OPTIMISING PROJECT ECONOMICS WITH HIGH PERFORMANCE CONCRETE

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Economics and Sustainability in Construction

It is not just about the concrete – although concrete is the main target for criticism.
It is all about getting the best use of all our construction materials.
It is about less damage to the environment as we build.
It is about building as efficiently as possible.
It is about building something that will do its job for as long as possible.

And… It’s all about doing that with cost efficiency – NOT as cheaply as possible, but at the price that gives the best lifetime value.
Ugly Concrete?
Elegance and Sustainability!
‘Engineered’

The concrete we use has to be designed to give the right performance:
Plastic – how long will it last at a certain workability; how is it going to be conveyed / placed / finished / cured? Criteria for the rheology of the mix.
Hardened – strength gain, final strength, impact,
Durability – chlorides, sulfates, water, other chemicals
Lifetime – 50 years, 100, 200, 800?

The better the design, the easier the concrete is to use, the less concrete consumed and the longer it lasts.
The longer it lasts, the less resources we use because we don’t have to re-build it in 10 or 20 years time.
Engineered for the Army…
It all adds up...

Improved Plastic Properties: ease of placing, faster construction, less machinery

= Better Economics.

Increased Strength: faster construction, less volume

= Better Economics.

Increased Durability: increased lifetime, fewer repairs

= Better Economics.

Combining the key points: less machinery, less volume, fewer repairs = less impact on the environment

= Sustainability.
SCM’s

Fly Ash – from coal fired power stations.
  \( \text{SiO}_2 \) 40 ~ 50%.
  Replacement rate 15% - 50%: rheology, heat reduction, long term benefits.

GGBS – from the steel industry.
  \( \text{SiO}_2 \) 35 ~ 40%.
  Replacement rate 25% - 90%: major heat reduction, long term benefits.

Microsilica – from the ferrosilicon industry.
  \( \text{SiO}_2 \) 90 ~ 95%.
  Addition rate 5% - 15% (max 25%): rheology, reduced permeability, improved durability, UHPC
So let’s use lot’s of Fly Ash and GGBS then...

Well, yes and no… You can’t just throw them in ‘blanket fashion’...

“All Concrete Shall Use GGBS: because equivalence can be achieved at 56 to 90 days…”

But the major drawback is time. Larger quantities of FA or GGBS can have great effects on setting time, hardening rate, strength gain and real time durability.

While in some cases, waiting – and curing the concrete – for another two to three months – could be feasible, it is not on most projects.

We can use good quantities – but the mixes have to be engineered to give the required performance.
Real time durability

When does the concrete need to be durable?
Is it going straight into the ground – piling, foundations, basement walls?
Will it be coated – or in direct contact with ground conditions?
If on superstructures, when will the formwork be stripped? Will the column / slab / wall be covered and cured after that?
The answer to most of these is immediately, or within a few days, and probably covered for a couple of days.

If the concrete is not going to reach the required level of ‘performance’ for two or three months – measured under perfect lab conditions – then how will it survive when exposed in a matter of days?
Being Green for Green’s sake...

There is no point in going for green materials if they aren’t sustainable! It defeats the object:

The First Platinum LEED project on the East Coast of the USA, had to replace the cladding on the building in less than 5 years, because it wasn’t durable enough. It was replaced with concrete...

A Chinese speaker once said they wanted construction to use more bamboo cladding, because it grows faster than current use. When asked “Have you calculated the balance point – when accelerated new use, and repair, exceeds the regrowth rate?” The answer was “I don’t know – I don’t believe we’ve thought about that”...
Balance in the design.

Yes, let’s use between 20 and 30% FA – in combination with 8 to 10% MS.*

Yes, let’s use 40 to 60% GGBS – in combination with 6 to 10% MS.**

Yes, let’s use recycled aggregates and wash down water.

Yes, let’s use particle packing to blend the aggregates and use less total cementitious materials.

** Mix design experience of 32 years, the presenter.
But that Costs Money now!

But if we use high performance concrete, it will cost more!
Per cubic metre, depending on your mix design, probably yes, it may cost more.

BUT! Does it actually cost more to build the project?
What is the ‘value’ of the high performance microsilica / scm mix for the project?
Analysis of actual construction costs on a number of projects has shown that it actually costs less... That’s less to build – not including the increased lifetime value

Let’s take a look at that...
‘Green’ High Performance Concrete:

311 South Wacker – concrete was 50% extra per m³. The actual building was finished ahead of time, for less cost than the original design, and the owner got more rentable space.

Mumbai Pune Expressway Tunnels – the microsilica shotcrete cost 21% extra per m³. The finished, ’on the wall’, cost was 11% less than using standard shotcrete...

Indianapolis Airport Parking – 7,100 spaces. Normal cost - $15,000 per space. Used OPC/FA/MS concrete with recycled aggregates and optimised particle packing, achieving a LEED rating and saving volume and time: the actual cost was only $12,000 per space....That’s a saving of...
Life-365.org

- Service life prediction model, based on Fick’s second law
- Software developed at University of Toronto
- Widely adopted by industry
Whole-life-cost example, Mediterranean Sea, 150 yrs

<table>
<thead>
<tr>
<th>Alt name</th>
<th>D28</th>
<th>m</th>
<th>Ct</th>
<th>Init.</th>
<th>Prop.</th>
<th>Service life</th>
</tr>
</thead>
<tbody>
<tr>
<td>mix a = PC 405 kg/m3</td>
<td>-&gt; 4.10E-12 m²m/sec</td>
<td>-&gt; 0.2</td>
<td>-&gt; 0.05 % wt. conc.</td>
<td>8.4 yrs</td>
<td>-&gt; 6 yrs</td>
<td>14.4 yrs</td>
</tr>
<tr>
<td>mix b = PC 200 kg/m3 + GGBS 200 kg/m3</td>
<td>-&gt; 8.00E-13 m²m/sec</td>
<td>-&gt; 0.45</td>
<td>-&gt; 0.05 % wt. conc.</td>
<td>124.9 yrs</td>
<td>-&gt; 6 yrs</td>
<td>130.9 yrs</td>
</tr>
<tr>
<td>mix c = PC 200 + GGBS 190 + SF 40 kg/m3</td>
<td>-&gt; 1.00E-13 m²m/sec</td>
<td>-&gt; 0.45</td>
<td>-&gt; 0.05 % wt. conc.</td>
<td>150 yrs</td>
<td>-&gt; 6 yrs</td>
<td>156 yrs</td>
</tr>
</tbody>
</table>

![Diagram](image)

- Slabs and walls (1-D)
- Outer dim: 200mm; clear cover: 40mm
- Surface Concentration
  - Max surface: 1
  - Years to buildup: 10
- Monthly Temperatures
  - Loc: Crete, Greece
  - Type: Marine spray zone
Whole-life-cost example, Mediterranean Sea, 150 yrs

<table>
<thead>
<tr>
<th>Name</th>
<th>Construction Cost</th>
<th>Barrier Cost</th>
<th>Repair Cost</th>
<th>Life-Cycle Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>mix a = PC 405 kg/m³</td>
<td>$38.69 per sq. m.</td>
<td>$0.00 per sq. m.</td>
<td>$220.20 per sq. m.</td>
<td>$258.89 per sq. m.</td>
</tr>
<tr>
<td>mix b = PC 200 kg/m³ + GGBS 200 kg/m³</td>
<td>$37.69 per sq. m.</td>
<td>$0.00 per sq. m.</td>
<td>$12.64 per sq. m.</td>
<td>$50.33 per sq. m.</td>
</tr>
<tr>
<td>mix c = PC 200 + GGBS 190 + SF 40 kg/m³</td>
<td>$41.59 per sq. m.</td>
<td>$0.00 per sq. m.</td>
<td>$0.00 per sq. m.</td>
<td>$41.59 per sq. m.</td>
</tr>
</tbody>
</table>

Life-Cycle Costs, by Alternative

- mix a = PC 405 kg/m³ = $258.89/sq. m.
- mix b = PC 200 kg/m³ + GGBS 200 kg/m³ = $50.33/sq. m.
- mix c = PC 200 + GGBS 190 + SF 40 kg/m³ = $41.59/sq. m.
Singapore MRT

- Somerset to Newton Circus – cast 1986:
- Pictures taken after 15 years
DTSS – Deep Tunnel Sewage System

High Early Strength: Demoulding after 6 – 10 hrs

Design life: 120 years
Marine Environments
Recommended specification for Reinforced Concrete in Marine Environment

The main features of the specification are summarised as follows:

- The minimum characteristic strength of the concrete mix shall be **45 MPa**.
- The maximum water/cementitious ratio shall not exceed **0.38**.
- **Condensed silica fume is to be added to reduce the permeability of the concrete.**
- **The cementitious content shall be 380-450 kg/m$^3$, including 5 - 10% CSF, with either: FA at 25 – 40%, or GGBS at 60 – 75%.**
- The cover to all reinforcement in all exposure zones shall be **75 mm**.

First published in 2002, revised to stipulate ternary blend in 2013.
Design life: **100 years**  
Quad blend (PC/GGBS/FA/MS)  
Total length: **32.5 km**
Sustainability

311, South Wacker Drive, Chicago
70 Floors, 293 m high
121,000 m² office tower completed in 1990
83 MPa concrete for columns of the first 14 floors
MS for pumpability: 69 to 52 MPa concrete from 15th floor

Benefits:
Saving rebar & concrete – 3,000t and 7,650m³
Same column forms for each floor
Less equipment – one pump, ground to top
Rapid construction – finished 6 weeks ahead of time
More rentable space - $$$
Think about those concrete numbers...

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>3,000 tonnes</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>7,650 tonnes</td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>5,250 tonnes</td>
</tr>
<tr>
<td><strong>Water</strong></td>
<td><strong>1,071,000 litres</strong></td>
</tr>
</tbody>
</table>

About 1,000 truck movements / washdowns...
And then, there is this place...

828m tall

Concrete pumped over 600m – with one pump

Ternary blend: MSRPC / FA / MS

Structure: 260,000m³

Rafting: SCC - 16,000m³

Piling: SCC - 70,000m³
## Specifications.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strengths:</td>
<td>45 to 80MPa</td>
</tr>
<tr>
<td>Minimum Cement:</td>
<td>252 + 168 + 30 kg/m³ <em>(56:37:7)</em> (MSRPC + FA + MS)</td>
</tr>
<tr>
<td>W/C ratio:</td>
<td>0.34</td>
</tr>
<tr>
<td>Flow (at site):</td>
<td>&gt; 600mm</td>
</tr>
<tr>
<td>Water Penetration</td>
<td>&lt;10mm <em>(BS EN 12390 - 8)</em></td>
</tr>
<tr>
<td>Water Absorption</td>
<td>&lt;1.5% <em>(BS 1881:122)</em></td>
</tr>
<tr>
<td>RCPT</td>
<td>&lt;1200 <em>(AASHTO T-277)</em></td>
</tr>
<tr>
<td>Water Permeability</td>
<td>&lt;5mm <em>(Din 1048)</em></td>
</tr>
</tbody>
</table>
Results – 60MPa SCC piling.

Compressive Strengths (150mm cubes - averages)
- 7 days: 40.5 MPa
- 14 days: 51.5 MPa
- 21 days: 60.5 MPa
- 28 days: 64.5 MPa
- 56 days: 75.5 MPa

Tensile Strength (300 x 150mm cylinders - averages)
- 14 days: 3.75 MPa
- 28 days: 4.35 MPa
## Results - Durability

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Penetration (10mm)</td>
<td>Zero</td>
</tr>
<tr>
<td>Water Absorption (1.5%)</td>
<td>0.7%</td>
</tr>
<tr>
<td>RCP Test (1200)</td>
<td>590</td>
</tr>
<tr>
<td>Water Permeability (5mm)</td>
<td>Zero</td>
</tr>
</tbody>
</table>
B&Q Pontypridd – after 21 years...

300kg OPC + 30kg MS
100mm thick slab

42 tonne delivery trucks – 363 days a year.
Parking Structures

Sustainability also means reducing waste...
Indianapolis International Airport Parking Garage

60MPa columns

40MPa deck and beams

22m x 20m bays
16 months - 5 floors - 46,500m²/floor...

$21,300,000
Sustainability is for the future...
ADVANCED MATERIALS
SHAPING THE FUTURE