Investigation into the feasibility of Hybrid Concrete Construction (HCC) in South Africa

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ABSTRACT

Positive development requires a healthy construction industry. The South African construction industry is hampered by a shortage of skills. The expected growth in the coming years requires that new approaches are investigated to enable delivery of projects at a faster rate, at lower cost, with more safety and at improved quality standards.

It is believed that the concept of hybrid construction can rationally address these problems. The concept of hybrid construction consists of making use of the benefits of pre-fabrication and in-situ concrete works. Although the benefits have been shown for construction in the UK, a dedicated program is required to investigate the possibilities and applications in the South African market.

This paper introduces the subject and presents preliminary results of a study into the suitability of hybrid concrete construction for the South African construction industry.

KEYWORDS: Hybrid Concrete Construction; HCC; Pre-fabricated Construction; Pre-fabricated Connection design;
1. INTRODUCTION

South Africa is currently facing a serious shortage of engineers, technicians and other skilled workers in the construction industry. Being a developing country, with a positive growth rate, it is expected that the current growth in construction activities will prevail until at least 2014. Even beyond that date, the demand will be high on the construction industry to provide infrastructure for the growing population (Botha, 2007).

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 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 manpower, 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 UK and other countries to address these problems, and we can surely take some lessons from their experience. Having recognized these and other problems specific to their conditions, the UK has investigated the concept of hybrid concrete construction and released several best practice guidelines for HCC (Goodchild, 2004).

The investigation into the concept of Hybrid Concrete Construction to improve the South African project delivery rate is therefore justified. This paper presents preliminary results of a study into the suitability of hybrid concrete construction for the South African market.

2. OBJECTIVES

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

- Identify any obstacles that 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.
• Draw conclusions and make recommendations about the feasibility of HCC in South Africa.

3. RESEARCH METHODOLOGY

This paper is based on the findings of three main components, namely a literature review, a survey of the South African construction industry and the evaluation of a case study, as is explained in the following sections.

4. BACKGROUND AND LITERATURE

A literature study was undertaken to correctly define HCC, study the experience of other countries, determine the current state of HCC in the South African market and justify the validity of this research paper. Both local and international research was included in this review.

4.1 WHAT IS HYBRID CONCRETE CONSTRUCTION?

Hybrid Concrete Construction (HCC) is “a method of construction which integrates pre-cast 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” (Goodchild, 2004).

Furthermore, hybrid construction 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.

4.2 WHY IS HCC IMPORTANT?

Figure 4.1 compares the value of all the building plans passed, to the value of all the projects reported as having been completed for larger municipalities in South Africa (Statistics South Africa, 2006). The graph shows that the difference between the value of the projects planned and projects completed has been widening steadily since 2003. This proves that the construction industry has become unable to keep up with the required rate of development and that a new strategy may be needed.
Figure 4.1: 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 in R’000 000. (Statistics South Africa, 2006).

Although the South African pre-cast industry has had various levels of success in the past, attention is once again drawn to this aspect 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.

5. HCC IN SOUTH AFRICA

After careful evaluation of the Best Practice Guidelines for HCC (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. These subsections, to be investigated for the South African environment are as follows:

- Project Management challenges specific to HCC
- Technical properties of structural details and construction methods
- Contractual aspects of HCC projects
Recognizing that the use of new materials and techniques, together with precasting, are shown to be widely used in European markets (Van Acker, 2007) (Bruck, 2007), it was decided to perform a brief survey of the South African construction industry to determine the extent to which HCC is being implemented, and if so at all. The results of the survey were then tested on an example project.

5.1 CONSTRUCTION INDUSTRY SURVEY

Through personal interviews with individual staff members, data was collected from representatives of Murray & Roberts, Grinnaker-Lta, Group 5, Infraset and Stevens Construction.

The objective of these interviews was to identify any obstacles that are preventing the widespread use of HCC in South Africa. The following paragraphs provide an overview of the information obtained from the personal interviews.

5.1.1 Project Management Aspects

- In many cases, current projects undertaken in South Africa lack the team approach that 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 projects is not currently widely experienced in South Africa.

- Communication between the project team participants is vital to the financial 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: project managers and design engineers with experience in HCC projects and high quality crane operators and riggers.

- It was 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. Investments into the development of the required skills are also needed by individual companies.
5.1.2 Technical Aspects

- It is found that the South Africa’s precasting industry currently produces similar types of products as their European counterparts (e.g. Echo Group, South Africa (2006), SEAC, France, (2003)), but the widespread knowledge and experience about the advantages of HCC is locally lacking.
- The use of pre-cast 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, before construction commences, where the best application of precast elements will be with the contractor (Goodchild, 2004). Some of the interviewees confirmed that this problem can be eliminated by constructing several similar buildings such as schools or parking garages.

5.1.3 Contractual Aspects

- 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 staff who were interviewed 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 staff interviewed, that such procedures normally do not exist, and that initiatives for collaboration are often initiated by individual companies or persons on the project teams.

5.2 EXAMPLE PROJECT: VWSA PAINT SHOP

An example project was identified for which the principles of HCC could be tested. The example project consisted of a site visit to Volkswagen’s new Paint shop in the Eastern Cape, as well as a detailed discussion with the Project’s Construction Management team. The project consisted of the construction of an R750million automotive paint shop. The paint shop has a surface area of 45 000 m², employs 530 people and will double the Uitenhage plant’s capacity to 1200 vehicles a day. The extensive use of precast elements enabled the project to be completed in a very short time (Volkswagen SA, 2006).

The objectives of this investigation of this example project were to:

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

Each of the three subsections as identified for the investigation into HCC were considered. These are discussed below:

5.2.1 Project Management Aspects

- The Construction team confirmed that effective communication between the client, architect, design team and the construction team was vital to the success of the overall project.
- Because the project team did not finalize all aspects of the design before construction began, over 400 different beams configurations were used, which complicated the precasting operation and restricted on-site management. The Contractor agreed that they did not spend sufficient time discussing the initial design and that time and costs can be saved if this stage of the project can receive adequate attention.
- It was suggested that the contractor should make use of a separate design manager, a role which had not been considered before the start of the project. This person needs to coordinate between the design team and the precasting yard 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.

5.2.2 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 and the Construction team agreed that this might be HCC’s biggest advantage.
- Sub-contractors highly recommended the use of precast columns, as in-situ columns can cause delays in the project schedule. The columns have to be cast as a single unit as this brings down the cost of the mould, the construction time and leads to simpler joints.
- The contractor had to train riggers and had difficulty due to workers not being used to this type of construction method. The crane operators were not used to the high precision work and struggled to correctly place the first elements.
5.2.3 Contractual Aspects

- This was a design and build project.
- The client took the initiative and proposed the HCC design to the contractor as alternative. The contractor used their in-house design engineers for the concept and an estimated Bill of Quantities to determine their tendering price. The contractor feels that the tendering process would have been more difficult to manage if they had to outsource the architect and the design team.

Following the industry survey and the visit to the example project, a case study was performed to investigate the information obtained. The next paragraphs give an overview of the case study.

6. CASE STUDY: OFFICE BUILDING

A double storey office building was identified to be considered in a case study. The building consists of a total floor area of 1800m². This building was chosen because of its square and relatively modular arrangement (see Figure 4). Also, the effect of size can be studied by an increase in the number of floors as required. The building will be designed and priced according to the HCC and the conventional construction methods.

The objectives of this case study were:

- Apply the knowledge gained from the surveys to a case study.
- Identify any unforeseen managerial, technical or contractual problems that require further investigation for the HCC case.
- Compare HCC to the conventional construction method in terms of the overall project cost and construction time.

This investigation has not been completed and the following are preliminary results.
6.1 PROJECT MANAGEMENT ASPECTS

It is evident that a structure needs to be adopted to suit an option where precasting can be used extensively. This requires a mutual understanding and commitment from all participants, including the architect, engineer and client. The layout of structural elements for the building was based on an in situ construction method. It was very clear that the layout needs some adjustment to accommodate a pre-cast component. This type of changes is something that needs to be decided between the architect, engineer, contractor and client. A building can therefore not be changed from one construction type to another without involvement fo the entire project team.
6.2 TECHNICAL ASPECTS

- Although connection design can be based on current design codes, it was clear that in order to achieve architecturally acceptable connections, there is a lack of information to assist South African designers. Guidelines are needed for the design of typical aesthetically acceptable connections between the precast elements and in-situ 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. Changes included adding some columns. These small changes made it possible to design the entire structure with three different beams, one column design and one precast floor panel type. Shear walls, some foyer’s semi-circular beam and smaller staircase beams will still be built with in-situ concrete.

- The precast contractor agreed that it would be faster and more economical to use continuous columns, as in a corbel frame structure. The architect did not want any visible joints and therefore it was decided to use an invisible corbel connection. Current design codes (SABS 10100,1992) are however not explicit in the use of bending reinforcement as component when designing for shear friction. Refer to section 7 for more information about this connection investigation.

6.3 CONTRACTUAL ASPECTS

The contractual aspects of this case study have not been investigated yet.

6.4 COST EFFECTIVENESS STUDY

A desk top study is now being undertaken, with the help of a quantity surveyor, precast contractor and an in-situ contactor, to compare the cost and erection time of the HCC and in-situ designs for the Office Building.

After consulting with the above mentioned parties, it became clear that the following items would heavily influence the cost and time requirements of the project:

- Cost of the moulds: In order to keep the cost per precast unit down, many similar units will have to be cast from one mould. This necessitates the standardisation of the project’s design to keep the number of moulds to a minimum.
• Cost and time management of the Cranes: This area will require effective management. Issues such as the use of two smaller cranes vs. one big crane require further discussion with the contractor.

• Temporary supports and formwork: These are very expensive items to hire. It also limits the installation of secondary services on the bottom floors while work is being done overhead. In the HCC project it may not be necessary for any formwork. This would be a very big advantage in terms of cost and construction time.

Eventually, the same floor layout will be used for varying the number of floors of the building to determine the effect of project size in the comparison between HCC and in-situ approaches.

7. TECHNICAL INVESTIGATION

The case study identified some technical aspects of HCC construction that require further investigation.

As mentioned above, available examples are limited on the design of hidden corbel that are both simple to design and easy to manufacture. The aim was to have a simple concept where the flow of forces and the failure mechanisms are relatively simple to represent in calculations.

After consulting with the contractors, the task was set: create a connection that is simple to design, easy and relatively cheap to manufacture, which can work with a continuous column and doesn’t require any grouting.

After a trial-and-error process it was decided to focus on a connection consisting of a steel corbel (or shoe) cast inside the beam. Although preliminary calculations have been completed according to SABS 0100-1 to determine the element dimensions, it is the aim of this investigation to perform a 3-D finite element analysis of the connection. This will answer several important questions that arose during the preliminary design stage. These are:

• Does the design need to comply with the simplified rules in SABS 0100-1 for curtailment of longitudinal reinforcement.
• Can the tensile reinforcement in the slab be used both for the transfer of shear (shear friction) and for the bending moment?
• What friction coefficients can be relied upon and is this a redundant approach in the design?

This technical investigation is currently in progress.
8. CONCLUSIONS: THE WAY FORWARD

The expected growth in the coming years requires that new approaches are investigated to enable delivery of projects at a faster rate, at lower cost, with more safety and at improved quality standards.

It is believed that the concept of hybrid construction can rationally address these problems. Preliminary results from a study on HCC in South Africa show that investments into the development of the required skills are however needed. Project managers and design engineers with experience in HCC projects and high quality crane operators and riggers are required for the successful application of HCC in South Africa. It may also be required that the tertiary education programs for engineering students and project managers be altered.

It is furthermore found that technical guidelines are needed to assist design engineers with typical details of the joints between precast elements and in-situ work. Guidelines that define a minimum HCC project size may also be required. Although preliminary results indicate that HCC may have a definite advantage in large, repetitive projects, close collaboration between academics, contractors, quantity surveyors and design engineers will be required to confirm these results.

9. REFERENCES

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