Stellenbosch University
South Africa

CONSTRUCTION ENGINEERING & MANAGEMENT CHAIR

Jan Wium
Academic offering (CEM)

Stellenbosch University/Engineering Faculty

Industry & programme

Civil Engineering

CMP
- Leaders in Industry
- 10-15 years experience

Undergraduate
- Civil Engineering

Post Graduate
- Engineers (MEng, PhD)
- Allied Professionals (PDE)

National Development Plan

- Vision for the year 2030
- Reduce unemployment levels to 6%
- Increase level of education
- Reduce poverty
- Provide supporting infrastructure:
  - schools, hospitals, clinics
  - Industrial development zones
  - harbours
  - rail
  - ......
RESEARCH AT CEM

Key Research Areas:

1. **Improving project delivery**
   - Modular Construction (Hybrid Construction)
   - Construction Risk Management
   - Design Management & Large Projects

2. **Infrastructure Asset Management**

3. **Management & Modern Technology**

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**Modular Construction (Hybrid Concrete Construction, HCC):**

- faster delivery
- improved quality
- improved safety
- **BUT it’s not being used in South Africa!? Why not?**

- In support of the National Development Plan
Hybrid Concrete Construction

• HCC has the potential to assist in improved project delivery

• Research objective:
  – Define parameters which play a role when a choice is made for a suitable method of construction
  – Empower projects teams to make the correct decisions

Shell Nigeria

Photos: Aurecon
Nova Vida Angola

Photos: Aurecon

Nova Vida Angola

Photos: Aurecon
Cobute Cape Town

Photo: Cobute

Cobute Cape Town

Photo: Cobute
Tubular Track Namibia

Photo: Tubular Track

Tubular Track Namibia

Photo: Tubular Track
Hollow core slabs

Corestruc Polokwane

Photo: Corestruc
Conceptual design
Participants preference for in-situ or precast concrete

<table>
<thead>
<tr>
<th>Consultants</th>
<th>Contractors</th>
</tr>
</thead>
<tbody>
<tr>
<td>YES</td>
<td>44% YES 50%</td>
</tr>
<tr>
<td>PROJECT DEPENDENT</td>
<td>44% PROJECT DEPENDENT 40%</td>
</tr>
<tr>
<td>NO</td>
<td>12% NO 10%</td>
</tr>
</tbody>
</table>

Preference for in-situ vs precast

<table>
<thead>
<tr>
<th>Consultants</th>
<th>Contractors</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN-SITU</td>
<td>50% IN-SITU 50%</td>
</tr>
<tr>
<td>DEPENDS ON THE SITUATION</td>
<td>31% DEPENDS ON THE SITUATION 33%</td>
</tr>
<tr>
<td>PRECAST CONCRETE</td>
<td>19% PRECAST CONCRETE 17%</td>
</tr>
</tbody>
</table>
### Cost, quality and time comparison between in-situ and precast

<table>
<thead>
<tr>
<th></th>
<th>Consulting engineers</th>
<th>Contractors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Precast</td>
<td>In-situ</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>33%</td>
<td>67%</td>
</tr>
<tr>
<td><strong>Time-efficiency</strong></td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Quality</strong></td>
<td>92%</td>
<td>8%</td>
</tr>
</tbody>
</table>

### Concerns for design and construction of precast concrete

<table>
<thead>
<tr>
<th>Rating</th>
<th>Consultant’s concerns</th>
<th>Contractor’s concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Connection details</td>
<td>Correct and accurate levels</td>
</tr>
<tr>
<td>2</td>
<td>Contractor’s capability</td>
<td>Accurate tolerances</td>
</tr>
<tr>
<td>3</td>
<td>Seismic considerations</td>
<td>Stability during installation</td>
</tr>
<tr>
<td>4</td>
<td>Tolerances</td>
<td>Connecting precast elements</td>
</tr>
<tr>
<td>5</td>
<td>Scope changes</td>
<td>Construction sequence</td>
</tr>
<tr>
<td>6</td>
<td>Detailing of levels</td>
<td>Transport of precast elements</td>
</tr>
<tr>
<td>7</td>
<td>Stability of elements during installation</td>
<td>Crane capacity and access</td>
</tr>
<tr>
<td>8</td>
<td>Size and mass of elements</td>
<td>Consultant buys into concept</td>
</tr>
<tr>
<td>9</td>
<td>Creating structural integrity</td>
<td>Colour consistency</td>
</tr>
<tr>
<td>10</td>
<td>Force transfer</td>
<td>Correct standards and quality</td>
</tr>
</tbody>
</table>
HCC vs in-situ
Project parameters

Connect
Programme
Aesthetics
Sustainability
Labour
Safety
Cost
Quality

HCC vs in-situ
Project parameters

Connect
Programme
Aesthetics
Sustainability
Labour
Safety
Cost
Quality
Programme and cost

• Interviews:
  – Consultants
  – Contractors
  – Case studies

Objective: Factors that influence a choice between in-situ and HCC

DESIGN PHASE: Consultants

• Standardization and repetition
• Technical aspects
• Outsourced design
• Design guidance
• Late changes
• Professional fees
• Early involvement and collaboration
• Investment
Standardization and repetition

• Is the repeated use of processes, components and methods
• Economically viable when sufficient standardization occurs.
• Consider during the early phases of a project
• Negatives:
  – precast elements are often over designed - cost increase
  – lack of flexibility and creativity
  – standardized designs may lead to dull standard buildings
  – 15 % of the respondents were negative towards standardization
• Positives
  – designs applied with good knowledge, innovative spirit, experience
  – will result in a project with potential time and cost savings.

• Outcome: It depends on the individual

Technical aspects

• connection design,
• yard and equipment design,
• detailing of reinforcement
• placement and transportation

Outcome: Training and experience
Outsourced design

- Consultant to coordinate the design of suppliers
- Design duration (of the consultant) may be reduced.
- The supplier’s cost for the design and manufacturing of precast elements may be higher in comparison with the professional fees of the consultant.
- Project teams should consider the additional costs versus possible time savings

Design guidance

- United Kingdom (2004): lack of exposure and inexperience with the design of precast concrete was the main cause for lack of precast concrete within the country
- Consultants in South African industry not familiar with the specifications of HCC designs (shortage of local precast design manuals)
- Lack of precast design criteria and assistance in South Africa.

Need for training and guidance
Late changes

• HCC is less flexible than in-situ concrete construction
• Early involvement of the contractor during the early stages of a HCC project is critical
• Construction industry has developed the habit of late changes
• Planning during the early stages of a project may be more time consuming for HCC.

Industry culture must change

Professional fees

• 50 % respondents: more time consuming
• 50 % respondents: precast concrete design is faster
• Some of the professionals said it does not affect the decision, whilst other professionals mentioned that it does play a role.
• No guidelines on estimating professional fees for precast design
• Consultant’s responsibility to convince the client.

More experience and case studies needed
Early involvement and collaboration

- Early involvement of all parties assist project teams to decide between various construction methods.
- Use design-build, contract management, PPP or target price contract as a procurement method.
- Challenge for South Africa, especially in the public sector.

**Advocate for use of NEC contract document**

Investment

- Time consuming during the first attempt.
- Faster once faster once sufficient experience and knowledge have been gained.
### Consultant feedback

<table>
<thead>
<tr>
<th>Factors</th>
<th>In-situ concrete construction</th>
<th>HCC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standardization &amp; Repetition</strong></td>
<td>In the case where limited standardization and repetition occurs, in-situ construction will be more beneficial in terms of time and cost.</td>
<td>Greater potential for standardization and repetition. Result in more time and cost savings when compared to in-situ concrete construction.</td>
</tr>
<tr>
<td><strong>Technical aspects:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Connection design</td>
<td>Technical aspects might be less time consuming when compared to the technical aspects of HCC.</td>
<td>Technical aspects might be more time consuming when compared to in-situ concrete design.</td>
</tr>
<tr>
<td>• Precast yard design</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Detailing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Extras</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Outsourced design</strong></td>
<td>Not applicable</td>
<td>Reduced time required for design, however, associated costs are often higher</td>
</tr>
</tbody>
</table>

### Consultant feedback (cont.)

<table>
<thead>
<tr>
<th>Factors</th>
<th>In-situ concrete construction</th>
<th>HCC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design guidance</strong></td>
<td>Available, will result in time savings for design</td>
<td>Limited guidance is limited, time consuming designs</td>
</tr>
<tr>
<td><strong>Late changes</strong></td>
<td>Late changes more possible, reduced impact on time and cost</td>
<td>Reduced possibility for late changes is reduced.</td>
</tr>
<tr>
<td><strong>Professional fees</strong></td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td><strong>Earl involvement and collaboration</strong></td>
<td>Less dependent on early involvement and collaboration</td>
<td>More dependent on procurement strategies that promote early involvement and collaboration.</td>
</tr>
<tr>
<td><strong>Investment</strong></td>
<td>Not applicable</td>
<td>May result in a good reputation and innovative culture.</td>
</tr>
</tbody>
</table>
Construction phase:

- The factors were identified through case study projects:
  - site visits to the various projects
  - discussions with project teams
- **Grootegeluk and Shandoni coal bunkers**
- **Cape Town dispatch plant for Value logistics**
- **Bloemfontein Longridge reservoir**
- **VWSA paint shop**
Grootegeluk coal bunkers
In-situ
Grootegeluk coal bunkers
In-situ

Shandoni coal bunkers

Photo: Stefanutti Stocks
Bloemfontein Longridge reservoir

VW paint shop
HCC connections

- Interviews and questionnaires
- Contractors
- Consultants

**Aim:**
- Determine preferences:
  - Design
  - Construction
- Identify factors that play a role
Considerations for the design and construction of precast connections

- Standardisation
- Simplicity
- Tensile capacity
- Ductility
- Movements
- Durability
- Fire resistance
- Aesthetics

Alternative Connection types

- Foundation-to-Column connections
  - Pocket foundation
  - Baseplate connections
  - Projecting steel bars connection

- Column-to-Column connections
  - Column shoe connection
  - Welded plate connection
  - Projecting bar connection

- Column-to-Beam connections
  - Type 1: Continuous column connection
  - Type 2: Continuous beam connection

- Connections between floor slabs
  - Concrete or grouted connections
  - Welded or bolted connections
  - Reinforced topping
  - Loop connection

- Beam-to-Slab connections
  - (i) At the edge of the structure
  - (ii) Interior connections
Column to base


Ratings of column-to-footing connection types

<table>
<thead>
<tr>
<th>Connection type</th>
<th>Consultants Average rating</th>
<th>Contractors Average rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pocket foundation</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Steel baseplate</td>
<td>2.94</td>
<td>2.4</td>
</tr>
<tr>
<td>Dowel connection</td>
<td>3.5</td>
<td>3.8</td>
</tr>
</tbody>
</table>
### Column to column

**Column shoe connection**

Peikko Group 2013

**Welded plate connection**

Paradigm 2008

**Dowel connection**

The Shockey Precast Group 2001

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### Ratings of column-to-column connection types

<table>
<thead>
<tr>
<th>Connection type</th>
<th>Consultants Average rating</th>
<th>Contractors Average rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column shoe</td>
<td>2.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Welded plate</td>
<td>2.15</td>
<td>1.4</td>
</tr>
<tr>
<td>Dowel connection</td>
<td>3.5</td>
<td>3.4</td>
</tr>
</tbody>
</table>
Beam to column

Ratings of beam to column connection types

<table>
<thead>
<tr>
<th>Connection type</th>
<th>Consultants Average rating</th>
<th>Contractors Average rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel billet</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Welded plate</td>
<td>2.6</td>
<td>1.9</td>
</tr>
<tr>
<td>Hidden corbel</td>
<td>2.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Corbel connection</td>
<td>4.2</td>
<td>4.6</td>
</tr>
</tbody>
</table>
Floor to floor connections

Ratings of floor-to-floor connection types

<table>
<thead>
<tr>
<th>Connection type</th>
<th>Consultants</th>
<th>Contractors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grouted connection</td>
<td>3.94</td>
<td>3.8</td>
</tr>
<tr>
<td>Welded or bolted</td>
<td>2</td>
<td>1.7</td>
</tr>
<tr>
<td>Reinforced topping</td>
<td>3.75</td>
<td>4</td>
</tr>
<tr>
<td>Loop connection</td>
<td>3.82</td>
<td>3.7</td>
</tr>
<tr>
<td>Rib and Block</td>
<td>3.94</td>
<td>3.6</td>
</tr>
</tbody>
</table>
Beam to slab

![Simply supported](Walraven 2013)
![Bolted or built-in connection](Mishra 2012)
![Hollow core slab](Unknown reference)

![Ties and reinforcement](Unknown reference)
![Rib and block slab](Unknown reference)

Ratings of beam-to-slab connection types

<table>
<thead>
<tr>
<th>Beam-to-Slab Connection type</th>
<th>Consultants Average rating</th>
<th>Contractors Average rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simply supported</td>
<td>4.13</td>
<td>4.4</td>
</tr>
<tr>
<td>Bolted</td>
<td>2</td>
<td>2.3</td>
</tr>
<tr>
<td>Ties and reinforcement</td>
<td>3.94</td>
<td>3.6</td>
</tr>
<tr>
<td>Hollow core slab</td>
<td>3.81</td>
<td>3.9</td>
</tr>
<tr>
<td>Rib and Block</td>
<td>3.63</td>
<td>3.7</td>
</tr>
</tbody>
</table>
Preferred connection characteristics

<table>
<thead>
<tr>
<th>Consultants</th>
<th>Contractors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connections should provide allowable tolerances</td>
<td>Connections should provide allowable tolerances</td>
</tr>
<tr>
<td>Connections that provide efficient force transfer and flow or forces (e.g., moment fixed connections)</td>
<td>Connections that include in-situ components are preferred</td>
</tr>
<tr>
<td>Prefer designing connections that include components of in-situ concrete</td>
<td>Standardizes connection methods – ensures quick and easy assembly</td>
</tr>
<tr>
<td>Prefer connections that provide good stability requirements</td>
<td>Provide accurate levels during setting out and assembly</td>
</tr>
<tr>
<td>Prefer connections that has a high shear capacity</td>
<td>Connections that ensures instant stability is preferred</td>
</tr>
<tr>
<td>Precast connections should compensates for movements (restricted and unconstrained)</td>
<td>Simply supported connection types are easy and fast to construct</td>
</tr>
<tr>
<td>The connection method should be able to compensate for scope changes during the project.</td>
<td>The size, complexity and all the components of precast element and its connection must be easy to transport</td>
</tr>
</tbody>
</table>

Connections : conclusions

- Provide information on connections typically used in the local industry
- Provide guidance on design of precast connections
- Organize workshops or seminars
- Make use of precast pilot projects that can be used as reference for other precast projects.
- Develop a manual with design guidelines
- Early stage of learning such as universities and colleges
Quality

• Components of quality
  – Durability
  – aesthetics
  – fitness for purpose
• Aspects to be investigated:
  – Labour
  – Management
  – Subcontractors
  – Safety
  – Access
  – Plant and equipment
• Attributes which influence them

Summary of in-situ results after prioritisation

<table>
<thead>
<tr>
<th></th>
<th>Durability</th>
<th>Fitness for purpose</th>
<th>Aesthetics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access</td>
<td>*</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Labour</td>
<td>*</td>
<td>–</td>
<td>0</td>
</tr>
<tr>
<td>Management</td>
<td>0</td>
<td>0</td>
<td>*</td>
</tr>
<tr>
<td>Subcontractors</td>
<td>0</td>
<td>–</td>
<td>*</td>
</tr>
<tr>
<td>Safety</td>
<td>–</td>
<td>0</td>
<td>*</td>
</tr>
<tr>
<td>Plant and Equipment</td>
<td>–</td>
<td>0</td>
<td>*</td>
</tr>
</tbody>
</table>
## Summary of precast results after prioritisation

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Access</strong></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Labour</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Management</strong></td>
<td></td>
<td>*</td>
<td></td>
</tr>
<tr>
<td><strong>Subcontractors</strong></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td><strong>Safety</strong></td>
<td></td>
<td>◊</td>
<td></td>
</tr>
<tr>
<td><strong>Plant and Equipment</strong></td>
<td></td>
<td>◊</td>
<td></td>
</tr>
</tbody>
</table>

### Barriers that prevent more frequent use of HCC in South Africa.

- Design
- Procurement
- Production
- Industry traps
- Training
- Regulations
- Fragmentation
- Market conditions
Requirement to change the methods of construction in South Africa

- Early involvement from the whole project team
- Procurement methods that implement partnering strategies
- Use of NEC
- Reduce changes on projects
- Use of accredited precast elements
- Different training methods (even in tertiary institutions)
- Labour-intensive construction and green building regulations pose a threat to the utilisation of HCC.
- A database that illustrates different HCC project are required
- Encourage ‘innovation champions’