**

Deflection Limitations:

L/d base	=	24	One end continuous		
Span (k1)	=	1.00			
Tension R (k2)	=	1.44		fs	249.10
Comp R (k3)	=	1.00		% Comp R	0.13
Flange beam (k4)	=	1.00			
L/d allowed	=	34.62			
L/d	=	32.26	**OK**		

In-situ Beam and Slab Office Building

200mm RC cantilever slab, Top reinforcement design

Reactions					Design	
SABS	M+ max	=	17.7	kNm	**17.7**	**kNm**
	M- max	=	-17.7	kNm	**17.7**	**kNm**
	V max	=	22.1	kN	**22.1**	**kN**

Flexural Design:					
Section	L	=	1500	mm	
	h	=	200	mm	
	bw	=	1000	mm	
	bf	=	1000	mm	
	hf	=	200	mm	
	d	=	155	mm	
	d'	=	45	mm	
	fcu	=	30	Mpa	
	fy	=	450	Mpa	
	K'	=	0.132		20% redistribution
	K	=	0.025		

K < K'		**Yes**		**No Compression reinforcement required**			
z	=	147.3	mm	also z < 0.95d			
						0.13% <As<	
As	=	307	mm^2		260	4%	8000
Y12 @ 300	=	377	mm^2		OK		
As'min	=	260	mm^2				
Y10 @ 300	=	262	mm^2		OK		

x	=	5.2	mm			
Mr	=	18.9	kNm	**OK**		
K > K'	**No**			**Compression reinforcement required**		

Shear Reinforcement:

v	=	0.14	Mpa	**OK**		
vc	=	0.45	Mpa	vc max	4.11	Mpa
Stirrups required	**Asv min**					
sv	=	150	mm			
fyv	=	450	Mpa			
Asv min	=	153	mm^2			
Asv	=	-118	mm^2			
2Y10	=	157	mm^2			

In-situ Beam and Slab Office Building

200mm RC cantilever slab, Bottom reinforcement design

Reactions **Design**

SABS	M+ max	=	17.7	kNm	**17.7**	**kNm**
	M- max	=	-17.7	kNm	**17.7**	**kNm**
	V max	=	22.1	kN	**22.1**	**kN**

Flexural Design:

Section	L	=	1500	mm			
	h	=	200	mm			
	bw	=	1000	mm			
	bf	=	1000	mm			
	hf	=	200	mm			
	d	=	155	mm			
	d'	=	45	mm			
	fcu	=	30	Mpa			
	fy	=	450	Mpa			
	x	=	10	mm	M =	**18.29**	**kNm**
	Is x < 1.11hf?		**Yes**				
	K'	=	0.132		20% redistribution		
	K	=	0.025				
	K < K'		**Yes**		**No Compression reinforcement required**		
	z	=	147.3	mm	also z < 0.95d		
	As	=	307	mm^2	260	0.13% <As< 4%	8000
	Y12 @ 300	=	377	mm^2		OK	

As'min	=	260	mm^2	
Y10 @ 300	=	262	mm^2	OK
x	=	5.2	mm	OK
Mr	=	18.9	kNm	**OK**

K > K' **No** **Compression reinforcement required**

Deflection Limitations:

L/d base	=	7	Cantilever		
Span (k1)	=	1.00			
Tension R (k2)	=	1.46		fs	298.92
Comp R (k3)	=	1.00		% Comp R	0.13
Flange beam (k4)	=	1.00			
L/d allowed	=	10.20			
L/d	=	9.68	**OK**		

In-situ Beam and Slab Office Building

10m span, RC beam, Bottom reinforcement design

Reactions **Design**

SABS	M+ max	=	1034	kNm	**1034**	**kNm**
	M- max	=	-919	kNm	**919**	**kNm**
	V max	=	496	kN	**496**	**kN**

Flexural Design:

Section	L	=	10000	mm			
	h	=	680	mm			
	bw	=	400	mm			
	bf	=	1800	mm			
	hf	=	200	mm			
	d	=	630	mm			
	d'	=	50	mm			
	fcu	=	30	Mpa			
	fy	=	450	Mpa			
	x	=	80	mm	M =	**1039.26**	**kNm**
	Is x < 1.11hf?		**Yes**				
	K'	=	0.132		20% redistribution		
	K	=	0.048				
	K < K'		**Yes**		**No Compression reinforcement required**		
	z	=	594.2	mm	also z < 0.95d		
					0.13% <As< 4%		
	As	=	4445	mm^2	354		10880
	8Y32	=	6433	mm^2	OK		

As'min	=	354	mm^2	
4Y32	=	3216	mm^2	OK
x	=	67.5	mm	OK
Mr	=	1489.7	kNm	**OK**

K > K' **No** **Compression reinforcement required**

Deflection Limitations:

L/d base	=	20			
Span (k1)	=	1.00			
Tension R (k2)	=	0.80		fs	253.60
Comp R (k3)	=	1.28		% Comp R	1.18
Flange beam (k4)	=	0.80			
L/d allowed	=	16.41			
L/d	=	15.87	**OK**		

In-situ Beam and Slab Office Building

10m span, RC beam, Top reinforcement design

Reactions						**Design**	
SABS	M+ max	=	1034	kNm		**1034**	**kNm**
	M- max	=	-919	kNm		**919**	**kNm**
	V max	=	496	kN		**496**	**kN**

Flexural Design:					
Section	L	=	10000	mm	
	h	=	680	mm	
	bw	=	400	mm	
	bf	=		mm	
	hf	=		mm	
	d	=	630	mm	
	d'	=	50	mm	
	fcu	=	30	Mpa	
	fy	=	450	Mpa	
	K'	=	0.132		20% redistribution
	K	=	0.193		

K < K'	**No**			**No Compression reinforcement required**			
K > K'	**Yes**			**Compression reinforcement required**			
z	=	517.5	mm	also z < 0.95d			
As'	=	1545	mm^2	544	0.2% <As< 4%	10880	
2Y32	=	1608	mm^2		OK		

						0.13% <As<	
As	=	4381	mm^2		354	4%	10880
6Y32	=	4825	mm^2		OK		
x	=	281.5	mm				
Mr	=	990.7	kNm		**OK**		

Shear Reinforcement:

v	=	1.97	Mpa		**OK**		
vc	=	0.63	Mpa	vc max		4.11	Mpa
Stirrups required	**Asv**						
sv	=	100	mm				
fyv	=	450	Mpa				
Asv min	=	41	mm^2				
Asv	=	137	mm^2				
2Y10	=	157	mm^2				

In-situ Beam and Slab Office Building

5m span, RC beam, Bottom reinforcement design

Reactions						**Design**	
SABS	M+ max	=	236	kNm		**236**	**kNm**
	M- max	=	-210	kNm		**210**	**kNm**
	V max	=	227	kN		**227**	**kN**

Flexural Design:									
Section	L	=	5000	mm					
	h	=	680	mm					
	bw	=	400	mm					
	bf	=	750	mm					
	hf	=	200	mm					
	d	=	630	mm					
	d'	=	50	mm					
	fcu	=	30	Mpa					
	fy	=	450	Mpa					
	x	=	45	mm	M =			**250.04**	**kNm**
	Is x < 1.11hf?		**Yes**						
	K'	=	0.132		20% redistribution				
	K	=	0.026						
	K < K'		**Yes**		**No Compression reinforcement required**				
	z	=	598.5	mm	also z < 0.95d				
	As	=	1007	mm^2		354	0.13% <As< 4%		10880

4Y20	=	1257	mm^2	OK
As'min	=	354	mm^2	
2Y16	=	402	mm^2	OK
x	=	39.7	mm	OK
Mr	=	297.1	kNm	**OK**

K > K'	**No**	**Compression reinforcement required**

Deflection Limitations:

L/d base	=	20			
Span (k1)	=	1.00			
Tension R (k2)	=	1.19		fs	294.09
Comp R (k3)	=	1.00		% Comp R	0.15
Flange beam (k4)	=	0.87			
L/d allowed	=	20.60			
L/d	=	7.94	**OK**		

In-situ Beam and Slab Office Building

5m span, RC beam, Top reinforcement design

Reactions					**Design**	
SABS	M+ max	=	236	kNm	**236**	**kNm**
	M- max	=	-210	kNm	**210**	**kNm**

	V max	=	227	kN		**227**	**kN**

Flexural Design:

Section	L	=	5000	mm				
	h	=	680	mm				
	bw	=	400	mm				
	bf	=		mm				
	hf	=		mm				
	d	=	630	mm				
	d'	=	50	mm				
	fcu	=	30	Mpa				
	fy	=	450	Mpa				
	K'	=	0.156		No redistribution			
	K	=	0.044					
	K < K'		**Yes**		**No Compression reinforcement required**			
	z	=	597.5	mm	also z < 0.95d			
							0.13% <As<	
	As	=	898	mm^2	354		4%	10880
	4Y20	=	1257	mm^2		OK		
	As'min	=	354	mm^2				
	2Y16	=	402	mm^2		OK		
	x	=	74.5	mm				
	Mr	=	291.4	kNm		**OK**		
	K > K'		**No**		**Compression reinforcement required**			

Shear Reinforcement:

v	=	0.90	Mpa		**OK**		
vc	=	0.40	Mpa	vc max		4.11	Mpa
Stirrups required		**Asv**					
sv	=	150	mm				
fyv	=	450	Mpa				
Asv min	=	61	mm^2				
Asv	=	76	mm^2				
2Y8	=	101	mm^2				

HCC Office Building

Precast, RC beam, Top reinforcement design

Reactions: **Design:**

SABS	M+ max	=	446	kNm	**446**	**kNm**
	M- max	=	-396	kNm	**396**	**kNm**
	V max	=	428	kN	**428**	**kN**

Flexural design:

Section	L	=	5000	mm				
	h	=	680	mm				
	bw	=	400	mm				
	bf	=	1800	mm				
	hf	=	250	mm				
	d	=	630	mm				
	d'	=	100	mm				
	fcu	=	50	Mpa				
	fy	=	450	Mpa				
	x	=	25	mm	M =		**563.84**	**kNm**
	Is x < 1.11hf?		**Yes**					
	K'	=	0.132		20% redistribution			
	K	=	0.012					
	K < K'		**Yes**		**No Compression reinforcement required**			
	z	=	598.5	mm	also z < 0.95d			
	As	=	1903	mm^2	354	0.13% <As< 4%	10880	
	4Y25	=	1963	mm^2		OK		

As'min	=	354	mm^2		
2Y16	=	402	mm^2	OK	
x	=	17.5	mm	OK	
Mr	=	466.1	kNm	**OK**	
K > K'	**No**			**Compression reinforcement required**	

Deflection Limitations:

L/d base	=	20			
Span (k1)	=	1.00			
Tension R (k2)	=	0.82		fs	355.89
Comp R (k3)	=	1.00		% Comp R	0.15
Flange beam (k4)	=	0.78			
L/d allowed	=	12.78			
L/d	=	7.94	**OK**		

HCC Office Building

Precast, RC beam, Top reinforcement design

Reactions: **Design:**

SABS	M+ max	=	446	kNm	**446**	**kNm**
	M- max	=	-396	kNm	**396**	**kNm**
	V max	=	428	kN	**428**	**kN**

Flexural design:

Section	L	=	5000	mm
	h	=	680	mm
	bw	=	400	mm
	bf	=		mm
	hf	=		mm
	d	=	430	mm
	d'	=	50	mm
	fcu	=	50	Mpa
	fy	=	450	Mpa
	K'	=	0.132	
	K	=	0.107	

All the reinforcement could not fit into the cast in-situ section between the hollowcore slabs. Half the reinforcement was therefore placed in the top of beam, and half in cast in-situ section.

20% redistribution

K < K' **Yes** **No Compression reinforcement required**

z	=	370.6	mm	also z < 0.95d				
					0.13% <As<			
As	=	2729	mm^2	354	4%	10880	OK	
6Y25	=	2945	mm^2	OK				
As'min	=	354	mm^2					
2Y16	=	402	mm^2	OK				

x	=	126.3	mm				
Mr	=	431.2	kNm		OK		
K > K'		**No**		**Compression reinforcement required**			

Shear Reinforcement:

v	=	2.49	Mpa		**OK**		
vc	=	0.79	Mpa	vc max		4.75	Mpa
Stirrups required		**Asv**					
sv	=	75	mm				
fyv	=	450	Mpa				
Asv min	=	31	mm^2				
Asv	=	130	mm^2				
2Y10	=	157	mm^2				

HCC Office Building

Precast, RC beam, Top reinforcement design

Reactions:					**Design:**	
SABS	M+ max	=	311	kNm	**311**	**kNm**
	M- max	=	-277	kNm	**277**	**kNm**
	V max	=	299	kN	**299**	**kN**

Flexural design:

Section	L	=	5000	mm				
	h	=	680	mm				
	bw	=	400	mm				
	bf	=	750	mm				
	hf	=	200	mm				
	d	=	630	mm				
	d'	=	100	mm				
	fcu	=	50	Mpa				
	fy	=	450	Mpa				
	x	=	40	mm	M =		**371.79**	**kNm**
	Is x < 1.11hf?		**Yes**					
	K'	=	0.132		20% redistribution			
	K	=	0.021					
	K < K'	**Yes**			**No Compression reinforcement required**			
	z	=	598.5	mm	also z < 0.95d			
	As	=	1327	mm^2	354	0.13% <As< 4%	10880	
	5Y20	=	1571	mm^2		OK		

As'min	=	354	mm^2		
2Y16	=	402	mm^2	OK	
x	=	31.9	mm	OK	
Mr	=	367.5	kNm	**OK**	
K > K'	**No**			**Compression reinforcement required**	

Deflection Limitations:

L/d base	=	20			
Span (k1)	=	1.00			
Tension R (k2)	=	1.04		fs	310.09
Comp R (k3)	=	1.00		% Comp R	0.15
Flange beam (k4)	=	0.87			
L/d allowed	=	17.96			
L/d	=	7.94	**OK**		

HCC Office Building

Precast, RC beam, Top reinforcement design

Reactions: **Design:**

SABS	M+ max	=	236	kNm	**236**	**kNm**
	M- max	=	-210	kNm	**210**	**kNm**
	V max	=	227	kN	**227**	**kN**

Flexural design:

Section	L	=	5000	mm
	h	=	680	mm
	bw	=	400	mm
	bf	=		mm
	hf	=		mm
	d	=	430	mm
	d'	=	50	mm
	fcu	=	50	Mpa
	fy	=	450	Mpa

All the reinforcement could not fit into the cast in-situ section between the hollowcore slabs. Half the reinforcement was therefore placed in the top of beam, and half in cast in-situ section.

K'	=	0.132	20% redistribution
K	=	0.057	

K < K' **Yes** **No Compression reinforcement required**

z	=	400.9	mm	also z < 0.95d				
						0.13% <As<		
As	=	1338	mm^2		354	4%	10880	OK
2Y16 + 2Y25	=	1384	mm^2		OK			
As'min	=	354	mm^2					
2Y16	=	402	mm^2		OK			

x	=	50.8	mm				
Mr	=	217.1	kNm		**OK**		
K > K'		**No**		**Compression reinforcement required**			

Shear Reinforcement:

v	=	1.32	Mpa		**OK**		
vc	=	0.62	Mpa	vc max		4.75	Mpa
Stirrups required		**Asv**					
sv	=	125	mm				
fyv	=	450	Mpa				
Asv min	=	51	mm^2				
Asv	=	90	mm^2				
2Y8	=	101	mm^2				

HCC Office Building

Precast, RC beam, Top reinforcement design

Reactions: **Design:**

SABS	M+ max	=	91	kNm	**91**	**kNm**
	M- max	=	-81	kNm	**81**	**kNm**
	V max	=	87	kN	**87**	**kN**

Flexural design:

Section	L	=	5000	mm
	h	=	680	mm
	bw	=	400	mm
	bf	=	400	mm
	hf	=	680	mm
	d	=	630	mm
	d'	=	50	mm
	fcu	=	50	Mpa
	fy	=	450	Mpa

x	=	20	mm	M =		**100.60**	**kNm**
Is x < 1.11hf?		**Yes**					
K'	=	0.132		20% redistribution			
K	=	0.011					
K < K'		**Yes**		**No Compression reinforcement required**			
z	=	598.5	mm	also z < 0.95d			
As	=	388	mm^2	354	0.13% <As< 4%	10880	
2Y16	=	402	mm^2		OK		

As'min	=	354	mm^2		
2Y16	=	402	mm^2	OK	
x	=	3.4	mm	OK	
Mr	=	92.6	kNm	**OK**	
K > K'	**No**			**Compression reinforcement required**	

Deflection Limitations:

L/d base	=	20			
Span (k1)	=	1.00			
Tension R (k2)	=	1.24		fs	354.59
Comp R (k3)	=	1.00		% Comp R	0.15
Flange beam (k4)	=	1.00			
L/d allowed	=	24.85			
L/d	=	7.94	**OK**		

HCC Office Building

Precast, RC beam, Top reinforcement design

Reactions:					**Design:**	
SABS	M+ max	=	91	kNm	**91**	**kNm**
	M- max	=	-81	kNm	**81**	**kNm**
	V max	=	87	kN	**87**	**kN**

Flexural design:

Section	L	=	5000	mm				
	h	=	680	mm				
	bw	=	400	mm				
	bf	=		mm				
	hf	=		mm				
	d	=	630	mm				
	d'	=	50	mm				
	fcu	=	50	Mpa				
	fy	=	450	Mpa				
	K'	=	0.132		20% redistribution			
	K	=	0.010					
	K < K'		**Yes**		**No Compression reinforcement required**			
	z	=	598.5	mm	also z < 0.95d			
							0.13% <As<	
	As	=	346	mm^2	354		4%	10880
	2Y16	=	402	mm^2		OK		
	As'min	=	354	mm^2				
	2Y16	=	402	mm^2		OK		

x	=	3.4	mm				
Mr	=	92.6	kNm		**OK**		
K > K'		**No**		**Compression reinforcement required**			

Shear Reinforcement:

v	=	0.35	Mpa		**OK**		
vc	=	0.33	Mpa	vc max		4.75	Mpa
Stirrups required		**Asv min**					
sv	=	200	mm				
fyv	=	450	Mpa				
Asv min	=	82	mm^2				
Asv	=	4	mm^2				
2Y8	=	101	mm^2				

Flat Slab Office Building

Middle strip, Top reinforcement design

Reactions: **Design:**

SABS	M+ max	=	65.8	kNm	**65.8**	**kNm**
	M- max	=	-27.8	kNm	**27.8**	**kNm**
	V max	=	0	kN	**0**	**kN**

Flexural design:

Section	L	=	5000	mm
	h	=	255	mm
	bw	=	2500	mm
	bf	=	2500	mm
	hf	=	255	mm
	d	=	210	mm
	d'	=	45	mm
	fcu	=	30	Mpa
	fy	=	450	Mpa

K'	=	0.132		20% redistribution
K	=	0.008		

K < K' **Yes** **No Compression reinforcement required**

z	=	199.5	mm	also z < 0.95d

					0.13% <As<		
As	=	356	mm^2	829		4%	25500
	=	830	mm^2		OK		
As'min	=	829	mm^2				
	=	830	mm^2		OK		
x	=	1.8	mm				
Mr	=	56.1	kNm		**OK**		

K > K' **No** **Compression reinforcement required**

Flat Slab Office Building

Middle strip, Bottom reinforcement design

Reactions: **Design:**

SABS	M+ max	=	65.8	kNm	**65.8**	**kNm**
	M- max	=	-27.8	kNm	**27.8**	**kNm**
	V max	=	0	kN	**0**	**kN**

Flexural design:

Section	L	=	5000	mm
	h	=	255	mm
	bw	=	2500	mm
	bf	=	2500	mm
	hf	=	255	mm
	d	=	210	mm
	d'	=	45	mm
	fcu	=	30	Mpa
	fy	=	450	Mpa

x	=	11	mm	M =	**68.51**	**kNm**
Is x < 1.11hf?		**Yes**				
K'	=	0.132		20% redistribution		
K	=	0.020				

K < K' **Yes** **No Compression reinforcement required**

z	=	199.5	mm	also z < 0.95d		
					0.13% <As<	
As	=	842	mm^2	829	4%	25500
	=	950	mm^2	OK		
As'min	=	829	mm^2			
	=	830	mm^2	OK		
x	=	3.4	mm	OK		
Mr	=	65.8	kNm	**OK**		

K > K' **No** **Compression reinforcement required**

Deflection Limitations:

L/d base	=	21.6	One end continuous		
Span (k1)	=	1.00			
Tension R (k2)	=	1.25		fs	325.48
Comp R (k3)	=	1.00		% Comp R	0.13
Flange beam (k4)	=	1.00			
L/d allowed	=	27.09			
L/d	=	23.81	**OK**		

Flat Slab Office Building

Column strip, Top reinforcement design

Reactions: **Design:**

SABS	M+ max	=	80.5	kNm	**80.5**	**kNm**
	M- max	=	-83.3	kNm	**83.3**	**kNm**
	V max	=	464.5	kN	**464.5**	**kN**

Flexural design:

Section	L	=	5000	mm	
	h	=	255	mm	
	bw	=	2500	mm	
	bf	=	2500	mm	
	hf	=	255	mm	
	d	=	210	mm	
	d'	=	45	mm	
	fcu	=	30	Mpa	
	fy	=	450	Mpa	
	K'	=	0.132		20% redistribution
	K	=	0.025		

K < K'		**Yes**		**No Compression reinforcement required**			
z	=	199.5	mm	also z < 0.95d			
						0.13% <As<	
As	=	1067	mm^2		829	4%	25500
	=	1186	mm^2		OK		
As'min	=	829	mm^2				
	=	830	mm^2		OK		
x	=	6.4	mm				
Mr	=	84.8	kNm		**OK**		
K > K'		**No**		**Compression reinforcement required**			

Flat Slab Office Building

Column strip, Bottom reinforcement design

Reactions: **Design:**

SABS	M+ max	=	80.5	kNm	**80.5**	**kNm**
	M- max	=	-83.3	kNm	**83.3**	**kNm**
	V max	=	0	kN	**0**	**kN**

Flexural design:

Section	L	=	5000	mm
	h	=	255	mm
	bw	=	2500	mm
	bf	=	2500	mm
	hf	=	255	mm
	d	=	210	mm
	d'	=	45	mm
	fcu	=	30	Mpa
	fy	=	450	Mpa

Positive bending	x	=	13	mm	M =	**80.61**	**kNm**
	Is x < 1.11hf?		**Yes**				
	K'	=	0.132		20% redistribution		
	K	=	0.024				
	K < K'		**Yes**		**No Compression reinforcement required**		
	z	=	199.5	mm	also z < 0.95d		

					0.13% <As<		
As	=	1031	mm2	829	4%	25500	
	=	1146	mm2		OK		
As'min	=	829	mm2				
	=	830	mm2		OK		
x	=	5.9	mm		OK		
Mr	=	81.6	kNm		**OK**		

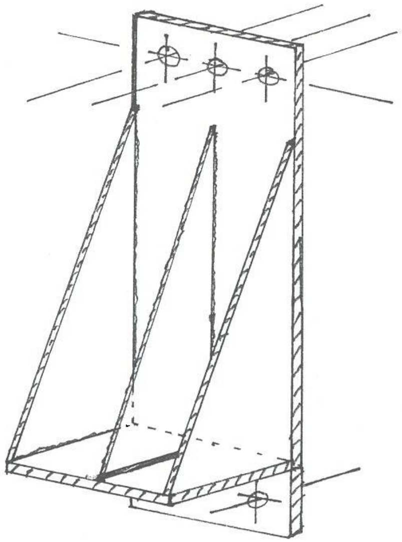
K > K' **No** **Compression reinforcement required**

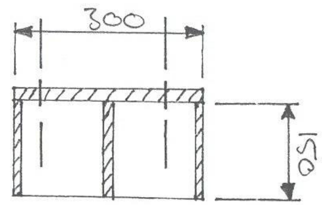
Deflection Limitations:

L/d base	=	21.6	One end continuous		
Span (k1)	=	1.00			
Tension R (k2)	=	1.17		fs	330.10
Comp R (k3)	=	1.00		% Comp R	0.13
Flange beam (k4)	=	1.00			
L/d allowed	=	25.29			
L/d	=	23.81	**OK**		

APPENDIX E:
HIDDEN CORBEL CONNECTION

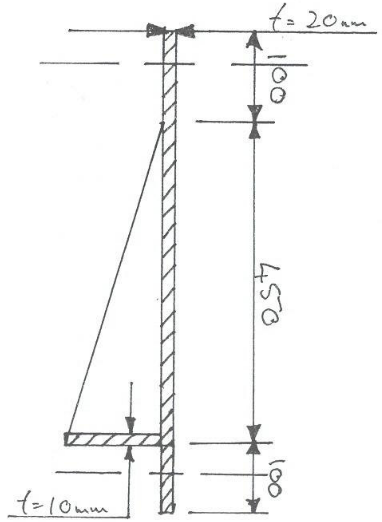
Connection Detail

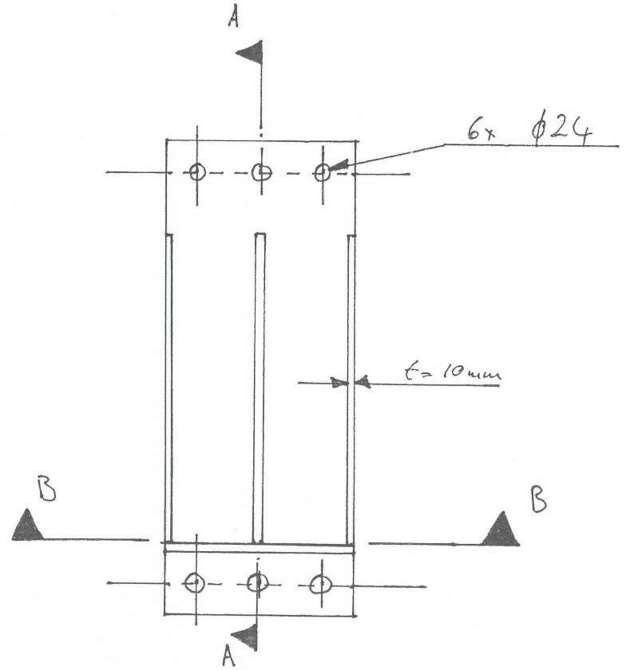




Note:

- All welds are 6mm fillet
- Use 6x 500mm long ϕ20 HSFG bolts





APPENDIX F:
COST vs. TIME CALCULATIONS

The tables presented below contain the estimated material quantities and erection times. The assumptions in Chapter 7 are also valid.

Table F.1 The construction quantities for the In-situ Beam and slab version of the Office Building

In-situ Beam and slab
Quantities

		No. of storeys					
		3	**6**	**9**	**12**		
Columns:	Concrete	41.31	111.08	215.73	361.69	**m^3**	21 external columns & 24 internal columns
	Reinforcement	9.9144	26.6592	51.7752	86.8056	**t**	240kg/m^3 of concrete
	Formwork	40	92	159	243	**m^2**	sides of columns, 4 casts per floor, 3 floors per mould
Beams:	Concrete	161.28	322.56	483.84	645.12	**m^3**	280m of beams
	Reinforcement	19.3536	38.7072	58.0608	77.4144	**t**	120kg/m^3 of concrete
	Formwork	95	190	286	381	**m^2**	sides of inverted beam, 4 casts per floor, 3 floors per mould
Slab:	Concrete	540	1080	1620	2160	**m^3**	900m^2 with 170m of edges
	Reinforcement	54	108	162	216	**t**	100kg/m^3 of concrete
	Formwork	450	450	450	450	**m^2**	soffit of slab, 2 casts per floor
	Formwork	85	85	85	85	**m**	edges, 2 casts per floor
	Crane hire	900	1000	1100	1200	**R/hour**	80 ton crane, 1 crane to be used
Time:		14	15	16	17	**days/floor**	

The tables presented below contain the estimated material quantities and erection times. The assumptions in Chapter 7 are also valid.

Table F.2 The construction quantities for the Hybrid Concrete Construction version of the Office Building

HCC Quantities

		No. of storeys					
		3	**6**	**9**	**12**		
Columns:	Concrete	39.5	83.3	144.5	232	**m^3**	14 primary columns and 29 secondary columns
	Reinforcement	9.48	19.992	34.68	55.68	**t**	240kg/m^3 of concrete
	Formwork	6	6	6	6	**moulds**	2 primary, 4 secondary, 3m adaptable steel moulds
Beams:	Concrete	108	217	325	433	**m^3**	210m of beams
	Reinforcement	12.96	26.04	39	51.96	**t**	120kg/m^3 of concrete
	Formwork	4	4	4	4	**moulds**	4x 5m adaptable steel moulds
Slab:	Echo slabs	450	450	450	450	**R/m^2**	900m^2, J+4 prestressing, 250mm echo slabs
	Crane hire	900	1000	1100	1200	**R/hour**	80 ton crane, 2 cranes to be used
Time:		7	7	7	7	**days/floor**	

The tables presented below contain the estimated material quantities and erection times. The assumptions in Chapter 7 are also valid.

Table F.3 The construction quantities for the In-situ Flat slab version of the Office Building

In-situ Flat slab Quantities

		No. of storeys					
		3	**6**	**9**	**12**		
Columns:	Concrete	84	175	274	392	**m^3**	24 internal columns and 29 edge columns
	Reinforcement	20.16	42	65.76	94.08	**t**	240kg/m^3 of concrete
	Formwork	65	133	204	283	**m^2**	sides of columns, 4 casts per floor, 3 floors per mould
Slab:	Concrete	689	1377	2066	2754	**m^3**	900m^2 with 170m of edges
	Reinforcement	75.79	151.47	227.26	302.94	**t**	110kg/m^3 of concrete
	Formwork	450	450	450	450	**m^2**	soffit of slab, 2 casts per floor
	Formwork	85	85	85	85	**m**	edges, 2 casts per floor
	Crane hire	900	1000	1100	1200	**R/hour**	80 ton crane, 1 crane to be used
Time:		14	15	16	17	**days/floor**	

At the contractor's request, no individual prices are given due to their sensitive nature.

Table F.4 The total construction cost and estimated erection time of the In-situ Beam and slab, HCC and In-situ Flat slab versions of the Office Building.

	No. of Storeys				
Cost	**0**	**3**	**6**	**9**	**12**
In-situ Beam and slab	R 500 000	R 1 797 824	R 3 759 008	R 6 009 708	R 8 606 353
HCC	R 1 000 000	R 2 101 139	R 4 092 279	R 6 135 202	R 8 361 418
In-situ Flat slab	R 500 000	R 1 954 549	R 3 970 135	R 6 196 780	R 8 697 429

	No. of Storeys				
Time	**0**	**3**	**6**	**9**	**12**
In-situ Beam and slab	7	49	94	142	193
HCC	28	49	70	91	112
In-situ Flat slab	0	42	87	135	186

APPENDIX G:
CONTACT DETAILS

The following people contributed greatly to the outcome of this investigation through personal interviews and various site visits. Their contact details are listed here as references.

Brown, Richard - RBD construction
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Miller, Keith - Group 5
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The following people participated in the Precast Questionnaire Survey. Their contact details are listed here as references.

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