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Sustainable Development of Ready-Mixed Concrete in Hong Kong

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Presentation Outline

1. Introduction to Sustainable Development of Ready-Mixed Concrete (present by Mr. Casey Chan)
2. Sustainable Concrete Mix Design

   (present by Mr. Kenneth Mak)
3. Plant Operation and Production of Concrete (present by Ir. Billy Cheema)
4. QC/QA and Conclusion

   (present by Mr. K.M. Chan)

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Part 1
Introduction to Sustainable Development of Ready-Mixed Concrete

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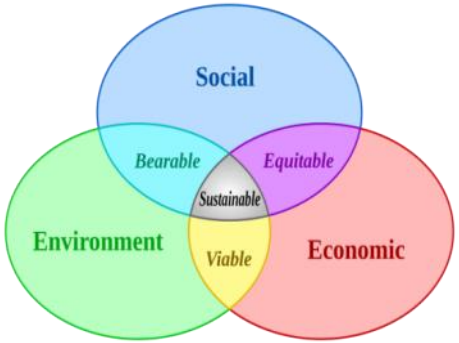
Why is concrete sustainability important?

- Commonly and widely used materials
- About 4-5 times higher than the world's average (per person)
- Concrete's versatility → Sustain our city's development
- Non-sustainable → expensive cost and difficult to maintain production

What is sustainable development?

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."



"*Our common future*", World Commission on Environment and Development (WCED), *1987*.

Sustainable development in ready-mixed concrete:

1) *Durability concern without exorbitant strength requirement*
2) *Reduction in embodied CO_2 (overall CO_2 emission into the atmosphere during the entire cycle of producing a product)*
3) *Conservation of raw materials*
4) *Use of recycled or supplementary materials*
5) *Avoidance of disposal of concrete*
6) *Etc…*

Who should participate in sustainable development?

- Project owners
- Designer/Specifiers
- Contractors
- Concrete producers or other associated parties, etc…

All of us!!!

Concrete Life Cycle

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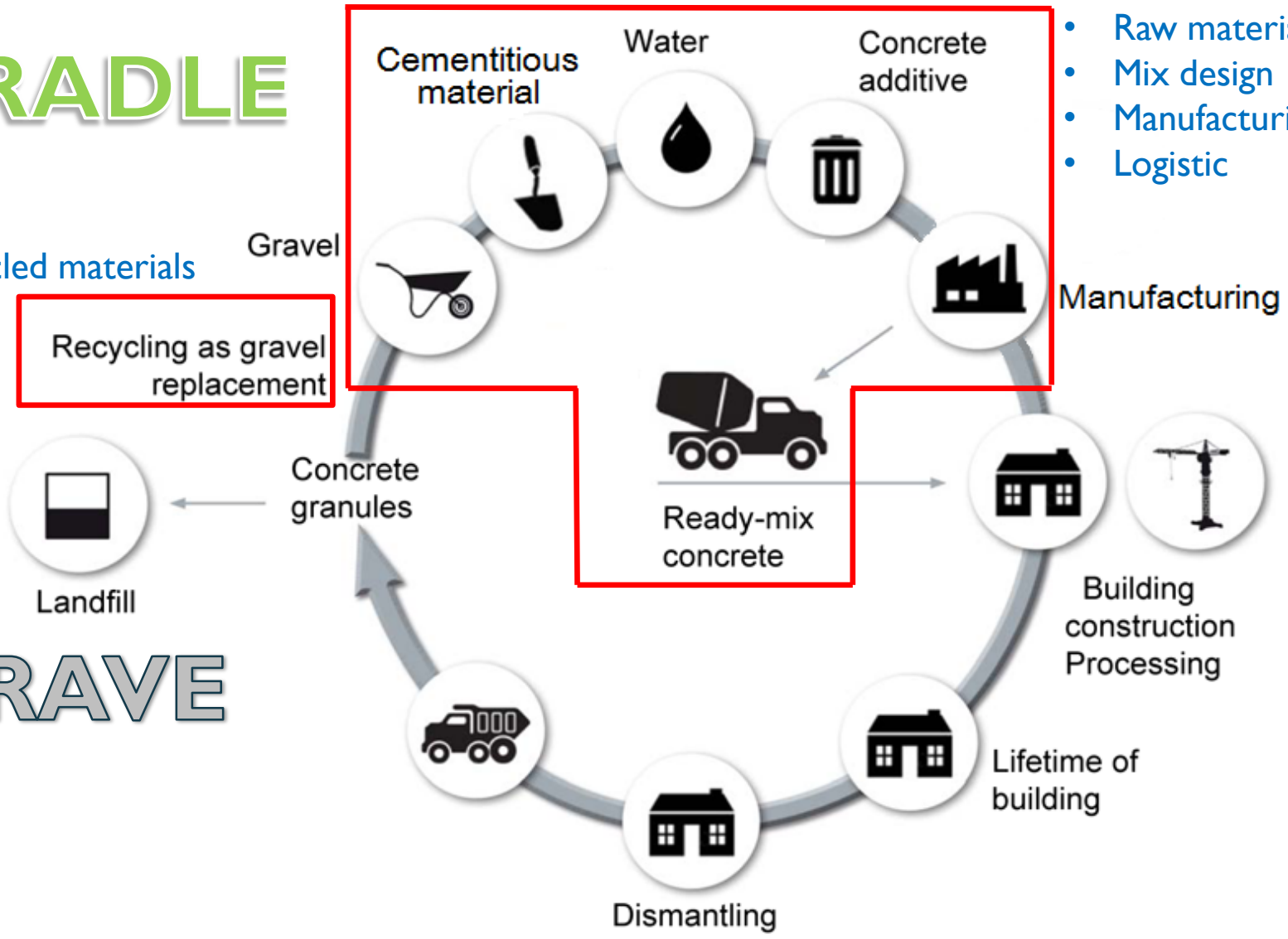
CRADLE

- Raw materials
- Mix design
- Manufacturing
- Logistic



- Recycled materials

GRAVE

Concrete Sustainability

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- Limited raw materials for cement and concrete production
  - Limestone, iron ore, gypsum, etc. (for cement)
  - Natural aggregates, admixture chemicals, etc. (for concrete)
- Conservation of natural resources (Explore other sustainable or recycled materials)
  - Recycled materials
  - Supplementary cementitious materials

- Carbon emission concern

  - Cement → Primary ingredient in concrete
  - Cement industry → Major CO_2 producer, energy consumer
  - 1 ton cement → About 1 ton of CO_2 generate
  - Use of cement ↓ → Emission of greenhouse gases ↓
  - Avoid unnecessarily high strength requirements
  - Adopt cement substitutes

Cement kiln

Concrete Sustainability

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- Landfill problem
  - Limited space for landfill in Hong Kong
  - Recycling → Alleviate the stress in landfill sites

Some sustainable/recycled materials for concrete production

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Cement substitutes:

Pulverized fuel ash

Ground granulated blast-furnace slag

Condensed silica fume

Concrete fillers:

Recycled aggregates

Recycled glass

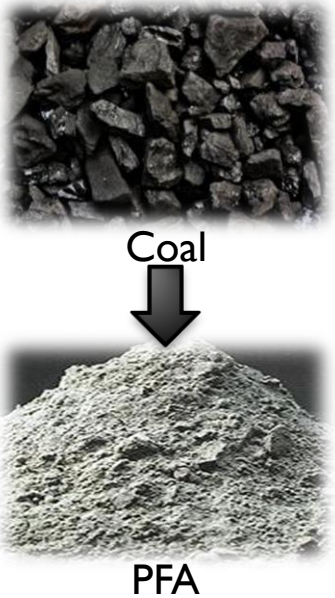
Manufactured sand(Processed)

Pulverized Fuel Ash (PFA)

- A by-product from coal burning power plant
- Captured by electrostatic precipitators
- Two local suppliers (CLP & HKE)
- Coal-firing ↓ → Local PFA supply ↓
- Mainly import from mainland

HKE – Lamma Power Station

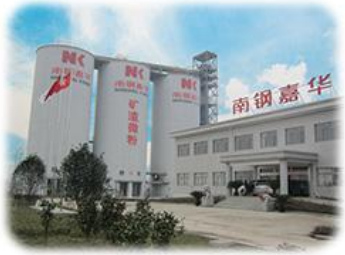
CLP – Castle Peak Power Station



Ground Granulated Blast-furnace Slag (GGBS)

- An industrial waste from iron or steel mill
- By water quenching molten iron slag from a blast furnace
- Mainly from mainland or other overseas countries
- CoP 2013 → GGBS✓
- HA spec. → Use in precast concrete façade

Blast furnace



Iron/Steel mill

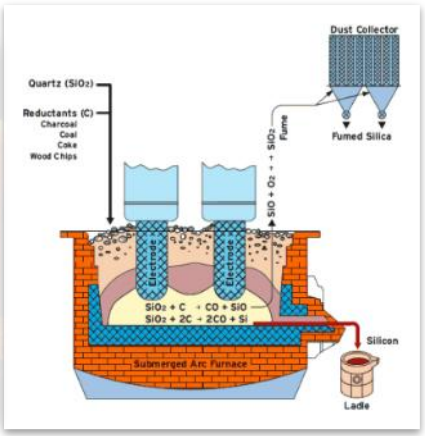
Precast concrete facade

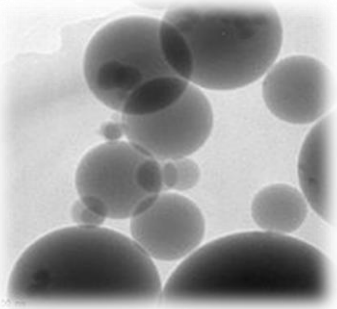
Condensed Silica Fume (CSF)

- A by-product from silicon production industry
- From the carbothermic reduction of high-purity quartz in electric arc furnace
- Supply from mainland or other foreign countries
- Use in high performance or high strength concrete

Silicon production plant

Electric arc furnace





Silica fume particles

Recycled Aggregates (RA)

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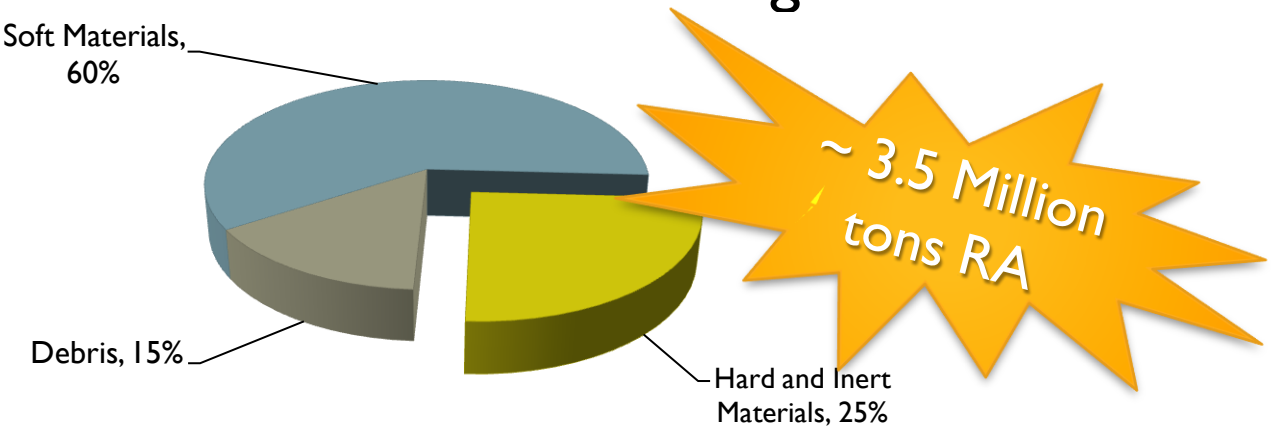
- Retrieved from construction and demolition (C&D) waste
  - Building demolition

  (Crushing old concrete)

- About 14 Million tons of C&D waste is generated each year in HK



- Challenges:
  - Hesitation of engineers (quality concern)
  - Lack of Gov. support
  - Lack of demand & supply
  - Etc…

Recycled Glass

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- Collected from glass recycling industry
- Use as coarse or fine aggregates
- Very small quantity (5% <) is processed and used
- Use in ready-mixed concrete?
- Challenges:
  - High cost in collection, transportation and production
  - Lack of Gov. support
  - Lack of local glass recycling and processing practitioners
  - Unprevailing recycling culture
  - Etc…

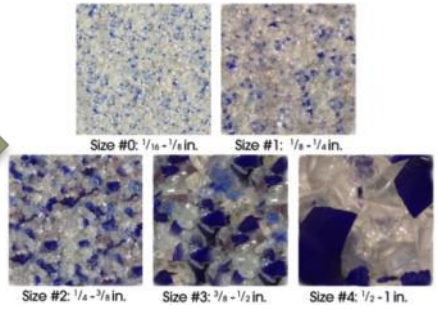
Precast concrete paving block

Architectural product

Glass recycling bin

Recycled glass

Glass crushing machine



Manufactured Sand

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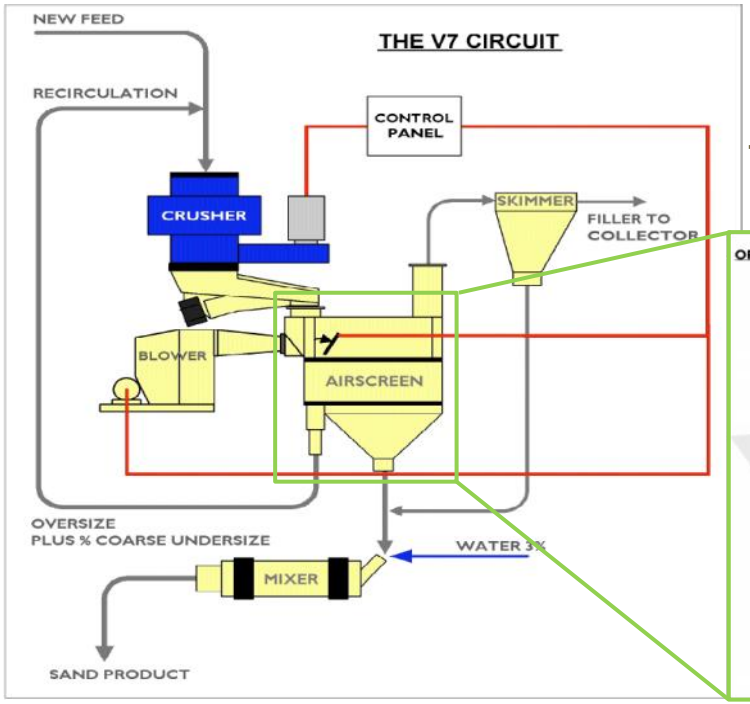
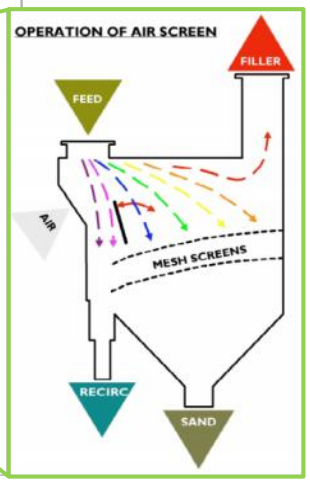
- Further processing of crushed rock fines
- Can be applied in both concrete and mortar production
- Dependency of river sand ↓
- Challenges:
  - Limited source of supply
  - Deep-rooted custom in using river sand
  - Etc…





further processing to improve its grading & particle shape

Part 2
Concrete Mix Design Considerations


reduce
reuse
recycle


Reduce
Reuse
Recycle


REUSE
REDUCE
RECYCLE


REUSE
RECYCLE
REDUCE


REDUCE REUSE
RECYCLE

Reduce

- Reduce Carbon Dioxide (CO_2)and Green House Gases (GHG) emission

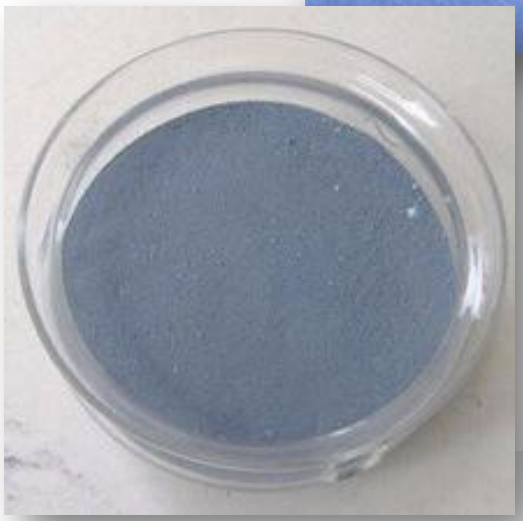
  - ✓Select constituent materials with lower embodied CO_2e

  - ✓Consider constituent materials from a nearer source

Recycle

- Constituent materials with lower embodied CO_2e

  - ✓ PFA
  - ✓ CSF
  - ✓ GGBS



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Reuse

- Reuse of concrete
  - ✓ Fresh Concrete
  - ✓ Hardened Concrete

Embodied CO2e of Cement and SCMs

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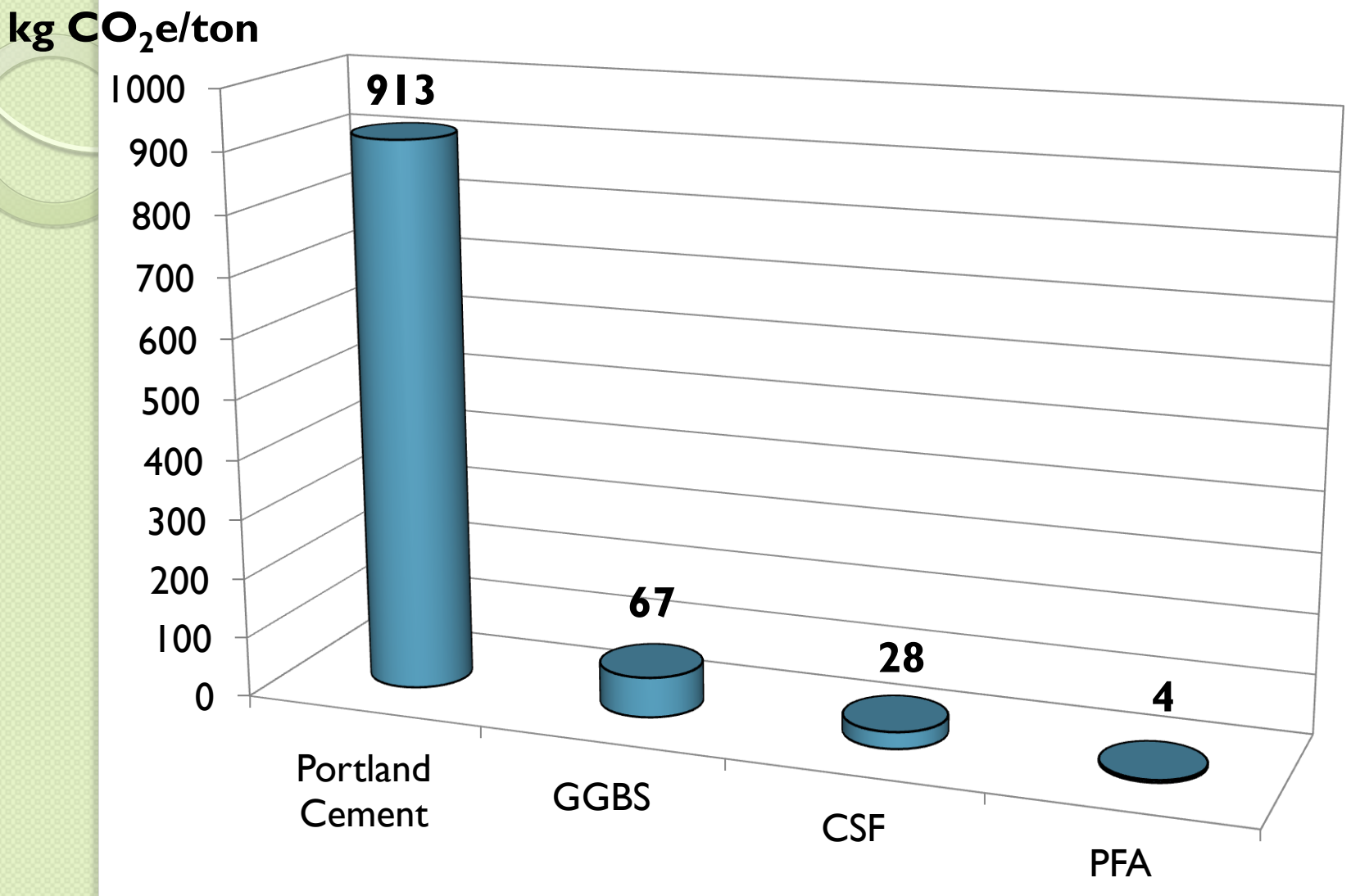

Mineral Products Association (UK) – Fact Sheet 18

Evaluate embodied CO_2e of Concrete Mixes

- Different combinations of SCMs are selected
- Total cementitious content : 450kg/m^3
- Same free water / binder ratio and aggregate / binder ratio
- Same sources of cement and aggregates are assumed
- Same brand and type of admixtures, dosage varies slightly to achieve desired slump

Evaluate embodied CO_2e of Concrete Mixes

- List of Concrete Mixes

Concrete Mixes	OPC	PFA	GGBS	CSF	20mm	10mm	CRF	Water
100% OPC	450				590	280	820	171
PFA (25%)	340	110			590	280	820	171
PFA (35%)	290	160			590	280	820	171
GGBS (60%)	180		270		590	280	820	171
GGBS (70%)	135		315		590	280	820	171
GGBS (75%)	110		340		620	300	770	171
GGBS (75%) +CSF(5%)	90		337	23	620	300	770	171

CO_2e of Concrete Mixes with different combination of Cementitious Materials (Total Cementitious Content : 450kg/m³)

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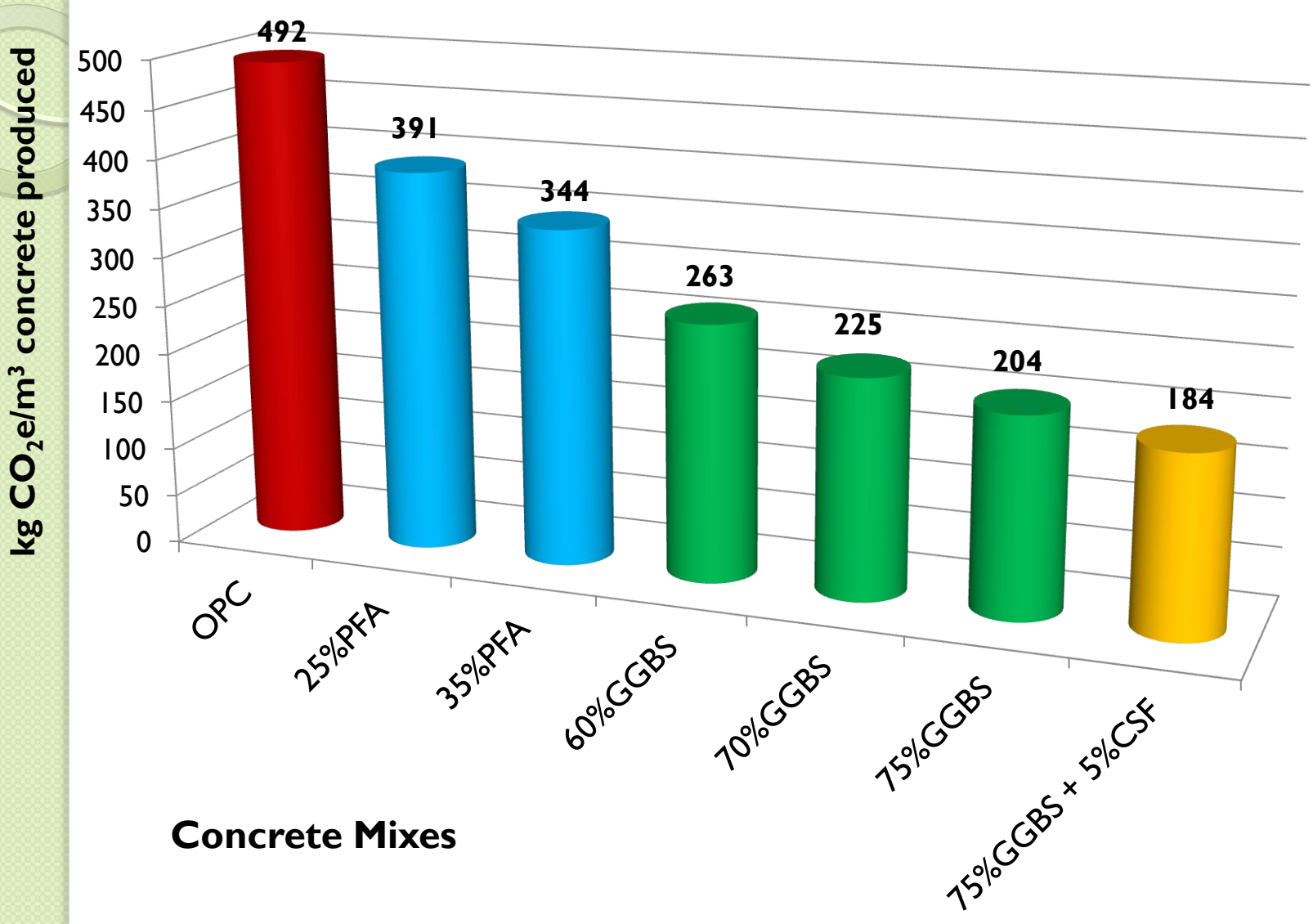

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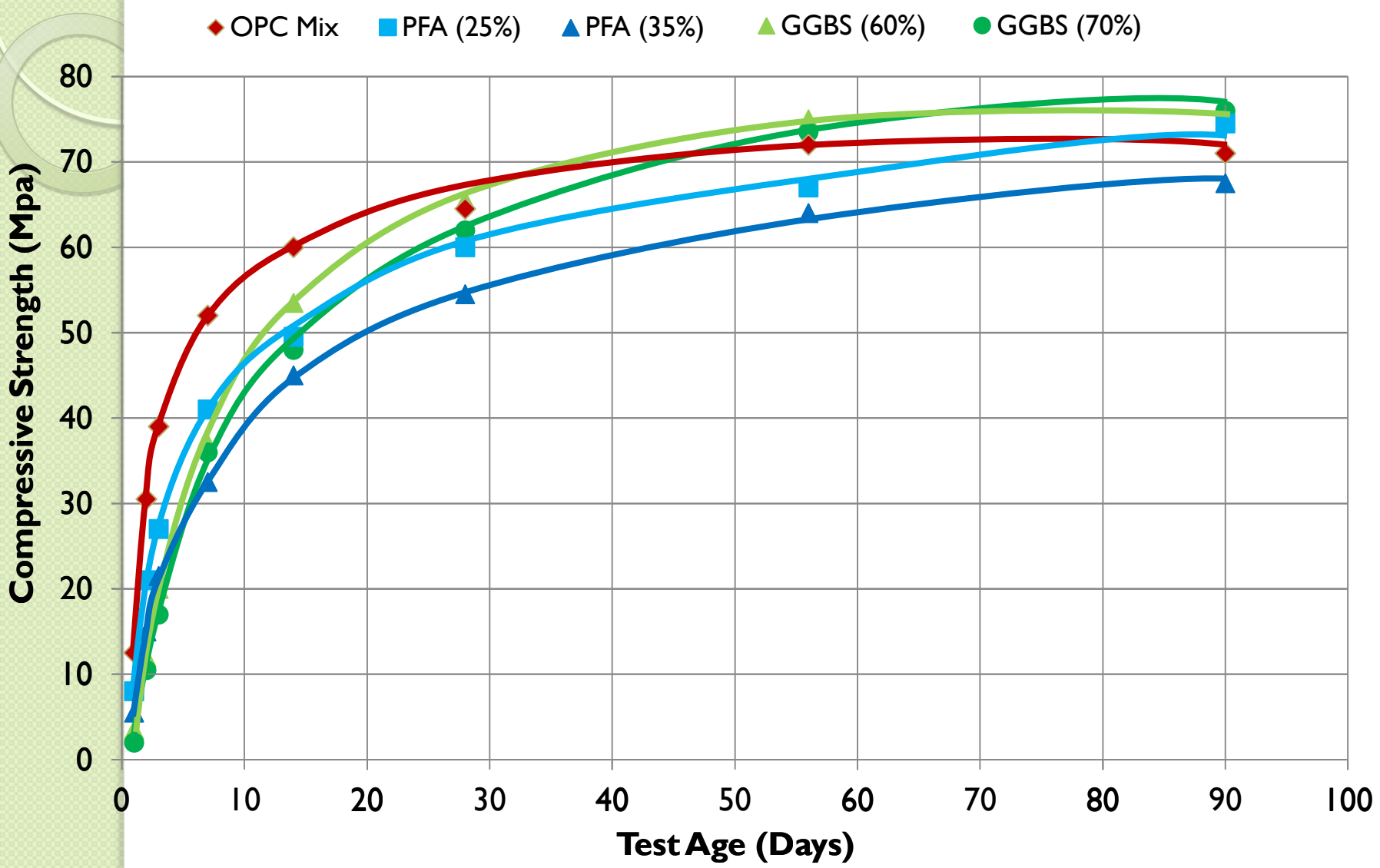
Compressive Strength Development of Concrete Mixes with different binders combinations



Net Temperature Rise of Concrete Mixes with Different Cementitious Materials (from TRET result)

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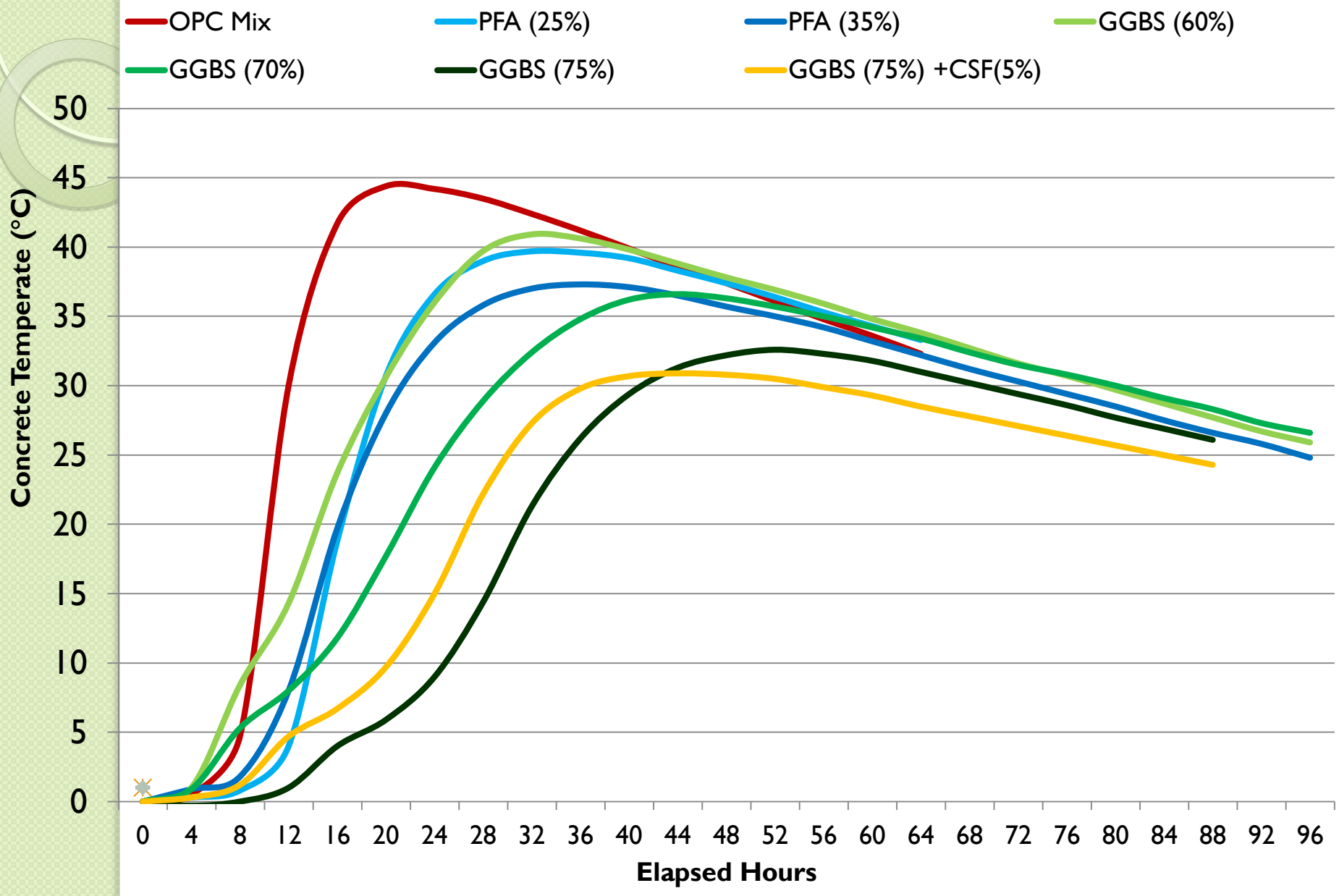

Chloride Permeability at 35 Days (in accordance to ASSHTO T277-93)

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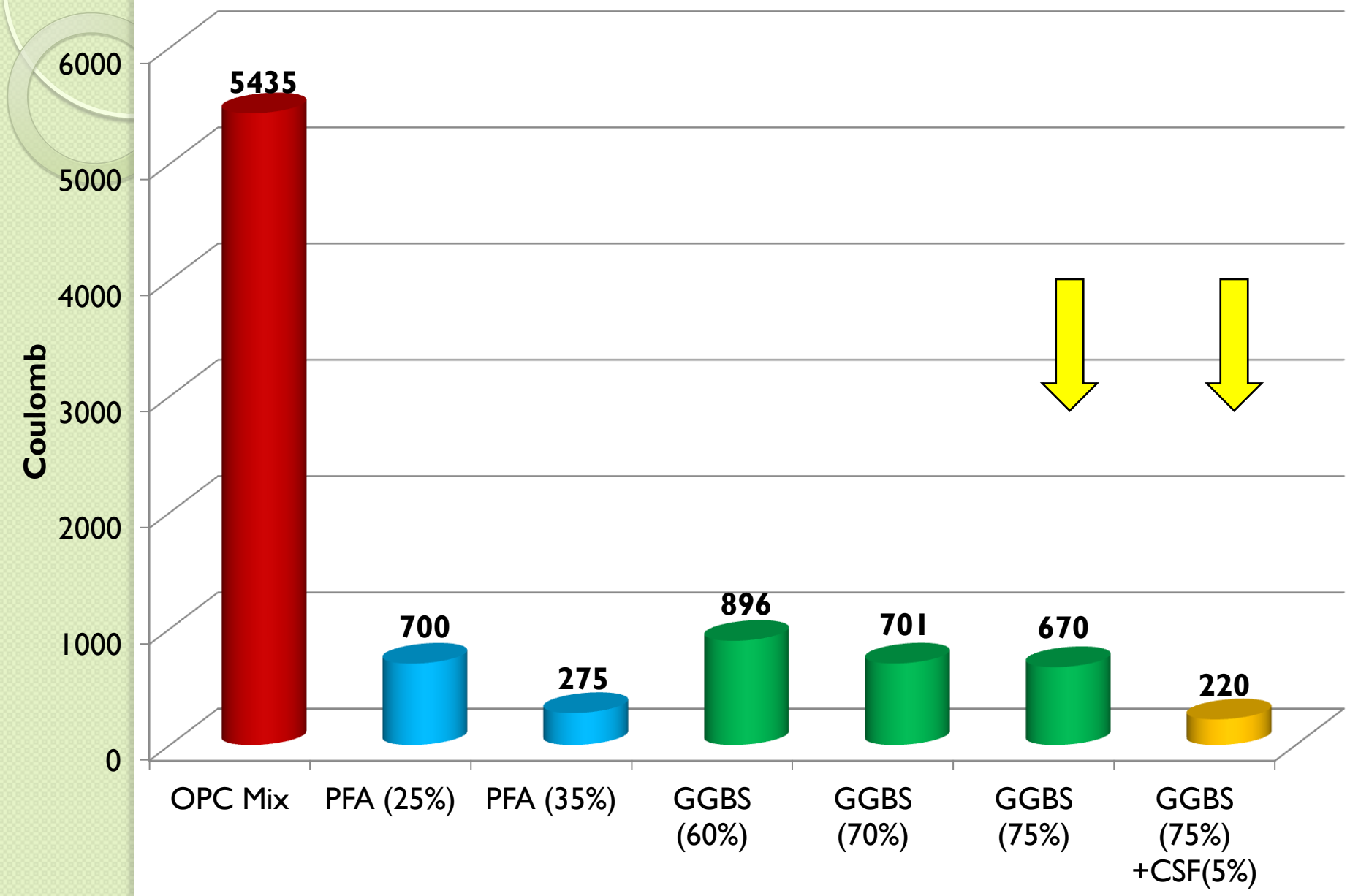

Added Values of considering SCM in concrete design mix

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- Further strength development at later ages
- Lower heat of hydration
- Improvement in durability
- Control measure for Alkali-silica reaction
- Lower cementitious content for lower CO_2e emission

Other considerations of using SCM in concrete

- Construction cycling time
  - formwork striking time
  - strength development of binder combination
  - design methodology
  - ambient temperature
- Cost effectiveness
- Supply of materials

Reuse

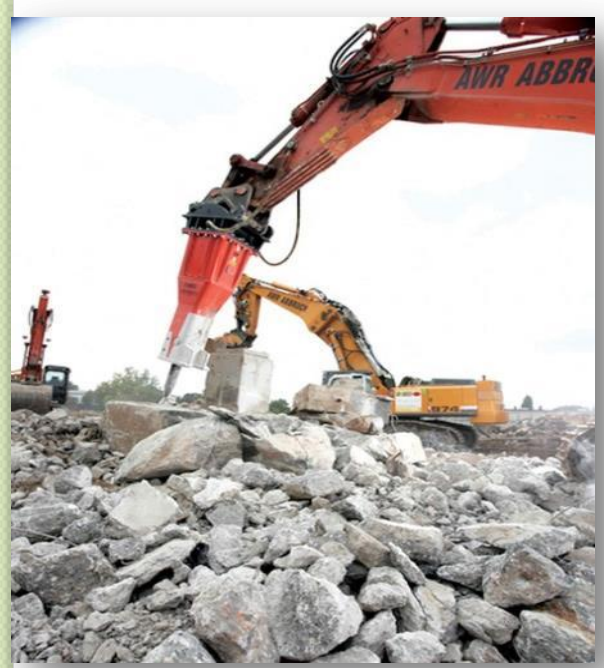
- Reuse of concrete
  - ✓ Fresh Concrete

Aggregates can be retrieved by Concrete Reclaimer or Filter-Press

Reuse

- Reuse of concrete
  - ✓ Hardened Concrete

Crushed and sized to become Recycled Aggregates



Concrete Mix Design with Recycled Aggregates (RA)

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- Comply with RA Specifications

Mandatory Requirements	Limits	Testing Method
Minimum dry particle density (kg/m^3)	2000	BS 812: Part 2
Maximum water absorption	10%	BS 812: Part 2
Maximum content of wood and other materials less dense than water	0.5%	Manual sorting in accordance with: BRE Digest 433
Maximum content of other foreign materials (e.g. metals, plastics, clay lumps, asphalt and tar, glass etc)	1%	
Maximum content of fines	4%	BS 812: Section 103.1
Maximum content of sand (<4mm) (% m/m)	5%	BS 812: Section 103.1
Maximum content of sulphate (% m/m)	1%	BS 812: Part 118
Flakiness index	40 %	BS 812: Section 105.1
10% fines test	100 KN	BS 812: Part 111
Grading	Table 3 of BS 882:1992	
Maximum chloride content	Table 7 of BS 882 – 0.05% by mass of acid soluble chloride ion of combined aggregates	

Concrete Mix Design with Recycled Aggregates (RA)

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- Comply with RA Specifications
- Allow to use 100% RA for concrete up to Grade 20
- Allow max. replacement of 20% RA for concrete up to Grade 25 to 35
- RA must be crushed old concrete, fines retrieved shall not be allowed

Manufactured Sand (M-Sand)

- Cubical in shape that resembles the shape of river sand
- Well graded to the required proportion
- Gives a higher packing density which enhance the durability of the concrete
- Does not contain organic and other compound that may affect the setting time and cement hydration
- Minimize impurities such as clay, dust, and silt coatings
- Use lower binder materials to enhance lower CO_2e emission

Conclusion

- Supplementary Cementitious Materials can greatly reduce the CO_2e and gives other added values to concrete products
- Recycled Aggregates can relief landfill pressure and conserve natural aggregates reserves
- Manufactured Sand can reduce the overall binder content required when compared with crushed rock fines

Part 3
Plant Operation and Production of Concrete

Challenges arising from use of new constituent materials

(Concrete Batching Plant Operation in Hong Kong)

Concrete Batching Plant Operations

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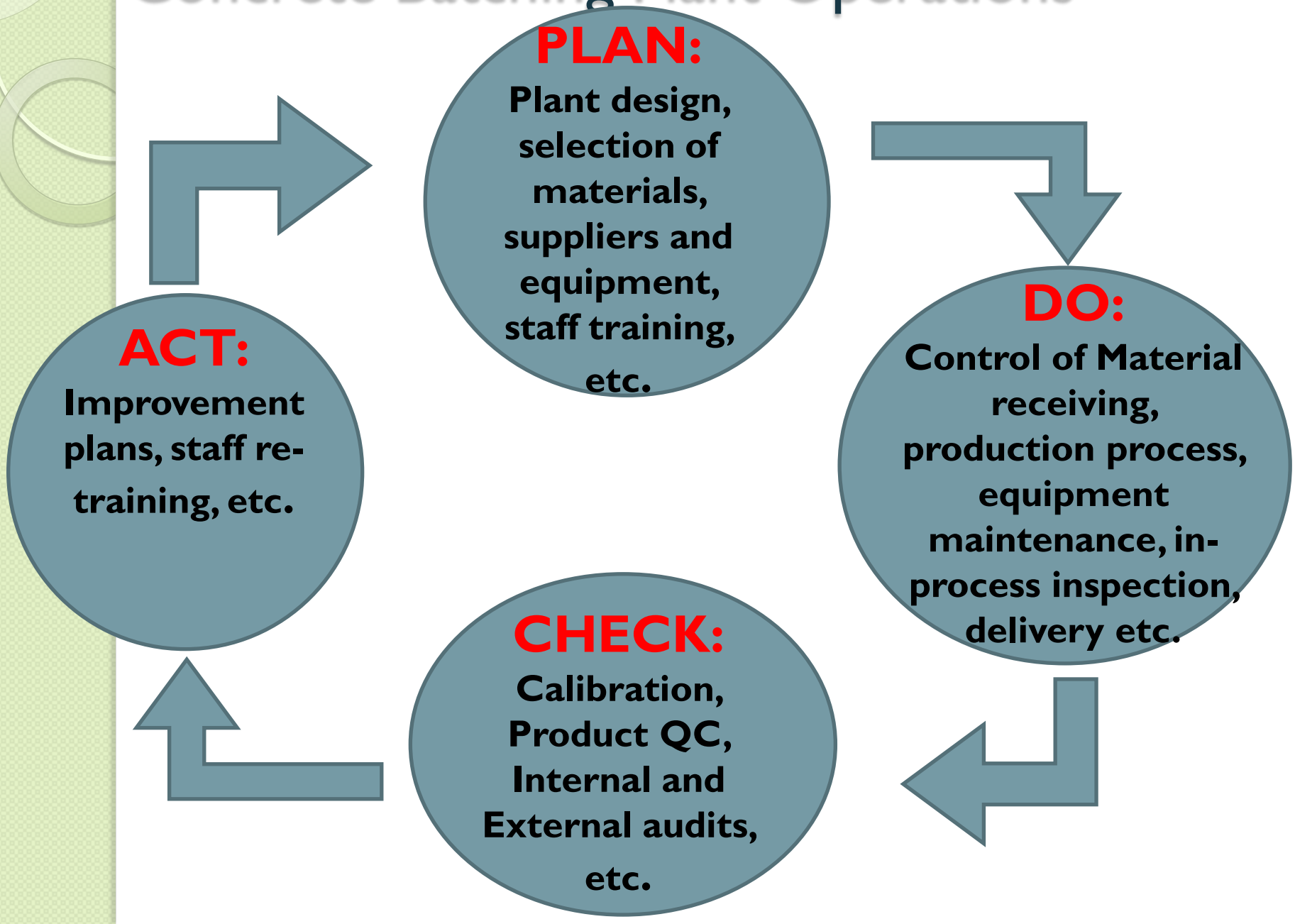

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Plant considerations on using new constituent materials

- Quality Consistency
- Supply Availability
- Logistic mode, time
- **Storage**
- Supply Consistency
- Transport mode

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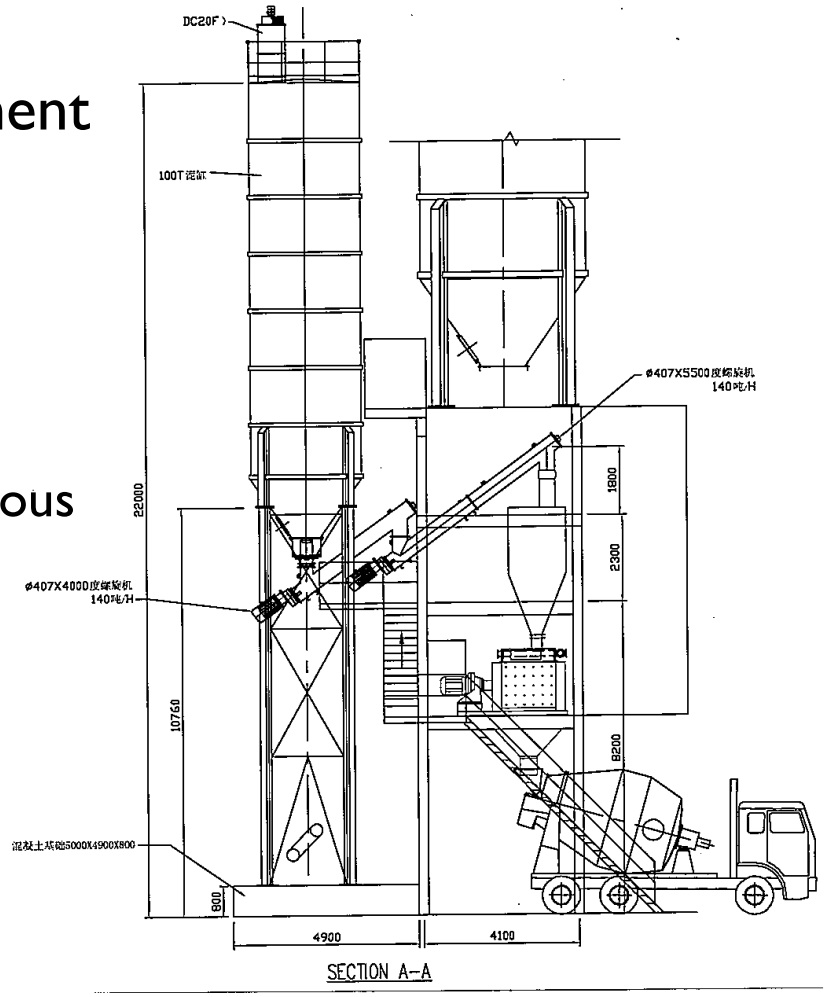
PFA / GGBS / CSF Cementitious Materials

- Stored in Silo

PFA / GGBS / CSF

- Typical Concrete Plants erected in the past and are still in operations
- One or Two Silos for Cement
- One Silo for PFA
- One Silo for Silica Fume

- Where can the other cementitious
- materials including GGBS go?
  - Shift Silo
  - Erect New Silo



Manufactured Sand / Recycled Aggregates

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- Stored
  - Stockpiles
  - Overhead Storage Bin

PFA / GGBS / CSF

- Challenges for Erecting Additional Silo
  - Space availability
  - Building Department Approval
  - Environmental Protection Department Approval
  - Lands Department Approval (Depends)

Manufactured Sand / Recycled Aggregates

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- Challenges for Erecting Additional Stockpile
  - Occupies large area of land space
  - Load moving machinery
  - Lands Department approval
  - Environmental Protection Department approval
  - Building Department approval

Manufactured Sand / Recycled Aggregates

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- Challenges for Erecting Additional Storage Bin
  - Large area
  - Conveyor System
  - Building Department
  - Lands Department
  - Environmental Protection Department

Building Department Approval

- PNAP 255 (APP-120)
- Foundation, Structural, Stability Calculation
- Building Services, Fire Hazard
- Submission / Approval / Consent
- Design to as-build Checking

Environmental Protection Department Approval (Specified Processes)

- Air Impact Modelling
- Air Pollution Control Plan
- Submission / Approval
- Newspaper Notification
- Draft License

Environmental Protection Department Approval (Specified Processes)

- Air Impact Modelling
  - Calculate impact of haul road travelling by cement tanker and emission by dust collector.
- Dust Collector emission
  - Dust suppression efficiency > 99.9%.

Lands Department Approval

- Covered Area
- Coordination among other government departments for their concerns

The way forward.

Are the Concrete Batching Plants ready?

- Is Government procedures the problem?
- Or the approval system?
- Is Concrete Production a niche market in Hong Kong or it is robust?

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Part 4

Use of SCM in Hong Kong
QA/QC of using sustainable materials

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Use of Supplementary Cementitious Materials in Local Specifications

Max % of cementitious materials by mass	HKHA Spec Library 2012 CON1	CEDD GS:2006 Section 16	COP of Structural Use of Concrete 2013
PFA	35% for foundation 25% for others	25-35% for ordinary concrete	25-35% for ordinary concrete
GGBS	Only allow 35% for precast concrete façade	35-75% for ordinary concrete	35-75% for ordinary concrete
Combination of PFA & GGBS is Prohibited!			

- Use of SCM is not mandatory

- High early strength of concrete is required for fast track construction.

Use of Supplementary Cementitious Materials in Local Specifications

- Limited by the local regulation, concrete strength must be measured at 28 days after concreting.
- Concrete with PFA and/or GGBS will have 10-20% strength growth after 28 days.
- Studies is carrying out to fully utilize the ultimate strength of PFA/GGBS concrete in design and construction.
- Incorporation of PFA and GGBS in concern as adopted in other localities should be further studied.

Quality Control & Assurance

- QA/QC shall comply with Quality Scheme for the Production and Supply of Concrete (QSPSC)

- QSPSC covers Quality Management System, Concrete Mix Design, Maintenance of Equipment, Materials Control, Production Control, Product Quality Control

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Material Control-QSPSC basic requirements

Physical test	PFA	GGBS
PFA & GGBS Fineness Density Water Requirement Setting Time Moisture Content	Once per week or 1000m3 production Testing Method BS EN 196	Once per week or 1000m3 production Testing Method BS EN 196
PFA Soundness Strength Factor	Compliance Standard BS3892	Compliance Standard BS EN 15167-1
GGBS Compressive Strength (Prism)		
Other tests required in project specification		

Setting Time test apparatus

Material Control-QSPSC basic requirements

Chemical test	PFA	GGBS
PFA & GGBS Loss of Ignition CaO, SO_3, Cl, Na_2O and K_2O Content, Total Alkali Content GGBS S, MgO, Al_2O_3, Mn_2O_3, Impure Silica, Pure Silica Content	Once per year Testing Method BS EN 196 Compliance Standard BS3892	Once per year Testing Method BS EN 196 Compliance Standard BS EN 15167-1
Other tests required in project specification		

Furnace for LOI

Material Control-QSPSC basic requirements

CSF	Requirement
Performance certificate from CSF supplier	Every 100T delivery or 3000m3 production

Other tests required in project specification

Sample description: Silica Fume (
Source:
Sample Location : -
Client sample ID.: -
Date sampling of materials: 30-Dec-2014
Test Method: CAN/CSA-A23.5-M86

Test Results
Date Received: 30-Dec-2014
Sample Mass as Received: 15 kg
Lab Sample ID: CE141807

1. Fineness — Date tested: 09-Jan-2015
   0.8%
2. Density — Date tested: 13-Jan-2015
   2.25 g/cm³
3. Soundness — Date tested: 18-Jan-2015
   0 mm
4. Flow Test — Date tested: 12-Jan-2015
   Control mix — Flow Value: 85.5 %
   Test mix — Flow Value: 89.0 %
5. Pozzolanic Activity Index With Portland Cement
   7 days Pozzolanic Activity Index: 128 %

   Compressive Strength (N/mm²)
   (Age at test : 7 days)
   Control Mix
   ① 29.10 ② 29.40 ③ 29.95 Mean = 29.5 Date tested : 19-Jan-2015

   Test Mix
   ① 38.20 ② 36.85 ③ 38.45 Mean = 37.8 Date tested : 19-Jan-2015
6. Increase of drying shrinkage — Date tested : 09-Feb-2015
   Increase of drying shrinkage of mortar bar at 28 d = 0.00 %
   Average drying shrinkage of the control specimens = 0.017 %
   Average drying shrinkage of the test specimens = 0.021 %

PRODUCT ANALYSES

Product:
Grade:

Sampling Date:	**24th Nov,2014**

LOT ID:4814

These are the latest available test results corresponding to the material with the reference number above.

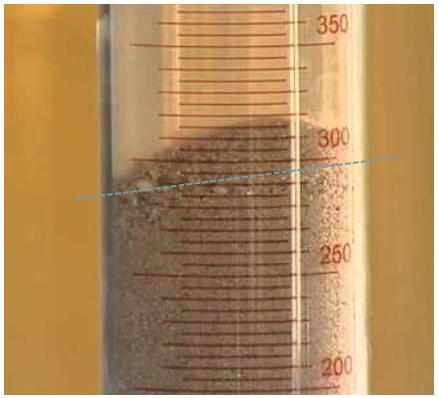
PARAMETER:	UNITS	SPEC	ANALYSES
Silicon dioxide (SiO_2)	min %	85.0	*92.5*
Loss On Ignition	max %	4.0	*0.8*
Chloride (Cl^-)	max %	0.20	*0.01*
Sulfate (SO_3)	max %	2.0	*0.6*
Alkalies (Na_2Oeqv)	max %	4.0	*1.4*
Free silicon (Free Si)	max %	0.4	*0.1*
Free calcium oxide (Free CaO)	max %	1.0	*≤ 1.0*
Specific Surface	m^2/g	≥ 15.0 ≤ 35.0	*21.4*
Pozz. Activity Index	min %	100	*129*

Material Control-QSPSC basic requirements

M. Sand (fine aggregate)	Testing Method & Compliance Standard CS3:2013 Aggregate for Concrete
Grading	1 sample / day / source
Fines Content	1 sample / day / source
Relative Density	2 samples / year / source
Water absorption	2 samples / year / source
Moisture content	2 samples / day / source
Alkaline Reactivity of Aggregate	Accelerated Mortar Bar Test (AMBT) at least 1 sample /4 month / source
Other tests required in project specification	

Sieving Test

Oven dry for water absorption / Moisture content



Silt Content (by Volume)

AMBT

CS3 has introduced a new compliance criterion for fines content of aggregate

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CS3:2013 Table 3.3 Limits for Fines Content			
		Max % by mass passing 75μm	Methylene Blue Value (MBV)
Fine aggregate	Class I	10	-
	Class II	>10 & ≤14	≤1.4

$$MBV = \frac{V_1}{M_1} \times 10$$

where

M_1 is the mass of the test portion (in g);
V_1 is the total volume of dye solution added (in mL); and
10 is the density factor for converting the volume of the dye solution used to the mass of dye adsorbed per kilogram of the fine aggregate tested.

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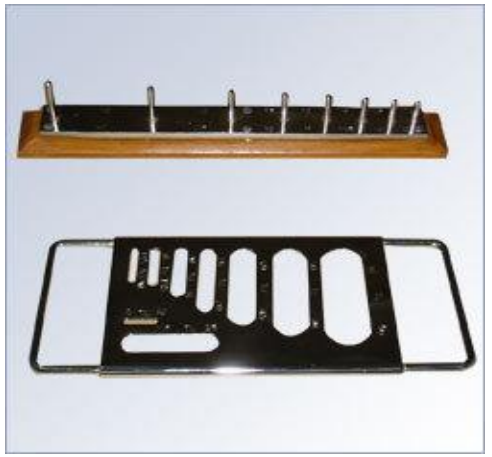
Material Control-QSPSC basic requirements

Recycled coarse aggregate	Testing Method & Compliance Standard CS3:2013 Aggregate for Concrete
Tests same as M. Sand	
Grading	1 sample / day / source (% passing 4mm sieve shall not exceed 5%)
10% fines	1 sample / month / source
Elongation & Flakiness	2 samples / year / source
Tests required in CS3 Foreign Materials Content, Presence of Organic Substances, Acid Soluble Chloride Ion / Sulphate Content	
Other tests required in project specification	



Flakiness & Elongation apparatus

10% fines test

C & D Waste

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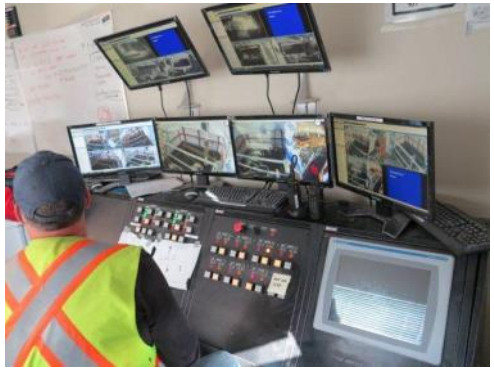
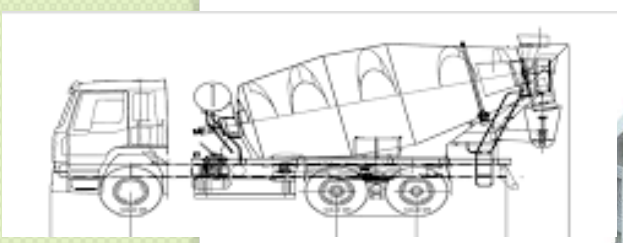
Production Control -QSPSC basic requirements

Process	Requirement
Batching	Production by computerized system
Weighting	±5% for Chemical Admixture ±2% for Cement, PFA, GGBS, Aggregate, Water 0% to +5% for CSF
Calibration of Scale	BS5781 at least once every 3 months
Mixer	Table 1 of Appendix C of QSPSC
Mixing Time	Not less than recommendation from mixer manufacturer or the mixing time verified by the uniformity test described in QSPSC
Transportation	Delivered in an agitator

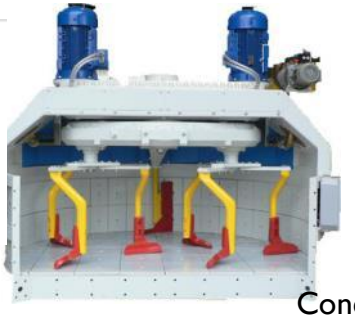
Concrete Batching Plant



Computerized Batching System



Truck Mixer



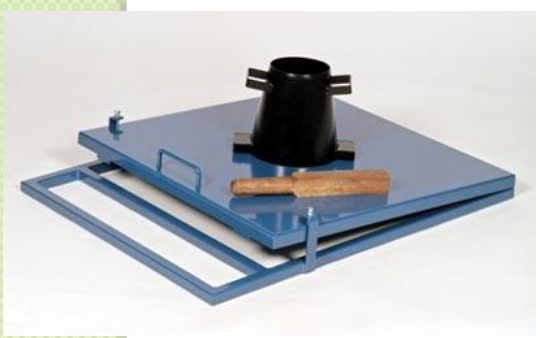
Concrete Mixer

Weighting of Materials

Product Control-QSPSC basic requirements

Test	Frequency
Cube Compressive Strength	1 pair (1st 25 to 150m3 production), 1 additional pair per 150m^3 with max 4 pairs. Control concrete strength based on early age (≤7 days) cube test
Workability Test	Testing rate same as cube test
Total Alkaline Content of Concrete	Equivalent Na_2O content (<3kg/m3) of concrete mixes will be checked during regular audit
Other tests required in project specification	

Cube Compression Test



Flow Table Test Apparatus

Slump Test

Making Test Cube

Concluding Remarks

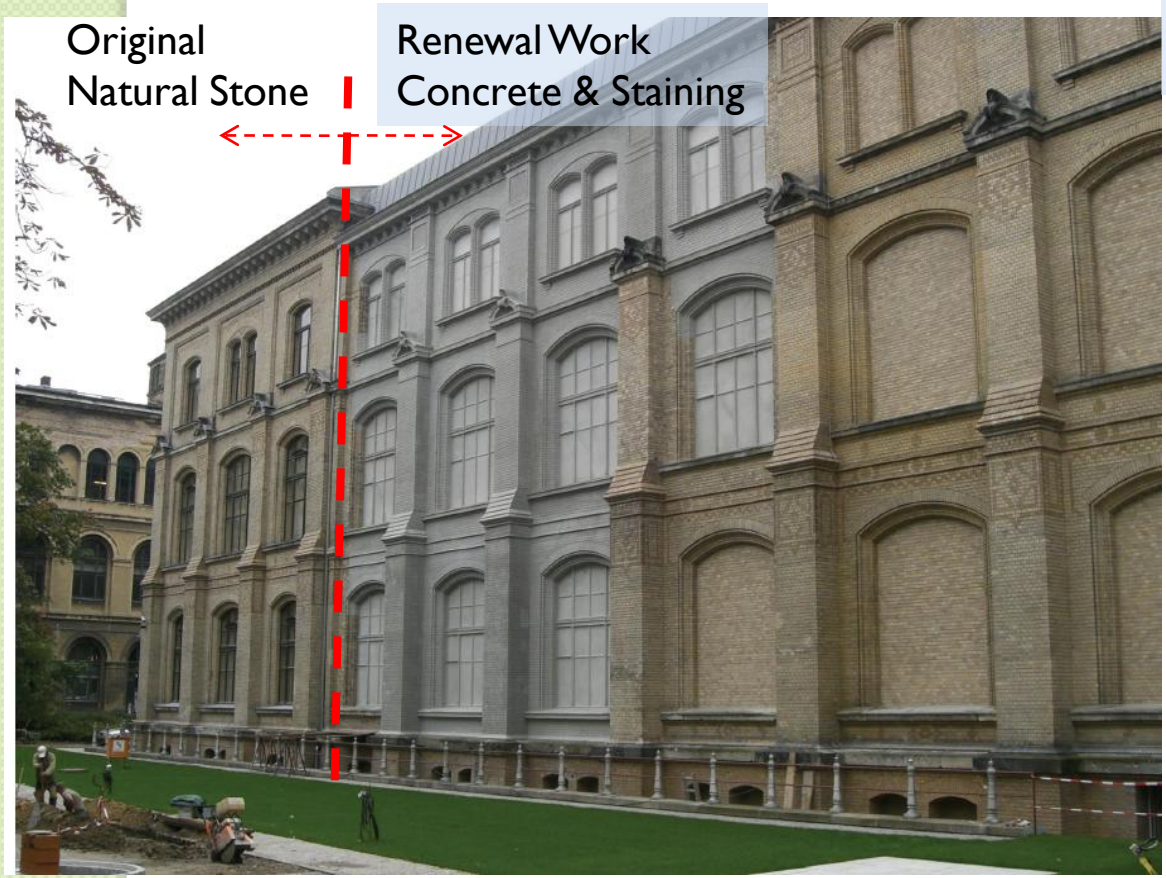
- Use of sustainable materials (e.g. PFA, GGBS, CSF, M. sand, recycled aggregate.) is welcome by Concrete Producers.
- Advantages:

  (i) Reduce carbon emission ; (ii) Reduce solid waste; (iii) Enhance durability; (iv) Enhance performance of concrete
- Overcoming Challenges:

  (i) government policy ; (ii) local researches; (iii) review of regulation & specifications; (iv) education & training in construction industry.
- Quality Control of sustainable materials is already included in QSPSC.

Concluding Remarks

- Apart from sustainable use of raw materials, use of sustainable concrete by Architects and Engineers are also essential.



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~Thank You~