Multiple Cementitious Blends:
Keeping our concrete – and the planet – ‘cool’.

Rob Lewis, FACI, FCS, FICT

Concrete is BAD!

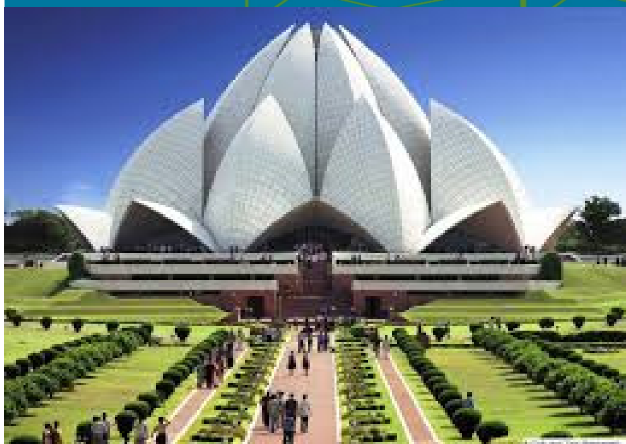
‘People’ don’t like concrete – but it is the worlds most used construction material.

Concrete uses Portland Cement which has the worst CO_2 emissions on the planet: ***QED all concrete is bad for the environment.***

Concrete uses Natural Resources – for the Cement; the Aggregates and Drinking Water: ***QED all concrete is bad for the environment.***

‘People’ think concrete is all the same: grey and ugly. Yet some of the worlds most magnificent buildings are constructed in concrete.

Ugly Concrete?






Elegance, Durability and Sustainability!

Engineering the design…

Lifetime – 50, 100, 200, 800 or even 1,000 years?

Structural – strength gain, final strength, impact, abrasion, erosion…

Durability – water, chlorides, sulfates, other chemicals…

Rheology – what workability; how is it going to be placed / finished / cured? *Think of 'the man at the end of the pipe'…*

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 repair it, or worse re-build it, in 10 or 20 years time.

Engineered for the Army…

Strength and abrasion resistance, paving train placement – *and a specific grey colour*…

Saving Resources

Cement – improvements to production, higher qualities

SCMs – use of by-products, less use of 'pure' cement

Recycled Aggregates – buildings come down, so use the bits! Less quarrying, or destroying mountains

Lightweight Aggregates – less dead weight, insulation

Water – better design, admixtures to use less water, recycled water

Optimise the design – multiple cementitious blends allow for flexibility, to give the performance needed, and not 'cost us the planet'…

Remove the Cement…

Yes – some – but we still need a good cementitious blend for performance.

'Cement Free' and Alkali Activated Cementitious Materials – such as geopolymers… These materials are not in mass production and, even if they don't have portland cement in them, they may not be 'better':

[When all things are taken into consideration] "….it appears that geopolymer concrete has a similar impact on global warming to standard concrete."

An Environmental Evaluation of Geopolymer Based Concrete Production: Reviewing Current Research Trends – Habert et al; Journal of Cleaner Production · July 2011.

Supplementary Cementitious Materials

Fly Ash – from coal fired power stations.

SiO_2 40 ~ 50%.

Replacement rate 15% - 50%: rheology, heat reduction, long term benefits.

GGBS – from the steel industry.

SiO_2 35 ~ 40%.

Replacement rate 25% - 90%: major heat reduction, long term benefits.

Silica Fume – from the silicon / ferrosilicon industry.

SiO_2 90 ~ 95%.

Addition rate 5% - 15% (max 25%): rheology, reduced permeability, increased strength, 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: Equivalence can be achieved at 56 to 90 days…'

But the major drawback is *time*. Larger quantities of FA or GGBS can effect setting time, hardening rate, strength gain and *real time durability*.

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 be affected when exposed in a matter of days?

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

Balance in the design.

Yes, let's consider 20 to 50% FA – with 5 to 10% SF.*

Yes, let's consider 40 to 80% GGBS – with 5 to 10% SF.**

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.

*based on unpublished Thesis dissertation, Loughborough University, 2016.

**Mix design experience of over 33 years, the presenter.

It's not Rocket Science…

We've been using binary blends – OPC/FA and OPC/GGBS – for almost a century – and the Romans used volcanic ash and lime over 2,000 years ago, so we know how to do this.

In the last 50 years that has expanded to OPC/SF binaries and then to ternary and quaternary blends, using all the SCM's. We are using the synergistic effects of these materials to engineer even better concretes.

It is no longer the case of asking "Should I use FA, or GGBS, or SF?" but "What's the best combination to give me the performance I need?"

Marine Environments

Hong Kong Marine Specification.

Recommended specification for Reinforced Concrete in Marine Environment (Civil Engineering Department – Government of Hong Kong)

The minimum characteristic strength of the concrete mix shall be *45 MPa.*

The maximum water/cementitious ratio shall not exceed *0.38.*

The cover to all reinforcement in all exposure zones shall be *75 mm.*

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%.

First published in 2002, revised to stipulate ternary blend in 2013.

Then there's this place…

828m tall

Concrete pumped over 600m – with one pump

Ternary blend: MSRPC / FA / SF

Structure: 260,000m^3

Rafting: SCC - 16,000m^3

Piling: SCC - 70,000m^3

Specifications.

Compressive Strengths:	45 to 80MPa	
Minimum Cement:	252 + 168 + 30 kg/m^3 (56:37:7) (MSRPC + FA + SF)	
W/C ratio:	0.34	
Flow (at site):	> 600mm	
Water Penetration	<10mm	(BS EN 12390 - 8)
Water Absorption	<1.5%	(BS 1881:122)
RCPT	<1200	(AASHTO T-277)
Water Permeability	<5mm	(Din 1048)

Comparison of the SCC piling mix.

CO_2			Heat
OPC	252 kg x 0.913	= 230 kg	x 5,000 = 1,260 kj
FA	168 kg x 0.004	= 0.7 kg	x 270 = 45 kj
SF	30 kg x 0.014	= 0.5 kg	x 5,000 = 150 kj
Ternary Blend total		= 231.2 kg	= 1,455 kj

If the mix had been pure OPC:

	450 kg x 0.913	= 411 kg	x 5,000 = 2,250 kj
Reduction per m^3		179.8 kg	795 kj
Reduction on 70,000 m^3		12,586 T	55,560 Mj

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**

Results - Durability.

Water Penetration	(10mm)	Zero
Water Absorption	(1.5%)	0.7%
RCP Test	(1200)	590
Water Permeability	(5mm)	Zero

Bridges, USA

Bridge Deck - New York State DOT

Performance requirement:
Resist chloride attack & minimize cracking

Mix Design	
Portland cement	300 kg/m^3
Fly ash	80 kg/m^3
Microsilica	25 kg/m^3
w/cm	0.40
Slump	75 - 100 mm
Air	6.5 %
Wet cure	7 days

Comparison of Bridge Deck.

<u>CO_2</u>			<u>Heat</u>
OPC	300 kg x 0.913	= 274 kg	x 5,000 = 1,500 kj
FA	80 kg x 0.004	= 0.3 kg	x 270 = 22 kj
SF	30 kg x 0.014	= 0.4 kg	x 5,000 = 150 kj
Ternary Blend total		<u>= 274.7 kg</u>	<u>= 1,672 kj</u>

If the mix had been pure OPC:

	410 x 0.913	<u>= 374 kg</u>	x 5,000 <u>= 2,050 kj</u>
Reduction per m^3		99.3 kg	378 kj

Tsing Ma bridge: 120 year lifetime.

Tsing Ma bridge concrete requirement

Good pumpability
Rheology for slip-forming
Low heat development
High early strength
Very high resistance to chloride attack

Original Design: 390 kg at 30% OPC and 70% GGBS

Actual Design used: 30% OPC, 65% GGBS, 5% Silica Fume

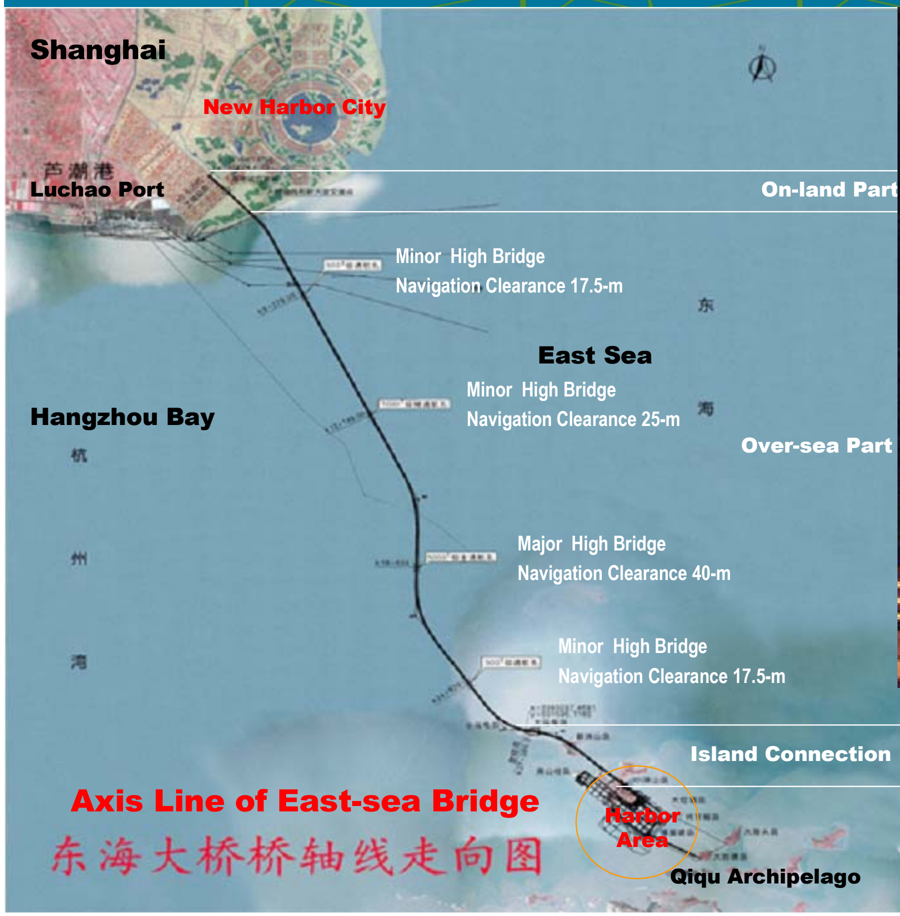
Comparison of tower mix – Tsing Ma.

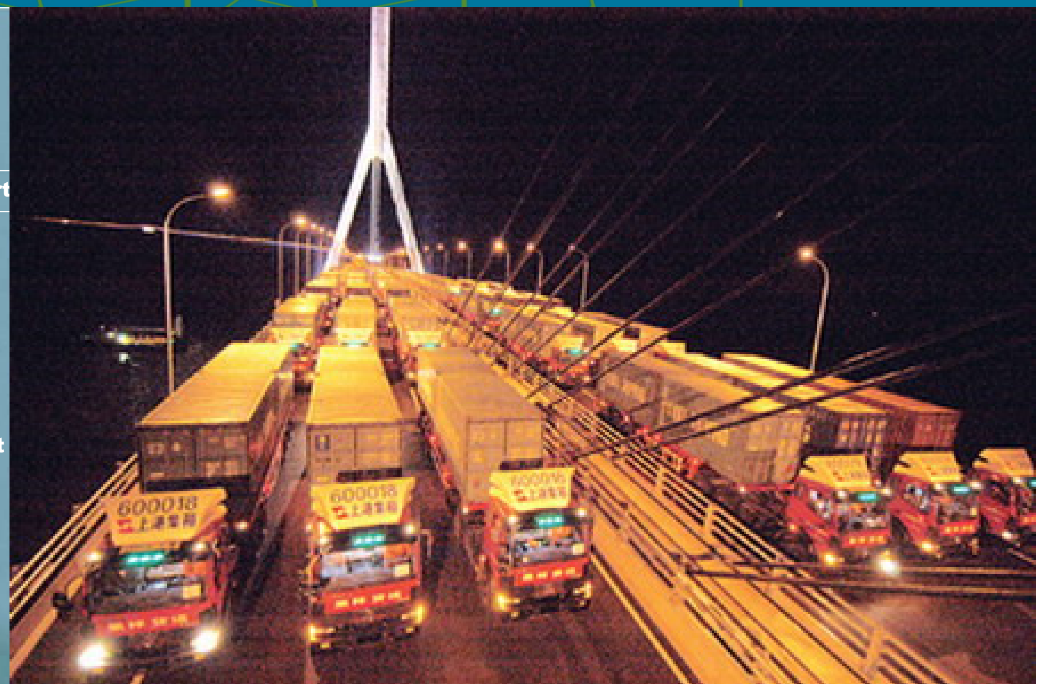
CO_2			**Heat**
OPC	117 kg x 0.913	= 107 kg	x 5,000 = 585 kj
GGBS	253.5 kg x 0.067	= 17 kg	x 1,320 = 335 kj
SF	19.5 kg x 0.014	= 0.3 kg	x 5,000 = 97.5 kj
Ternary Blend total		= 124.3 kg	= 1,017.5 kj

If the mix had been pure OPC:

	390 x 0.913	= 356 kg	x 5,000 = 1,950 kj
Reduction per m^3		231.7 kg	932.5 kj

Confidence





Design life: **100 years**
Quad blend (PC/GGBS/FA/SF)
Total length: 32.5 km

Synergy

Technically designed multiple cementitious blends,

using combinations of OPC, Fly Ash, GGBS and Silica Fume,

can significantly:

reduce the heat evolution of the concrete,

reduce the CO_2 footprint per cubic metre,

improve the rheology, particle packing and pozzolanic efficiency

without compromising the performance.

And, given the right ‘optimisation’ of concrete design and structural engineering, give excellent construction and life cycle values…

Indianapolis International Airport Parking Garage

5 floors – 46,500m^2 per floor

7,100 parking spaces

LEED rating for the concrete design:

OPC / FA / SF – low CO_2/m^3 and reduced heat in the columns and beams

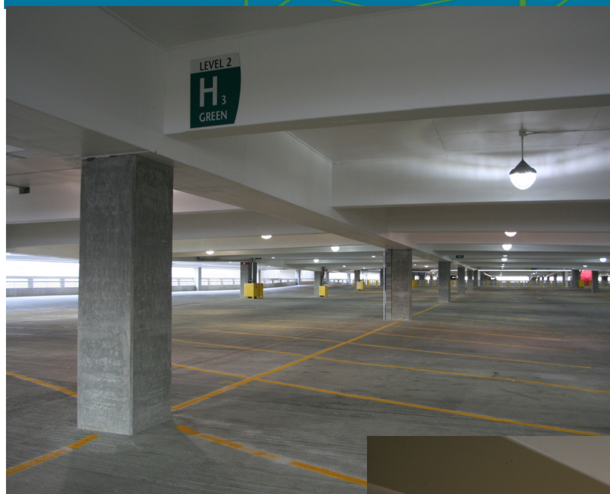
Recycled Aggregates – less natural aggregates

High fluidity / pumpable for ease of placing

Moderate design strengths coupled to simple structural design.

Fast turnaround – post tensioning at 20 hours.

Indianapolis International Airport Parking Garage



60MPa columns

22m x 20m bays

40MPa deck and beams

A 5 floor, 7,100 space car park...

Original design cost $15,000 / space.
Actual construction cost $12,000 / space.

<u>$21,300,000</u>

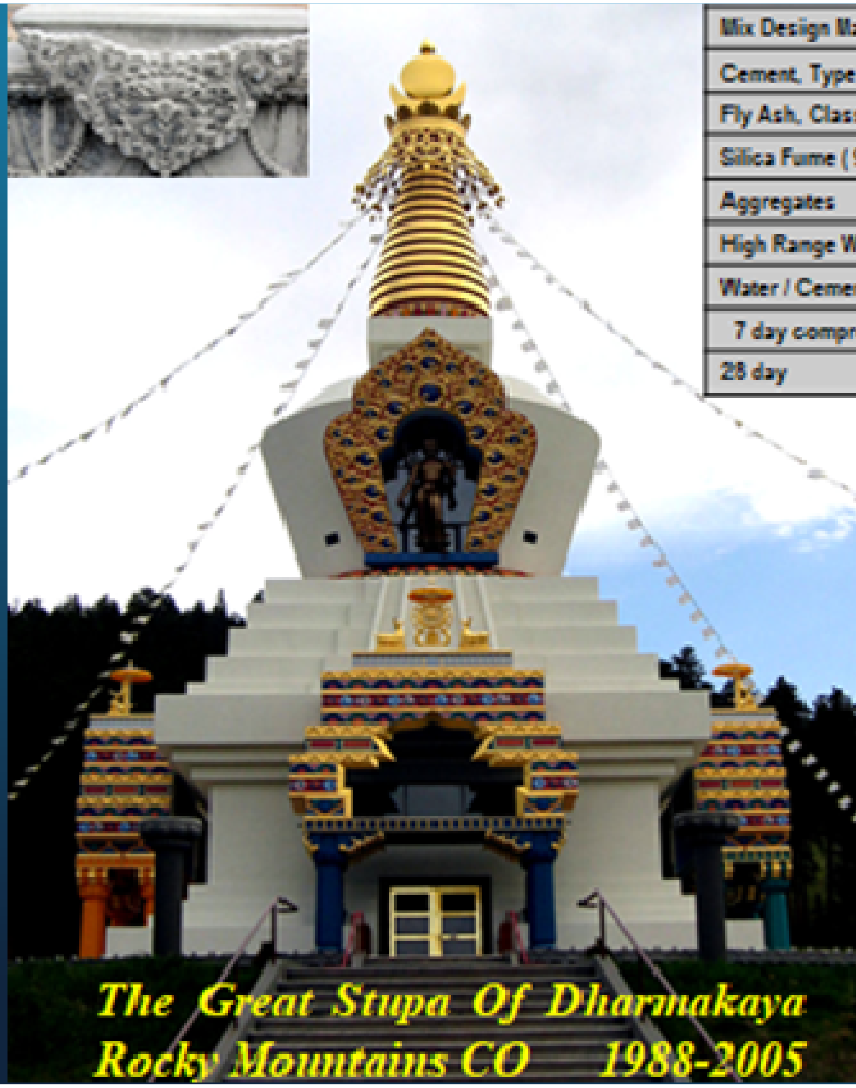
Optimisation?

Requirements	**High Fluidity (ease of placement)**
	Low Heat (moderately large sections)
	5% Air Entrained (freeze-thaw resistance)
	60 MPa at 28 days
Drawbacks	**90 minute minimum travel time**
	At 2,500m above sea level
Target Life Time	**1,000 years**

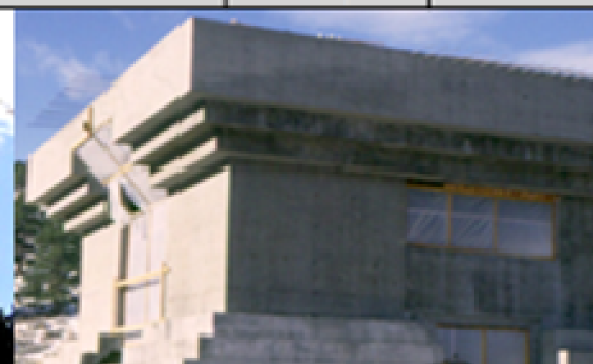
Ternary Blend

Basic Mix design

Component	Proportion / m3	
CEM I / II	433 kg	
Fly Ash (type C)	56 kg	(11%)
Silica Fume	45 kg	(9%)
HRWR	4 – 5 litres	
W/CM	0.35	



Mix Design Materials :	lbs / yd³	kg / m³
Cement, Type I / II	730	433
Fly Ash, Class C (11 % replacement)	94	56
Silica Fume (9 % addition)	76	45
Aggregates	to yield;	5 % air-entrained
High Range Water Reducer	1.3 - 1.5 gal / yd³	4 - 5 ltr / m³
Water / Cementitious Ratio	0.35	0.35
7 day compressive strength	6,900 psi	48 MPa
28 day "	8,700 psi	60 MPa



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