Benefit of fly ash in ready mixed concrete

By Balamohan Balakrishnan

Table of Content

Background of fly ash

- The Fly Ash story begins 2000 years ago...
- When the Romans built the Colosseum in the year 100 A.D. - that still stands until now

Background of fly ash

- The Romans mix volcanic materials (finely ground) with lime and sand, yielded a mortar that was not only cementitious, but water resistant and very strong.
- When volcanic ash mixed with lime & water, a pozzolanic reactions happens, similar to fly ash

Pantheon in Rome. (115-125 A.D.)

Background of fly ash

"Roman concrete is . . . considerably weaker than modern concretes. It's approximately ten times weaker,"

Despite the success of Roman concrete, the use of the material disappeared along with the Roman Empire

Renato Perucchio, University of Rochester in New York.

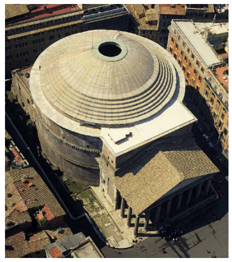
Background of fly ash

The first known book written about architecture was written by a Roman architect named Vitruvius. Romans were well-known for their architecture. They believed every building should be strong in:

Durability (how long a building will last)
Utility (how well it fits its purpose)
Beauty (how pretty it is)

Background of fly ash

- Both the Pantheon and the Roman Coliseum were built with high volumes of volcanic ash in the cement mixture. It has a circular concrete temple with walls 6.1 meters thick and a dome measuring 43.3 meters in diameter. The building still stands in its original form due to the excellent quality of material used. In the event of an earthquake, the building distorts rather than collapsing and moves with the shifts of the earth instead of cracking.

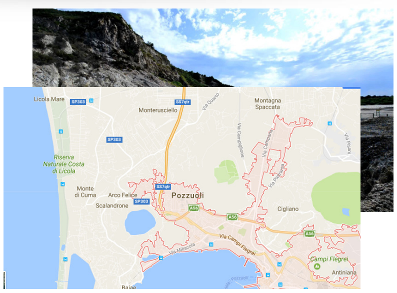


Background of fly ash

- Colosseum is a classic example of durability achieved by using pozzolanic materials

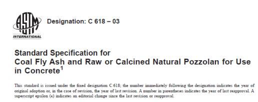
Background of fly ash

- The Romans used volcanic materials tuffs found in neighboring territories, the most famous ones found in Pozzuoli (Naples), hence the name pozzolan / pozzolanic



Background of fly ash

- ASTM C618, defines Pozzolanic materials as siliceous or siliceous and aluminous materials which themselves possess little or no cementitious properties but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties
- Pozzolanic reactions happens between amorphous silica and calcium hydroxide.


Designation: C 618 – 03

Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete[1]

Background of fly ash

- Today's ashes from coal-fired power plants have similar properties to the volcanic ash used by the Romans.
- By coincidence, the fly ash contained the same amorphous silica compounds as the ash from explosive volcanoes

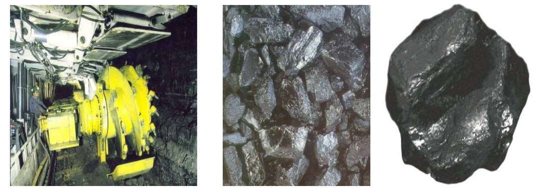
Background of fly ash

- When finely ground coal is blown into the power plant's boiler, the carbon is consumed and leaving molten particles rich with silica, alumina and calcium. These particles solidify as microscopic, glassy spheres that are collected using high technology electrostatic precipitators.

Background of fly ash

Coal Fired Power Plants

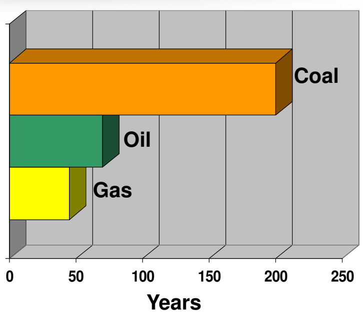
Background of fly ash



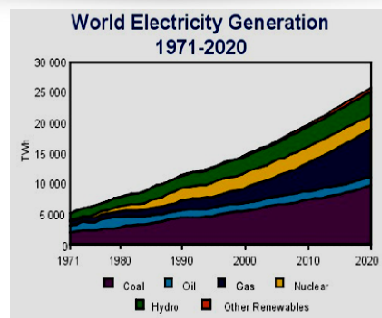
Coal Fired Power Plants

Background of fly ash

- World fuel reserve
- *estimated at current consumption

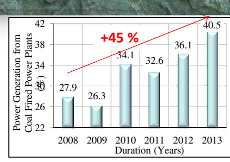


Background of fly ash

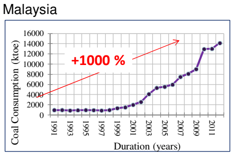


Background of fly ash

- Serious increasing trend of power generation as a result capacity addition and expansion of coal fired power plants.
- This have resulted in coal consumption has increased over 1000% over from 1991 to 2012.

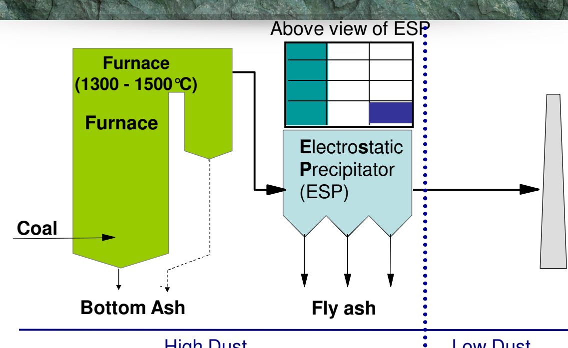


Proportions of power generation from coal fired power plants in Malaysia

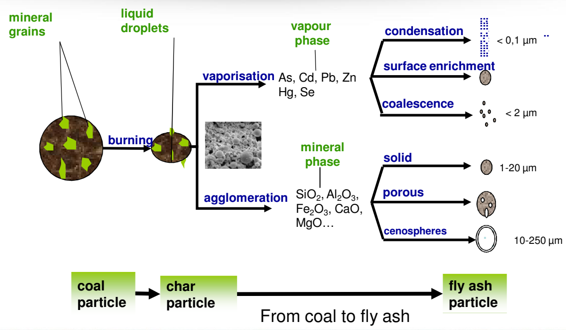


Malaysian power plant coal consumptions, 1991 to 2012

Background of fly ash



Background of fly ash



From coal to fly ash

Background of fly ash

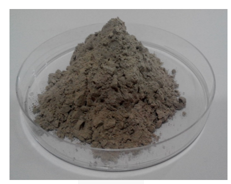
Fly ash - a miracle powder

470 million tonnes produced in 2000 worldwide

Background of fly ash

Different types of fly ash

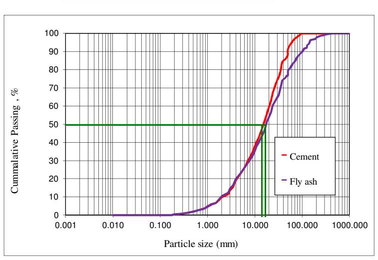
Background of fly ash



Fly ash

Cement

Background of fly ash



Physical properties differences between cement and fly ash

Background of fly ash

Hard coal

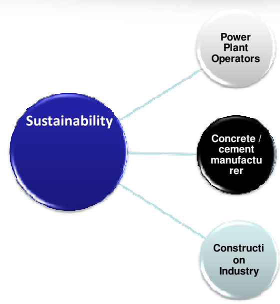
Lignite

Colours of fly ash

Background of fly ash

- The potential for using fly ash as a supplementary cementitious material in concrete has been known almost since the start of the last century (Anon 1914), although it wasn't until the mid-1900s that significant utilization of fly ash in concrete began (The last 50 years has seen the use of fly ash in concrete grow dramatically)
- Fly ash concrete was first used in the United States in 1929 for construction of the Hoover Dam.

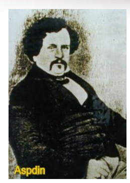
Background of fly ash



- ✓ Power plant operators don't need to dump the fly ash.
- ✓ Reduced damages to the environment.
- ✓ Fly ash replacement reduce the production of cement thus the CO_2 emission. 1 tonne of cement replaced with fly ash, 1 tonne of CO2 is reduced.
- ✓ Consumption of natural resources reduces
- ✓ Fly ash gives excellent durability properties to concrete.
- ✓ This reduces the resources needed to repair the damaged structures.

Table of Content

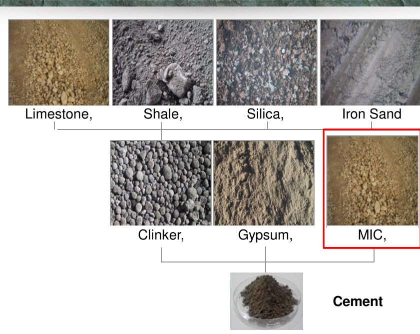
History of Portland Cement



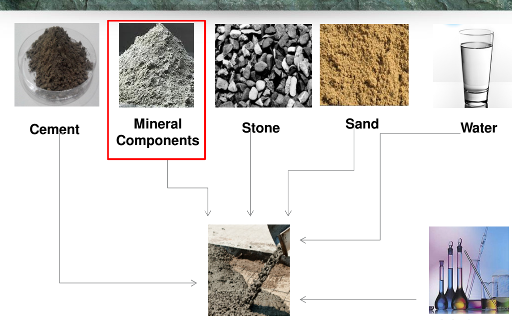
The term 'Portland cement' was first applied by Joseph Aspdin which describes a process for making artificial stone by mixing lime with clay in the form of a slurry and calcining (heating to drive off carbon dioxide and water) the dried lumps of material in a shaft kiln. The calcined material (clinker) was ground to produce cement.

Cement was named "Portland" because it resembles the stones from the small island of Portland

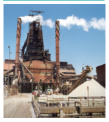
Cement Composition



Concrete Composition



Additives in Cement and Concrete

Additives	Granulated blast furnace	Fly Ash, siliceous	Pozzolans	Limestone and other Fillers
				
Reactivity	Latent hydraulic	Pozzolanic		Inert

Latent hydraulic
- Hydrates in presence of water
- Activator accelerates hydration

Pozzolanic
- Does not hydrate in presence of water
- Needs an activator to react

Inert
- Not reactive
- No significant participation in the hydration process

fppt.com

EN 197-1 Cement Standard

Clause 5.2.4 Fly ash (V,W)

5.2.4.1 General

Fly ash is obtained by electro static or mechanical precipitation or dust-like particles from the flue gases from furnaces fired with pulverized coal.

EUROPEAN STANDARD — EN 197-1
NORME EUROPÉENNE
EUROPÄISCHE NORM — June 2000

ICS 91.100.10 — Supersedes ENV 197-1:1992

English version

Cement - Part 1: Composition, specifications and conformity criteria for common cements

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EN 450-1 Concrete Standard

Clause 3.2
fly ash
fine powder of mainly spherical, glassy particles, derived from burning of pulverised coal, with or without co-combustion materials, which has pozzolanic properties and consists essentially of SiO2 and Al2O3, the content of reactive SiO2 as defined and described in EN 197-1 being at least 25 % by mass.

BRITISH STANDARD — BS EN 450-1:2005+A1:2007

Fly ash for concrete —

Part 1: Definition, specifications and conformity criteria

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ASTM C618 Concrete Standard

Close 1. Scope *
1.1 This specification covers coal fly ash and raw or calcined natural pozzolan for use in concrete where cementitious or pozzolanic action, or both, is desired, or where other properties normally attributed to fly ash or pozzolans may be desired, or where both objectives are to be achieved.

ASTM INTERNATIONAL — Designation: C 618 – 03

Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete[1]

This standard is issued under the fixed designation C 618; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

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AS 3582.1Concrete Standard

Clause 3 DEFINITIONS
3.1 Flyash—solid material extracted from the flue gases of a boiler fired with pulverized coal.

Australian Standard®

Supplementary cementitious materials for use with portland and blended cement

Part 1: Fly ash

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GB1596-91 Cement & Concrete Standard

GB1596-91, "Fly ash for cement and concrete," as standard class II.

GB1596-91	Class 1	Class 2	Class 3
Amount retained on 45µm max,%	12	20	45
Water demand, max, % of control	95	105	115
Loss on ignition, max,%	5.0	8.0	15.0
Moisture, max,%	1.0	1.0	-
SO_3, max,%	3.0	3.0	3.0

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PCA Recommendation

Recommended addition dosage ranges for mass concrete from PCA

Cementitious materials	Maximum allowed by ACI 318*	Recommended dosage range (% of total cementitious materials by mass)			
		Unreinforced pavements and slabs	Mass concrete	Structural concrete	Bridge decks and parking garages
Fly ash or other pozzolans	25%	< 25%†	30%-80%	15%-25%	15%-25%
GGBFS	50%	15% to 30%	30%-80%	25%-40%	30%-40%
Silica fume	10%	5% to 10%	< 10%‡	Up to 10%	Up to 8%
Total of fly ash or other pozzolans, GGBFS, and silica fume	50%	< 50%	Up to 80%	Up to 40%	Up to 40%
Total of fly ash or other pozzolans and silica fume	35%	< 35%	Up to 80%	Up to 30%	Up to 25%

Source: Rachel J. Detwiler, Peter C. Taylor, Specifier's Guide to Durable Concrete, Portland Cement Association, Engineering bulletin 221, 2005

MS 1226 Concrete Standard

- According to **MS 1226 : Part 1: 1991**, cement with greater than 25% of fly ash will have significant improved sulfate resistance compared to OPC.

MALAYSIAN STANDARD

MS 1226 : PART 1 : 1991
ICS : 91.080.40

PULVERIZED-FUEL ASH
PART 1 : SPECIFICATION FOR PULVERIZED-FUEL ASH FOR USE AS A CEMENTITIOUS COMPONENT IN STRUCTURAL CONCRETE

Sustainability – Green Construction

Mt Piper, Australia

Sustainability – Green Construction

What is Sustainable Construction?

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

Sustainable construction should also:

- Enhance living, working and leisure environments for individuals and communities.
- Consume minimum energy over its life cycle
- Generate minimum waste over its life cycle
- Integrate with the natural environment
- Use renewable resources where possible

Sustainability – Green Construction

Sustainable Construction should NOT

Sustainable construction should NOT:

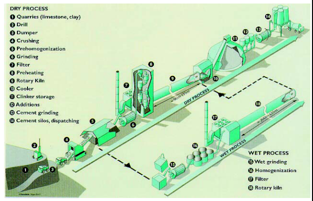
- Cause permanent damage to the natural environment or consume a large amount of resources during construction, use or demolition.
- Cause unnecessary waste of energy, water or materials due to short life, poor design, inefficiency or low standard construction techniques.

Sustainability – Green Construction

Landfilled Fly ash at Tg. Bin Power Plant

Sustainability – Green Construction

*Cement is made by heating limestone (and some other ingredients) to 1450 °C in a kiln. The resulting .clinker. is then ground with a small amount of gypsum into a powder***.** *Portland cement.*



Sustainability – Green Construction

$$CaCO_3 \rightarrow CaO + CO_2$$

1 tonne cement releases around 1 tonne of CO_2

Carbon dioxide is released during the production of clinker, a component of cement, in which calcium carbonate (CaCO3) is heated in a rotary kiln to induce a series of complex chemical reactions. Specifically, CO2 is released as a by-product during calcination, which occurs in the upper, cooler end of the kiln, or a precalciner, at temperatures of 600-900°C, and results in the conversion of carbonates to oxides.

Sustainability – Green Construction

- Certain countries like Hong-Kong seen number of “cold-days” are declining, and number of “hot nights” are increasing.
- Urban areas are warmer than countries side.

Sustainability – Green Construction

Table 1. Embodied CO_2 of factory made cements and combinations

Cement[a] Factory made cement	Combination[b] CEM I and addition combined at concrete plant	Secondary Main Constituent (smc) or Addition Low - High Content,%	Embodied CO_2[c] smc content Low - High, kg CO_2/ tonne
CEM I Portland Cement			930
CEM II/A-V Portland fly-ash cement	CIIA-V	6 - 20 fly ash	870 - 750

Sustainability – Green Construction

Many more green labels will have their local market – and they all ask questions regarding construction materials

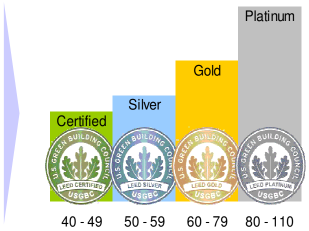
green star	Green Star	Australia & New Zealand
BCA GREEN MARK	Green Mark	Singapore
DGNB	DGNB	Germany, Eastern Europe

Sustainability – Green Construction

Sustainability – Green Construction

- LEED's holistic approach of rating:

Core categories	Credits
Sustainable sites	26
Water efficiency	10
Energy & atmosphere	35
Materials & resources	14
Indoor environmental quality	15
Bonus categories	**Credits**
Innovation in design	6
Regional priority	4



Sustainability – Green Construction

	Credit	Requirements	Comments / examples
Materials & resources (MR)	Recycled content (1-2 pts + EP)	• Recycled content has to contribute to at least 10% or 20%, based on cost, to the total materials value of a project to achieve 1 or 2 points respectively • Eligibility for exemplary performance credit for 30% recycled materials	• Recycled fraction of an assembly multiplied by cost of assembly to obtain recycled content value • Recycled content may be calculated for cement alone instead of concrete
	Regional materials (1-2 pts + EP)	• Use materials or products that have been extracted, harvested or recovered, as well as manufactured within 500 miles of project site. • Minimum regional materials content of 10% or 20%, based on cost, to achieve 1 or 2 points respectively • Eligibility for exemplary performance credit for 30% regional materials	

SGBC

	CRITERIA FOR PRODUCTS								Possible Documents Submitted	Inputs From Assessment
	S/N		Assessment Criteria	Required Documents						
					1 Tick	2 Ticks	3 ticks	4 Ticks		
SECTION B CRITICAL CRITERIA	B1	RE	Product – Clinker Content Reduction	To provide computation of the design mix to show that the clinker content per meter cube of concrete is less than 380Kg/m3. This table shows the following reduction of the total clinker content per meter cube of concrete in order to qualify for respective SGBP rating:	Clinker Content ≤ 380 Kg/m³	Clinker Content ≤ 360 Kg/m³	Clinker Content ≤ 340 Kg/m³	Clinker Content ≤ 320 Kg/m³	1) Letter of Declaration From CEO/ Authorised Representative AND 2) RMC Product Code(s)	

	CRITERIA FOR PRODUCTS							
	S/N		Assessment Criteria	Required Documents				
					1 Tick	2 Ticks	3 ticks	4 Ticks
SECTION B CRITICAL CRITERIA	B1	RE	Product – Recycled Content	Evidence or computation that the product is made of a minimum 5% recycled content by weight against the OPC (CEM I) content.	Value ≥ 5%	Value ≥ 10%	Value ≥ 20%	Value ≥ 30%

Singapore Green Labeling Scheme

SINGAPORE GREEN LABELLING SCHEME CERTIFICATION GUIDE

Category 22:
Cement and Concrete Products

Fly Ash	Fly ash is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases. In an industrial context, fly ash usually refers to ash produced during combustion of coal.

CEM II		CEM II/A-V	-	-	-	-	6-20	-	-	-	-
		CEM II/B-V	-	-	-	-	21-35	-	-	-	-
	Portland – fly ash cement	CEM II/A-W	-	-	-	-	-	6-20	-	-	-
		CEM II/B-W	-	-	-	-	-	21-35	-	-	-

Malaysia SIRIM Green Labelling Scheme

SIRIM …We Make Businesses Compete Better Through Quality and Technology Innovations

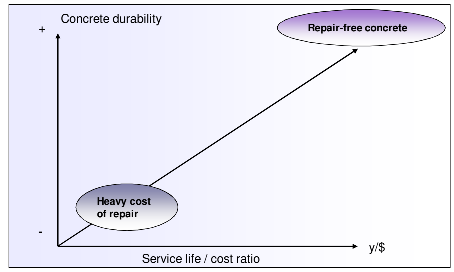
2.1 *Fly Ashes*
Fly ash is obtained by electrostatic or mechanical precipitation of dust-like particles from the flue gases from furnaces fired with pulverized coal. Ash obtained by other methods shall not be used in cement that conforms to EN 197-1.

Table of Content

- ➢ Background of fly ash
- ➢ Related standards on using fly ash as building materials.
- ➢ Why concrete don't always perform
- ➢ Benefit of using fly as in concrete
- ➢ Why Brunei needs fly ash concrete
- ➢ Fly ash projects references
- ➢ On-going researches on fly ash

Why concrete don't always perform ?

Why concrete don't always perform ?



Why concrete don't always perform ?

- Concrete abuse
- Insufficient understanding about potential problems

Why concrete don't always perform ?

- Many thinks concrete is still a low-tech commodity product not taking advantage of all the intrinsic properties of cement
  - It contains too much water (high W/C) and not enough admixtures and mineral components
  - For too many people, concrete is still just a question of number of MPa

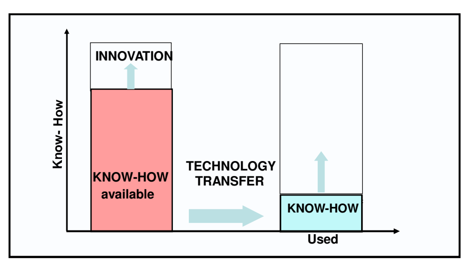
video

Why concrete don't always perform ?

- Many knowledge and do and don't reach the persons who ultimately influences the concrete performance and durability.

Why concrete don't always perform ?

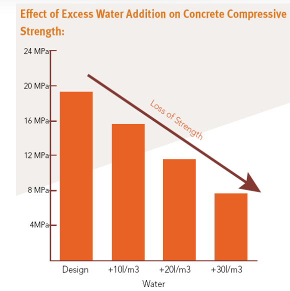
- Basic concrete technology not enough taught in our industry
- It is urgent to put into practice all the technologies that are well developed



Why concrete don't always perform ?

		Mixing & transporting	Placing
Level of technology	Low	video	video
	State of the art	video	video

Why concrete don't always perform ?

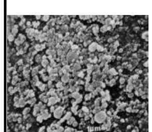


Effect of excess water on normal concrete, CemAust

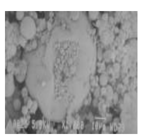
Why concrete don't always perform ?

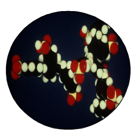
MIC: key components for durable concrete

- The latest developments in concrete technology are attributable to the use of superplasticizers and mineral components


Silica Fume


Slag


Fly ash


Superplasticizers

Why concrete don't always perform ?

Chosen the Right w/c Ratio

- Studies show that capillary porous start to be connected when w/c is higher than 0.40
- When w/c is higher than 0.70, all capillary porous are connected
- Based on this:
  - Standards tend to establish 0.65 – 0.70 as the maximum value for w/c ratio
  - The higher the aggressiveness of the environment the lower should be the w/c ratio
  - For concrete exposed to a very aggressive environment the w/c should be lower that 0.40

Why concrete don't always perform ?

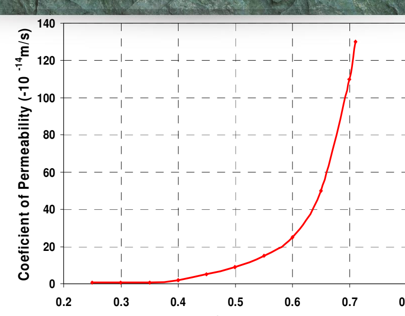
w/c = 0.50

w/c = 0.30

Looking Deeply into Concrete

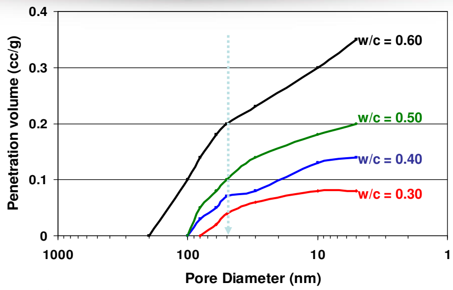
Concrete under scanning electron microscope

Why concrete don't always perform ?



After Neville (1995) Properties of Concrete

Why concrete don't always perform ?



Voids < 50 nm are detrimental to shrinkage

Why concrete don't always perform ?
➢ Chemical Attacks

- Chemical causes of deterioration
  - Acidic water
  - Chloride induces corrosion of the reinforcement
  - Carbonation
  - Sulfate attack
  - AAR
- Physical causes of deterioration
  - cracking
  - freezing and thawing
  - fire attack
- Mechanical damage
  - erosion or cavitation, impact, abrasion,….

Acid Attack Mechanism

Why concrete don't always perform ?
➢ Acid Attack

- Concretes made of Portland cement (OPC) are highly alkaline with pH values normally above 12.5 and are not easily attacked by acidic solutions.
- As the pH of the solution decreases the equilibrium in the cement matrix is being disturbed, and the hydrated cement compounds are essentially altered by hydrolytic decomposition which leads to the severe degradation of the technical properties of the material.
- At pH values lower than 12.5 portlandite is the first constituent starting dissolution.

Why concrete don't always perform ?
➢ Acid Attack

- Sulphuric acid attack causes extensive formation of gypsum in the regions close to the surfaces, and tends to cause disintegrating mechanical stresses which ultimately lead to spalling and exposure of the fresh surface.
- Owing to the poor penetration of sulphuric acid, the chemical changes of the cement matrix are restricted to the regions close to the surfaces.

Why concrete don't always perform ?
➢ Acid Attack

- However, in some cases it is observed that deterioration process occurs accompanied by the scaling and softening of the matrix due to the early decomposition of calcium hydroxide and the subsequent formation of large amount of gypsum.
- The chemical reactions involved in sulphuric acid attack on cement based materials can be given as follows:

$$Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4.2H_2O$$

$$3CaO.2SiO_2.3H_2O + H_2SO_4 \rightarrow CaSO_4.2H_2O + Si(OH)_4$$

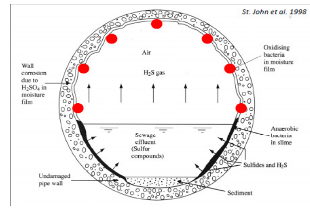
Why concrete don't always perform
Stages of Attack

pH Range	Effect
12.5 – 12	Calcium hydroxide and calcium aluminate hydrate dissolve and ettringite is formed CSH phase is subjected to cycles of dissolution and re-precipitation
11.6 – 10.6	Gypsum is formed
< 10.6	Ettringite is no longer stable and decomposes into aluminum hydroxide and gypsum
< 8.8	CSH becomes unstable

Why concrete don't always perform ?
➢ Acid Attack

LOS ANGELES SANITARY SEWER SYSTEM

ACI 210.1R-94



Deterioration of concrete pipe from H_2S attack

Why concrete don't always perform ?
➢ Acid Attack

pH of Johor State Coastal Soils

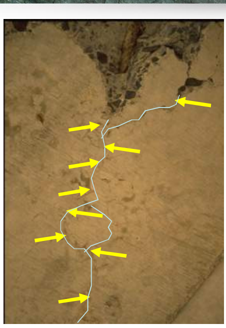
TEXTURE AND pH OF JOHOR STATE COASTAL SOILS

pH			Texture					
			% clay		% silt		% sand	
	mean	range	mean	range	mean	range	mean	range
Briah	4.9	4.6–5.3	54	46–62	29	25–34	16	9–29
Bungor	4.9	4.6–5.1	34	18–44	9	8–10	56	47–62
Kranji	6.3	5.3–7.1	81	62–94	17	2–36	2	2–4
Jerangau	4.6	4.5–4.7	51	50–51	2	1–3	47	46–48
Kulai	4.6	4.5–4.7	33	24–46	34	30–36	33	24–42
Linau	2.9	2.6–3.1	58	56–60	22	21–23	13	13-13
Munchong	4.6	4.5–4.6	41	35–43	4	2–6	51	49–54
Rengam	4.3	4.2–4.5	48	43–51	5	4–6	37	16–51
Segamat	4.8	4.6–5.2	65	51–74	27	22–34	4	4–5
Selangor	3.9	3.7–4.0	58	52–62	22	19–23	22	15–34
Serdang	4.4	4.1–4.9	31	24–38	3	1–3	68	63–73
Yong Peng	4.7	4.4–5.0	56	51–67	7	6–8	41	28–48
Marang	4.5	4.0–5.0		16–30	18		48	

Soil pH and texture characteristics were obtained from Paramananthan (1978) and from Sihibi Mohktar, Soil Division, Department of Agriculture (pers.comm.)

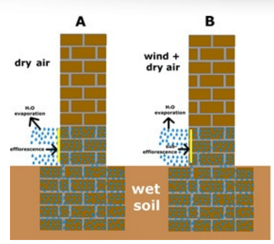
Chloride Attack Mechanism

Why concrete don't always perform ?
➢ Chloride Penetration



Consequences
1. Chloride ions diffuse in the concrete
2. Steel bars are no more protected
3. Corrosion of reinforced steel

Why concrete don't always perform ?
➢ Chloride Penetration



Why concrete don't always perform ?
➢ Chloride Penetration

Why concrete don't always perform ?
➢ Chloride Penetration

- According to the Federal Highway Administration (USA) 42% of the 575.600 American bridges can be consider unsafe or structurally deficient because corrosion
  - In the USA, from 1981 and 2000, approximately 102 billion US$ were applied in repair of these bridges. One estimates that 1 billion US$ could be saved only by improving concrete quality

Why concrete don't always perform ?
➢ Chloride Penetration

- ACI 318-2002 - Building code requirements of reinforced concrete define minimum concrete cover for reinforcement:
  - For concrete permanently exposed to earth: 7.5cm
  - For concrete not exposed to weather: 1.25cm

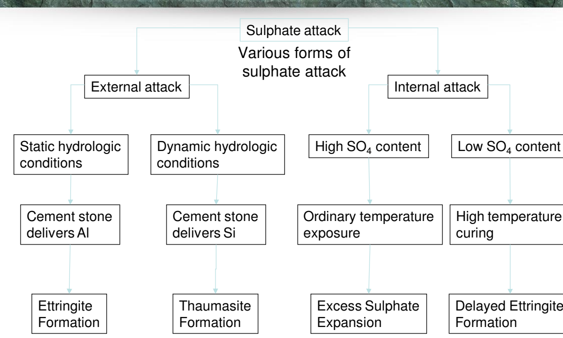
Concrete Protection for Reinforcement

Why concrete don't always perform ?
➢ Chloride Penetration

Chloride Penetration Video

Sulphate Attack Mechanism

Why concrete don't always perform ?
➢ Sulphate Attack



Kruspan, Adler, 2003

Why concrete don't always perform ?
➢ Sulphate Attack

Cement + H_2O → C-S-H + Hydration

External

SO_4^{2-} $CaSO_4$ + $Ca(OH)_2$ → Calcium Sulfate — Sulfate reaction with $Ca(OH)_2$

$CaSO_4$ (Calcium Sulfate) + C_3A $C3A{\cdot}CSO_4{\cdot}H_{32}$ (Hydrated Calcium Aluminates) → Calcium Sulphoaluminate — Calcium sulfate reaction calcium aluminates

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Alkali Silica Reaction

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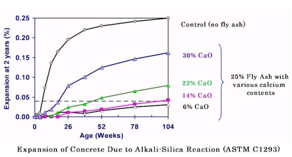
Why concrete don't always perform ?
➢ ASR



Expansion of Concrete Due to Alkali-Silica Reaction (ASTM C1293)

Alkali silica reaction (ASR)

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Why concrete don't always perform ?
➢ ASR

- Once started, the alkali aggregate reaction can not be stopped!
- So, prevention is fundamental

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Thermal Crack

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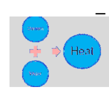
Why concrete don't always perform ?
➢ Thermal Crack

Cement Hydration Generates Heat

- Chemical reaction of cement with water (cement hydration) is a exothermic process.
- Typically a temperature rise at core is about 1.0-1.2ºC per 10 kilogram of cement

Peak Temp
Fresh Concrete Temp + Heat Generated from Cement Hydration



Example :

– Cement content is 450 kg, fresh concrete temperature at pouring is 32ºC

[450/10 x 1.1ºC] + 32ºC = 81.5ºC

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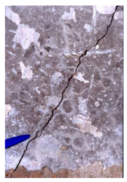
Why concrete don't always perform ?
➢ Thermal Crack



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Why concrete don't always perform ?
➢ Thermal Crack

Calculation fresh concrete temperature

$$T = \frac{0.22\,(T_aW_a + T_cW_c) + T_wW_w + T_aW_{wa} - W_i\,(79.6 - 0.5\,T_i)}{0.22\,(W_a + W_c) + W_w + W_i + W_{wa}}$$

Where:

Ta = temperature of aggregate
Tc = temperature of cement
Tw = temperature of batched mixing water from normal supply excluding ice
Ti = temperature of ice
Wa = dry mass of the aggregate
Wc = mass of cement
Wi = mass of ice
Ww = mass of batched mixing water
Wwa = mass of free and absorbed moisture in aggregate at Ta

note: the temperature of free and absorbed water on the aggregate is assumed to be the same temperature of the aggregate.

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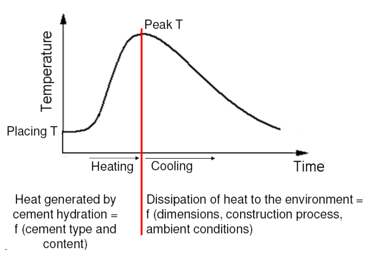
Why concrete don't always perform ?
➢ Thermal Crack

Thermal evolution over time in mass concrete



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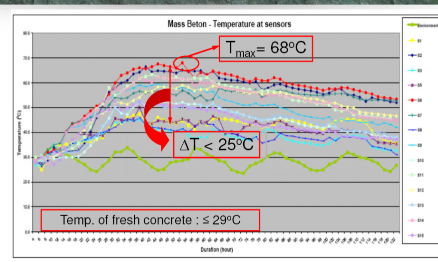
Why concrete don't always perform ?
➢ Thermal Crack



Most temp rise occurs in first 1-3 days after placement

Typical Temperature Curve

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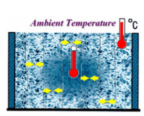
Why concrete don't always perform ?
➢ Thermal Crack

Thermal Cracking
- As the interior concrete increases in temperature and expands, the surface concrete may be cooling and contracting.
- This causes tensile stresses that may result in thermal cracks at the surface if the temperature differential between the surface and centre is too big.

- Typically a temperature differential of 20ºC can cause cracking.
- The width and depth of cracks depends upon the temperature differential, physical properties of the concrete, and the reinforcing steel.



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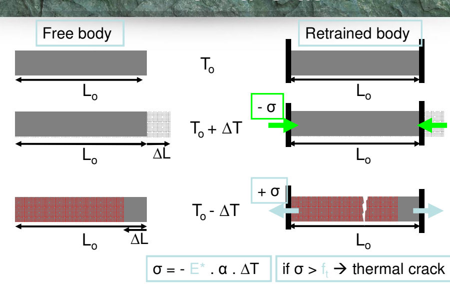
Why concrete don't always perform ?
➢ Thermal Crack



Temperature Change + Restraints → Stesses

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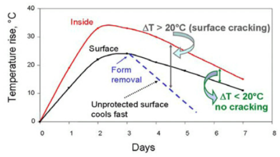
Why concrete don't always perform ?
➢ Thermal Crack

- To avoid temperature shock when removing the formwork, delay the removal of the formwork, if possible only when the core temperature is lower than the outside temperature + 20℃
- Dry Curing for 7 days



Why concrete don't always perform ?
➢ Thermal Crack

- Thermal cracks caused by excessive temperature differentials in mass concrete appear as random pattern cracking on the surface of the member.
- Checkerboard or patchwork cracking due to thermal effects will usually appear within a few days after stripping the formwork.
- Temperature-related cracks in pavements and slabs look very similar to drying-shrinkage cracks. They usually occur perpendicular to the longest axis of the concrete with a <u>time of appearance between 1 day and 2-3 weeks.g:</u>

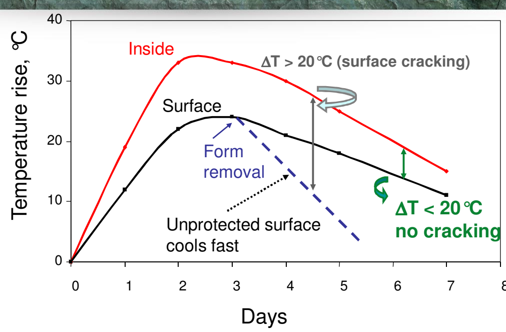
Closely spaced cracks resulting from thermal shock, Federal Highway Administration, USA

Thermal cracks in a thick slab

Courtesy CTLGroup

How to recognize thermal cracking:

Why concrete don't always perform ?
➢ Thermal Crack



Why concrete don't always perform ?
➢ Thermal Crack

- Thermal shrinkage is a consequence of cement heat of hydration.
- After 2 or 3 hours (dormant period), temperature of concrete is increasing up to a maximum value after about 10 hours or more, corresponding to the end of setting time, which is depending on many parameters
- Concrete tends to expand during this first phase and behaves like a relative soft paste.
- After that, a cooling phase of the already hardening and stiffer concrete is beginning
- This second phase is more or less long and steep, depending on many parameters which are :
  - mass of concrete (thickness of construction)
  - type of formwork and removal time
  - environmental conditions and curing measures
  - type and dosage of cement

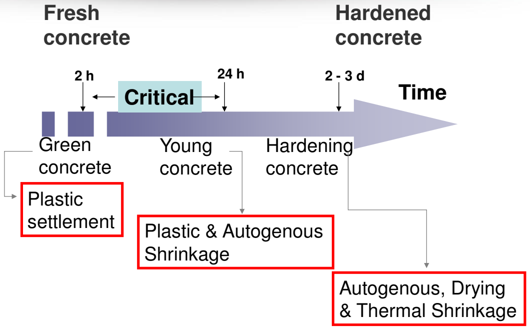
Shrinkage Cracks

Why concrete don't always perform ?
➢ Shrinkage Crack

Concrete volume change and type of shrinkage

- Most commonly, concrete volume changes deals with linear contraction due to moisture cycles and temperature
  - Plastic shrinkage
  - Drying shrinkage
  - Autogenous shrinkage
  - Thermal shrinkage or contraction

Why concrete don't always perform ?
➢ Shrinkage Crack

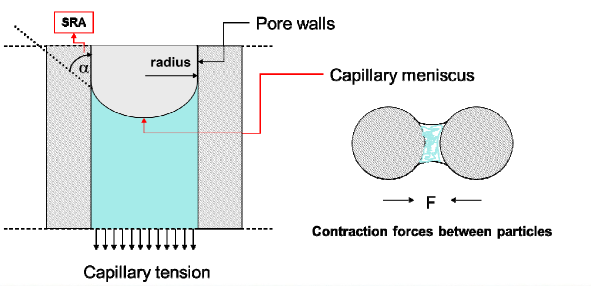


Why concrete don't always perform ?
➢ Shrinkage Crack

- Usually associated with hot weather concreting or any time when ambient conditions produce rapid evaporation
- Occurs when water is lost from concrete during plastic state (water evaporation > bleeding water)
  - by evaporation (bleeding, humidity, wind, T℃)
  - by suction of underlying dry concrete or soil
- Important in ordinary and HPC

Why concrete don't always perform ?
➢ Shrinkage Crack

- Result of the build up of tensile forces due to the formation of water menisci within the concrete pore system
- inversely proportional to the diameter of the pores



Why concrete don't always perform ?
➢ Shrinkage Crack

Fogging cools the air and raised RH

Dampening the subgrade

Why concrete don't always perform ?
➢ Shrinkage Crack

Drying Shrinkage

Occurs when water is lost from hardened concrete exposed to air with a low relative humidity

This is the only type of shrinkage which develops significantly in ordinary concrete

Table of Content

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Fresh State Properties

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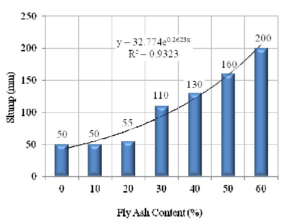
Benefit of Fly ash In Concrete
- Workability



Balakrishnan, 2016

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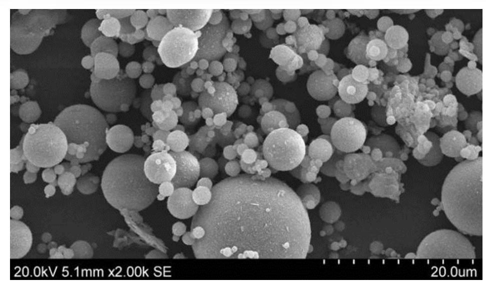
Benefit of Fly ash In Concrete
- Workability



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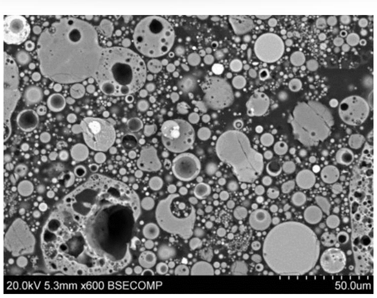
Benefit of Fly ash In Concrete
- Workability



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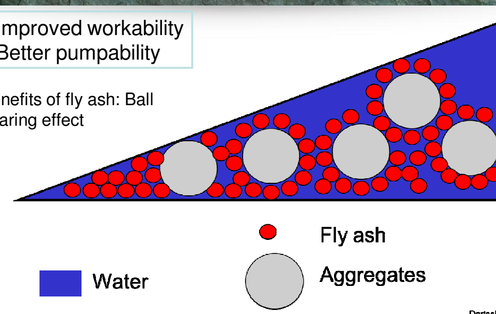
Benefit of Fly ash In Concrete
- Workability

- Improved workability
- Better pumpability

Benefits of fly ash: Ball bearing effect



Dartsch, Lutze
Betonwerk + Fertigteil-Technik, 58 (1992)

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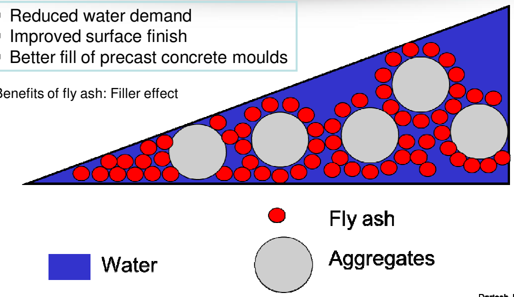
Benefit of Fly ash In Concrete
➢ Workability

- Reduced water demand
- Improved surface finish
- Better fill of precast concrete moulds

Benefits of fly ash: Filler effect



Dartsch, Lutze
Betonwerk + Fertigteil-Technik, 58 (1992)

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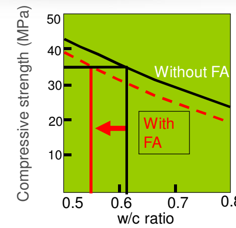
Benefit of Fly ash In Concrete
➢ Workability



Decrease of w/c ratio compensates strength loss at same workability

Reduce water to get the strength loss

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Strength Properties

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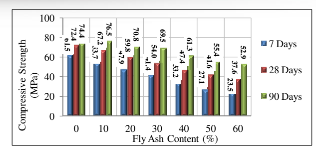
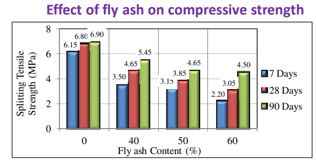
Benefit of Fly ash In Concrete
➢ Strength

- ➢ Strength up to 10% Fly ash
- ➢ Strength after 20% fly ash



Effect of fly ash on compressive strength

- ➢ Splitting Tensile Strength
  - Reduction in compressive strength.



Effect of fly ash on Splitting tensile strength

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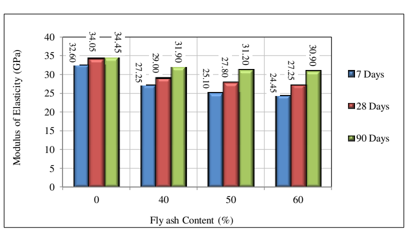
Benefit of Fly ash In Concrete
➢ Strength

- Modulus of Elasticity
- "less" affected due to dilution of reactive cement.
- MOE was lower at 7 and 28days, but 90% at 90 days



Effect of fly ash on modulus of elasticity

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Benefit of Fly ash In Concrete
➢ Strength

Mix		10% SF	20% FA
f'_c (MPa)	1d	44.1	21.6
	7d	73.6	71.4
	28d	110.2	90.0
	91d	117.6	111.3
	3 years	126.8	125.1
	5 years	129.3	134.3
E_c(GPa)	7d	38.6	39.7
	5 month	52.3	48.5
Splitting (MPa)	28d	4.4	5.0
	91d	6.8	4.8
Flexural (MPa)	28d	--	9.2

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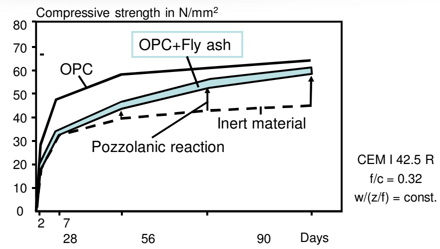
Benefit of Fly ash In Concrete
➢ Strength



Strength development of fly ash-OPC mix

Benefit of Fly ash In Concrete
➢ Strength

Cement hydration

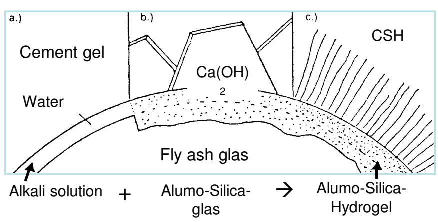
Cement + Water ⟶ CSH + $\boxed{Ca(OH)_2}$

Pozzolanic reaction of fly ash

Fly ash + $\boxed{Ca(OH)_2}$ + Water ⟶ CSH

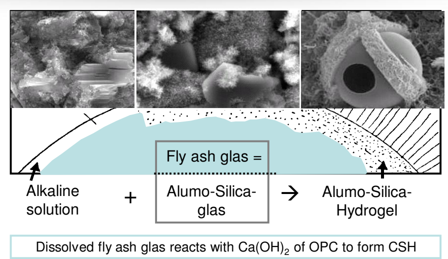
Pozzolanic Reaction

Benefit of Fly ash In Concrete
➢ Strength



Pozzolanic Reaction

Benefit of Fly ash In Concrete
➢ Strength



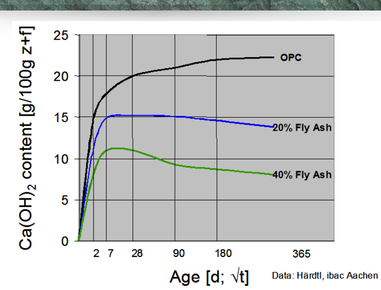
Pozzolanic Reaction

Benefit of Fly ash In Concrete
➢ Strength

SEM picture of dissolving fly ash sphere (B)

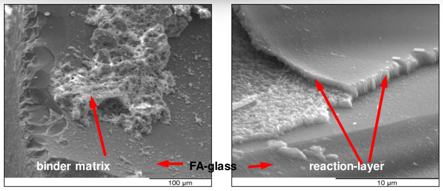
Pozzolanic Reaction

Benefit of Fly ash In Concrete
➢ Strength



Pozzolanic Reaction

Benefit of Fly ash In Concrete
➢ Strength



Strong bond matrix
OPC, fly ash, Binder. Interaction between Fly ash and matrix

Weak bond matrix
OPC, fly ash binder. Creation of reaction layer around the fly ash

Lower w/c

higher w/c

Crack stopping through fly ash strong bonding

Fly ash Minerology

Solid materials exist as either crystalline solids or amorphous solids, distinguished by the degree of geometric order of the constituent molecules. When a repeated arrangement of atoms extends throughout the entirety of a specimen without interruption, the result is a *crystal*. Crystalline solids are arranged in fixed molecular patterns, or lattices, and thus exhibit a high degree of structural order. However, this equilibrium process may be interrupted if the melt cools rapidly enough to prohibit the proper re-ordering of the molecular structure, resulting in a non-crystalline, or amorphous, material (Pietersen 1993). The transition temperature Tg in silicates is related to the energy required to break and re-form covalent bonds in an amorphous (or random network) lattice of covalent bonds. The Tg is clearly influenced by the chemistry of the glass.

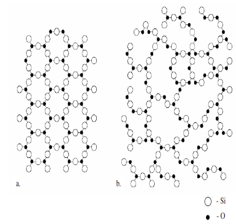


Figure 3.1 2-dimensional Representation of (a.) Crystalline and (b.) Amorphous Silica.

Reactive Silica Content

Benefit of Fly ash In Concrete
➢ Strength

Test Items		Fly Ash	BS EN 450-1 : 2005 Requirements
Total Insoluble Residue as IR,	% m/m	39.5	-
Magnesia as MgO,	% m/m	1.9	4.0% max
Sulphuric Anhydride as SO_3,	% m/m	0.2	3.0% max
Loss on Ignition,	% m/m	0.8	Cat A: 5.0% max Cat B: 2.0 – 7.0% max Cat C: 4.0 – 9.0% max
Total Silica as SiO_2,	% m/m	67.0	70.0% min
Iron Oxide as Fe_2O_3,	% m/m	5.8	
Aluminium Oxide as Al_2O_3,	% m/m	18.5	
Total Calcium Oxide as CaO,	% m/m	0.8	-
Reactive Calcium as CaO,	% m/m	0.3	10.0% max
Reactive Silica as SiO_2,	% m/m	27.4	25.0% min
Sodium Oxide as Na_2O,	% m/m	0.15	-
Potassium Oxide as K_2O,	% m/m	0.04	-
Total Alkalinity as $Na_2O + 0.658K_2O$,	% m/m	0.18	5.0% max
Chloride content as Cl^-,	% m/m	Less than 0.01	0.1% max
Soluble Phosphate as P_2O_5	mg/kg	5	100 mg/kg max

Reactive Silica Content

Resistance to Chemical Attack

Acid Attack

Benefit of Fly ash In Concrete
➢ Resistance to HCl 5%

0% Fly Ash

40% Fly Ash

50% Fly Ash

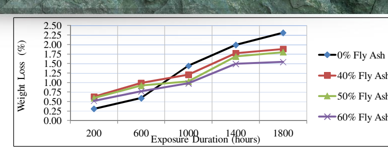
60% Fly Ash

Condition of cube after exposure to acid for 1800 hours.

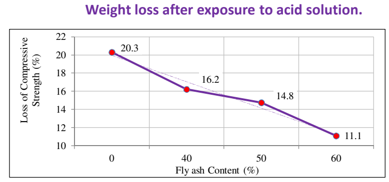
Balakrishnan, B., & Awal, A. A. (2014). Durability properties of concrete containing high volume malaysian fly ash. *Measurement*, *2*(2.94), 2-94.

Benefit of Fly ash In Concrete
➢ Resistance to HCl 5%

- Specimens lost weight and the concrete without any fly ash had the highest weight loss.
- OPC concrete strength loss is almost double of the 60% fly concrete.
- Concrete with lesser $Ca(OH)_2$ has better resistance to acid.

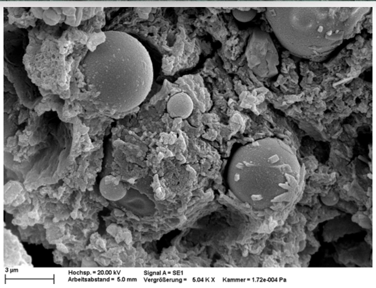


Weight loss after exposure to acid solution.



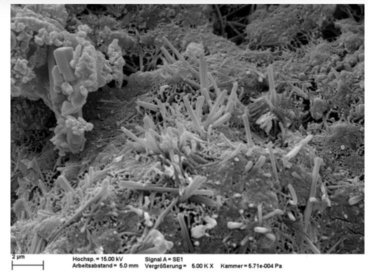
Compressive strength after 1800H in acid solution.

Benefit of Fly ash In Concrete
➢ Resistance to H_2SO_4 5%



Fly ash Mix After Acid

Benefit of Fly ash In Concrete
➢ Resistance to H_2SO_4 5%



OPC Mix After Acid

Benefit of Fly ash In Concrete
➢ Resistance to H_2SO_4 5%

Visual demonstration of specimen

Mortar specimen
- Cement
- Fly-ash

Mortar specimen
- Cement

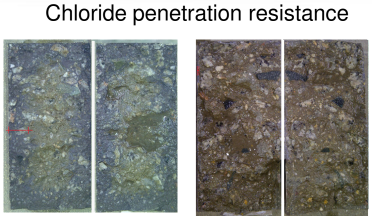
2 ½ months storage in sulfuric acid pH 2.5

Resistance to Chemical Attack

Chloride Penetration

Benefit of Fly ash In Concrete
➢ Resistance to NaCl 5%

Chloride penetration resistance



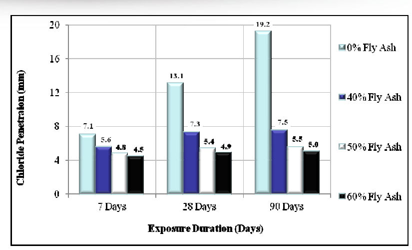
0% FA

50% FA

Balakrishnan, B., & Awal, A. A. (2014). Durability properties of concrete containing high volume malaysian fly ash. *Measurement*, *2*(2.94), 2-94.

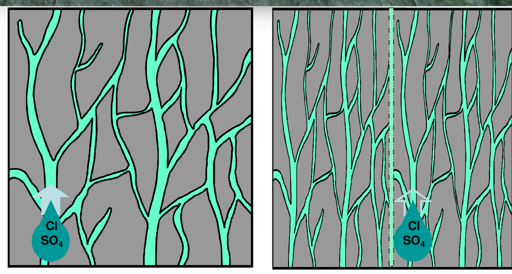
Benefit of Fly ash In Concrete
➢ Resistance to NaCl 5%

- ➢ Resistance to Chloride penetration
- ○ Reduction in capillary pores.



Effect of fly ash on chloride penetration

Benefit of Fly ash In Concrete
➢ Resistance Chloride Penetration

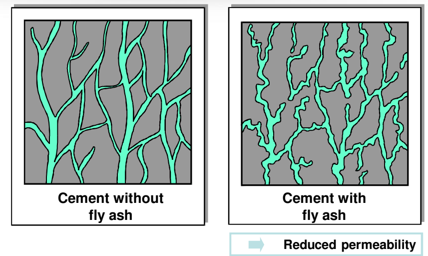


Pore size distribution in pure OPCs | **Pore size reduction in fly ash cements**

Reduced pore size at same total porosity ! (pore size reduction)

fppt.com

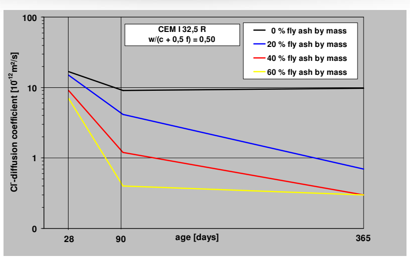
Benefit of Fly ash In Concrete
➢ Resistance Chloride Penetration



Pore Blocking effect

fppt.com

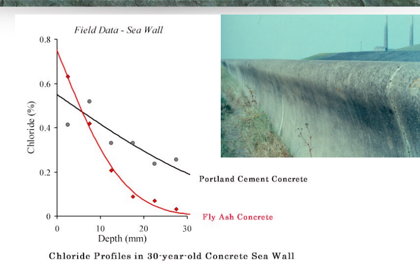
Benefit of Fly ash In Concrete
➢ Resistance Chloride Penetration



Cl⁻-diffusion as function of fly ash content

fppt.com

Benefit of Fly ash In Concrete
➢ Resistance Chloride Penetration

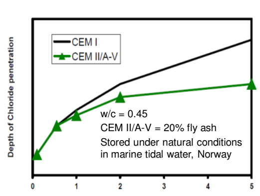


Chloride profile of 30 year fly ash concrete

fppt.com

Benefit of Fly ash In Concrete
➢ Resistance Chloride Penetration

- Composite cement products are more resistant to chloride attack due to their more compact microstructure



Durability - Chloride attack

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Resistance to Chemical Attack

Sulphate Attack

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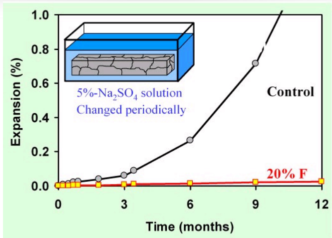
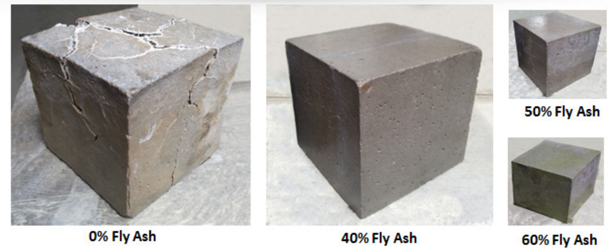
Benefit of Fly ash In Concrete
➢ Resistance Sulphate Attack



Expansion of Mortar Due to Sulfate Attack (ASTM C 1012)

Sulphate resistance

Benefit of Fly ash In Concrete
➢ Resistance Na_2SO_4 5%

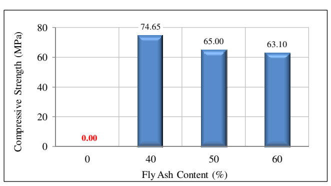


Condition of specimen after exposure to sulphate solution for 550 days

Balakrishnan, B., & Awal, A. A. (2014). Durability properties of concrete containing high volume malaysian fly ash. *Measurement*, *2*(2.94), 2-94.

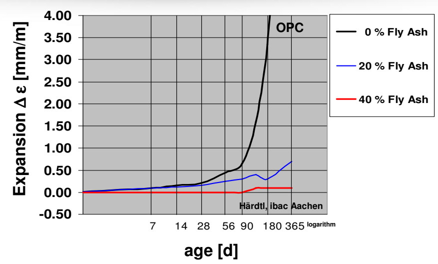
Benefit of Fly ash In Concrete
➢ Resistance Na_2SO_4 5%

- OPC concrete completely lost compressive strength.
- HVFA concrete stayed intact and continued to gain strength.
- Deformation in OPC caused by formation of expansive ettringite.

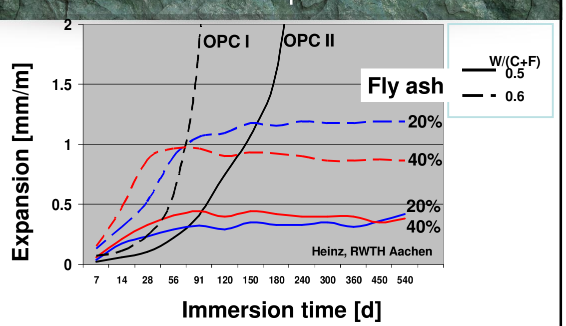


Compressive strength after 550 days in sulphate solution

Benefit of Fly ash In Concrete
➢ Resistance Sulphate Attack

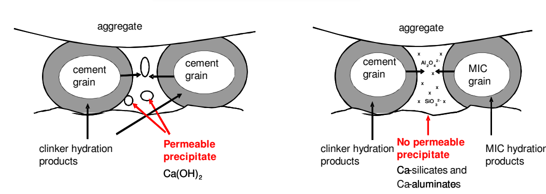


Benefit of Fly ash In Concrete
➢ Resistance Sulphate Attack



Sulphate resistance (4.4% Na_2SO_4)

Benefit of Fly ash In Concrete
➢ Resistance Sulphate Attack



Cement Application Course

Benefit of Fly ash in Concrete

Shrinkages

Benefit of Fly ash in Concrete

Temperature Rise

Benefit of Fly ash In Concrete
➢ Lower Temperature Rise

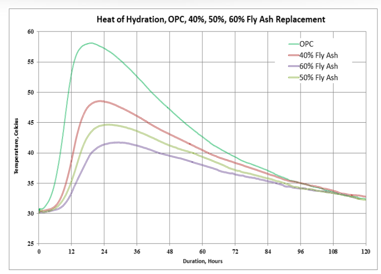
Cement hydration raises the temperature of the concrete depending on:

- Size of the concrete placement
- Surrounding environment
- Amount of cement hydrated
- Use of MIC

Rule: an 8 to 14 °C temperature rise per 100 kg of OPC

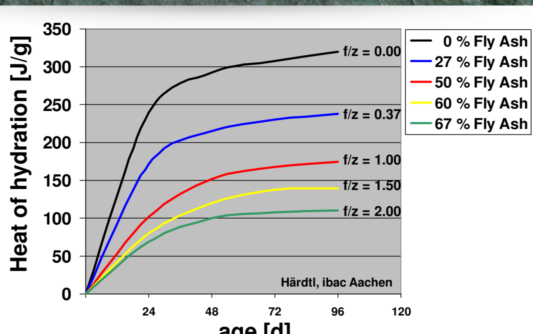
Fly ash reduces heat of hydration

Benefit of Fly ash In Concrete
➢ Lower Temperature Rise



Balakrishnan, B., & Awal, A. A. (2014). Influence of high volume fly ash in controlling heat of hydration of concrete. *Measurement, 2013*

Benefit of Fly ash In Concrete
➢ Lower Temperature Rise



Benefit of Fly ash In Concrete
➢ Lower Temperature Rise

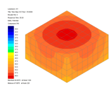
Cementitious materials	Maximum allowed by ACI 318*	Recommended dosage range (% of total cementitious materials by mass)			
		Unreinforced pavements and slabs	Mass concrete	Structural concrete	Bridge decks and parking garages
Fly ash or other pozzolans	25%	< 25%†	30%-80%	15%-25%	15%-25%
GGBFS	50%	15% to 30%	30%-80%	25%-40%	30%-40%
Silica fume	10%	5% to 10%	< 10%‡	Up to 10%	Up to 8%
Total of fly ash or other pozzolans, GGBFS, and silica fume	50%	< 50%	Up to 80%	Up to 40%	Up to 40%
Total of fly ash or other pozzolans and silica fume	35%	< 35%	Up to 80%	Up to 30%	Up to 25%

Recommended addition dosage ranges for mass concrete from PCA

Source: Rachel J. Detwiler, Peter C. Taylor, Specifier's Guide to Durable Concrete, Portland Cement Association, Engineering bulletin 221, 2005

Benefit of Fly ash In Concrete
➢ Lower Temperature Rise

- ACI doesn't use specific size limits to define mass concrete
- In ACI 116R-00, "Cement and Concrete Terminology." This document defines mass concrete as "any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat from hydration of the cement and attendant volume change
- ACI 301-99 , In general, heat generation should be considered when the minimum cross-sectional dimension approaches or exceeds 2-1/2 ft [750 mm] or when cement contents above 600 lb/yd ³ [356 kg/m ³] are used



What is mass concrete?

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Benefit of Fly ash in Concrete

Alkali Silica Reactions

fppt.com

Benefit of Fly ash In Concrete
➢ Prevent ASR

- Cement hydration produces $Ca(OH)_2$
- $Ca(OH)_2$ acts as a catalyser of alkali aggregate reaction
- Slag, pozzolan, fly ash, silica fume react with $Ca(OH)_2$, hindering the occurrence of the alkali aggregate reaction
- The use of active mineral components also leads to a more dense, impermeable microstructure, which makes difficult the ion migration and the occurrence of alkali aggregate reaction

Preventing the Alkali Aggregate Reaction by Using Mineral Components

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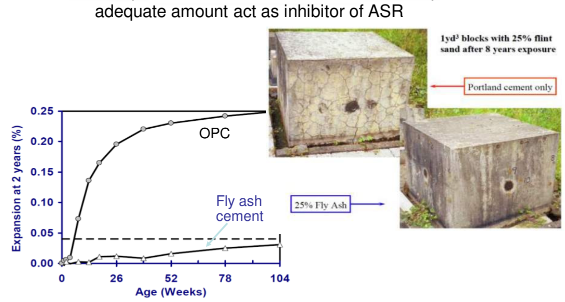
Benefit of Fly ash In Concrete
➢ Prevent ASR

- Composite cements with active mineral components in adequate amount act as inhibitor of ASR



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Benefit of Fly ash in Concrete

Resistance to High Temperature

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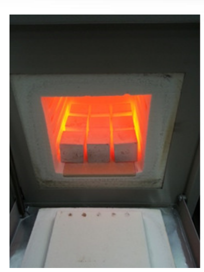
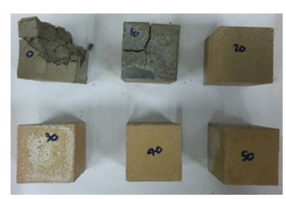
Benefit of Fly ash In Concrete
➢ Resistance to High Temperature





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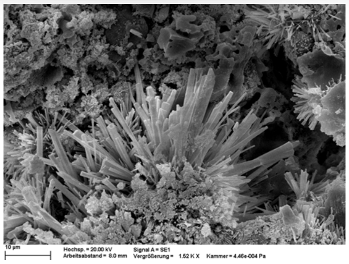
Benefit of Fly ash In Concrete

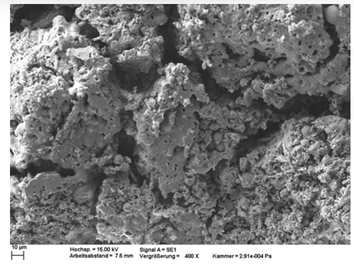
➢ Resistance to High Temperature



OPC Mix after 1000C

Benefit of Fly ash In Concrete

➢ Resistance to High Temperature



Fly ash Mix after 1000C

EN 206-1:2000 Part 1: Specification, performance, production and conformity

	EXPOSURE CLASSES									
	Carbonation-induced corrosion		Chloride-induced corrosion				Freeze-thaw attack		Aggressive chemical environment	
			Sea water		Chloride other than from sea water					
	XC1	XC4	XS1	XS3	XD1	XD3	XF1	XF4	XA1	XA3
Maximum w/c	0.65	0.50	0.50	0.45	0.55	0.45	0.55	0.45	0.55	0.45
Minimum cement content (kg/m^3)	260	300	300	340	300	320	300	340	300	360

XC1: dry or permanently wet environment: concrete inside buildings with low air humidity and concrete permanently submerged in water

XC4: cyclic wet and dry environment: concrete surfaces subject to water contact

XA3: highly aggressive chemical environment. For example, concrete subject to pH between 4 and 4.5

EN 206-1:2000 Part 1: Specification, performance, production and conformity

EN 206-1:2000 Part 1: Specification, performance, production and conformity

- Cement consumption:
  - ≥ 260kg/m^3 for concretes exposed to environment with low degree of aggressiveness
  - ≥ 360kg/m^3 for concretes exposed to highly aggressive environments
- Water/cement ratio
  - ≤ 0.45 for concretes exposed to highly aggressive environments
  - ≤ 0.65 for concretes exposed to environment with low degree of aggressiveness

Summary of Benefits

- Increase the final strength of concrete
- Improves the workability of concrete
- Lower the water to cement ratio
- Reduce risk of alkali silica reaction
- Lower heat of hydration
- Better resistant to chemical attack
- Less shrinkage
- Decreased Permeability
- Improved Finishing
- Reduce the CO_2 emissions

Table of Content

- ➢ Background of fly ash
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- ➢ Fly ash projects references
- ➢ On-going researches on fly ash

Brunei Environment

- Tropical Climate
- Aggressive Environments

Brunei Environment

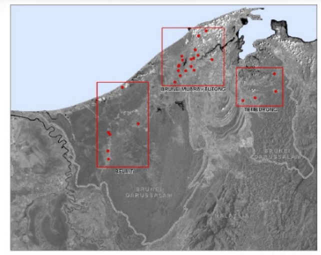

Figure 1: Location of the Surveyed Areas in Negara Brunei Darussalam (identified by the red dots).

Fitzpatrick, R., et al. "Inland acid sulfate soil systems across Australia." *Perth, Australia, CRC LEME* (2008): 189.

Brunei Environment

DISTRIBUTION

Brunei contains a wide range of different types of acid sulfate soils in various physical settings, which occur because of changing hydrological and biogeochemical conditions. There are two broad situations in which various organic matter fractions (mostly sapric) and minerals (e.g. pyrite, jarosite and schwertmannite) form acid sulfate soils via various micro-scale weathering pathways:

Soil pH and Electrical Conductivity

The floodplain soils and sediments generally have low pH values ranging from 2.5 for the sub-surface (80–180 cm) of the Soft poorly drained sulfuric soil at Limpaki (06 0002) to 6.2 in the surface (0–5 cm) of the Mineral sulfuric organic soil from Labi Lama (23 0001), indicating that acid neutralising capacity is already exhausted. Electrical Conductivity values ranged from 0.02 dS m^{-1} at 20–70 cm in the Organic poorly drained moderately deep sulfidic soil at site 2 Melayan A (22 0002) to 8.6 dS m^{-1} for the sub-surface (80–180 cm) of the Soft poorly drained sulfuric soil at Limpaki (06 0002).

Fitzpatrick, R., et al. "Inland acid sulfate soil systems across Australia." *Perth, Australia, CRC LEME* (2008): 189.

Brunei Environment

Sulfuric acid produced by acid sulfate soils corrodes concrete, iron, steel and certain aluminium alloys. It has caused the weakening of concrete structures and corrosion of concrete slabs, steel fence posts, foundations of buildings and underground concrete water and sewerage pipes.

Sammut, Jesmond. An Introduction to acid sulfate soils. 1995

Brunei Environment

Table 2 Selected soils showing key morphology and laboratory data (soil profiles are ordered alphabetically)

Soil class Site No./water-table depth	Horizon	Depth (cm)	Texture† class	Consistency‡	EC dS/m	pH ageing	OC %	Clay %	Silt %	Sand %
Haplic Sulfaquent	L	0–1	LL	L						
01_0013	A	1–5	SL	VFR	1.13	3.04	14			
WT = 30 cm	AB1	5–20	SCL	FR	0.41	3.22	15			
	AB2	20–30	SCL	FR						
	Oi	30–45	PEAT	S	0.98	3.26	8			
	Oe	45–50	MPM	S						
	Bj	50–150	SC	FI	2.64	2.97	3			
	BCgj	150–200	SC	FI	1.69	3.65	1			
Haplic Sulfaquent	A	0–5	CL	L	0.84	3.29	16	39	25	37
01_0016	Oi1	5–10	PEAT	FR						
WT = 30 cm	Oi2	10–30	PEAT	FR	0.59	3.38	6	53	24	23
	Oa	30–50	HPM	FI	0.71	3.29	5	47	26	26
	Bg1	50–70	SC	VFI	0.42	3.50	3	33	23	44
	Bg2	70–100	SC	VFI	1.89	3.08	2	33	31	36
	2Bgj1	100–130	SC	VFI						
	2Bgj2	130–175	SC	VFI	2.05	2.97	1	19	15	67
	3C	175–200	SC	FF						

Fitzpatrick, R., et al. "Inland acid sulfate soil systems across Australia." *Perth, Australia, CRC LEME* (2008): 189.

Brunei Environment

What are acid sulphate soils?

Acid sulphate soils are soils in which sulphuric acid may be produced, is being produced or was produced in amounts that have a lasting effect on major soil characteristics (Pons, 1973; Dent & Pons, 1995).

It Corrode concrete and steel in buildings and underground pipes (e.g. Dent & Pons, 1995).

Damage to Foundations Acid released from the soil can attack both the concrete, and the steel reinforcement within the concrete weakening the house foundation and the cement within the brick walls

Pulau Muara Besar Bridge

Durability is required for our region

Construction in Reclaimed Sea in Johor Bahru

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Fly Ash Project References

Great Belt Bridge
DK (1997)

Petronas Towers
MAY (1999)

Burj Khalifa
Dubai (2010)

Dialog Project Johor, Malaysia

Required minimum 25% fly ash
Grade 40MPa & 50%
Sulfate resistant concrete
Retardation 4 hours for transport

Dialog Project Johor, Malaysia

Pulau Muara Bridge, Brunei

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Temburong Bridge, Brunei

fppt.com

Low heat concrete – Tank foundation, Dialog Malaysia

fppt.com

Kimlun Condominium – Johor Malaysia

fppt.com

Paragon Residence – Johor Malaysia

Pile Cap

35 MPa 56 Days

40% Fly ash

fppt.com

Paragon Residence – Johor Malaysia

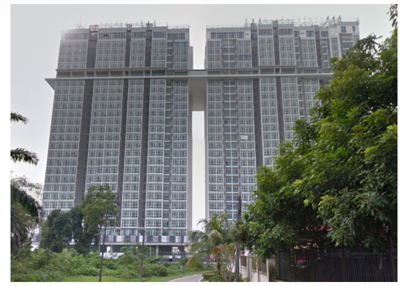
fppt.com

Paragon Residence – Johor Malaysia

Peak Temperature 66ºC

Paragon Residence – Johor Malaysia

Transfer Slab
Grade 40MPa
Thickness 1.5m
10,000m3 Total
Single pour 3000m3



Self Compacting Concrete, Johor

KLCC, Malaysia

Fly ash has been used in construction of world's tallest building "Petronas towers of Kuala Lampur". The concrete used in the building was of two grades 80 MPa and 60 MPa. The fly ash content was about 37.5 % of total cementitious content in mix. Construction completed in the year 1998.

High performance concrete

About 60,000 cum of fly ash concrete with an estimated saving of 3,000 tonne of Ordinary Portland Cement was used in Lednock Dam construction in UK during the year 1955.

Concrete elements

Zollhaus, Germany (1999)

Underground parking lot
concrete walls, columns

Upper walls and columns
Strength class B35

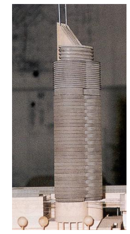
High performance concrete

Castor and Pollux, Germany (1998)

Self compacting concrete SCC

Millenium Tower, Austria (1999)

Strength class B60



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Self compacting concrete SCC

New Theatre Den Haag,
The Netherlands (2000)

Fly ash in the concrete mix

SCC for V shape columns

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High performance concrete

Cooling Tower, Germany (2000)

Acid/sulfate resisting concrete B85

- no inner coating

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High performance concrete

Collogne Tower, Germany (2001)

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High performance concrete

Great Belt Bridge, Denmark (1997)

47 kg fly ash / m^3 concrete

- 100 years service lifetime

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Lightweight concrete

Kai Centre, Düsseldorf, Germany (1999)

Lightweight high performance concrete fassade

fppt.com

Underwater concrete

Potsdamer Platz, Berlin (1998)

Steel fibre underwater concrete for foundation plates.
Strength class B25

fppt.com

Underwater concrete

River Este protecting Sluice, Hamburg (1998)

24’000m3 B25/B35 used as underwater concrete and in concrete walls

- reduced expansion and heat of hydration
- Increased durability (frost, chemical)

fppt.com

High performance concrete

Elbe Tunnel, Germany (2003)

Tunnel tubbings (precast elements)

- high durability against chemical attack

fppt.com

High performance concrete

Confederation Bridge, Prince Edward Island, Canada (1998)

- 100 years service life time
- Precast elements, mass concrete
- High durability: Freeze/Thaw; Seawater, ASR

fppt.com

High performance concrete

Chicago Tower, Hyatt (2000)

Strength class B85

fppt.com

Mass concrete

Messeturm, Frankfurt (1987)

17'000 m3 of B35 concrete used
in foundation slab
- Reduced heat of hydration
- Increased resistance to chemical attack (Sulphates/chlorides)

Mass concrete

Foundation plate, Power station Schkopau, Germany (1999)

160'000 m3 foundation plate
- Low hydration heat
- Sulfate resistance

Industrial concrete floors

Recycling company, Germany (1999)

High performance steel fibre
high performance concrete
for industrial floors
Strength class B85

Municipial sewage plant

Fouling tanks, Germany (2000)

High performance concrete
- Chemical attack resistant
- Reduced water permeability
- Denser concrete matrix

Visible concrete

University Munich, Germany (2000)

Lightweight concrete
Unprocessed concrete surface
- Improved workability
- Improved homogeinity and stability of fresh concrete
- Good shaping and finish

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Advanced Knowledge in Concrete Technology : Common Problems and Solutions

3/21/2017

Parnam Singh
RNC Technology(M) Sdn Bhd

23rd March 2017

Senate Room, Universiti Brunei Darussalam.

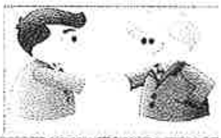
Speaker's Profile

Mr Parnam Singh *B.E (Hons), MSc (Civil), U.K MCSM, MACF, MACI (KL Chapter)* graduated from the Queen's University of Belfast (U.K) in 1989. He is a registered Civil Engineer with the Board of Engineers Malaysia and the Institution of Engineers Malaysia and has more than 27 years of experience in the assessment and repair of concrete structures.

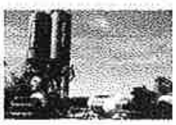
He is currently the General Manager of RNC Technology (M) Sdn Bhd., leading a team of managers and engineers specializing in concrete assessment and repair technology.

About the Presentation

- **Client**
- **Architect / Engineer**
- **Contractor**
- **Ready Mix Supplier**



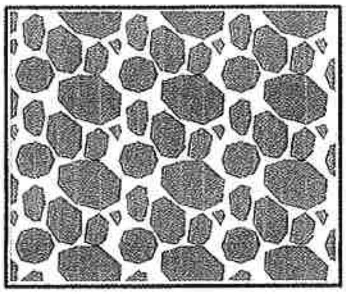




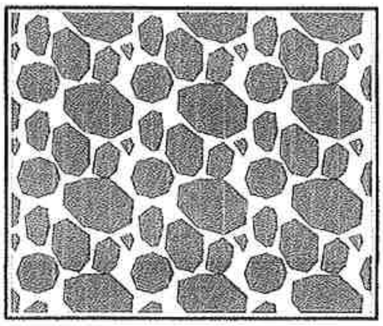
Presentation Outline

1. BASICS OF CONCRETE TECHNOLOGY
2. PHYSICAL DEFECTS IN CONCRETE AND THEIR CAUSES
3. PROBLEMS AND SOLUTIONS

1. BASICS OF CONCRETE TECHNOLOGY



Quality of concrete is dependent on the inherent properties of its constituent materials

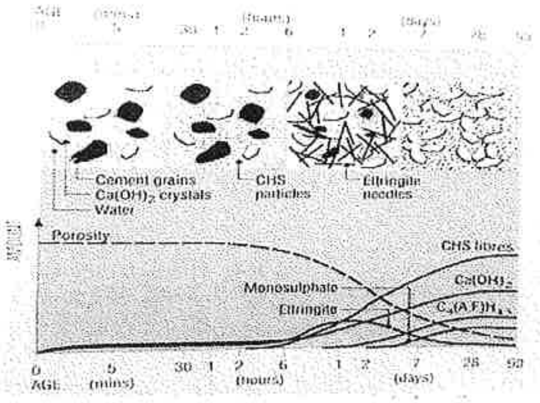


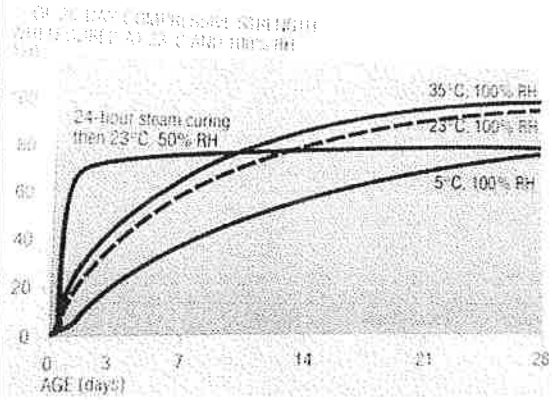
CEMENT PASTE

Cement paste binds coarse aggregates and fine aggregates during the process of setting and hardening.

Hydration of OPC particles takes place resulting in the production of a binder. Heat is liberated.

The liberation of heat needs to be managed. The cement paste forms a "skin" and serves as the first line of defence against external agents in its hardened state.





Technical Notes

- Cement paste functions as a binder, filler and finishing aid. However it is also the source of shrinkage in concrete.
- Cement paste lacks the restraint provided by aggregates; neat paste can shrink four to five times more than concrete with the same paste.
- Reducing paste quantity will reduce shrinkage and cracking and thereby improving durability.

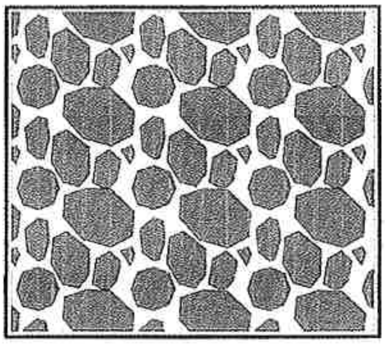
Technical Notes

- Rate of strength gain in addition to the total degree of hydration has a significant effect on the pore structure, micro and macro cracking and thus on the transport permeability properties of cementitious materials

At normal rates of strength gain,

- 3days- 50% of ultimate strength
- 7days- 70% of ultimate strength
- 28days- almost 95% or more of ultimate strength

the hydration products have sufficient time to diffuse throughout the cement matrix and precipitate uniformly.



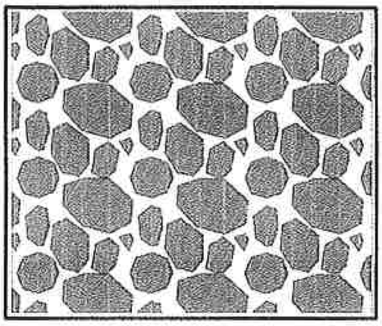
FINE AGGREGATES

Fine aggregates are locked with coarse aggregates in the presence of cement paste.

Fine aggregates fill voids between coarse aggregates.

Fine aggregates free from silt or other organic or deleterious matter produce a denser mix with high workability. Proper mixing is crucial during the batching stage.

Porosity of concrete will largely depend upon how well the fine aggregates are mixed during the batching stage.



COARSE AGGREGATES

Coarse aggregates are locked with fine aggregates in the presence of cement paste.

Coarse aggregates provide the mass or volume when mixed with fine aggregates.

Coarse aggregates which are uniformly graded produce a mix which is dense, strong, and more durable than coarse aggregates which are gap graded.
Density of concrete will largely depend upon how well the coarse aggregates are mixed during the batching stage.

Technical Notes

- Well graded mixtures generally have a uniform distribution of aggregates on each sieve
- There is a definite relationship between aggregate grading and concrete strength, workability and long term durability.
- Intermediate size aggregates fill voids typically occupied by less dense cement paste and thereby optimise concrete density.

Increasing concrete density in this manner will result in:

Technical Notes

- Reduced mixing water demand and improved strength because less mortar is necessary to fill space between aggregates.
- Increased durability through reduced avenues for water penetration in the hardened concrete.

Technical Notes

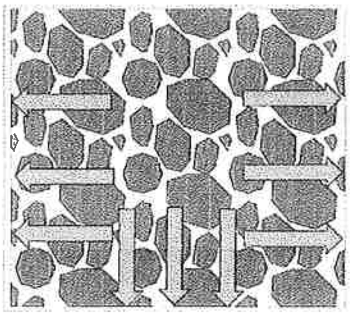
- At accelerated rates, the hydration is so much faster than the diffusion process that most of the hydration products remain static near the cement grains, leaving the interstitial space relatively open.
- Materials with low strength gain(for instance those containing fly ash and slag cement) perform better in hot climates.

Technical Notes

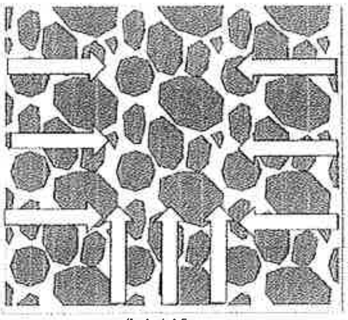
- Better workability and mobility because large aggregate particles do not bind in contact with other large particles under the dynamics of finishing and vibration, and
- Less edge slump because of increased particle to particle contact.
- Well graded aggregates also influence workability and ease of the placing , consolidating and finishing of concrete.
- 7day/70 years pledge

Technical Notes

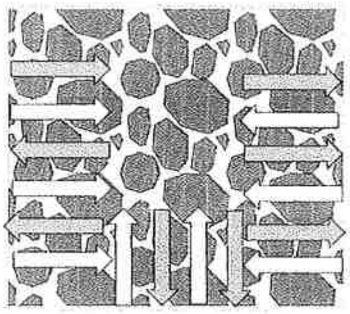
High performance concrete with a w/c ratio of 0.3 normally requires water reducing admixtures, which may be workable but may not necessarily reduce the amount of shrinkage



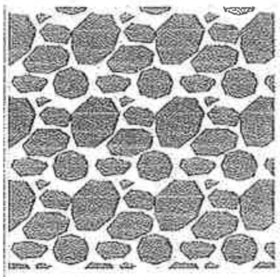
Concrete in Fresh State



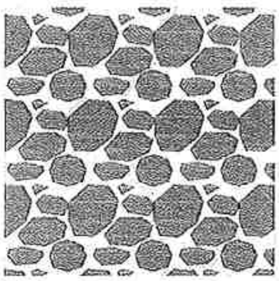
Restraint Forces



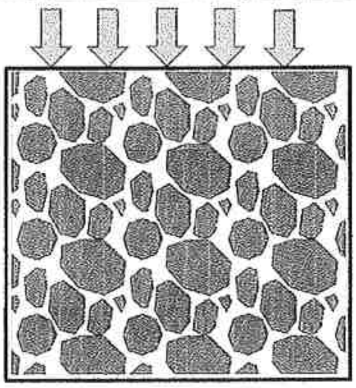
Concrete in Setting and Hardening State



Bond Failure

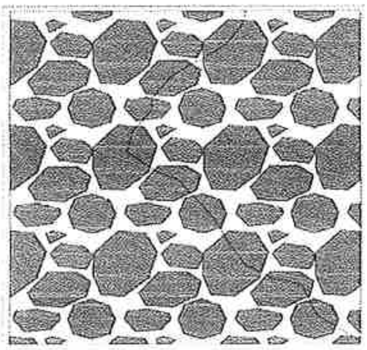


Cement Paste Failure



Technical Notes

- A stronger and stiffer cementitious material is more likely to crack because the higher the modulus of elasticity, higher the tensile stress because of drying shrinkage and other restrained volume changes.
- It is important to remember that durability is not a function of early strength but is a function of long term strength



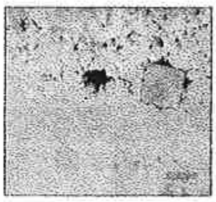
Aggregate Failure

2. Physical Defects in Concrete and Their Causes

Physical Defects in Concrete and Their Causes

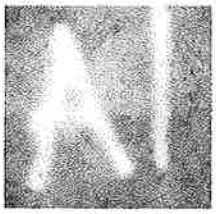
Defect	Description	Most probable causes
Honeycombing	Coarse stony surface with air voids, lacking in fines	• Formwork Leaking joints • Concrete mix Insufficient fines Workability too low • Placing methods Segregation Inadequate compaction • Design Highly congested reinforcement Section too narrow

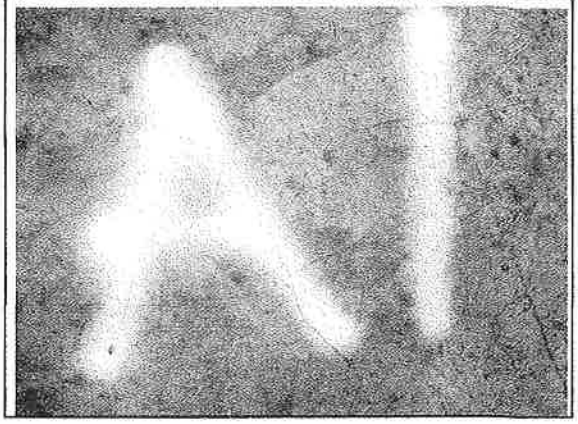
Defect	Description	Most probable causes
Blowholes (Bug holes)	Individual cavities usually less than 12mm diameter Smaller cavities approximately hemispherical; larger cavities often expose coarse aggregate	• Formwork Form face impermeable, with poor wetting characteristics Face inclined, face to flexible • Release agent Neat oil without surfactant • Concrete mix Too lean Too coarse sand Workability too low • Placing methods Inadequate compaction Too slow rate of placing



Defect	Description	Most probable causes
Mortar loss or grout loss or scouring	Sand textured areas, devoid of cement. Usually associated with dark colour on adjoining surface. Irregular eroded areas and channels having exposed stone particles	• Formwork Leaking at joints, tie holes, and the like • Concrete mix Excessively wet Insufficient fines Too lean • Placing methods Water in forms excessive vibration of wet mix Low temperature

Defect	Description	Most probable causes
Plastic cracking	Short cracks, often varying in width across their length. On vertical faces, cracks are more often horizontal than vertical.	• Formwork Poor thermal insulation Form profiles of reinforcement which restrain settlement of the concrete • Concrete mix High water-cement ratio Low sand content Excessive bleeding of mix • Ambient conditions Conditions leading to high evaporation of moisture from concrete

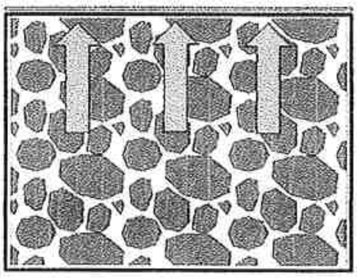


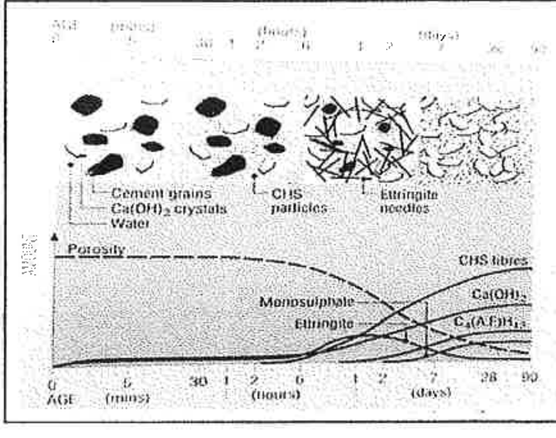


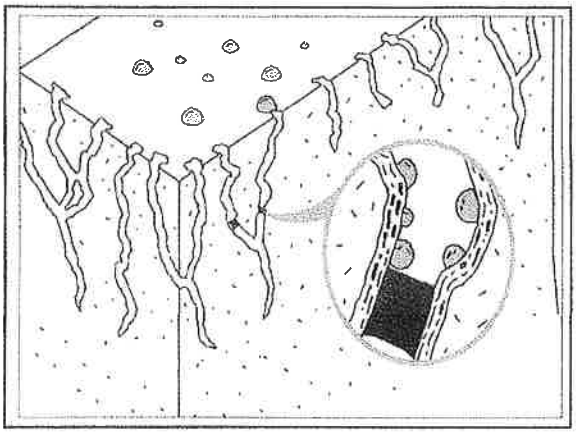
Defect	Description	Most probable causes
Scaling, spalling or chipping, and form scabbing	Scaling is the local flaking or peeling away of a thin layer of mortar from the concrete. Spalling or chipping is the local removal of a thicker layer or edge of mortar. Form scabbing is the adhesion of portions of form surface, including sealant or barrier paint, to the concrete	• Formwork Inadequate stripping taper Inadequate stiffness Movement of form lining due to change hydrostatic pressure of concrete with depth Key of concrete into wood grain, saw kerfing, and interstices in form surfaces Local weakness of form face • Ambient conditions Frost action may cause spalling • Stripping Too early stripping may cause scaling Too late stripping may cause scabbing

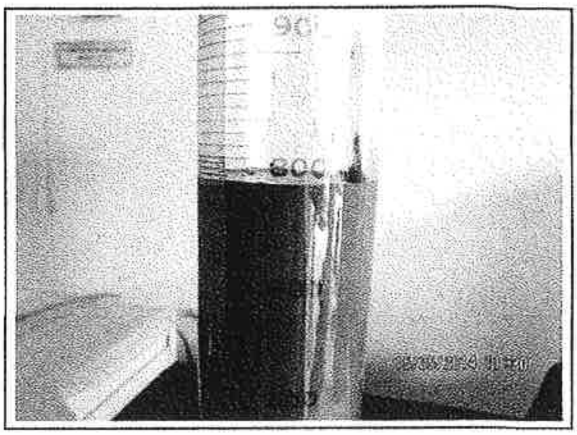
Defect	Description	Most probable causes
Crazing	A random pattern of fine shallow cracks dividing the surface into a network of areas	Form Form face of low absorbency, smooth or polished • Concrete mix A high water-cement ratio combined with a cement-rich mix can be a contributory cause • Curing Inadequate

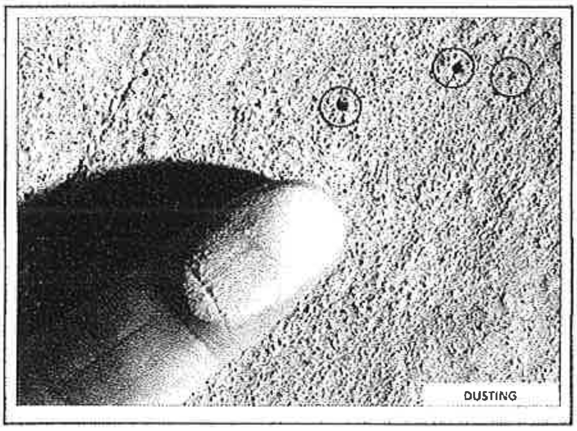
Effects of Bleeding on Strength and Durability

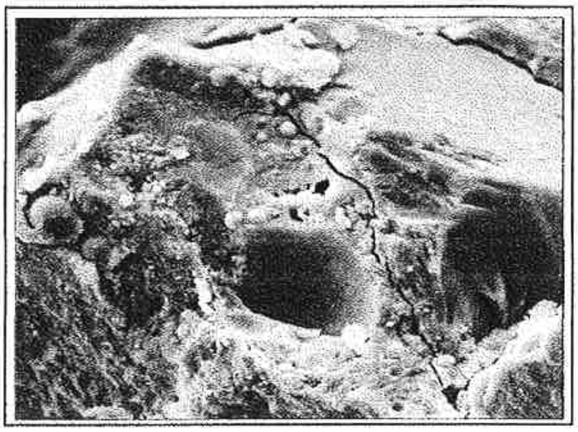












Colour variations in concrete and other causes

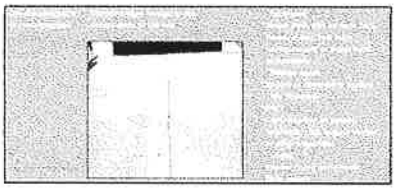
Inherent colour variation	Variation in colour of the surface	• Materials Change of cement brand Change of source of fine and coarse aggregate variation in admixtures • Concrete mix Variations in mixing procedure

Defect	Description	Most probable causes
Aggregate transparency	Dark areas of size and shape similar to the coarse aggregate. Mottled appearance.	• Formwork To flexible, causing a 'pumping' action during compaction • Concrete mix Low sand content Gap grading of sand • Placing methods Excessive vibration

Defect	Description	Most probable causes
Hydration discolouration (due to moisture movement with or from plastic concrete)	Variation in shape of the surface. Hydration staining and discolouration have a tendency to be severe at the top of a lift and at construction joints due to localized variations in water-cement ratio, incomplete compaction, and differential loss of moisture. Indentation of construction joints tends to disguise this discolouration by throwing the affected areas into shadow	• Formwork Variable absorbency Leaking through joints • Release agent Uneven or inadequate application • Curing Uneven

Defect	Description	Most probable causes
Segregation discolouration, or sand runs (separation of fine particles due to bleeding at the surface of the form)	Variation in colour or shade, giving a flecked appearance	• Formwork Low absorption • Concrete mix Lean, high water-cement ratio Unsuitably graded aggregate • Placing methods Excessive vibration Low temperature

Defect Description Most probable causes



Defect	Description	Most probable causes
Oil discolouration	Cream or brown discolouration. Sometimes showing sand or coarse aggregate	• Release agent Excessive amount Low viscosity Impure Applied too late or unevenly
Lime bloom, or efflorescence	White powder or bloom on surface	• Design Permitting uneven washing by rain • Release agent Type • Curing Uneven conditions

Defect	Description	Most probable causes
Retardation dusting	Matrix lacking in durability. Dusty surface which may weather to expose aggregate and which will erode freely under light abrasion at early ages, particularly in the period immediately following stripping of formwork	• Formwork Timber or plywood linings, the faces of which have had prolonged exposure to sunlight Retarder in or on form faces Loss of contact between form face and hardening concrete (rapid drying) • Release agent Unsuitable Excessive use of chemical release agent Water soluble emulsion cream" Oil with excessive surfactant • Curing Inadequate (very rapid drying)

Technical Notes

- Well graded mixtures generally have a uniform distribution of aggregates on each sieve
- There is a definite relationship between aggregate grading and concrete strength, workability and long term durability.
- Intermediate size aggregates fill voids typically occupied by less dense cement paste and thereby optimise concrete density.

Increasing concrete density in this manner will result in:

Technical Notes

- Reduced mixing water demand and improved strength because less mortar is necessary to fill space between aggregates.
- Increased durability through reduced avenues for water penetration in the hardened concrete.

Technical Notes

- Better workability and mobility because large aggregate particles do not bind in contact with other large particles under the dynamics of finishing and vibration, and
- Less edge slump because of increased particle to particle contact.
- Well graded aggregates also influence workability and ease of the placing , consolidating and finishing of concrete.
- 7day/70 years pledge

3. Problems and Solutions

RESPONSIBILITY MATRIX

Mix Design Trial Mixes	Batching and Mixing	PLACING Compacting
Material Selection	Transportation Delivery time Compliance Testing	CURING

Technical Notes

1. Pre-hardening Cracks in Concrete

Pre-hardening cracks in concrete occur in less than 8 hours from the time concrete is batched. They occur before concrete is fully hardened.

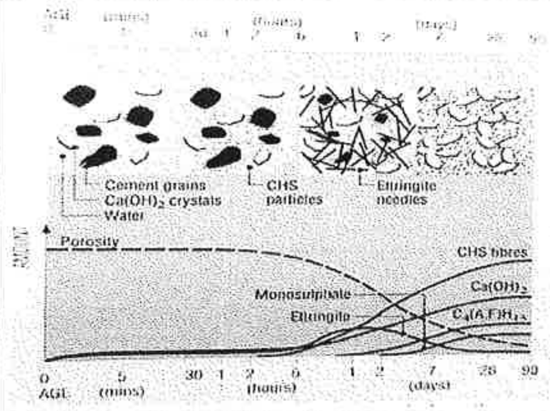
Types of pre-hardening cracks:

1.1 Plastic shrinkage cracks

1.2 Plastic settlement cracks

1.3 Cracks formed by formwork movement

Pre-hardening cracks can be overcome by the adoption of good concrete practices.



Technical Notes

1.1 Plastic shrinkage cracks

Plastic shrinkage cracks occur in the surface of the concrete while it is still in the plastic stage or before it has set and begun to haren. These cracks may not become visible until some time later. They form due to the too rapid loss of moisture from the surface of the concrete e.g during hot, dry and windy conditions. They do not have a regular pattern and may vary from 25mm to 2m in length.

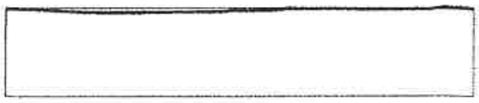
They are fairly straight and vary from hairline to perhaps 3mm in width.

Technical Notes

1.2 Plastic Settlement Cracks

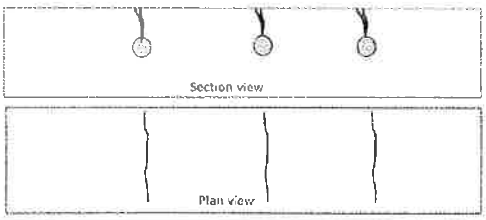
After concrete is placed, bleeding may occur. The bleed water rises to the surface as the solid particles settle. When the bleed water evaporates there is a loss of total volume. It means the concrete has settled.

If there is no restraint, the net result is simply a very slight lowering of the surface level.



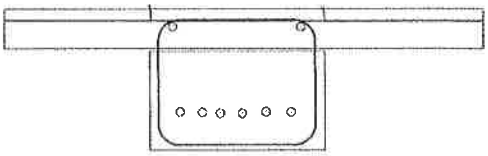
Technical Notes

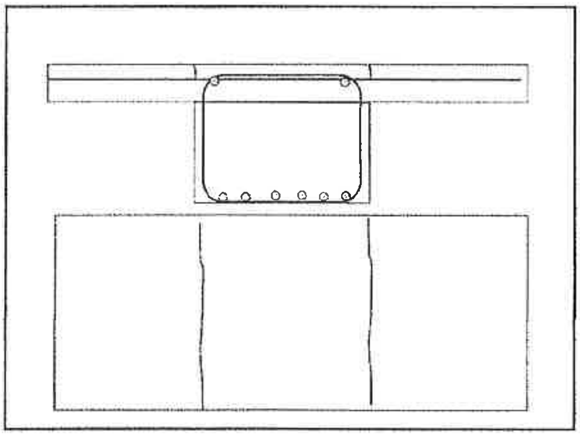
However if there is something near the surface such as reinforcing bar which restraints part of the concrete from settling while the concrete on either side continues to drop there is potential for a crack to form over the restraining element.

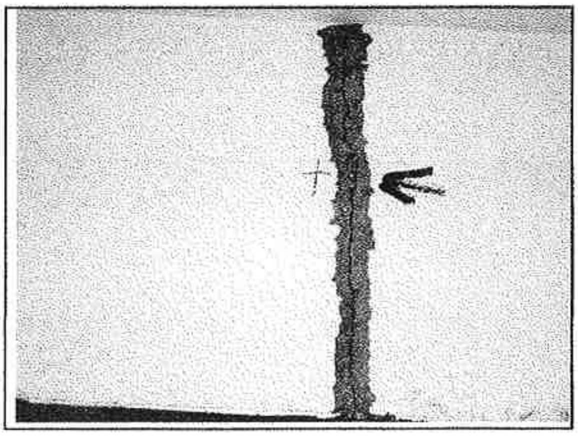


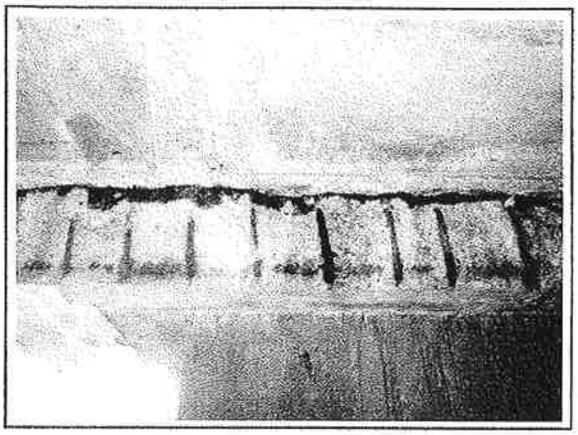
Technical Notes

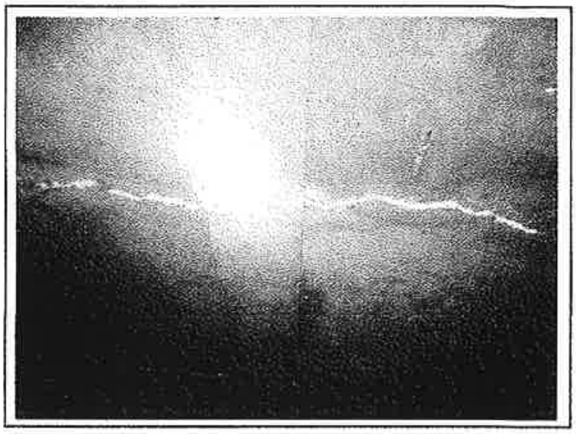
- Differential amounts of settlement may also occur when there is a change in the depth of section such as beam/slab junction.
- Settlement cracks tend to follow a regular pattern coinciding with a restraint usually the reinforcement or in the section.
- Generally the cracks are up to the depth of top rebar.

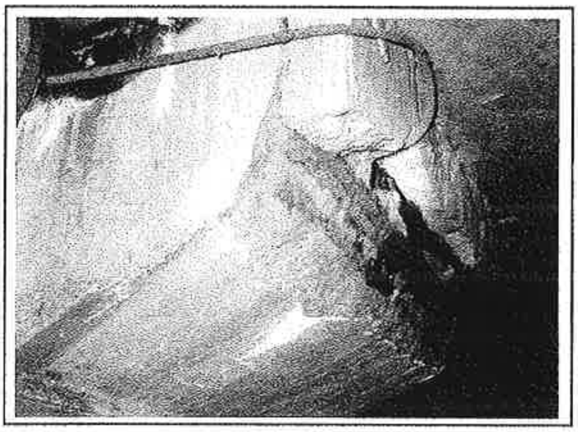


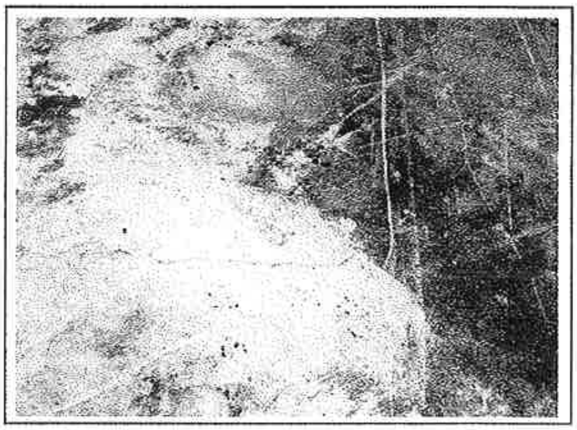


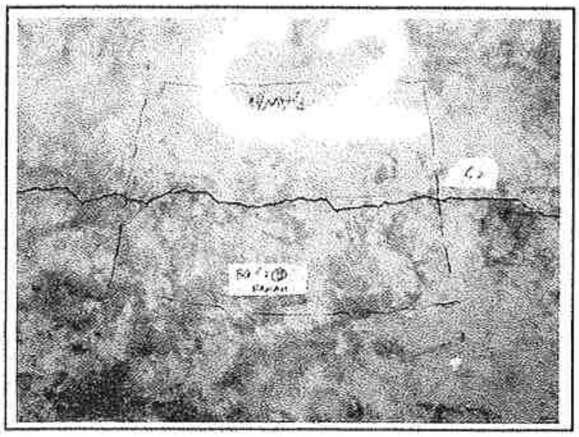


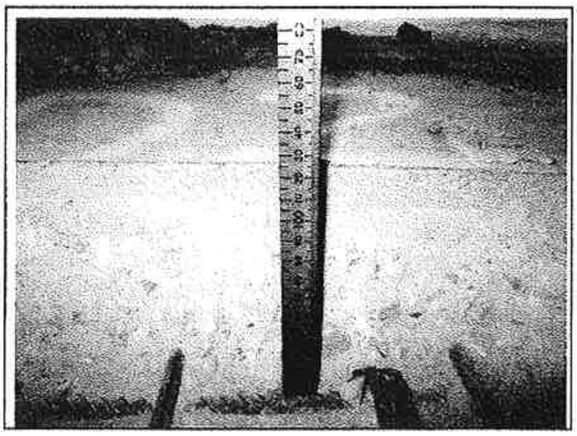


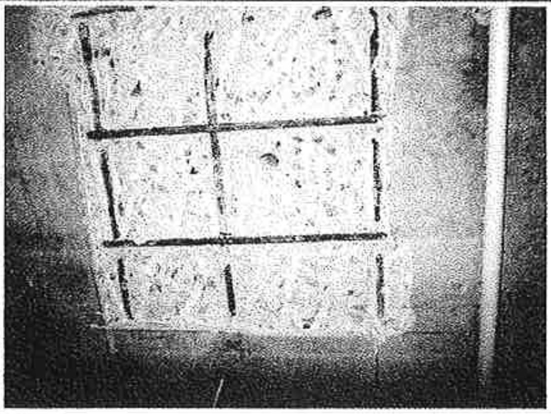












Technical Notes

Plastic settlement cracks are formed because of:

a) rate of bleeding
b) depth of reinforcement relative to total thickness
c) the total time of settlement
d) the depth of reinforcement /size of bar ratio
e) the constituents of the mix
f) the slump

Technical Notes

Prevention of Plastic Settlement Cracking

a) using lower slump mixes
b) using an air entrainer to improve cohesiveness and reduce bleeding
c) ssing more cohesive mixes
d) increasing cover to top bars

Technical Notes

1.3 Cracks Caused by Formwork Movement

Cracks may occur if the formwork moves after the concrete has stiffened but before it has gained enough strength to support its own weight. These cracks have no set pattern.

To avoid cracking, the formwork

a) must be sufficiently strong and rigid to support the weight of the concrete without excessive deflections and,
b) left in place until the concrete has gained sufficient strength to support itself.

Technical Notes

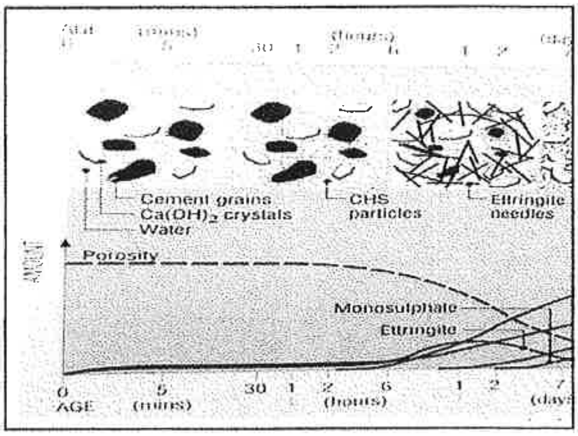
2. Cracks In Hardened Concrete

Cracks occur in hardened concrete for two principal reasons:

a) volume changes
b) chemical reactions within the body of the concrete which cause expansion and subsequent cracking of the concrete

Volumetric movement in concrete cannot be prevented. It occurs whenever concrete gains or loses moisture(drying shrinkage) or whenever its temperature changes and causes a thermal gradient. If such changes are excessive and no measures are taken to control them, the concrete will crack.

Provided adequate care is taken in the selection of materials, and good quality concrete is properly batched, placed, compacted and curd, these reactions should not occur except in extreme environment conditions.



Technical Notes

2.1 Crazing

Crazing is the very fine cracks which appear on the surface of concrete after it has been exposed to the atmosphere for some time. It occurs as the concrete surface expands and shrinks during alternate cycles of wetting or as it carbonates and shrinks during long exposure to the air.

To prevent crazing on trowelled surfaces

- avoid very wet
- do not use 'driers'
- do not overwork the concrete
- do not attempt finishing whilst bleed water is present
- do not steel trowel until the water sheen has gone
- do not subject the surface to wetting and drying cycles

On formed surfaces very wet and over-rich mixes should be avoided and curing should be continuous. The concrete should not be subjected to wetting and drying cycles.

Technical Notes

2.2 Drying Shrinkage Cracks

Hardened concrete shrinks , i.e it reduces in volume as it loses moisture due to

- The heat of hydration of the hygroscopic cement, and
- Evaporation

The shrinkage caused by moisture loss is not a problem if the concrete is free to move. Because it is usually restrained, tensile forces develop causing the concrete to crack as it cannot withstand the tensile stresses.

Technical Notes

Factors affecting shrinkage

- total water content in concrete
- the content , size and physical properties of the aggregates
- the relative humidity
- admixtures, especially those containing calcium chloride
- curing conditions

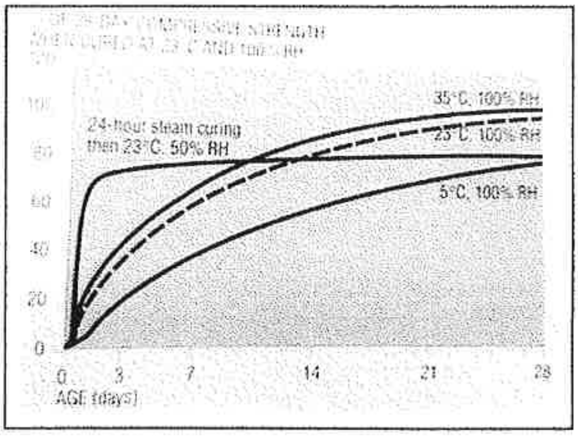
The cement content of concrete influences shrinkage drying almost only to the extent that it influences the amount of water used in a mix

Technical Notes

In order to reduce the total shrinkage of concrete:

- the water content should be minimised (consistent with the requirement for placing and finishing)
- the amount of fine material should be minimised
- the highest aggregate content should be used
- the largest possible maximum aggregate size should be used
- good curing practices should be adopted

However, reducing the shrinkage of concrete will not necessarily reduce cracking since this is also influenced by the restraint , detailing, geometry and construction practice.



Technical Notes

Preventing Cracking due to Drying Shrinkage

The prevention of uncontrolled cracking , due to drying shrinkage starts with the designer.

During the design stage,

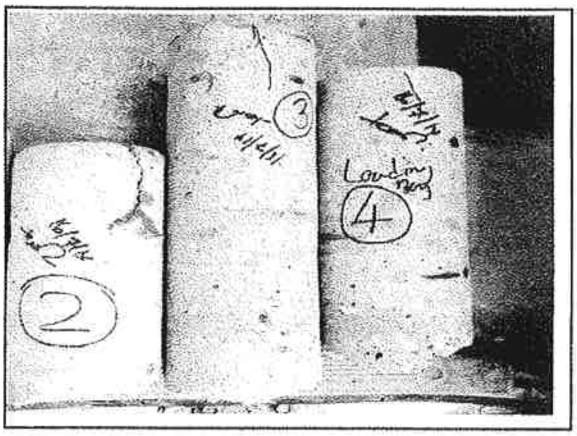
- the provision and location of adequate reinforcement to overcome tensile stresses in concrete will reduce cracking.
- the provision, location and detailing of joints to isolate restraints and permit movement between discrete parts of the construction.

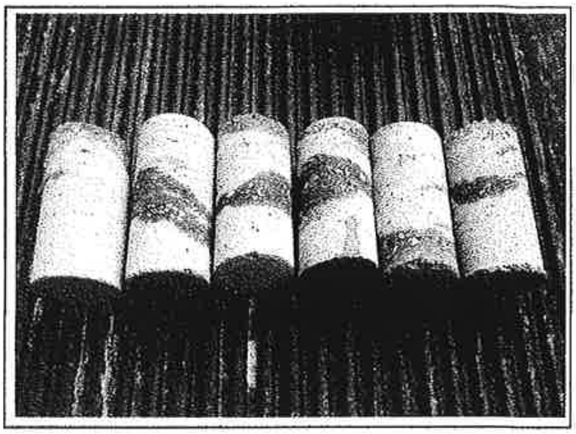
During the construction stage,

- ensure concrete is properly placed, compacted and cured.
- ensure designer's details are followed especially the position of rebars prior to concreting.

GREEN BUILDING COUNCIL

READYMIX





Technical Notes

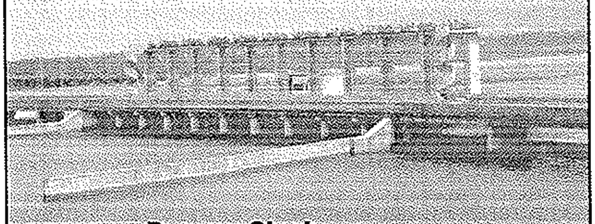
2.3 Thermal Movement Cracks

Thermal movement occurs when the temperature of concrete changes, due either to environmental changes or to the heat generated during hydration.

Controlled expansion and contraction by providing movement joints especially in large and continuous pours and monitoring temperature of concrete during pre-construction(trial mixes) and during construction can help reduce cracks due to thermal movements.

Q&A

Concrete Repair Techniques



Parnam Singh B.E.(Hons), MSc (Civil), FIE, MCSM, MACP, MACI (KL Chapter)

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Protecting your built environment

Presentation Outline

1.0 General Requirements For Quality Concrete Repair

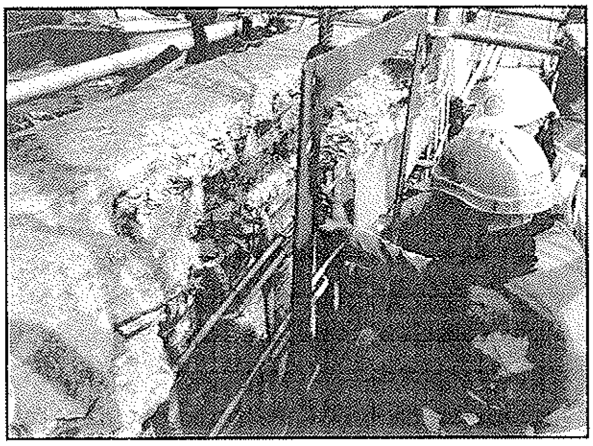
a) Repair must consider cause of defects.

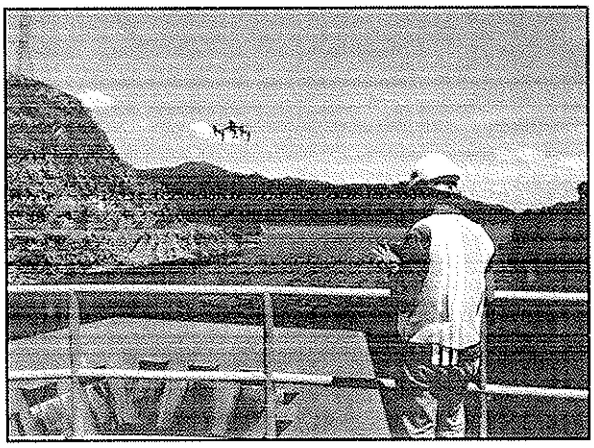
b) Adequate preparation of existing steel & concrete substrate

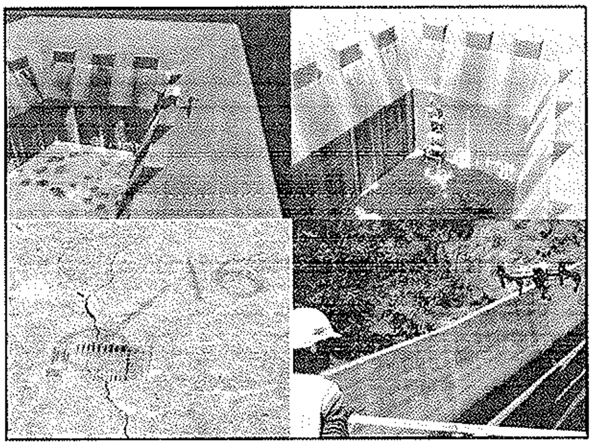
c) Well trained, competent and experienced workmen

d) Methods chosen & apply correctly

e) Materials - high quality & suitable



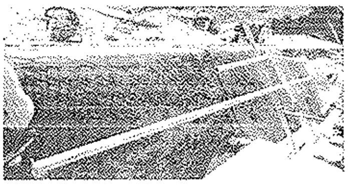




2.0 Preparation of Old Conc. for Repair – Surface Preparation

Table 2.0 : Condition of Substrate Surfaces to Receive Repair Material

	Types of Repair Material	Condition of Surface Required
1	Polymer Concrete & Epoxy bonded materials.	Dry
2	Cementitious material Mortar/Concrete (with or without polymer/epoxy modified)	Saturated Surface Dry (SSD) – soak surfaces with water for 2 to 24 hours prior to repair application to prevents the old concrete from absorbing mix water from the repair material and promotes development of adequate bond strength in the repair material



2.0 Preparation of Old Conc. For Repair–b) Concrete Removal

Objective:

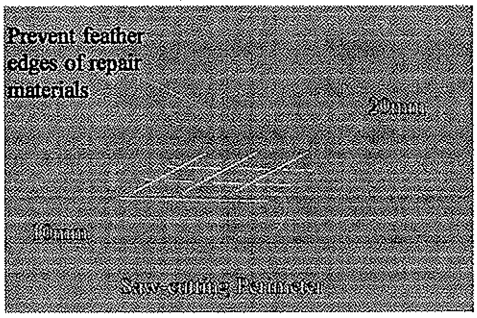
- remove distressed or deteriorated concrete
- provide sound concrete for bonding of repair material

Requirements

- Method to be safe and economical
- Minimum effect on in-place concrete
- Duration out of service
- Required one or more removal methods
- Cost removal-repair Vs total demolition/replacement
- Avoiding embedded components
- Operation requirements e.g. working space/time, noise, dust

2.0 Preparation of Old Conc. For Repair–b) Concrete Removal

Concrete removal techniques –
Saw Cutting Perimeter

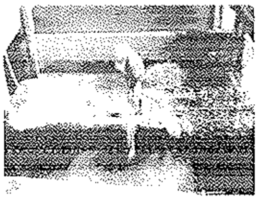


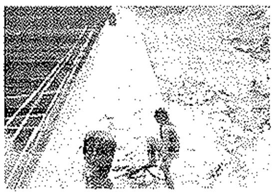
2.0 Preparation of Old Conc. For Repair–b) Concrete Removal

Some methods of concrete Removal

Blasting, Crushing, Cutting, Impactig, Milling , and Presplitting

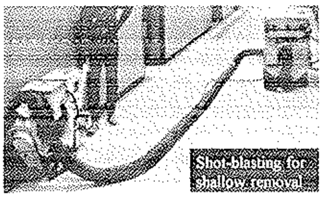
2.0 Preparation of Old Conc. For Repair–b) Concrete Removal





Mechanical Impacting

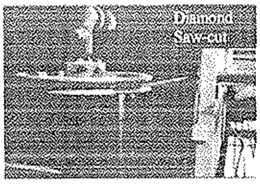
2.0 Preparation of Old Conc. For Repair–b) Concrete Removal

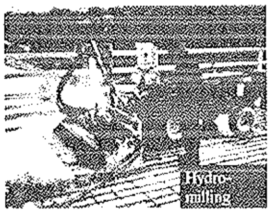


Shot-blasting for shallow removal

High pressure abrasive sand /Water jetting

2.0 Preparation of Old Conc. For Repair–b) Concrete Removal

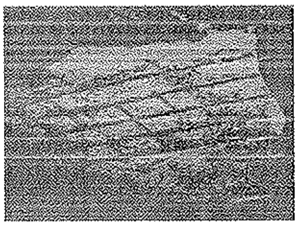




2.0 Preparation of Old Conc For Repair–c) Reinf. Steel Preparation

Exposed Rebars –

- Remove all scale, rust, corrosion, and bonded concrete by wire brushing or high pressure water or sand blasting.
- Corrosion > 15 % of steel areas – replaced or add bars
- Perimeter exposed > 1/3 – exposed bars all round & beyond
- Clearance between the steel and the concrete > 10 mm



2.0 Preparation of Old Conc. For Repair – e) Bonding Coat

Type of bonding agents: –

- Water
- Grout Slurry
- Polymer emulsions (e.g. polyvinyl acetate (PVA), styrene butadiene rubber latex (SBR))
- Polymer emulsions slurries (polymer with cement or cement mortar)
- Epoxies

Good bond can be achieved with proper surface preparation
(even without the use of bonding agents)

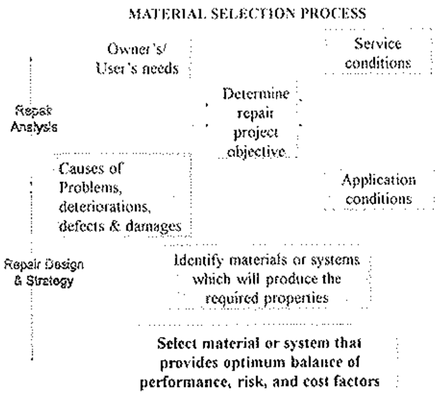
3.0 Repair Materials – a) Selection of Repair Materials

Selection of Repair Materials

Basic Considerations: –

- new material required to act compositely with existing material.
- Preferably cementitious based repair materials.

3.0 Repair Materials – a) Selection of Repair Materials



3.0 Repair Materials – a) Selection of Repair Materials

Prioritizing Properties of Repair Material

- Extremely difficult to get repair material that meet all the requirements for a durable and effective repair work
- It is important to prioritize and optimize the various competing material property in accordance to those properties most required and critical to the success of the repair.

Example

Increasing cement content for higher compressive strength ⟹ Result in higher heat of hydration hence, ⟹ Higher risk of drying shrinkage

3.0 Repair Materials - b) Types of Repair Materials

Classification of Repair Materials

1. Portland cement base + admixtures e.g. water reducer, retarder, accelerators, shrinkage compensating, and air entrainment agents
2. Portland cement base + pozzolanic (blended cement) e.g. pulverized fly ash (pfa), micro silica, and ground granulated blastfurnance slag (ggbs)
3. Polymer modified Portland cement base (acrylic copolymers, SBR, PVA)
4. Rapid setting cement base (magnesium phosphate, high alumina cement or special blended cement)
5. Resin based including
   - Epoxy resin with or without fillers
   - Polyester resin
   - Polyurethane resin (PU)

Road Map of Presentation (PART 2)_

4.0 Standard Methods of Repair

STANDARD METHODS OF REPAIR

Categorized as :

a) Small (Patch) Repairs

b) Large Repairs

c) Crack Repairs

d) Surface Protective Coatings

e) Cathodic Protection

4.0 Standard Methods of Repair – a) Small (Patch) Repairs

a) Small Patch Repairs

Materials

(i) Cementitious Mortar and Concrete (with or without additives and admixtures)

(ii) Polymer-modified Repair Mortar and Concrete

(iii) Resin-based Repair Mortars

4.0 Standard Methods of Repair – a) Small (Patch) Repairs

(i) Cementitious Mortar and Concrete (with or without additives and admixtures)

- "hand" trowel applied
- mortars or concretes containing fine aggregate
- cosmetic or shallow depth of repair (< 50mm).

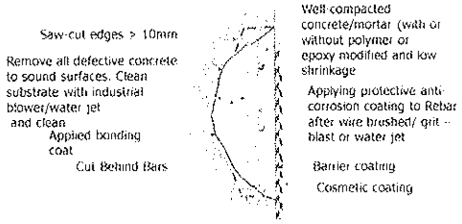


Figure 4.1: Some Features of Patch Repair

4.0 Standard Methods of Repair – a) Small (Patch) Repairs

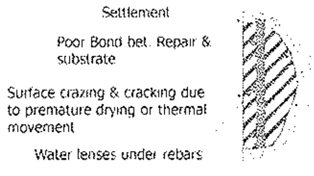
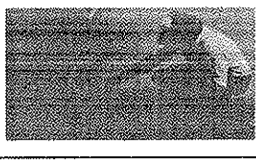


Figure 4.2:
Some Common Defects in Patch Repairs



Poor Patching

4.0 Standard Methods of Repair – a) Small (Patch) Repairs

ii) Polymer-modified Repair Mortar and Concrete

- Properties almost similar in many ways to conventional mortar/concrete but with some notable improvements
  - improve adhesion to conc surfaces; increase compressive/ tensile strength
  - improve abrasion resistance;
  - reduce permeability
  - improve resistance to attack from dilute acids
  - reduce shrinkage
  - help to maintain the passive alkaline environment around the reinforcement.

- Commonly used polymer additives in repair materials
  - Styrene butadiene rubber (SBR),
  - Acrylic co-polymers
  - Styrene acrylic co-polymers
- Normally factory blended pre-packaged (only needs to add water at site)

4.0 Standard Methods of Repair – a) Small (Patch) Repairs

iii) Resin-based Repair Mortars

- 2 common types - polyester & epoxy resin Vbased mortars
- Compressive & tensile strength > concrete
- Significant differences in strength and thermal coefficient (failure may occur due to excessive differential movement)
- Used in small patch repair eg. Overlay to inadequate steel rebar cover
- More expensive
- Highly impermeable - good protective barrier against the ingress of chloride ions and carbonation.
- Highly exothermic - filler (sand) is occasionally added to minimize thermal shrinkage.
- Polyester resins also exhibit large shrinkage strains during curing.

4.0 Standard Methods of Repair – b) Large Repair

b) Large Repair - General

- Main problem - workability and compaction
- Material - Polymer modified concrete/mortar are commonly used with added
  - Pozzolons e.g. pfa, ggbfs, microsilica (or silica fume) are frequently added to improve durability and performance
  - Superfine fibres - Polypropylene or steel
    - > inhibit early shrinkage cracking
    - > reduce bleeding and plastic settlement
    - > crack control
- Sprayed concrete very cost-effective for large areas

4.0 Standard Methods of Repair – b) Large Repair

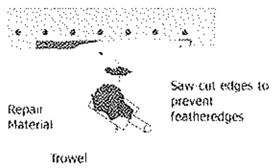
Figure 4.3 Trowel applied

Best application

-Surface restoration rebars not encountered

Material requirements:

Fine-grained material easily finished, with non-sag properties to stay in place in vertical or overhead applications



4.0 Standard Methods of Repair – b) Large Repair

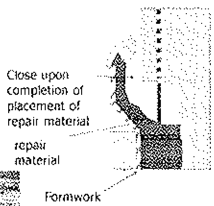
Figure 4.4 Form and cast-in-place (Partial-depth replacement)

Best application:

Columns, walls, and exterior slab edges.

Material requirements:

- Castable concrete or mortar
- Good bonding
- Low shrinkage
- Low water/cement ratio
- Flowable mixture



4.0 Standard Methods of Repair – b) Large Repair

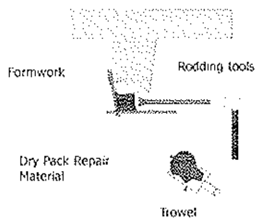
Figure 4.5 Dry Packing

Best application:

Post-tensioning grout pockets
Tie holes
Pan joist bottoms
Waffle pan joists
Vertical, overhead and horizontal locations.

Material requirements:

Mortar with consistency capable of being molded into a ball without sagging.

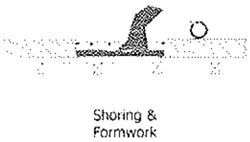


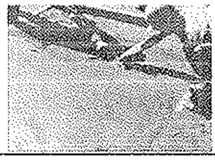
4.0 Standard Methods of Repair – b) Large Repair

Figure 4.6 Form and cast-in-place (Full-depth replacement)

Best application:
Extensive deterioration throughout the member.

Material requirements:
Conventional cast-in-place concrete with
- low shrinkage
- low water-cement ratio
- highly workable mixture



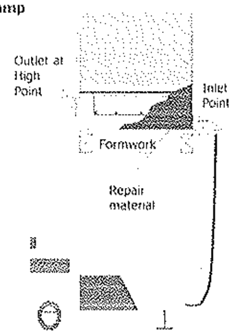


4.0 Standard Methods of Repair – b) Large Repair

Figure 4.7 Form and pump

Best application:
Overhead & vertical applications:
Beam bottoms, ribs, slab soffits, or sectionalized areas.

Material requirements:
Pumpable, good flow characteristics, self-bonding, aggregate size compatible with size of cavity and space between bars.

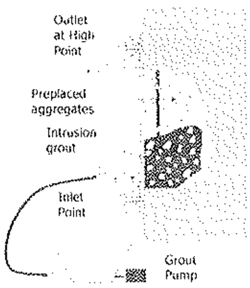


4.0 Standard Methods of Repair – b) Large Repair

FIGURE 4.8 PREPLACED AGGREGATES

Best application:
- Vertical & Overhead applications
- Intrusion grout where extremely low shrinkage of repair material is required
- column enlargements.

Material requirements:
- Gap-graded aggregate (40- 50% void ratio)
- pumpable grout, self-bonding portland cement or resin-based binder.
- 25 mm or larger aggregate typically used in cementitious applications.

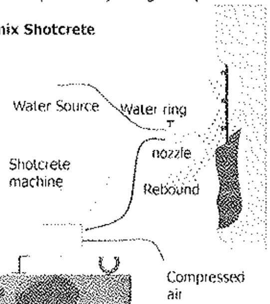


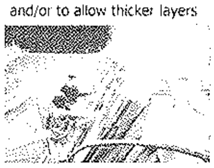
4.0 Standard Methods of Repair – b) Large Repair

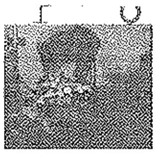
Figure 4.9 Dry-mix Shotcrete

Best application:
Large vertical & overhead areas
Minimal congestion of small bars, < 19 mm

Material requirements:
- Well-graded aggregate with binders (usually portland cement).
- Rebound losses
- Admixtures to shorten set time, and/or to allow thicker layers





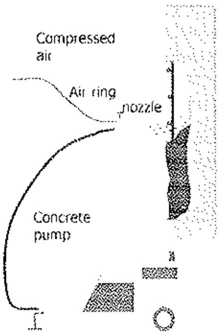


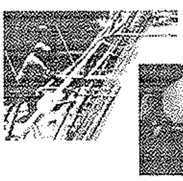
4.0 Standard Methods of Repair – b) Large Repair

Figure 4.10 Wet mix Shotcrete

Best application:
Large vertical areas with small bars, < 19 mm minimal congestion of embedded steel

Material requirements:
Pumpable,
low-slump mixture, no sag

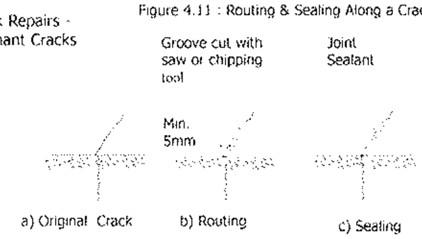


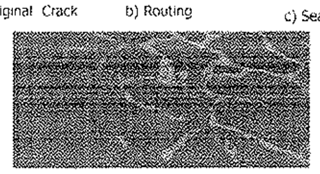


4.0 Standard Methods of Repair – c) Crack Repairs

Crack Repairs - Dormant Cracks

Figure 4.11 : Routing & Sealing Along a Crack





Unsightly

4.0 Standard Methods of Repair – c) Crack Repairs

Crack Repairs - Dormant Cracks

Injection or Impregnation of Cracks

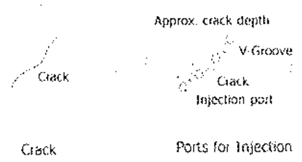


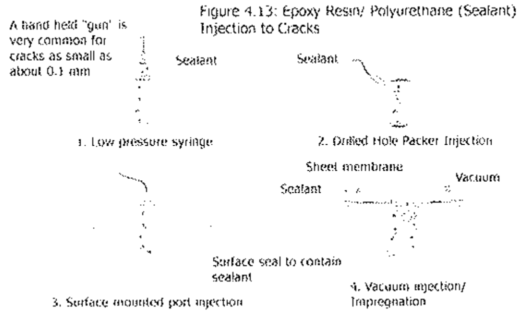
Figure 4.12: Injection Ports along Crack line

- Materials: - cementititious grout, epoxies or polyurethane under pressure.
- Coring can be undertaken to assess how far and effective the sealant has penetrated

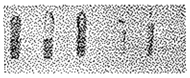
4.0 Standard Methods of Repair – c) Crack Repairs

Crack Repairs - Dormant Cracks

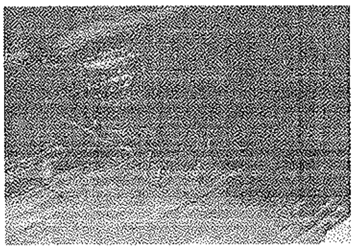
Figure 4.13: Epoxy Resin/ Polyurethane (Sealant) Injection to Cracks



4.0 Standard Methods of Repair – c) Crack Repairs



Different type of injection points



4.0 Standard Methods of Repair – c) Crack Repairs

Crack Repairs - Active Cracks

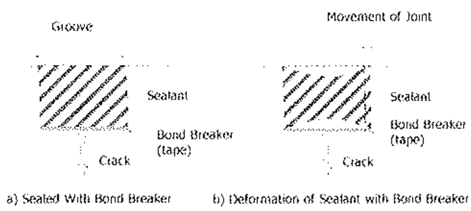


Figure 4.14: Sealing Active Crack to Form Movement Joint

- Material ;flexible sealant fillers for expected movement e.g.polysulphide and polyurethane
- Repairs are unsightly, and tend to be ineffective when the crack is wide

4.0 Standard Methods of Repair – c) Crack Repairs

Crack Repairs - Active Cracks

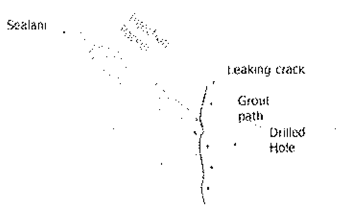


Figure 4.15: Polyurethane Injection to Seal Water Leakages

- Water-activated flexible polyurethane grouts are commonly used for sealing active and leaking cracks while allowing continuous movement.

4.0 Standard Methods of Repair – c) Crack Repairs

Crack Repairs - Active Cracks

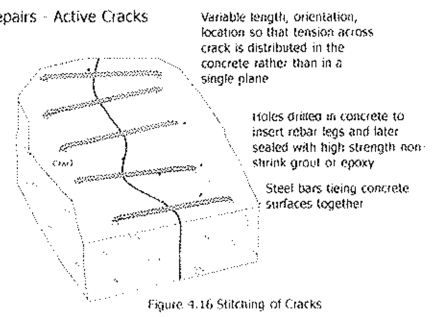


Figure 4.16 Stitching of Cracks

4.0 Standard Methods of Repair – c) Crack Repairs

Crack Repairs · Strengthening

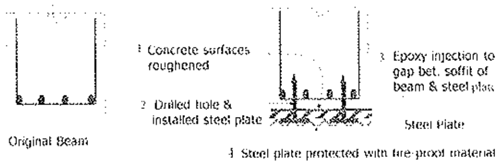
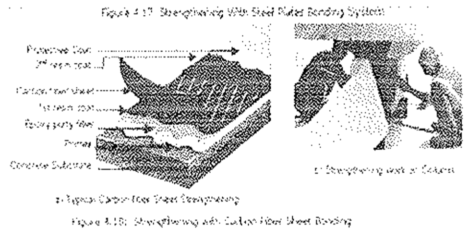


Figure 4.17 Strengthening With Steel Plates Bonding System

4.0 Standard Methods of Repair – c) Crack Repairs

Crack Repairs · Strengthening



Advantage: thinner, quicker, easier to install, more flexible and lightweight as compared to steel plate bonding.

4.0 Standard Methods of Repair – d) Surface Protective Coatings

General

Surface Protective Coatings

- Integral part of a repair treatment
- To improve the aesthetic appeal of concrete
- Protection against carbonation, & ingress of chloride ions.
- Must permeate water vapour ("breathing")
- Ineffective against a high concentration of chemical attack for prolonged periods

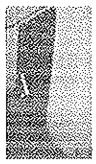
3 categories

a) Coating or Sealer
b) Pore liners
c) Pore blockers

4.0 Standard Methods of Repair – d) Surface Protective Coatings

a) Coating or Sealer

- Bituminous sheet waterproof membranes:
- Bitumen emulsions and cut-back bitumens
- Thermosetting polymers, e.g. epoxy and polyester resins
- Other polymer types (thermoplastics) e.g. acrylics, polyurethane, chlorinated rubber and butadiene copolymer.



b) Pore liners

i) **Silicones**

- not chemically stable on alkaline materials such as concrete
- large molecular size
- form a thin layer on the surface of the concrete

ii) **Silanes and siloxanes.**

- Reaction pore water and the coating (alkyl-alkoxysilanes) which penetrate into the concrete by as much as 2 to 4mm.

4.0 Standard Methods of Repair – d) Surface Protective Coatings

Large Repair · General

c) Pore blockers

- These materials penetrate the microstructure of the cement react with the C-H present to form compounds which block (or partially block) the surface capillary pores.
- Even though tests indicated that these coatings are successful in helping to improve the performance of concrete by reducing the ingress of harmful chemicals, their effective length of service need to be fully established

4.0 Standard Methods of Repair – 4.5 **Cathodic Protection**

Basic Concept

Create a corrosion cell in which the steel reinforcement becomes the cathode and an external component that is connected to the steel reinforcement becomes the anode. As corrosion occurs at the anode, the reinforcement (i.e. the cathode) is protected against corrosion hence the term "cathodic protection". As the anode corrodes it is often referred to as the "sacrificial anode"

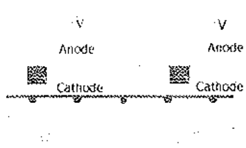


Figure 4.19: Outline of a Cathodic Protection System

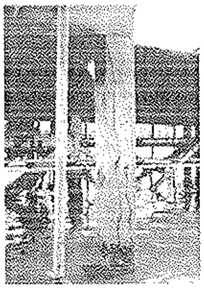
2 types :-

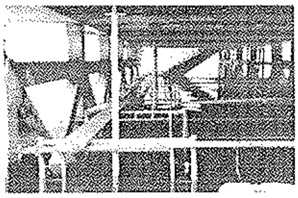
a) Impressed Current Cathodic Protection (ICCP) impressed direct current (d.c.) supply is connected to create a potential difference
b) Galvanic Cathodic Protection no impressing current but large number of individual "sacrificial" anodes

Repair Works (Illustrated)

ILLUSTRATIONS AND CASE STUDIES OF CONCRETE REPAIRS

Jetty



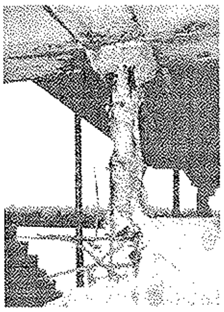


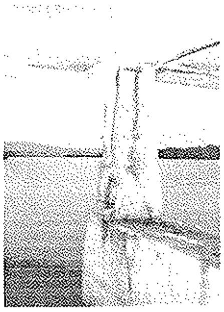
Condition of Jetty Before Repair

Cracks due to Chloride Attack
Cracking on Columns and Bracing of Jetty

Jetty

Repair of Columns and Bracing





Exposed and corroded steel bars

Jetty

Repair Works on Tie Beams in Progress

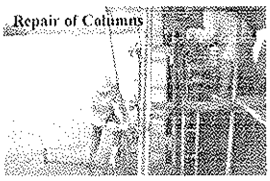
Removal of Concrete

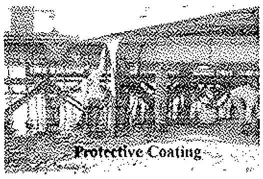
Installation of Steel Reinforcements

Jetty

Repair to Beams

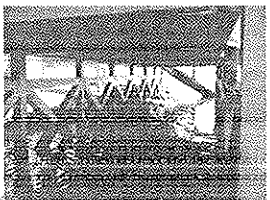
Repair of Columns





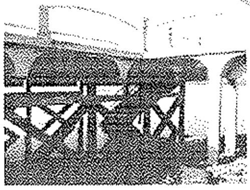
Protective Coating

Jetty



Operating Deck of Jetty

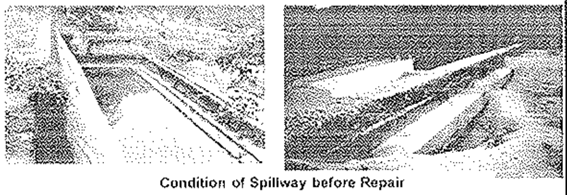
Conditions of Jetty below deck level



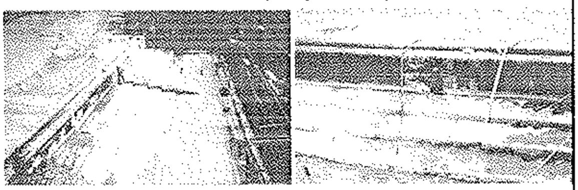
Overall View of Repaired Jetty

After Rehabilitation and Refurbishment

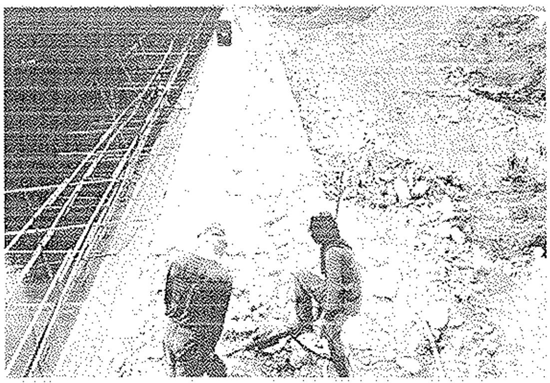
Spillway



Condition of Spillway before Repair

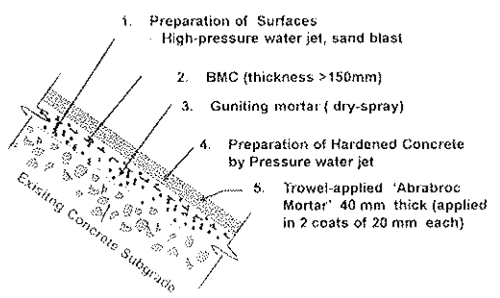


Spillway

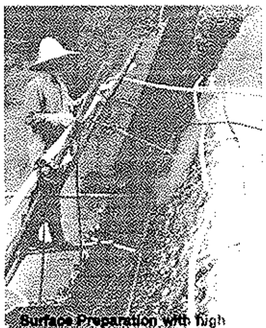


Spillway

Proposed Repair Works to Perting Dam Spillway



Spillway

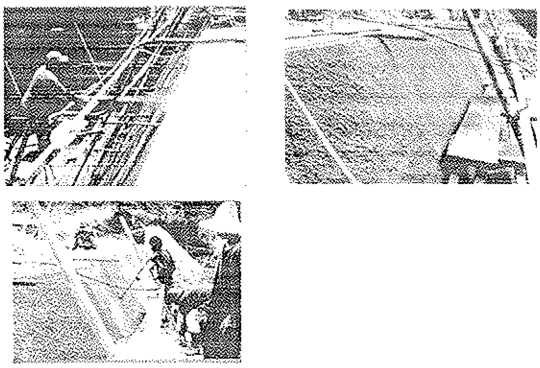


Surface Preparation with high pressure water jet

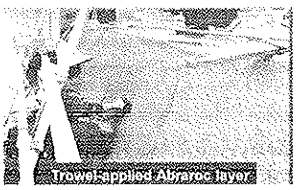
Preparation of Surfaces
- High-pressure water jetting, sand blasting
- Removal of all loosen aggregates
- Laying of BMC with anchor bars
- Saturated surface dry before application of gunite

Severely abraded surfaces

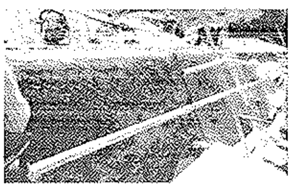
Spillway



Spillway

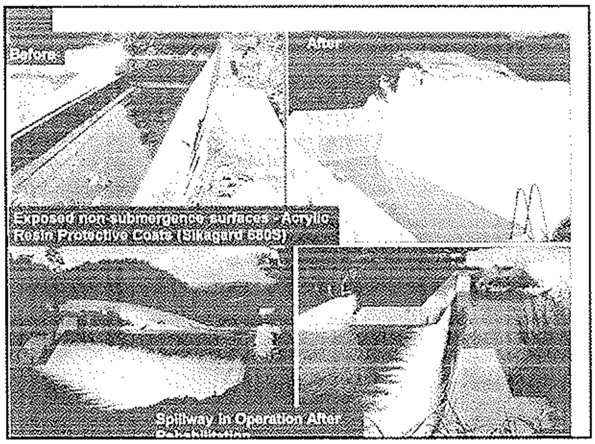


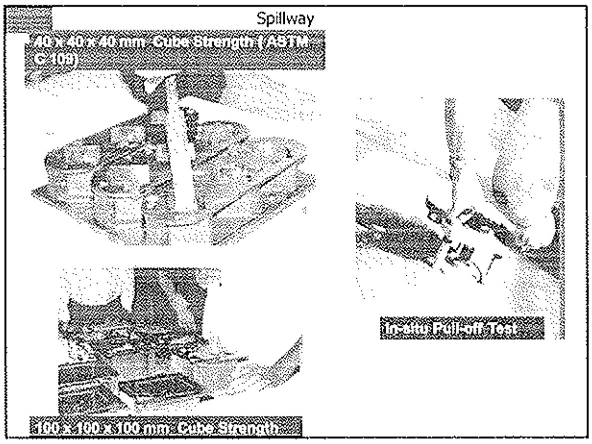
Trowel-applied Abraroc layer

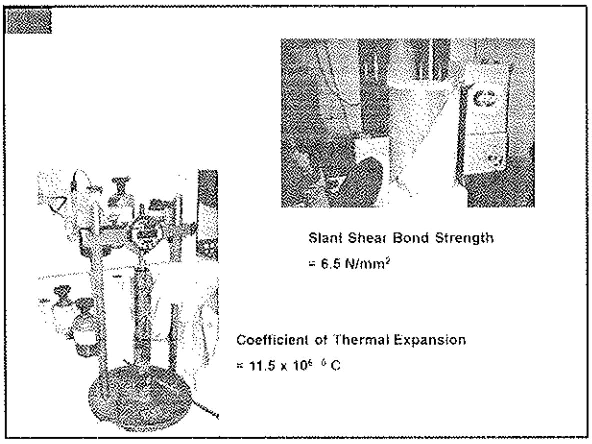


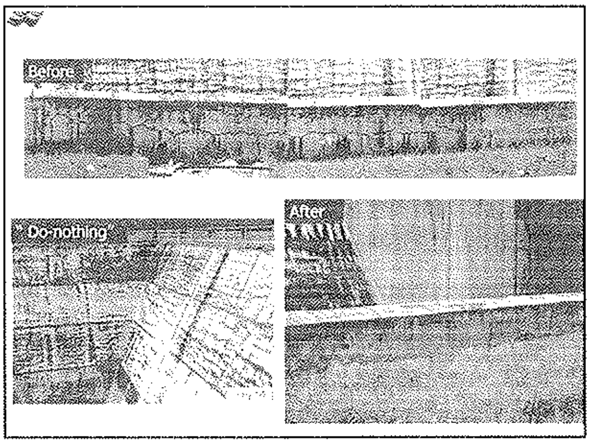
Guniting done in alternate panels

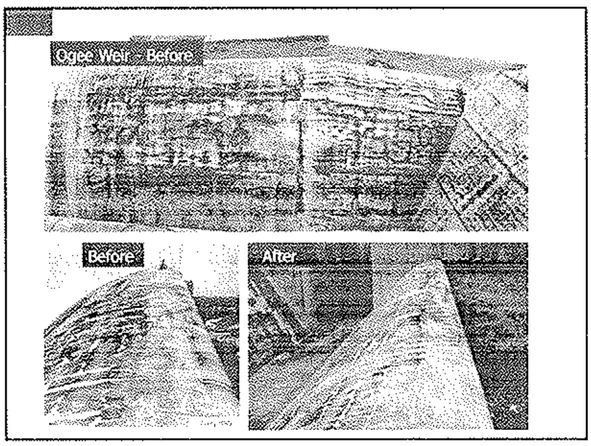
1st layer completed and roughened to receive 2nd layer

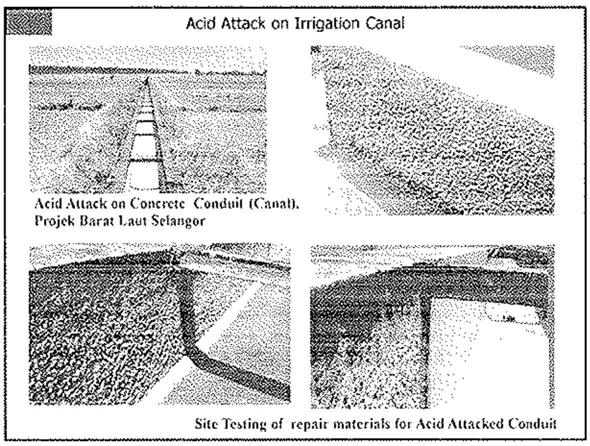

Before
After
Exposed non-submergence surfaces - Acrylic Resin Protective Coats (Sikagard 680S)
Spillway In Operation After


Spillway
40 x 40 x 40 mm Cube Strength (ASTM C 109)
In-situ Pull-off Test
100 x 100 x 100 mm Cube Strength

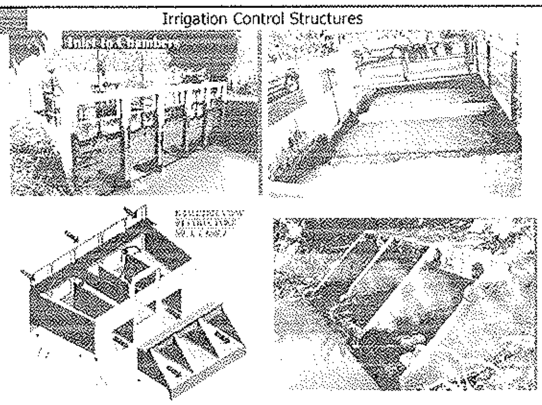

Slant Shear Bond Strength
= 6.5 N/mm^2
Coefficient of Thermal Expansion
= 11.5 x 10^{-6} °C


Before
"Do-nothing"
After

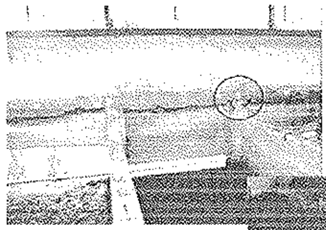

Ogee Weir - Before
Before
After


Acid Attack on Irrigation Canal
Acid Attack on Concrete Conduit (Canal), Projek Barat Laut Selangor
Site Testing of repair materials for Acid Attacked Conduit

Irrigation Control Structures



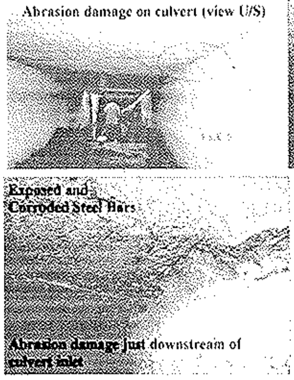
Irrigation Control Structures (ICS) at Kubang Haji Irrigation Scheme

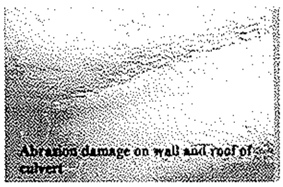


Severely Abraded Conditions of Vertical/Horizontal Members

Irrigation Control Structures

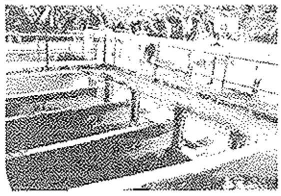
Abrasion damage on culvert (view U/S)

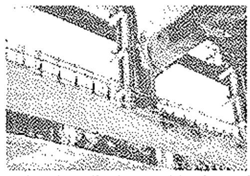




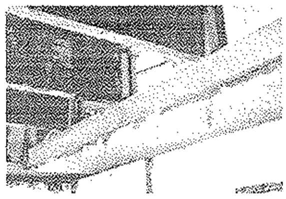
Culvert of ICS:
Exposed and Corroded Steel Bars/ Abraded Surfaces Inside Culverts

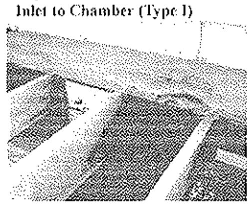
Irrigation Control Structures



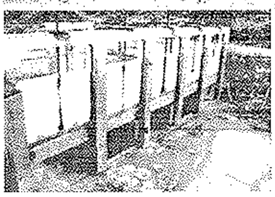


Repair to Horizontal Members of Inlet to Chamber (Type I)





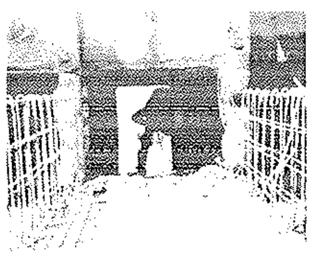
Irrigation Control Structures



Repair to Vertical Members of Inlet Chamber (Type I)

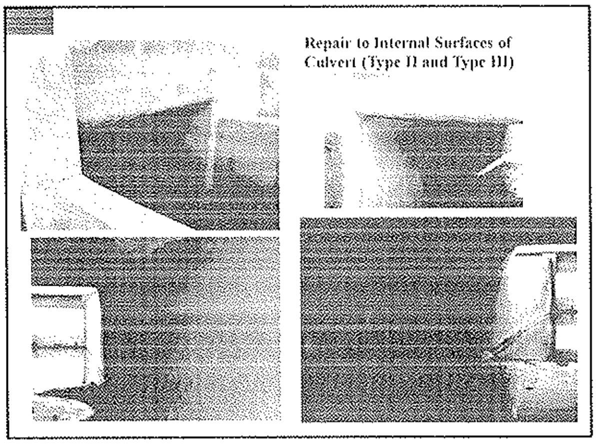
m s Gate Guide replaced with Stainless Steel

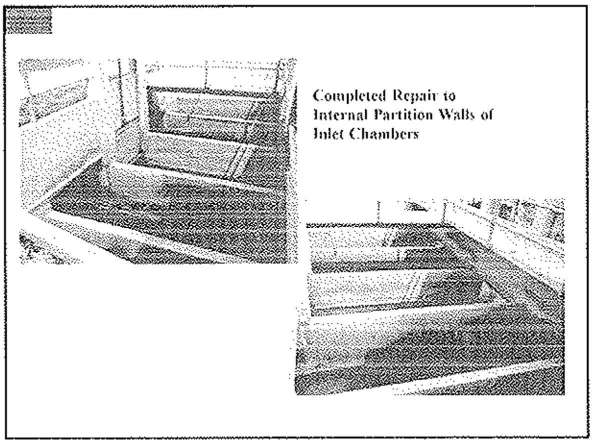
Before

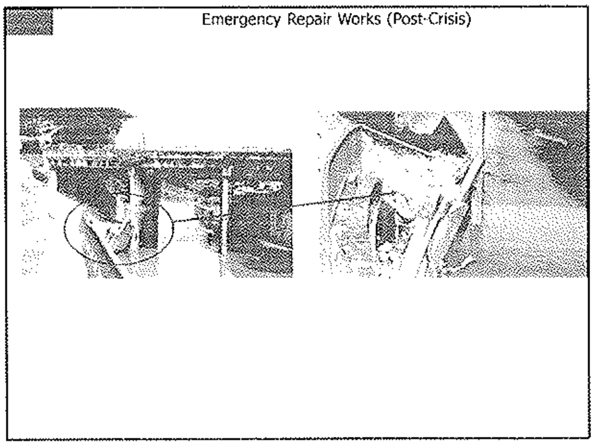


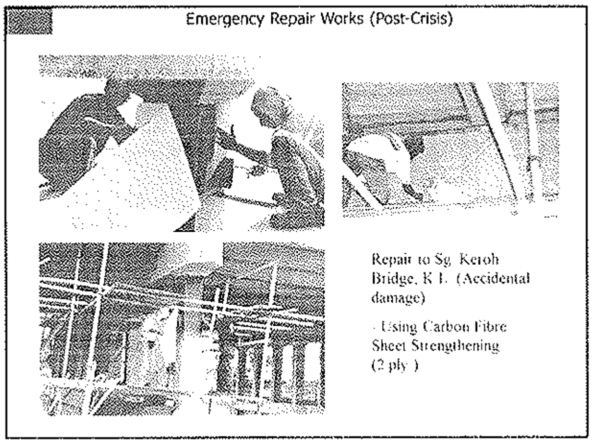
During Construction

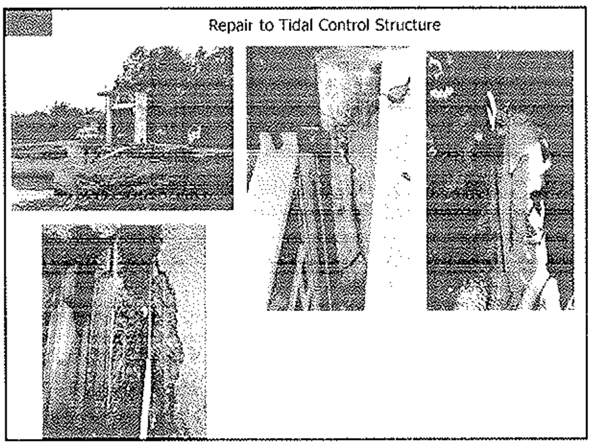
Repair to Inlet of Culvert (Type I)

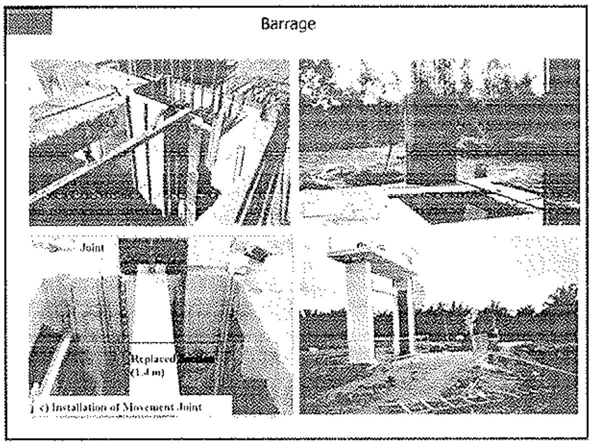

Repair to Internal Surfaces of Culvert (Type II and Type III)

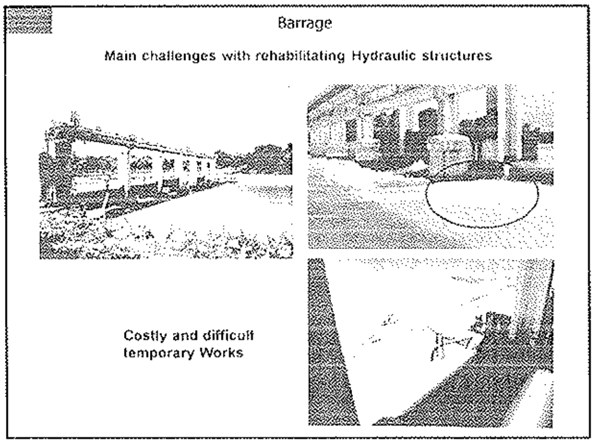

Completed Repair to Internal Partition Walls of Inlet Chambers

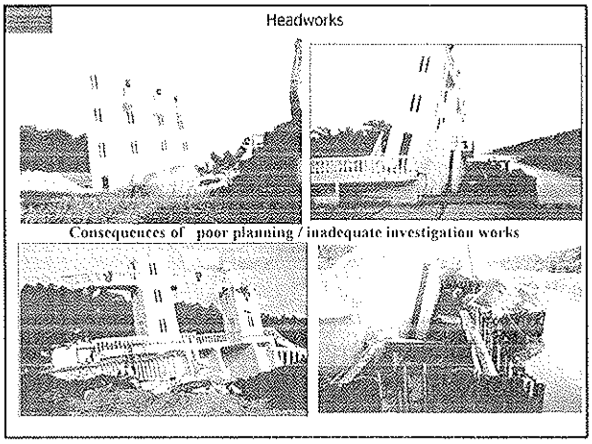

Emergency Repair Works (Post-Crisis)

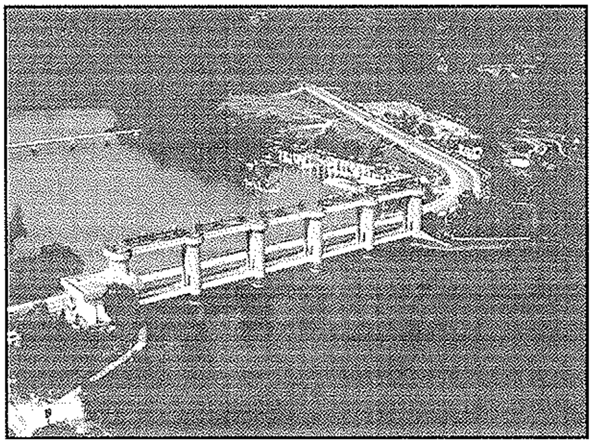

Emergency Repair Works (Post-Crisis)
Repair to Sg. Keroh Bridge, K.L. (Accidental damage)
- Using Carbon Fibre Sheet Strengthening (2 ply)

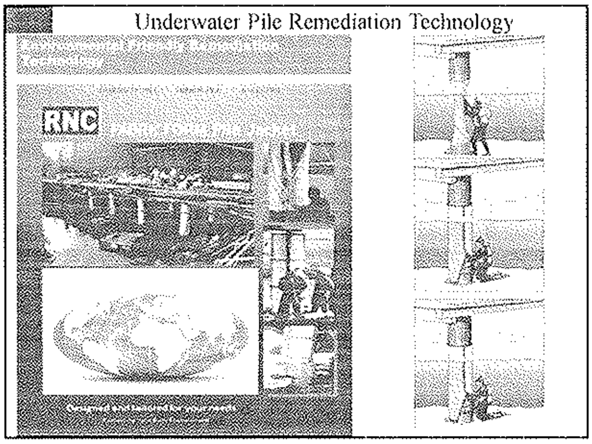

Repair to Tidal Control Structure

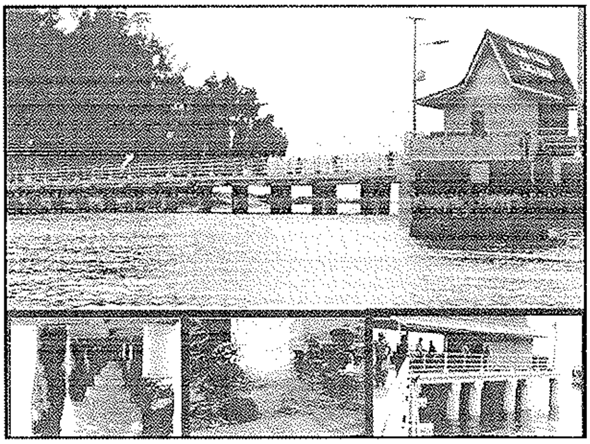

Barrage
Joint
Replaced
(1.4 m)
c) Installation of Movement Joint

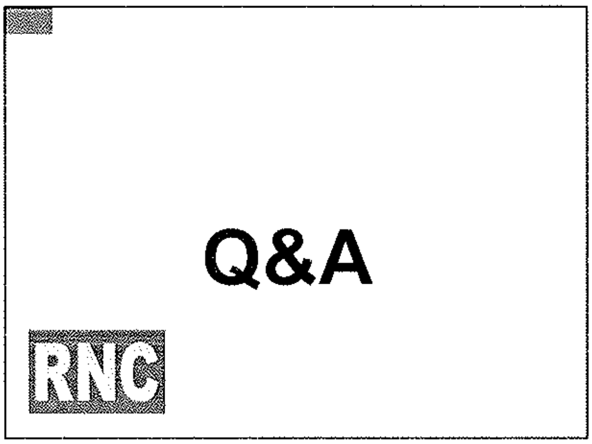

Barrage
Main challenges with rehabilitating Hydraulic structures
Costly and difficult temporary Works

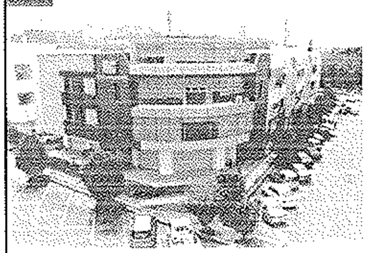

Headworks
Consequences of poor planning / inadequate investigation works




Underwater Pile Remediation Technology
RNC




Q&A
RNC



RNC

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