المؤتمر السعودي للخرسانة
SAUDI CONCRETE CONFERENCE

ارامكو السعودية
Saudi Aramco

# Strategies to achieve sustainable and Durable Concrete with Case Studies

Dr. Emad Abu-Aisheh, Engineering Specialist
Saudi Aramco
Consulting Services Department

SAUDI CONCRETE CONFERENCE – MAY 1 - 4, 2016

# Content



ارامكو السعودية
Saudi Aramco

# Content





ارامكو السعودية
Saudi Aramco

# Introduction

## FACTS: “The bottom line”

- At present, an average of 5 percent of global greenhouse gases emitted worldwide result from the manufacture of cement, with nearly one tone of $CO_2$ being emitted for every tone of cement produced
- More than half (60%) of the $CO_2$ emitted during cement production is due to calcination, a chemical reaction from heating limestone.

# Introduction

Besides water, concrete is the most commonly used material on earth.

Each year, approximately four metric tons of concrete are used for every one of the nearly seven billion people on our planet. (USGS 2009)

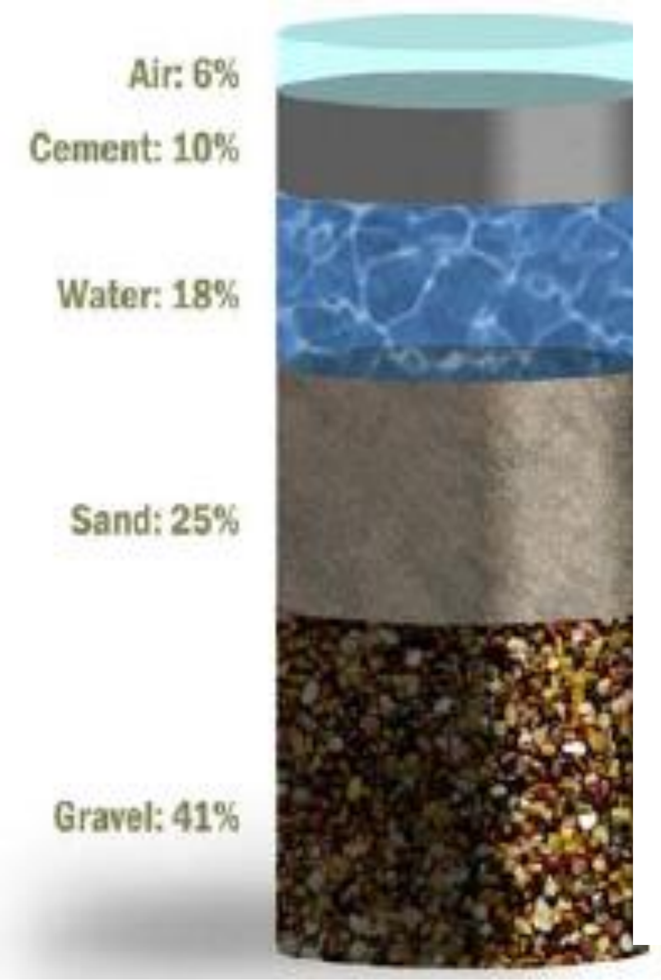
- 28 billion ton of concrete
- 3.6 billion ton of cement (14%)
- 2.4 billion ton of water (9%)
- 22 billion ton of aggregate (77%)

Problem!

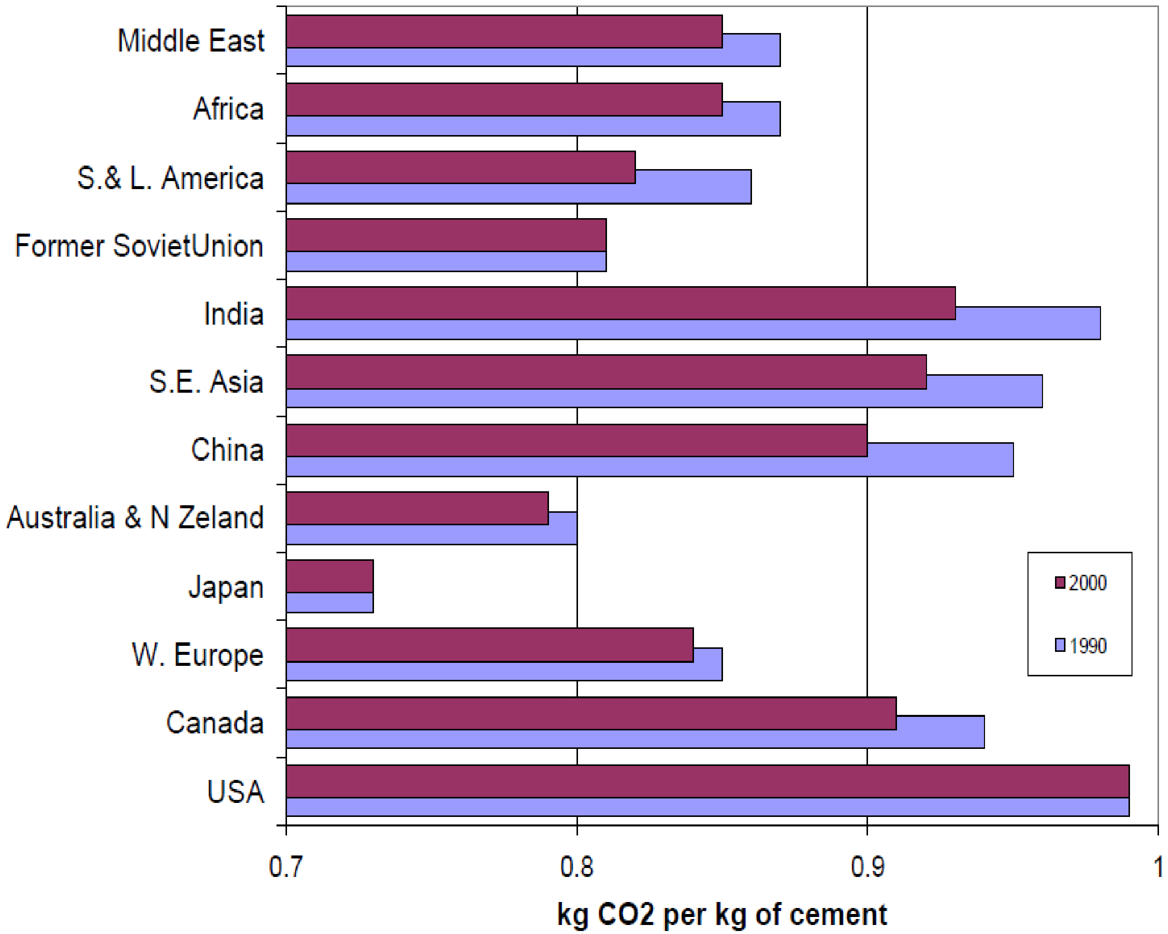
**Consequences of producing 3.6 billion tons of Cement**

- Generates 3.6 billion ton of $CO_2$
- Responsible for 5% CO2 world production

# Introduction



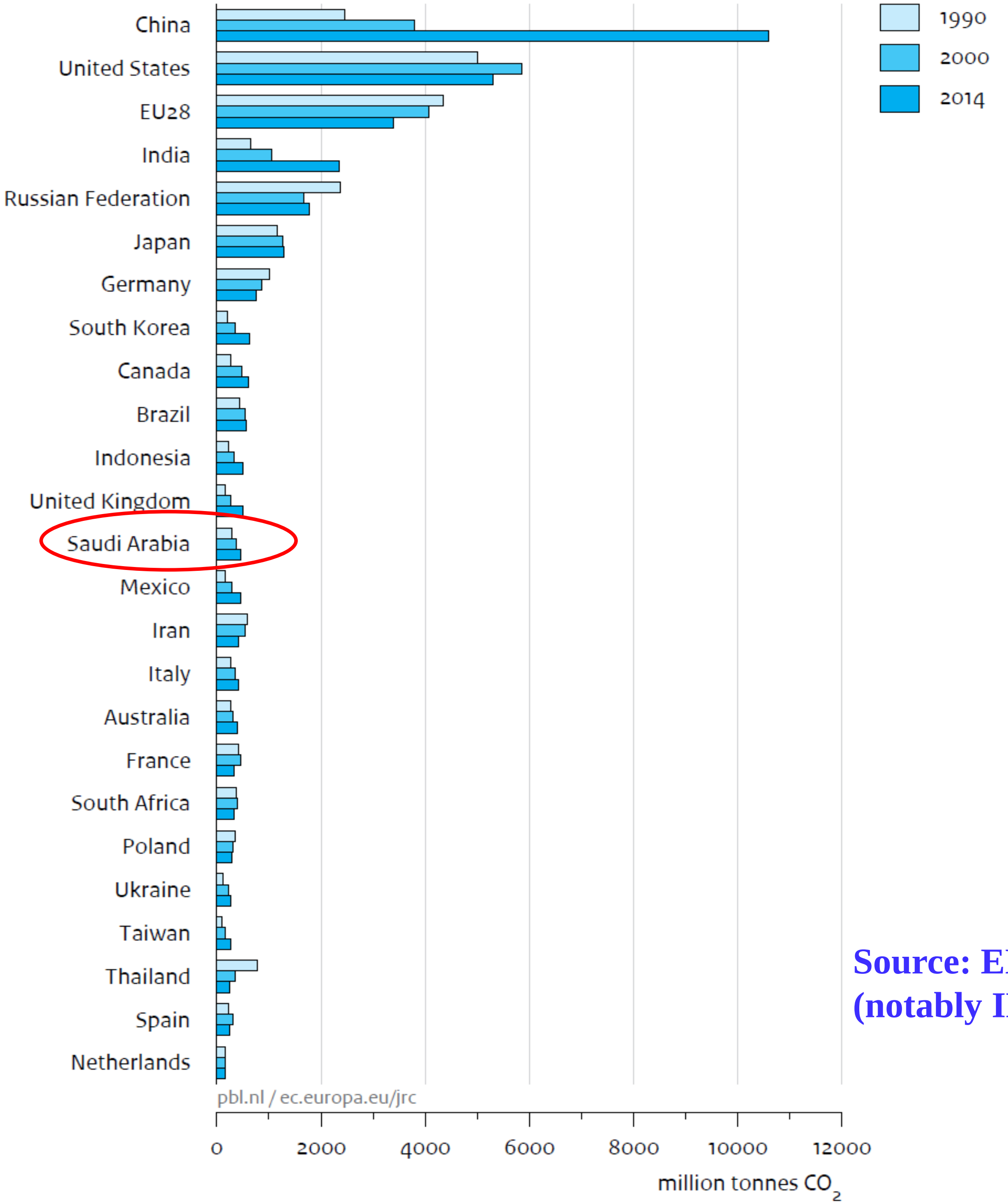

**The mix in ready mixed concrete**




**Evolution on $CO_2$ release per kg of cement produced in different regions**

Saudi Aramco

# CO2 emissions per country from fossil-fuel use and cement production




Source: EDGAR 4.3 FT2014 (JRC/PBL, 2015) (notably IEA 2014, NBS 2015 and BP 2015)

ارامكو السعودية
Saudi Aramco

# Introduction

ارامكو السعودية
Saudi Aramco


Acidic Environment


Epoxy coated Reba
Three years old chilled water retai


Offshore Be


Offshore Berth

# Content



Saudi Aramco

# Definitions:

## sustainability

The most commonly accepted definition of sustainable development is:

> "development that meets the needs of the present without compromising the ability of future generations to meet their own needs”

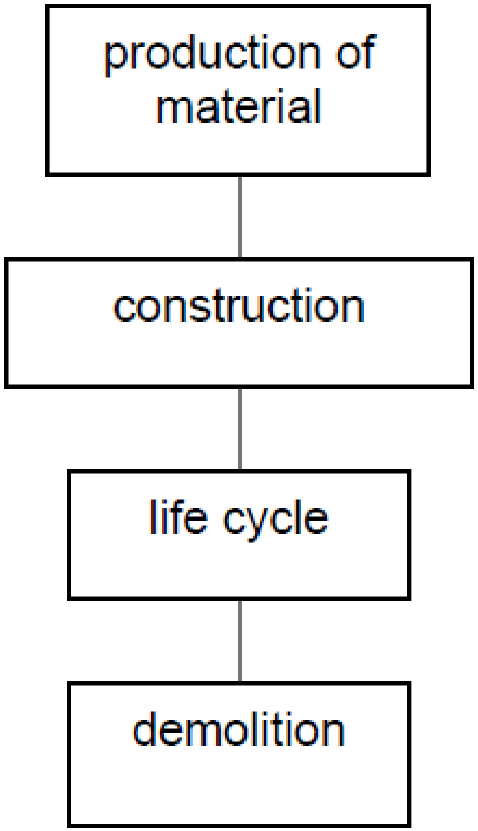
Sustainability objectives for infrastructure projects are best accomplished by ensuring:

- durable structures
- with long service life and minimal maintenance input. (long lasting)
- conserve natural resources and minimize waste (be an efficient, minimalist design, avoiding extravagant architectural statements)
- minimize material consumption over the whole of life.
- lowest whole-of-life economic cost (e.g. maintenance cost).
- disaster Resistant (earthquake, extreme wind, blast, etc.)

ارامكو السعودية
Saudi Aramco

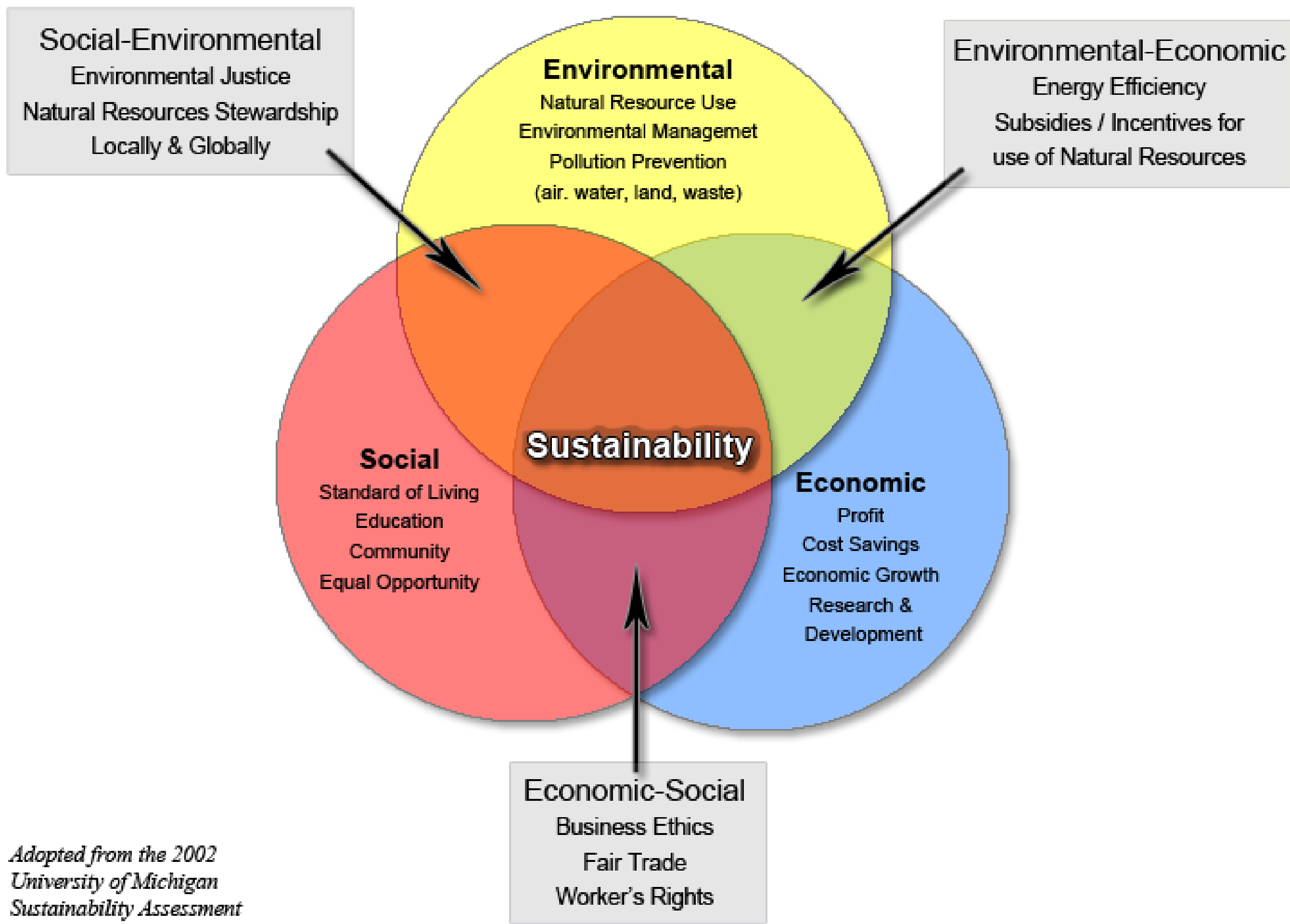
# Definitions:

## Sustainability




**Stages considered when estimating environmental impact**

### *The Three Spheres of Sustainability*




*Adopted from the 2002 University of Michigan Sustainability Assessment*

# Definitions:

## Durability

is defined as the design of a structure or facility to meet the design life requirement

- by material selection,
- degradation management,
- monitoring,
- inspection and maintenance

ارامكو السعودية
Saudi Aramco

# Definitions:

## Design Life

the period of time after the date of practical completion during which the item is expected to operate within its specified design parameters without replacement, refurbishment or major maintenance [*Fagerlund, Göran: Service Life of Structures 1979*].

Concrete structures shall be designed, constructed and operated in such a way that, under the expected environmental influences, they maintain their safety, serviceability and acceptable appearance during an explicit or implicit period of time without requiring unforeseen high costs for maintenance and repair

**Today many owners require service lives of 80, 100 or even 200 or 300 years for important concrete structures**

ارامكو السعودية
Saudi Aramco

# Indicative Values for Design Service Life

| Design Service Life, yrs | Examples |
|---|---|
| 10 | Temporary Structures (Structures or parts of structures that can be dismantled with a view to being reused are not to be considered temporary) |
| 10 – 25 | Replaceable structure parts, e.g., gantry girders, bearings, metal roofs, etc. |
| 15 – 30 | Agricultural and similar structures |
| 50 | Buildings and other common structures |
| 100 + | Monumental buildings, bridges, and other civil engineering structures |

CEN Eurocode 0: basis of design, EN 1990

ارامكو السعودية
Saudi Aramco

# Design Life Examples

the Gateway Bridge Arterial crossing the Brisbane River in Queensland, Australia **300 years design/service life**

**Opened for traffic 2010**

**A Joint Venture between Leighton Contractors and Abigroup Contractors**

ارامكو السعودية
Saudi Aramco

# Design Life Examples

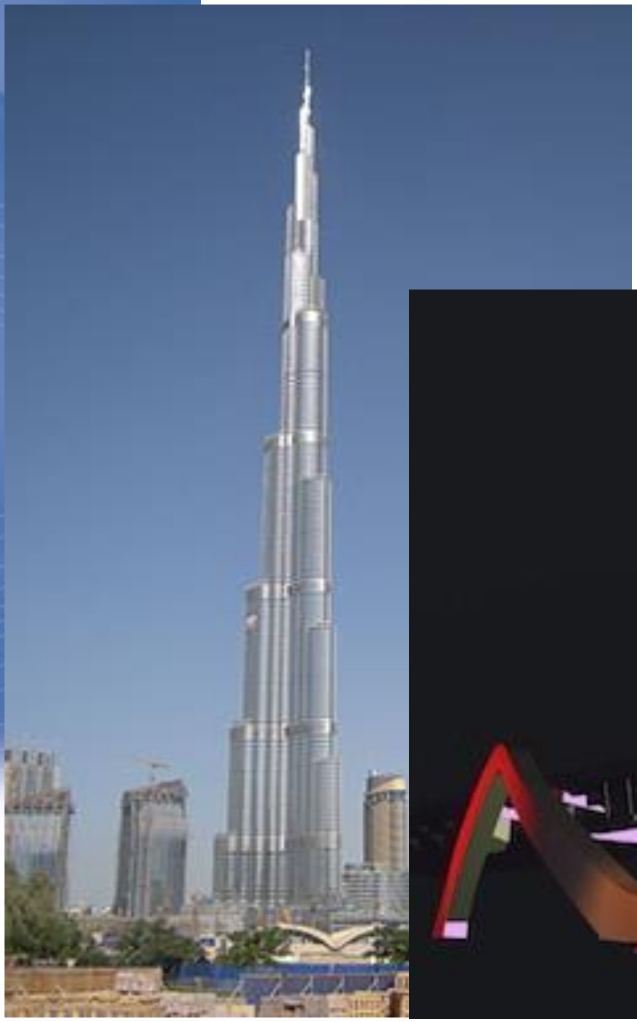
Southern Seawater Desalination Plant in Western Australia (Southern Seawater Alliance - WorleyParsons)

**100 years design /service life**

**Capacity 300 ML/d**

ارامكو السعودية
Saudi Aramco

# Design Life Examples



**Burj Khalifa Towers**
**100 year design life**

**Sheik Zayed Bridge – Abu Dhabi UAE**
**120 year design life**

# Content

1

2

3

4 Provisions to enhance sustainability through durability of concrete structures

5

# How concrete can be made more sustainable

Important notes

- the current emphasis on high strength and very high strength, and the design philosophy of Durability through Strength for concrete materials and concrete structures is fundamentally flawed. It is this misleading concept and vision that is primarily responsible for the lack of durable performance of concrete in real life environments.
- To change this scenario, current practices advocates that concrete materials must be manufactured for durability and not for strength.
- this concept of Strength through Durability can be achieved through careful design of the cement matrix and its microstructure

ارامكو السعودية
Saudi Aramco

# How concrete can be made more sustainable

1. Concrete specification shall be performance-based to achieve the durability requirements for a specific project. Prescription to Performance (P2P)

# SAES-Q-001 "Criteria for Design and Construction of Concrete Structures"

7.17 Sulfur Pits

7.17.5 High performance self-consolidating concrete with 65% Ground Granulated Blast Furnace Slag (GGBFS) and 5% silica fume in addition to 30% Type I to produce cement high chemical resistant shall be used for sulfur pit construction or repair. High performance concrete shall meet the following durability criteria:

a. Minimum compressive strength shall be 60 MPa as measured in accordance with ASTM C39;

b. Corrected 30 minute absorption of not greater than 1.2%, as measured by BS 1881: Part 122:1983. The absorption test is to be conducted by an independent testing authority on cores taken from cubes or cylinders (or from cast specimens where permitted by the Principal's Representative), from the trial mixes which shall be conducted prior to the commencement of the supply of concrete;

c. Chloride permeability test shall be carried out in accordance with ASTM C1202 or AASHTO T277. The total charged passed shall not exceed 1000 coulombs.

# SAES-Q-001 “Criteria for Design and Construction of Concrete Structures”

## 8 Marine and Coastal Concrete Structures

8.4.1 The HPI system shall produce concrete conforming with all specified requirements and shall be shown to produce concrete with a corrected 30 minute absorption of not greater than 1 % (one percent), as measured by BS 1881: Part 122:1983, except that the age at test shall be strictly 7 days. The absorption test is to be conducted by an independent testing authority on cores taken from cubes or cylinders (or from cast specimens where permitted by Saudi Aramco), from the trial mixes which shall be conducted prior to the commencement of the supply of concrete.

8.4.2 Chloride permeability test shall be carried out in accordance with ASTM C1202 or AASHTO T277. The total charged passed shall not exceed 1000 coulombs.

*Commentary Notes:*

*When HPI concrete is used, the following provisions apply:*

*a. Liners and coatings are not required.*

*b. No epoxy coated rebars are required. Uncoated steel rebars are adequate.*

*c. Backfilling can commence immediately after curing and concrete compressive strength achieve 70% of required strength.*

# Provisions to enhance durability of concrete structures

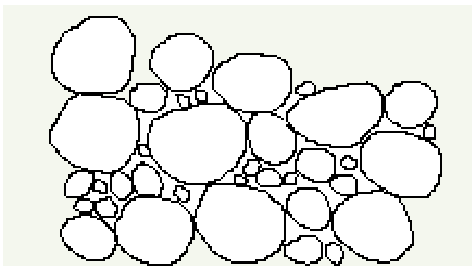
2. Interaction between durability design and execution.

3. Designer to adapt the design to the conditions under which the structure is to be constructed, operated and maintained.

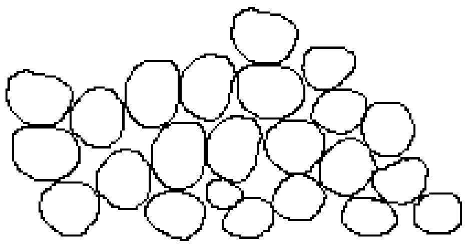
4. Provision of electrical continuity for reinforcement in more aggressive environments, to enable future cathodic protection installation if required.

well graded aggregates

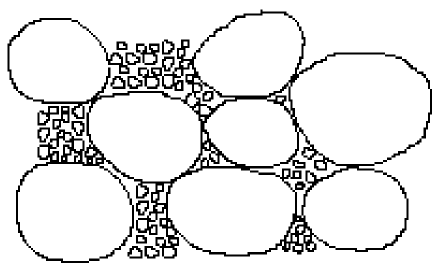
# How concrete can be made more sustainable



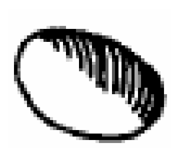
5. Well-graded aggregate can reduce the amount of cement required and the amount of water needed



Uniform size aggregate



Mixture of course and fine aggregate



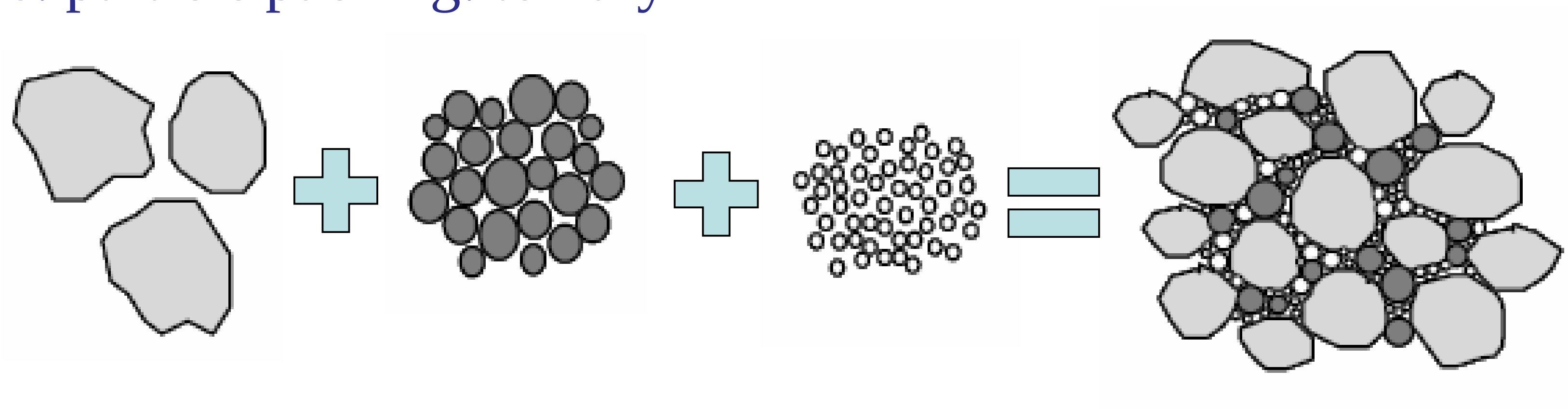
Rounded aggregates give a more workable mix. Angular aggregates make concrete harder to place, work and compact, but can make concrete stronger

ارامكو السعودية
Saudi Aramco

Cement Particle Packing

# How concrete can be made more sustainable

## 6. particle packing: ternary Mix



PC

PFA or GGBFS or Volcanic Ash

CSF

Optimum Packing Concrete

Concept of particle packing using different sized cementitious materials to minimize voids

# Provisions to enhance durability of concrete structures

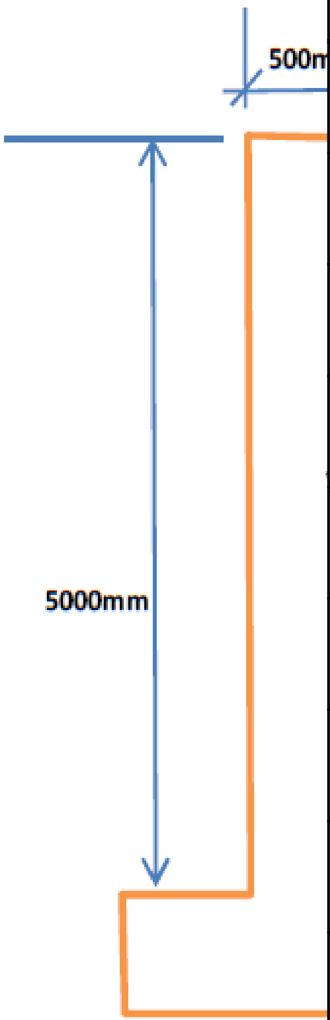
7. The use of various good quality supplementary cementitious materials, such as PFA, GGBS, microsilica (MS); Volcanic Ash and metakaolin (MK) refines the pore structure of concrete, achieving less permeable and chemical resistant concrete.

# Provisions to enhance durability of concrete structures

8. The use of self-compacting concrete (SCC). SCC is a concrete mix — where the placing and compaction has minimal dependence on the available workmanship on site — that would improve the quality of the concrete in the final structure.

ارامكو السعودية
Saudi Aramco

# Case Study #1: Upgrade Sewage Treatment Plant @ Udhailiyah

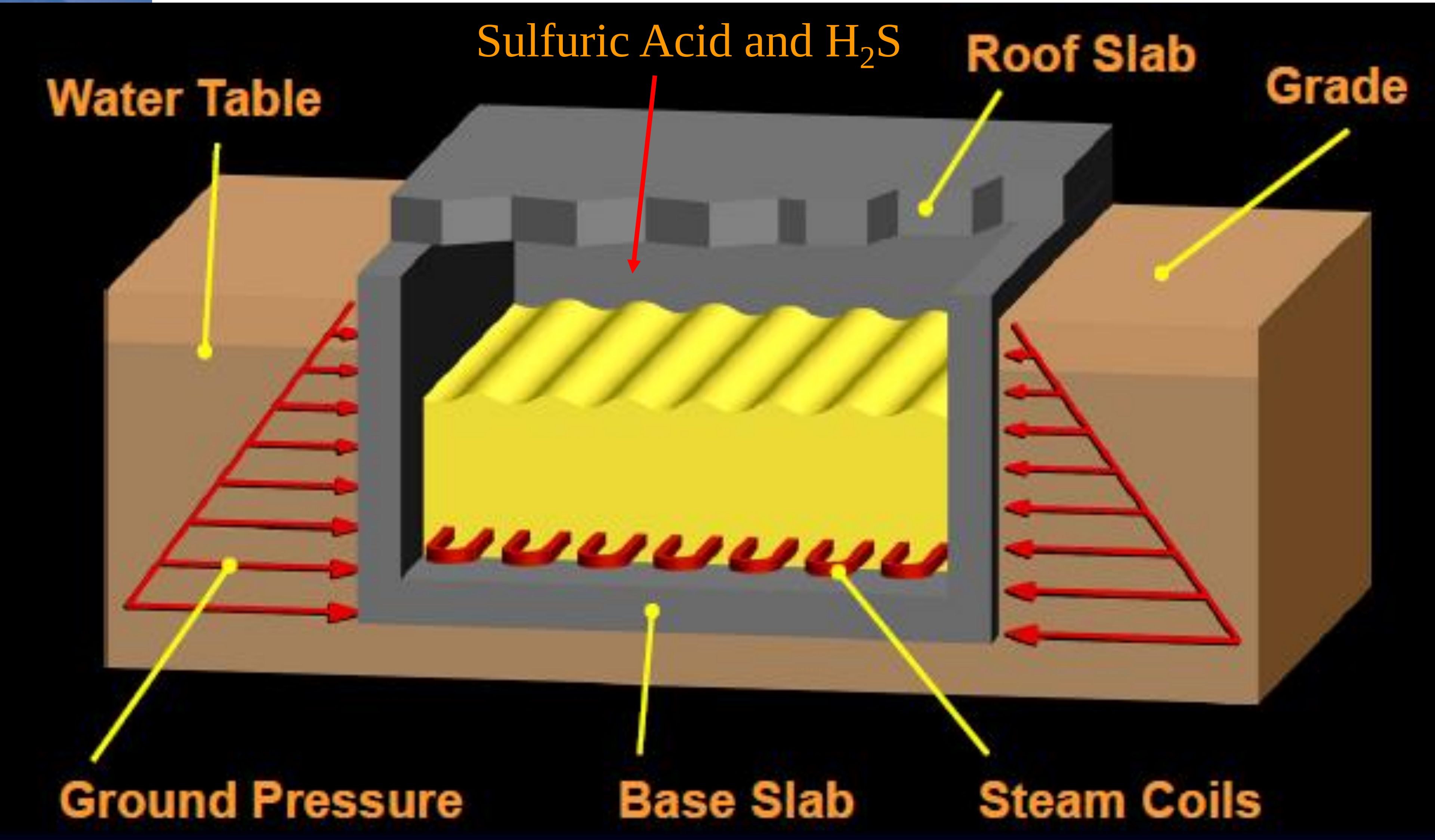



| | | |
|---|---|---|
| Supplier: | Saudi Readymix Co. | |
| **Cement Type I** | **350 Kg** | **65%** |
| Fly Ash Type F | 150 Kg | 30% |
| Silica Fume | 25 Kg | 5% |
| W/Cm | 152 Ltr | 0.30 |
| Total Cem. Mat. | 525 | 100% |
| Course aggr. | 10 mm | |
| Admixture | Viscocrte (Sika) | |
| Slump | 650 mm | |
| Flowability time | 6 hours | |
| Compressive strength | 120 Mpa @ 56 daya | |

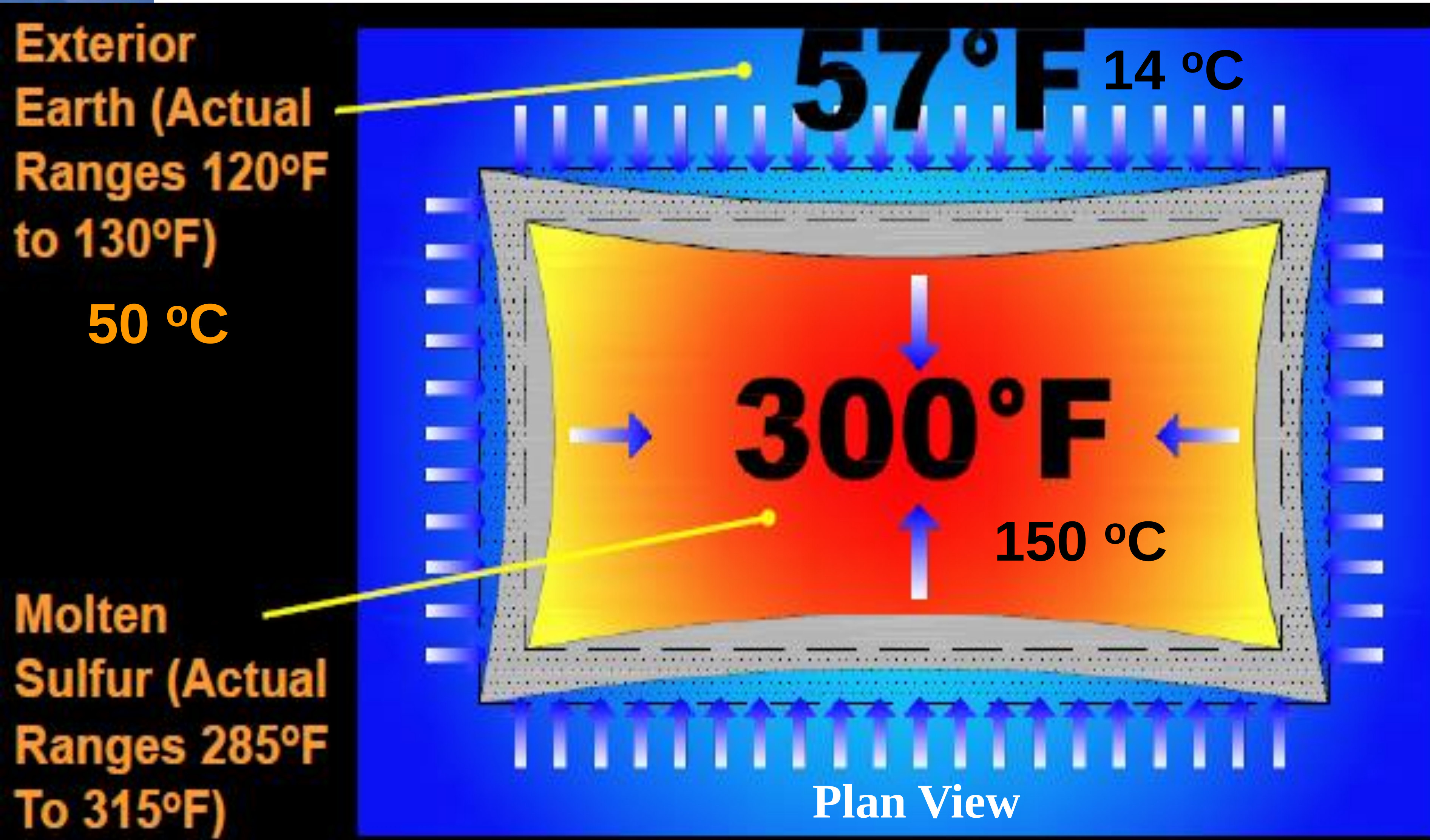
# Udhayilyiah Effluent Tanks 2010


15/03/2010

# Case Study #2: Rebuild Molten Sulfur Pits at Saudi Aramco: - Operating Conditions



# Operating Conditions
## Operating Parameters



Saudi Readymix Co.

| | | |
|---|---|---|
| Cement Type I | 350 Kg | 30% |
| Slag (GGBFS) | 150 Kg | 65% |
| Silica Fume | 25 Kg | 5% |
| W/Cm | 152 Ltr | 0.34 |
| Total Cem. Mat. | 525 | 100% |
| Course aggr. | 10/20 mm | |
| Admixture | | |
| Slump | 650 mm | |
| Flowability time | 3 hours | |
| Permeability ASTM C-1202 / AASHTO T-277 | 370 – 650 Coulombs | |
| Absorption BS 1881-122:2011 | 4 - 5% | |

| Cylinder No. | Date Tested | Age (days) | Maximum Load (kN) | Compressive Strength | |
|---|---|---|---|---|---|
| | | | | (MPa) | (psi) |
| A | 25 Nov 2015 | 3 | 878.6 | 49.7 | 7200 |
| B | 29 Nov 2015 | 7 | 1100.9 | 62.3 | 9030 |
| C | 20 Dec 2015 | 28 | 1522.2 | 86.1 | 12490 |
| D | 17 Jan 2016 | 56 | 1650.5 | 93.4 | 13540 |

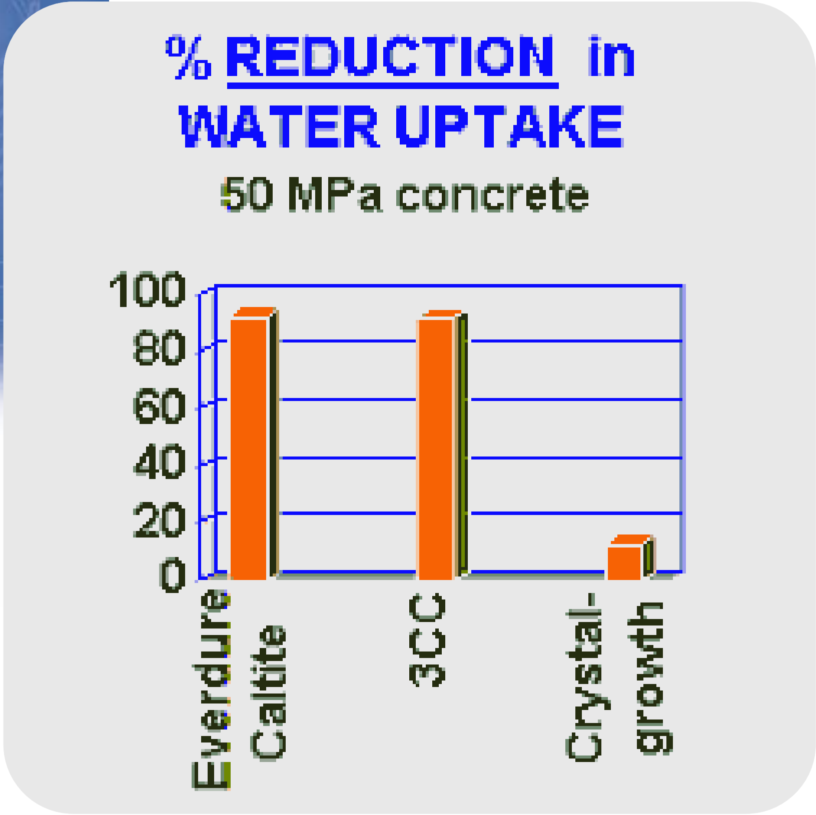
# Case Study: Rebuild Molten Sulfur Pits at Saudi Aramco

# Provisions to enhance durability of concrete structures

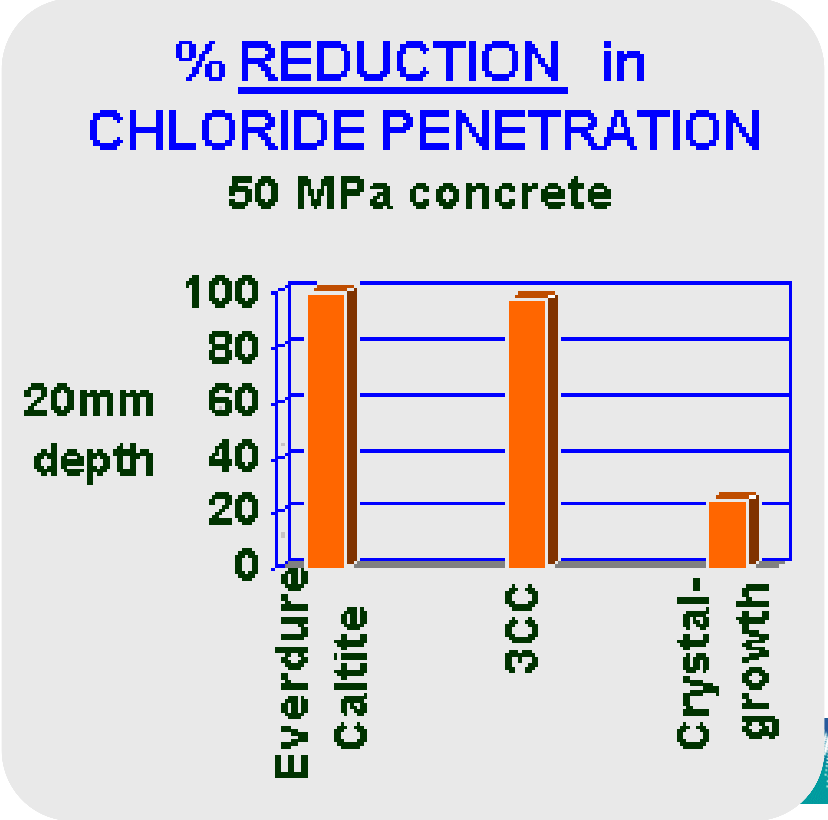
9. Use of permeability-reducing admixtures (concrete waterproofing from within).
   - The use of an admixture — characterized by hydrophobic and pore-blocking ingredients (HPI) — considerably improve concrete durability with respect to chloride-induced corrosion in concrete mixtures.
   - The effectiveness of two typical commercially available permeability-reducing admixtures, one characterized by crystal growth and the other by an HPI, were recently studied. Experimental chloride concentrations of concrete specimens exposed to a simulated coastal environment were reported.
   - The results were in favor of using HPI whereas the inclusion of a crystal growth admixture seemed to have almost no detectable effects.

# NSW Roads & Traffic Authority (RTA) (Australia)

Reduction in Water Uptake
Relative to "Control"
Everdure Caltite 92.4%
3CC 91.5%
"crystal-growth" 12.5%




Reduction in Chloride Penetration
(20 mm depth)
Salt Water Immersion & Drying Cycles
Everdure Caltite 100%
3CC 98.4%
"crystal-growth" 25.3



# Provisions to enhance durability of concrete structures

**Groundwater Analysis:**

**sulphates @ 7,200 mg/Lt. chlorides @ 53,000 mg/Lt**

PLAIN (OPC) CONCRETE @ 22 YEARS

Hot, tidal salt pans in South Australia’s Port Pirie in 1962

Inspected In 2012 the Caltite concrete still in excellent condition

CALTITE CONCRETE @ 52 YEARS

## Caltite System concrete •Membrane – Free • No Coatings required


# Case Study #3: KAUST CMOR Buildings (Laboratories)

*Waterproofing System*

**Seepage, between RC Wall & Base foundation (inside part of basement wall)**


Seepage, along sump pit wall and inside sump

ارامكو السعودية
Saudi Aramco


Additional waterproofing sheets and wall installed
Ground floor leaks and damage

# Supplier: Saudi Readymix Co.

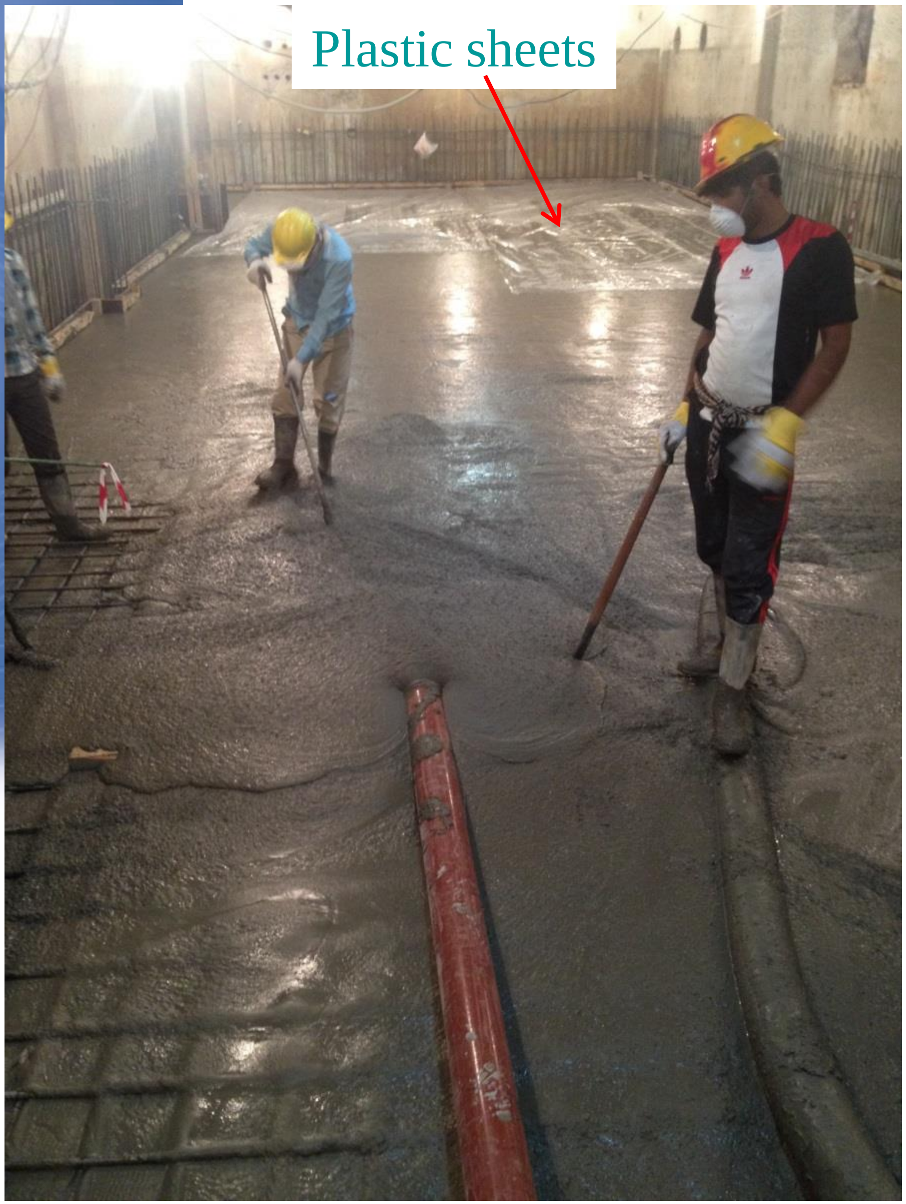
| | | |
|---|---|---|
| Cement Type I | 305 Kg | 63% |
| Fly Ash | 150 Kg | 30% |
| Silica Fume | 35 Kg | 7% |
| W/cm | 152 Ltr | 0.34 |
| Total Cem. Mat. | 490 | 100% |
| Course aggr. | 10 mm | |
| Admixture | Caltite + Superplastesizer + Viscosity & retarder | |
| Slump | 700 mm | |
| Flowability time | 4 hours | |
| Permeability ASTM C-1202 / AASHTO T-277 | 370 – 450 Coulombs | |
| Absorption BS 1881-122:2011 | 0.8 % | |
| Compressive strength @ 56 days | 82 MPa (11,900 psi) | |

| | |
|---|---|
| Source of Fine Aggregates | Wadi Qidyad – Madina Road |

أرامكو السعودية
Saudi Aramco

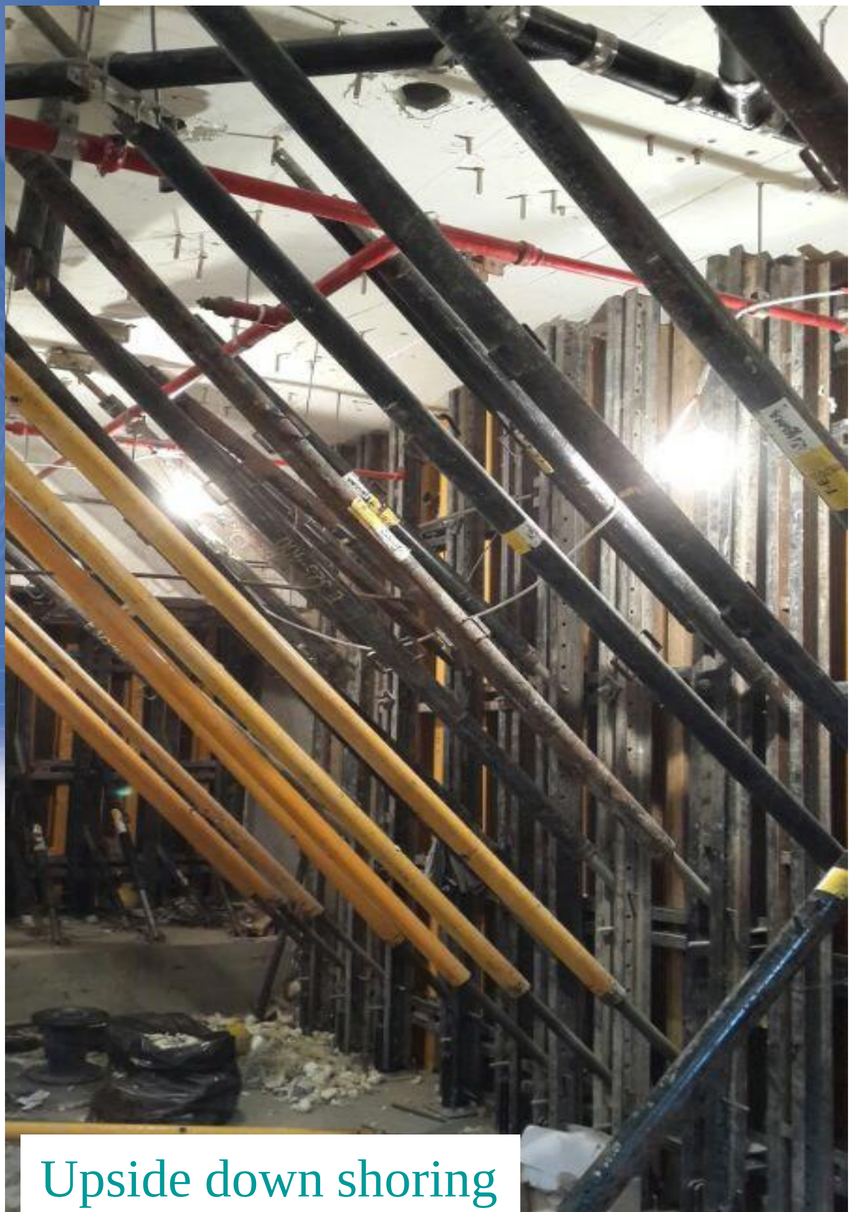

ارامكو السعودية
Saudi Aramco

# Casting floor Slab




# Wall Formwork

# Challenges



Upside down shoring

Many Pipe Penetrations

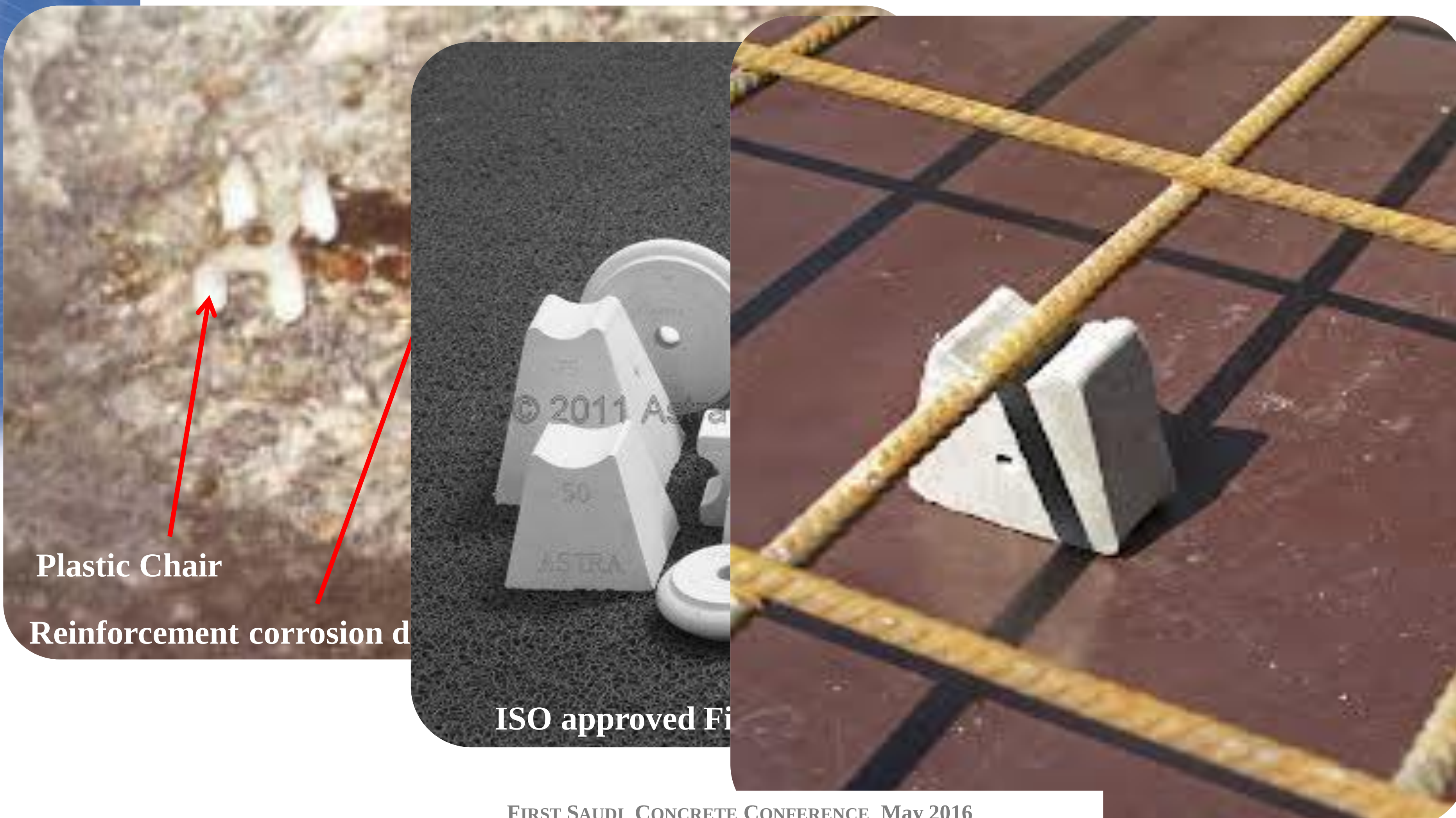
# How concrete can be made more sustainable

10. Selection of greater cover to reinforcement in aggressive environments
    - The spacer material shall have a good bond to the concrete and shall have similar hygro-thermal deformation characteristics as concrete.

- Plastic spacers have different temperature coefficients than concrete (a factor of about ten)
- Because of their lack of bond with concrete, plastic spacers should never be used for water retaining or any structure with durability requirements
- Fiber concrete spacers made by ISO approved manufacturers are considered by many to be the Rolls Royce of the industry
  - they have better load bearing capacity.
  - they have better bonding with in-situ concrete as they are made from the same material. Hairline cracks are discouraged.
  - They are fire resistant and not attacked by Alkalies.
  - they are more cost-effective.

# How concrete can be made more sustainable

at many a places, especially in bridges and jetties, corrosion was initiated at the locations of plastic spacers provided



**Plastic Chairs in Sulfur pit melted after operation**

# Provisions to enhance durability of concrete structures

11. Good detailing to enable compaction of concrete, along with good vibration and subsequent curing during construction, to ensure a dense layer of cover concrete.

ارامكو السعودية
Saudi Aramco

# Examples of poor specifications and construction Practices

Closely spaced
...nts that does not
...e course
...pass through

Improper compaction or low slump concrete

# Content

# Conclusions

- Durability is the key to sustainability.
- If the useful life of a structure can be extended by using concrete, that's a huge gain for sustainability.
- Performance based specifications are the basis for durable structures and the direction for the next era.
- Developments in concrete technology will continue to improve the industry's ability to respond.
- Durability plan is vitally important before starting any design and execution.
- A new design paradigm is needed for the design and execution of concrete structures. This is a precondition for concrete structures to increase competitiveness and thus remain the solid and reliable foundation for future societal prosperity.

ارامكو السعودية
Saudi Aramco

# Thank you

Any Questions?

# Content



ارامكو السعودية
Saudi Aramco

# Durability Plan and Sustainability

To achieve a sustainable structure, a durability plan prepared by specialist independent durability consultant is extremely important.

Durability planning process involves four main stages:

- environmental exposure assessment
- determination of the likely modes and rates of degradation
- selection of suitable materials for construction
- operation and maintenance requirements for the design life

# Impact of SCM characteristics on the fresh properties of concrete

| | Fly ash | | Slag cement | Silica fume | Natural pozzolans | | |
|---|---|---|---|---|---|---|---|
| | Class F | Class C | | | Calcined shale | Calcined clay | Metakaolin |
| **Water demand** | ↓ | ↓ | ↓ | ↑ | ↔ | ↔ | ↑ |
| **Workability** | ↑ | ↑ | ↑ | ↓ | ↑ | ↑ | ↓ |
| **Bleeding and segregation** | ↓ | ↓ | ↕ | ↓ | ↔ | ↔ | ↓ |

**KEY**

Increases ↑

Decreases ↓

No impact ↔

May increase decrease ↕

**Reproduced from PCA – Design and control of concrete mixtures - 2011**

ارامكو السعودية
Saudi Aramco

# Impact of SCM characteristics on the Hardened properties of concrete

| | Fly ash | | Slag cement | Silica fume | Natural pozzolans | | |
|---|---|---|---|---|---|---|---|
| | Class F | Class C | | | Calcined shale | Calcined clay | Metakaolin |
| Early age strength | ↓ | ↔ | ↕ | ↑ | ↓ | ↓ | ↑ |
| Long term strength gain | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ |
| Abrasion resistance | ↔ | ↔ | ↔ | ↔ | ↔ | ↔ | ↔ |
| Drying shrinkage and creep | ↔ | ↔ | ↔ | ↔ | ↔ | ↔ | ↔ |
| Permeability and absorption | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ |

**KEY**

Increases ↑

Decreases ↓

No impact ↔

May increase decrease ↕

# Examples of poor specifications and construction Practices

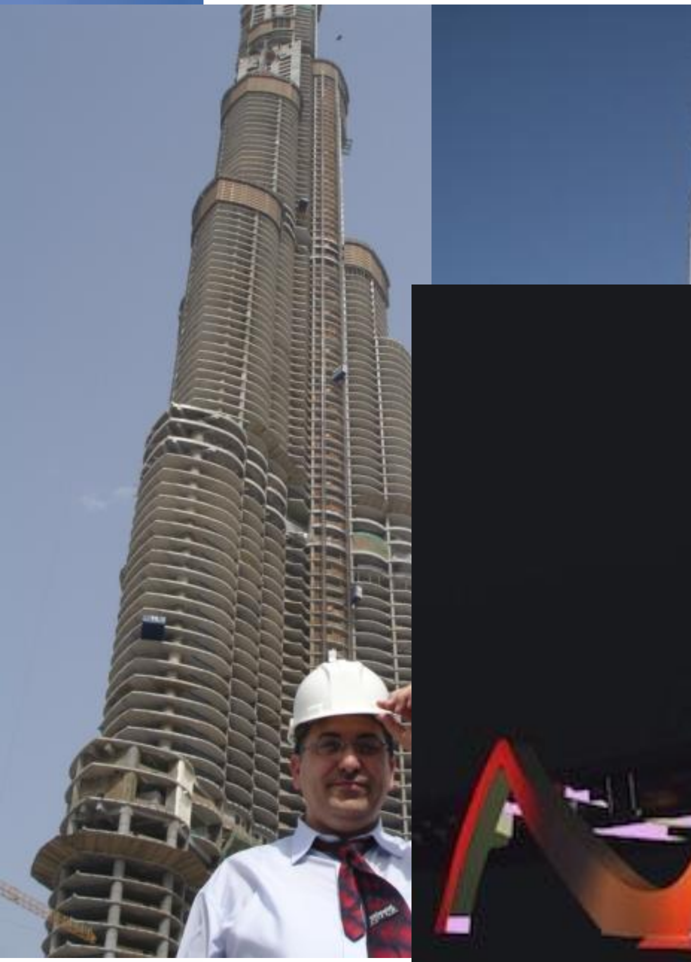

Closely spaced
...nts that does not
...e course
... pass through

Improper compaction or low slump concrete



ارامكو السعودية
Saudi Aramco

# Design Life Examples



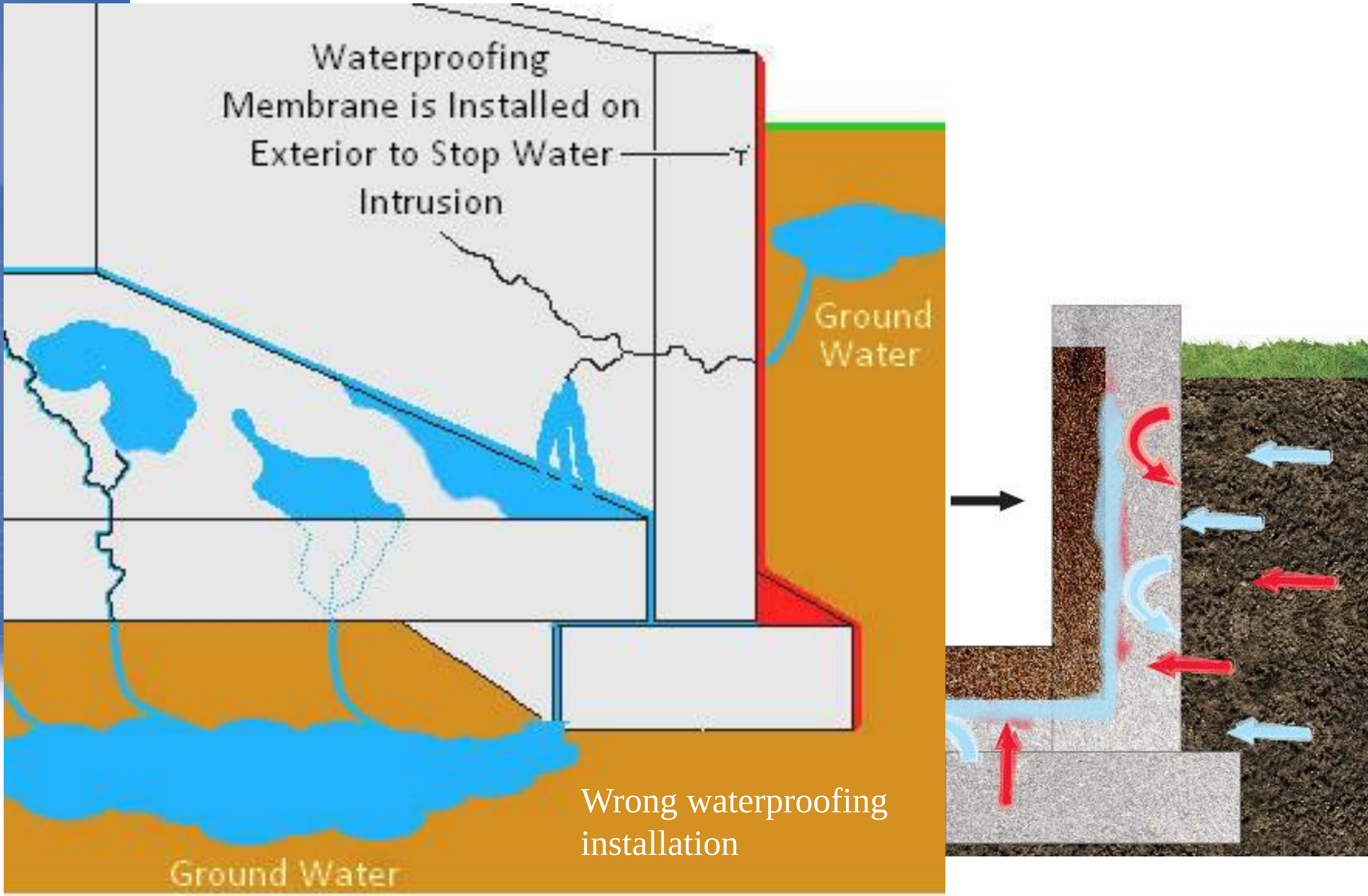
**Burj Khalifa Towers**
**100 year design life**

**Sheik Zayed Bridge – Abu Dhabi UAE**
**120 year design life**

# Dubai Mall Aquarium

*Waterproofing admixture used for Commercial, Marine, Pools & Tanks*

Saudi Aramco




Wrong waterproofing installation