Gammon

Concrete for Sustainability

Gammon Construction Ltd.

Ir. Dr. Herbert Zheng

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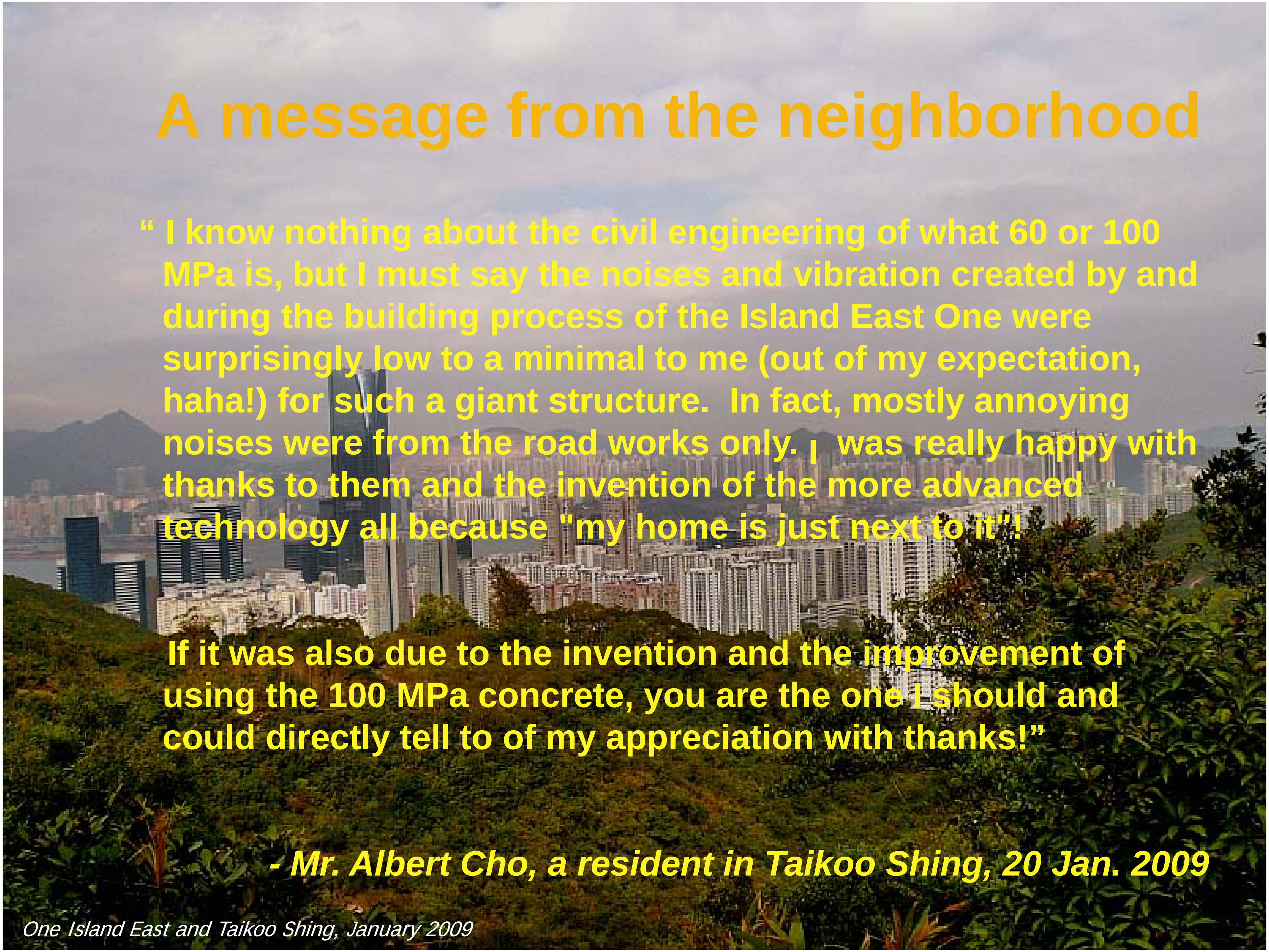
香港工商業獎
HONG KONG
AWARDS FOR
INDUSTRIES

A message from the neighborhood

" I know nothing about the civil engineering of what 60 or 100 MPa is, but I must say the noises and vibration created by and during the building process of the Island East One were surprisingly low to a minimal to me (out of my expectation, haha!) for such a giant structure. In fact, mostly annoying noises were from the road works only. I was really happy with thanks to them and the invention of the more advanced technology all because "my home is just next to it"!

If it was also due to the invention and the improvement of using the 100 MPa concrete, you are the one I should and could directly tell to of my appreciation with thanks!"

- Mr. Albert Cho, a resident in Taikoo Shing, 20 Jan. 2009



One Island East and Taikoo Shing, January 2009

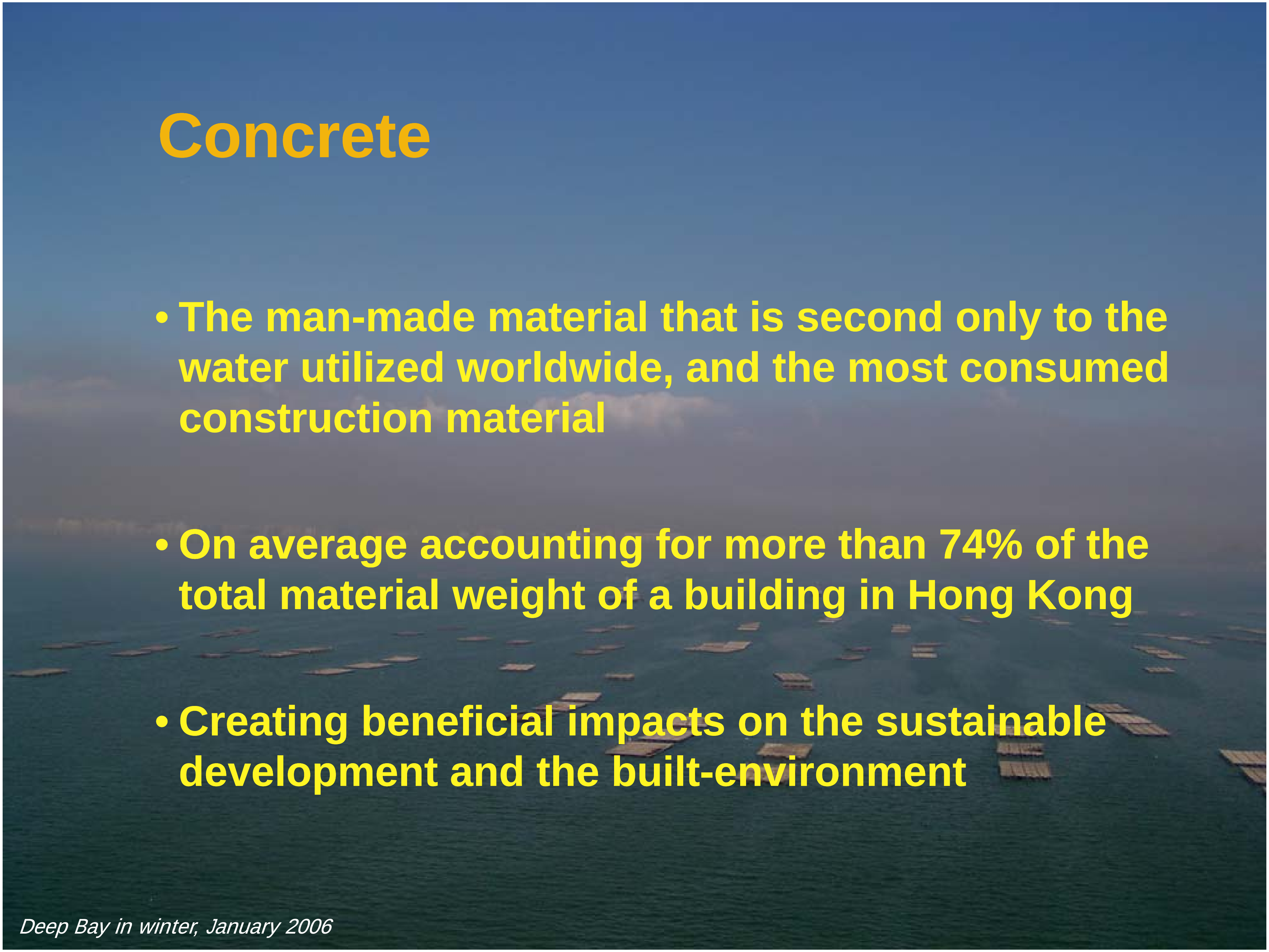
Outline

- Concrete sustainability
- Methods for concrete sustainability analysis
- Sustainability analysis of high-performance concrete
- Concluding remarks

Sunset at Deep Bay, August 2004

Concrete

- The man-made material that is second only to the water utilized worldwide, and the most consumed construction material
- On average accounting for more than 74% of the total material weight of a building in Hong Kong
- Creating beneficial impacts on the sustainable development and the built-environment



Deep Bay in winter, January 2006

Concrete and the environment

- Constituent materials are readily available.
- Choices of concrete constituent materials and proportions are entirely in the hands of engineers.
- The inherent alkalinity provides natural protection to the reinforcement of concrete structures.
- In normal to moderately aggressive environment, the concrete gives a trouble-free service life.

Sustainable development

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

– World Commission on Environment and Development

Sustainability credentials of concrete

"Concrete is one of the more sustainable building materials when both <u>the energy consumed</u> during its manufacture and <u>its inherent properties in use</u> are taken into account. The cement and concrete sector is making a concerted, <u>coordinated effort</u> to continually reduce its impact on the environment."

– **The Concrete Industry Sustainable Construction Forum, UK**

Approaches to sustainable concrete

- Reducing environmental footprint (embodied energy) of concrete and its products

- Reducing carbon dioxide emission for construction with concrete

- Improving sustainable characteristics of new concrete structures

Issues to address

- Reduce embodied energy
- Reduce CO_2 emission
- Reduce water use
- Increase the use of recycled material
- Reduce materials to landfill
- Reduce use of non-recycled material

Progress: construction industry

"Hong Kong has a relatively advanced green building agenda.

Drivers of green building in Hong Kong include government departments…such as the ASD, EMSD and HKHA…Their work has been reinforced by private sector property developers such as Swire Properties…non-profit organisations such as the PGBC and the HK-BEAM…

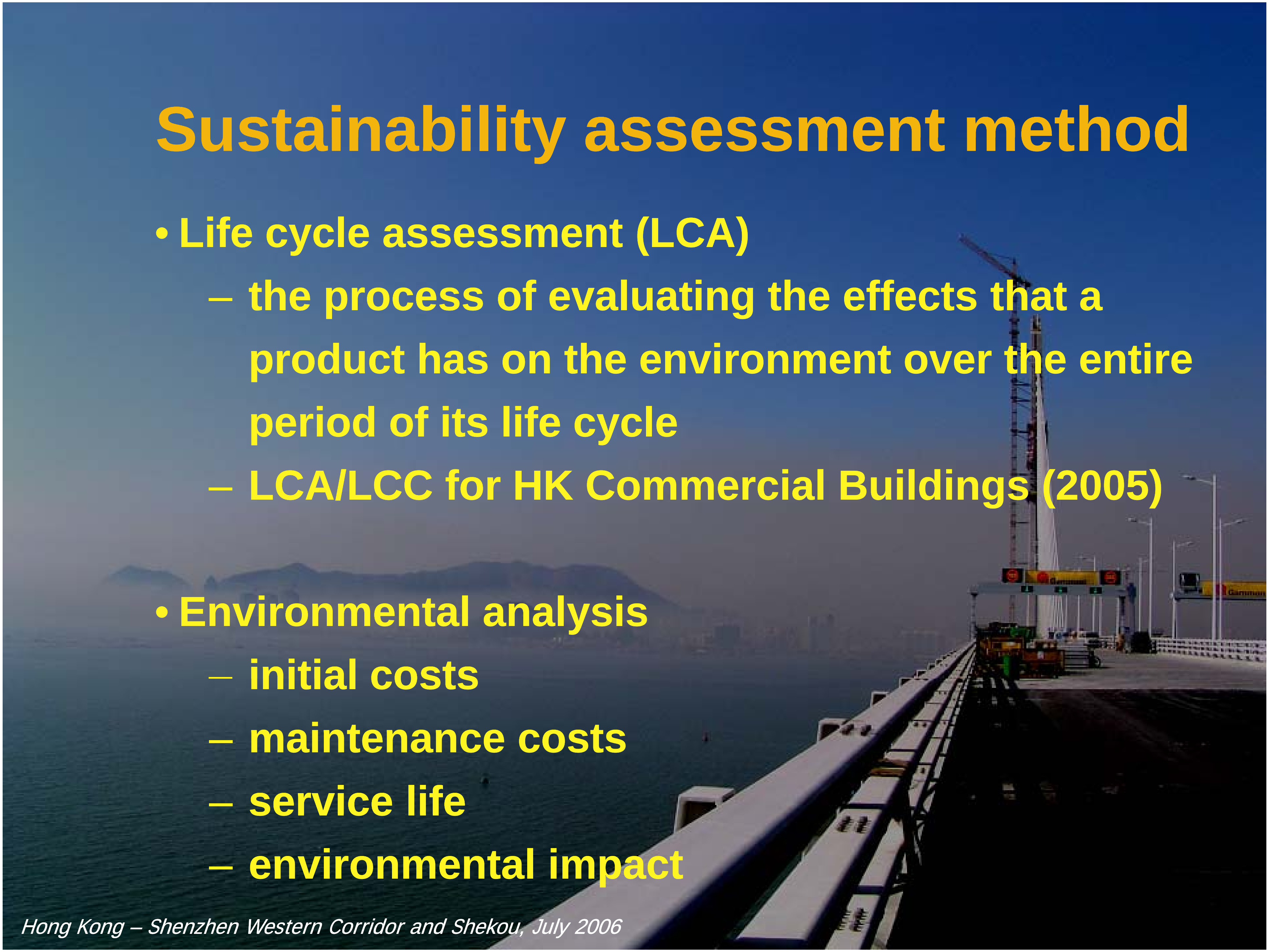
There are over 130 green building projects in Hong Kong. "

– Australian Trade Commission, 2008

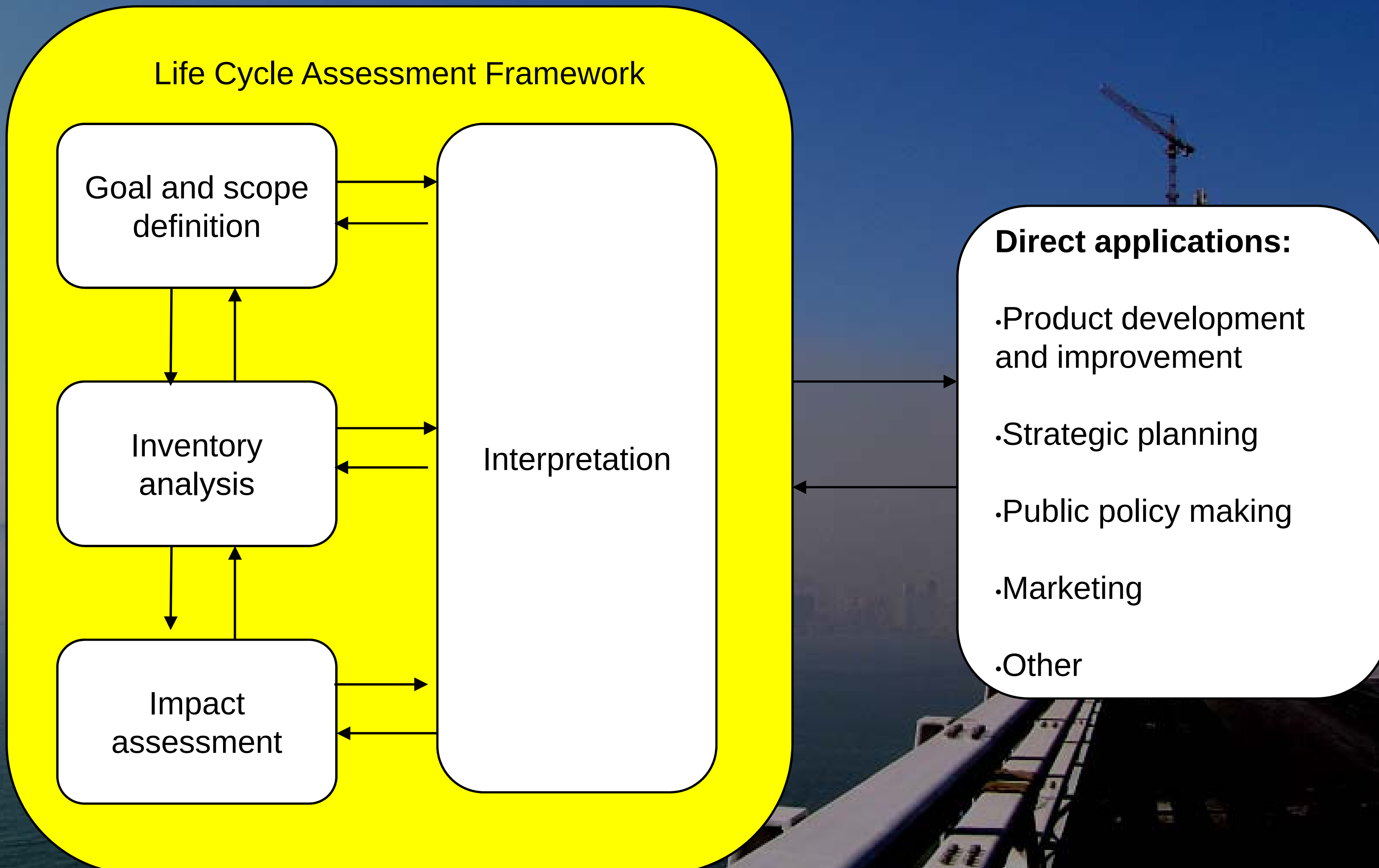
Progress: concrete industry

1. **Reducing water use**
2. **Increasing the use of recycled material**
3. **Reducing materials to landfill**
4. **Adoption of industrial cementitious byproducts**
5. **Design for structural performance, constructability and durability as a whole**

Methods for Concrete Sustainability Analysis


Sustainability assessment method
• Life cycle assessment (LCA)
– the process of evaluating the effects that a product has on the environment over the entire period of its life cycle
– LCA/LCC for HK Commercial Buildings (2005)
• Environmental analysis
– initial costs
– maintenance costs
– service life
– environmental impact
Hong Kong – Shenzhen Western Corridor and Shekou, July 2006

ISO Standard 14040 LCA steps



- Life Cycle Assessment Australian Data Inventory Project Summary Report, The Uni. of New South Wales, April 1999

Concrete sustainability analysis

Things to consider …

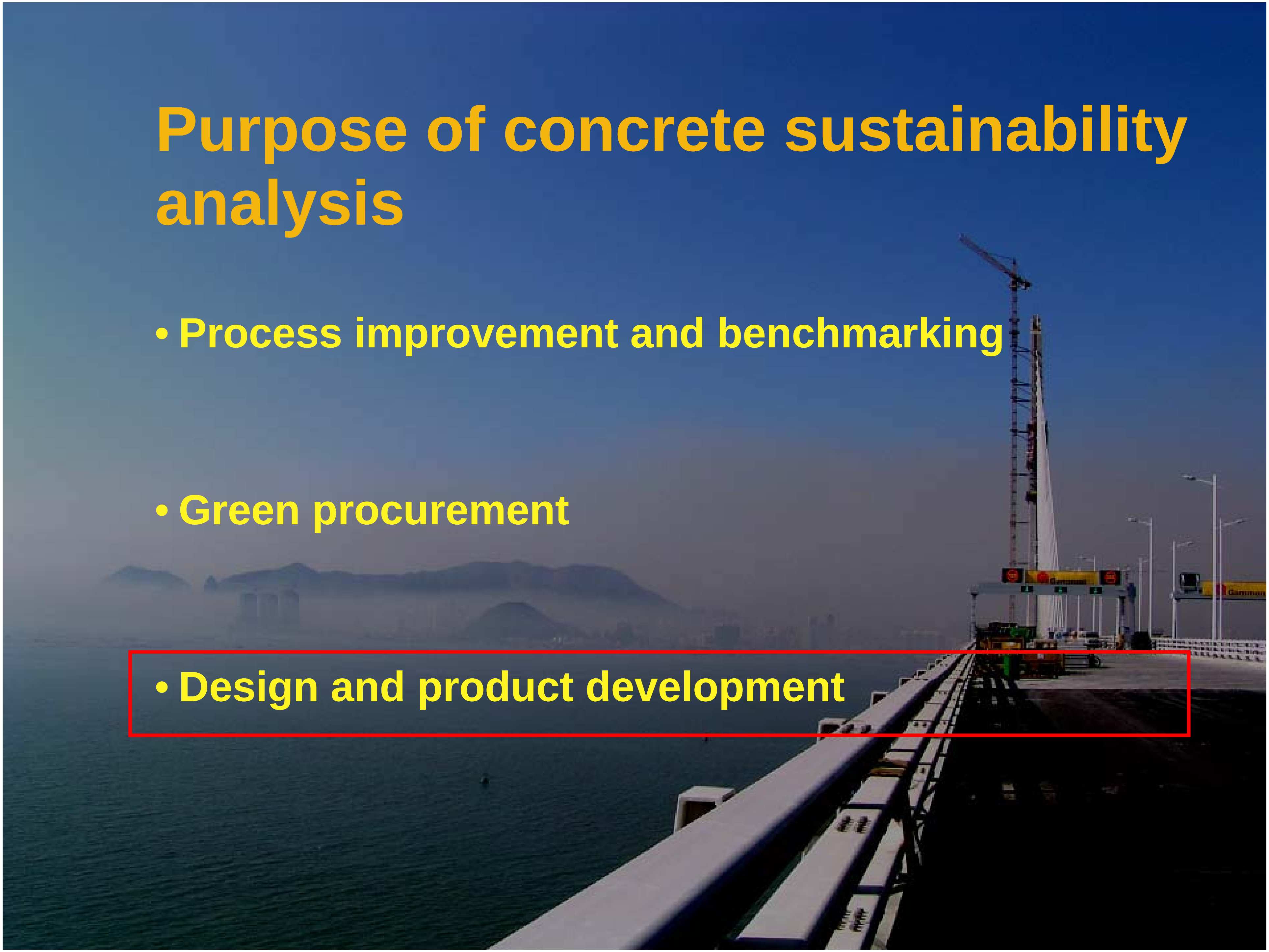
- function unit
- life time
- waste
- maintenance
- further processing energy

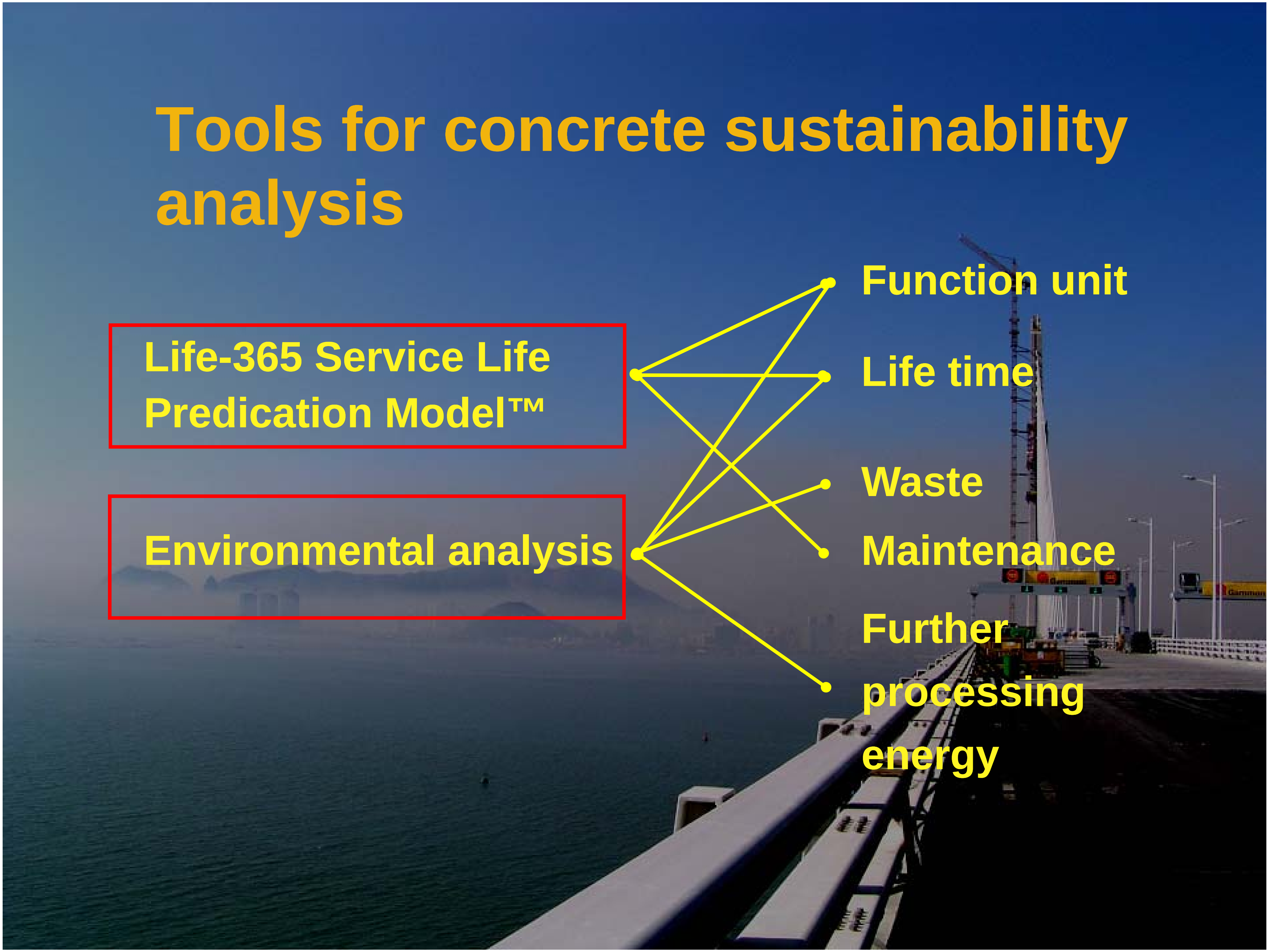
Purpose of concrete sustainability analysis

- Process improvement and benchmarking

- Green procurement

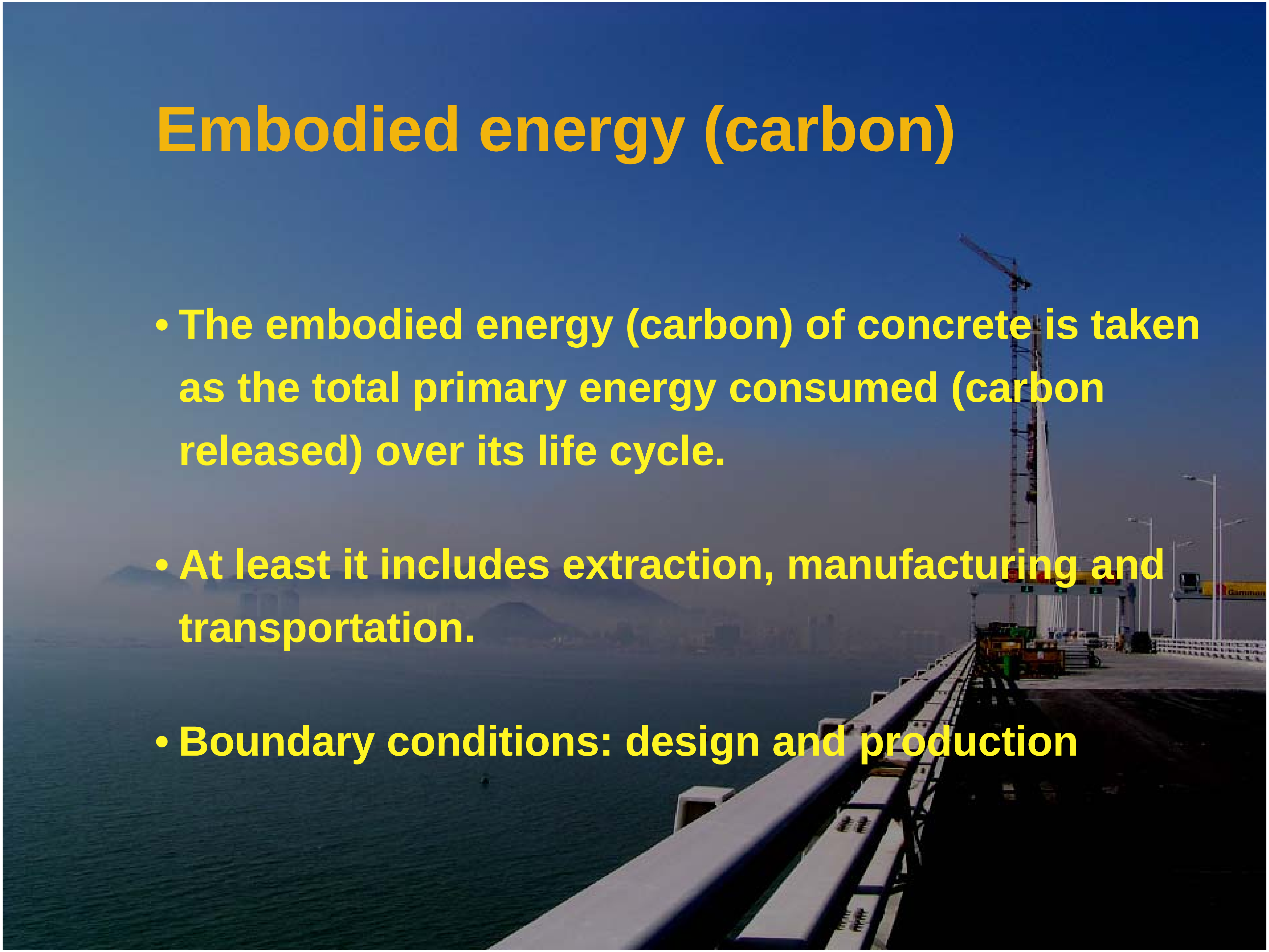
- Design and product development




Tools for concrete sustainability analysis
Life-365 Service Life Predication Model™
Environmental analysis
Function unit
Life time
Waste
Maintenance
Further processing energy

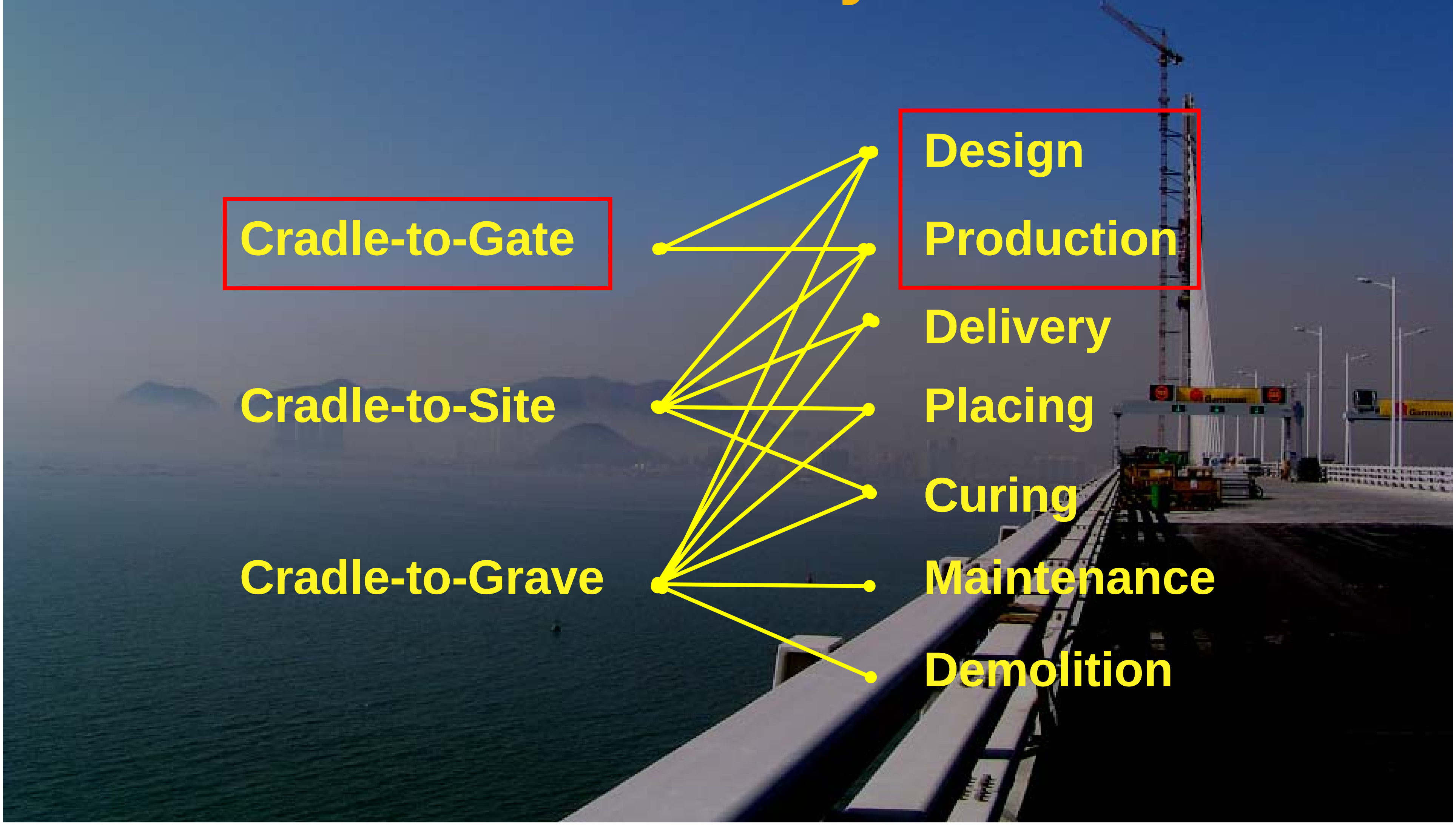
Environmental analysis

- Consumption of embodied energy (carbon)
- Pollution analysis
  - water
  - soil
  - air



Embodied energy (carbon)
• The embodied energy (carbon) of concrete is taken as the total primary energy consumed (carbon released) over its life cycle.
• At least it includes extraction, manufacturing and transportation.
• Boundary conditions: design and production

Boundary conditions for concrete environmental analysis



Inventory of carbon & energy (ICE)

Material	Embodied Energy (MJ/kg)	Embodied Carbon ($kgCO_2/kg$)
Cement	4.60	0.83
PFA / Silica fume*	0.10	0.01
Aggregates	0.10	0.005
Water	0.20	0
Naphthalene admixture*	16.26	0.51
Polycarbonate admixture*	11.47	0.6
Steel bar	36.40	2.68

** Derived by the author*

- *Source: Inventory of Carbon & Energy (ICE), Uni. of Bath, 2008*

Concrete properties related to further processing energy

"Concrete is one of the more sustainable building materials when both the energy consumed during its manufacture and its inherent properties in use are taken into account."

- Workability
- Strength development
- Durability

Importance of mix design

MYTH BUSTER - True or False?

A tonne of concrete produces a tonne of carbon dioxide.

FALSE!

The embodied carbon dioxide (ECO_2) of a tonne of concrete varies with mix design and is in the range of:

75-176 $kgCO_2$/tonne

- ***The Concrete Industry Sustainable Construction Forum, UK***

Sustainability Analysis of High-performance Concrete

Grade 100 MPa High-performance Concrete

(Winner of 2007 Hong Kong Awards for Industries – Technological Achievement)

Where is it used?

- One Island East - 308m high and the seventh tallest building in Hong Kong Island east
- In total about 32,000 m^3 (75,200 tonnes) were placed
- In comparison with the use of reference 45/20D concrete, the cross-section area of columns and core walls is reduced about 33%

Optimal packing mix design of Grade 100 MPa HPC

mix desi

Concrete grade 100/20D

Pozzolana 10% SF &

25% PFA

w/cm ratio 0.26

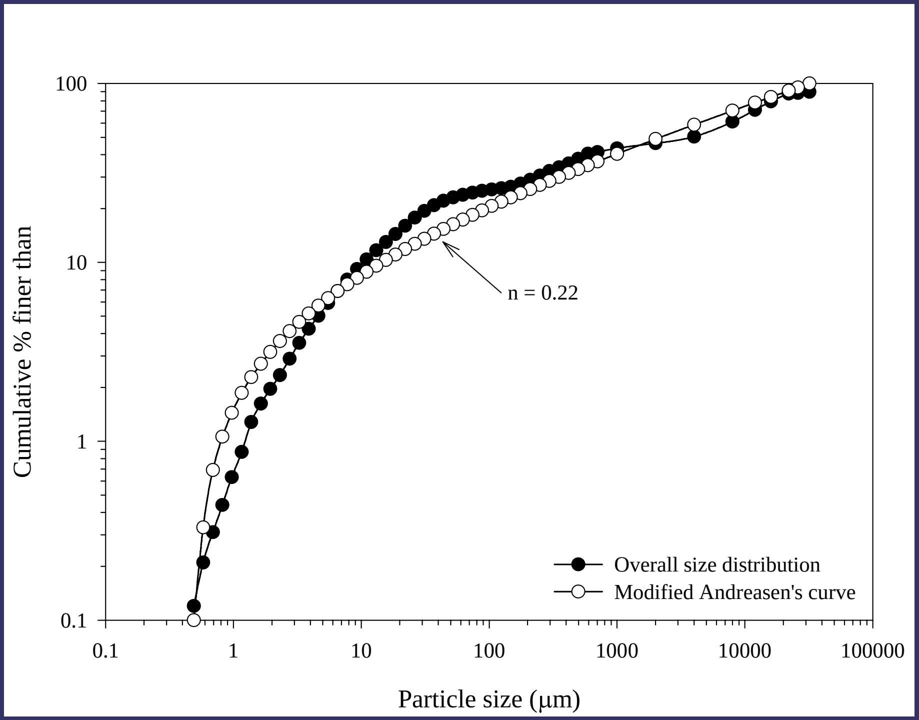
Cementitious (kg/m³)

Aggregates (kg/m³) 5831640

Water (kg/m³) 150

Admixtures (L/m³)

11

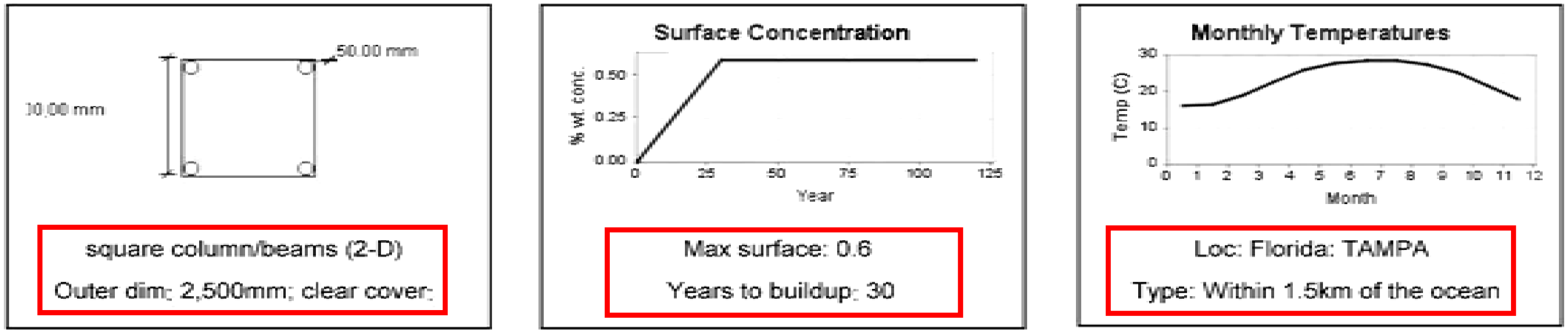


Optimized combined particle distribution,

Distribution Modulus = 0.22

M

Results of using Life-365 Service Life Predication Model™



Concrete Mixes

Alt name	User?	w/cm	SCMs	Inhib.	Barrier	Reinf.
45/20D normal PFA concrete		0.42	Class F Fly Ash (25%);			Black Steel
100/20D high-performance concrete		0.26	Class F Fly Ash (25%); Silica Fume (10%);			Black Steel

"n/a" indicates that, since the user is specifying the diffusion properties of this mix, this value is not specified.

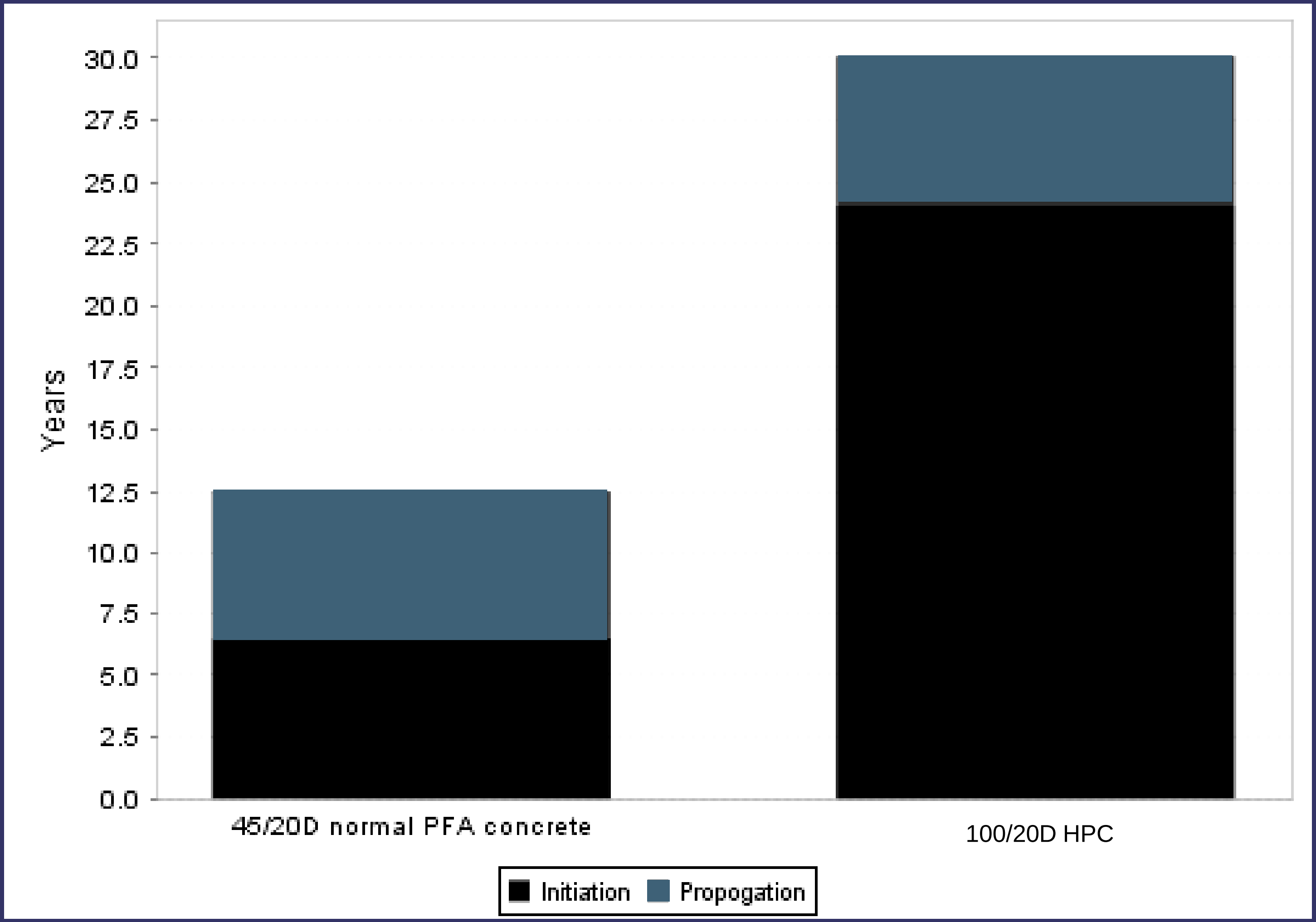
Diffusion Properties and Service Lives

Alt name	D28	m	Ct	Init.	Prop.	Service life
45/20D normal PFA concrete	8.87E-12 m*m/sec	0.4	0.05 % wt. conc.	6.5 yrs	6 yrs	**12 yrs**
100/20D high-performance concrete	7.04E-13 m*m/sec	0.4	0.05 % wt. conc.	24.1 yrs	6 yrs	**29 yrs**

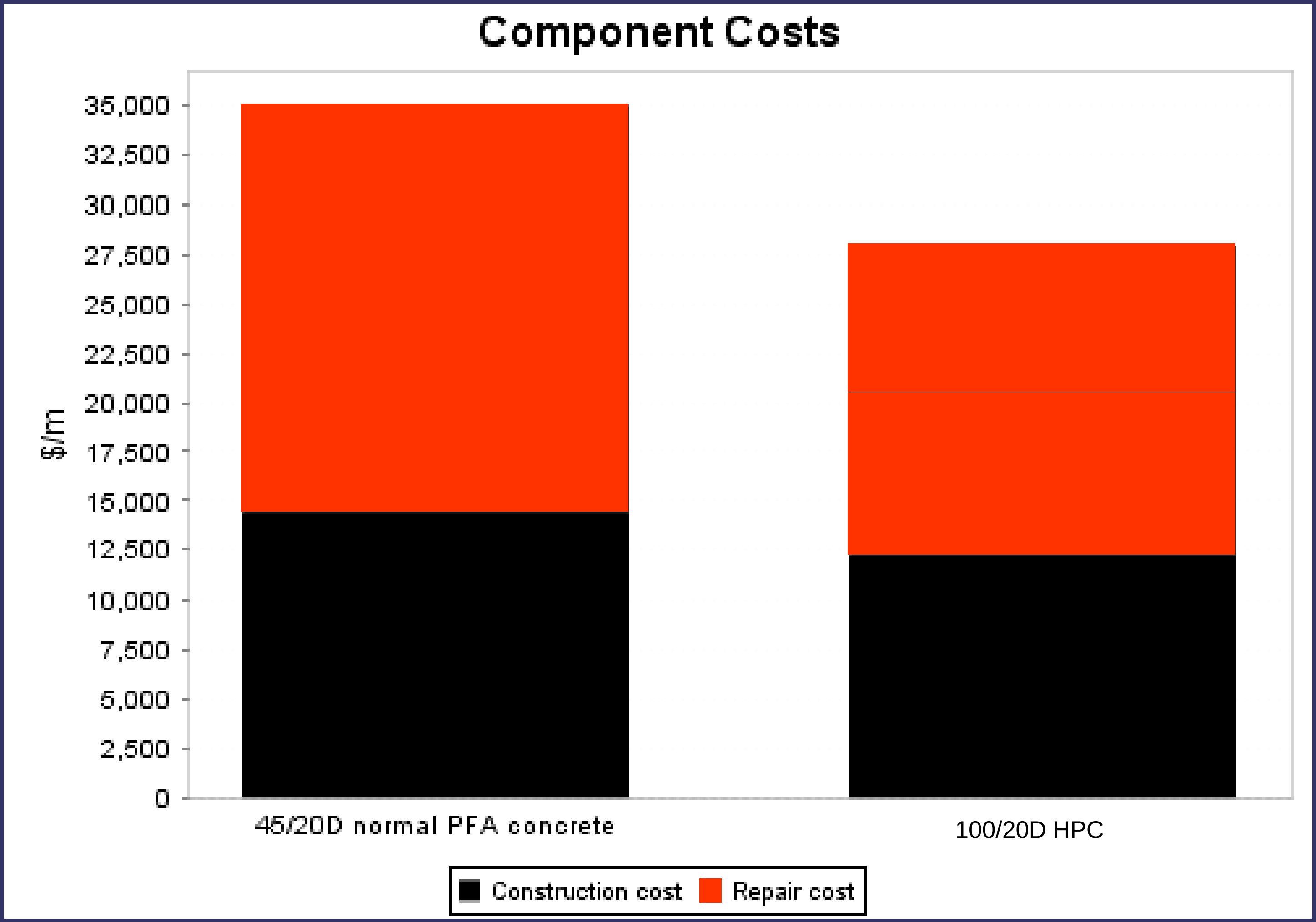
"->" indicates that the user has directly specified this value.

Note: The exposure condition and service life under investigation are different from One Island East project.

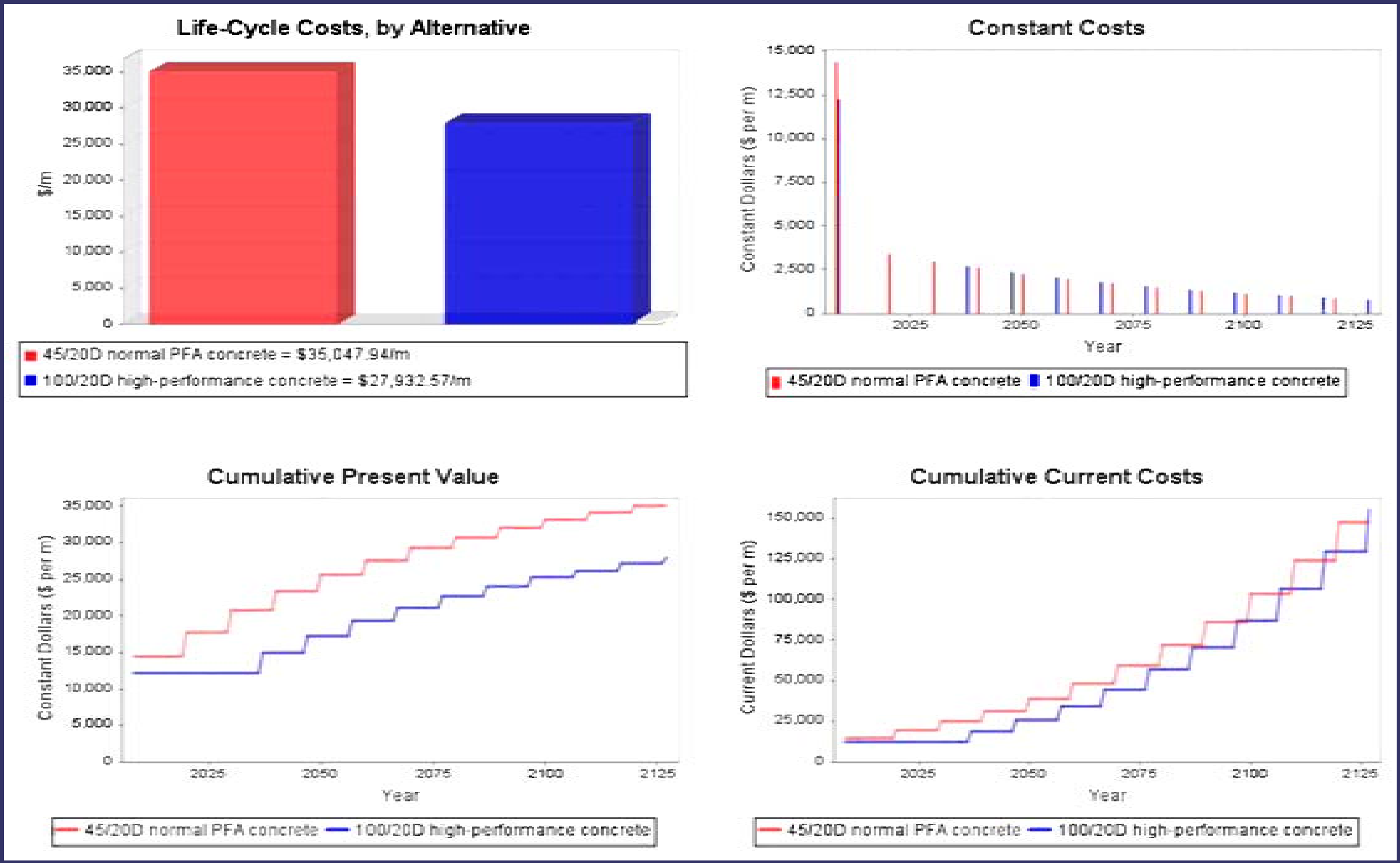
Comparison of service life in marine exposure condition



Comparison of life-cycle costs (120 years)



Details of life-cycle costs per meter height of column (120 years)



Comparison of embodied energy

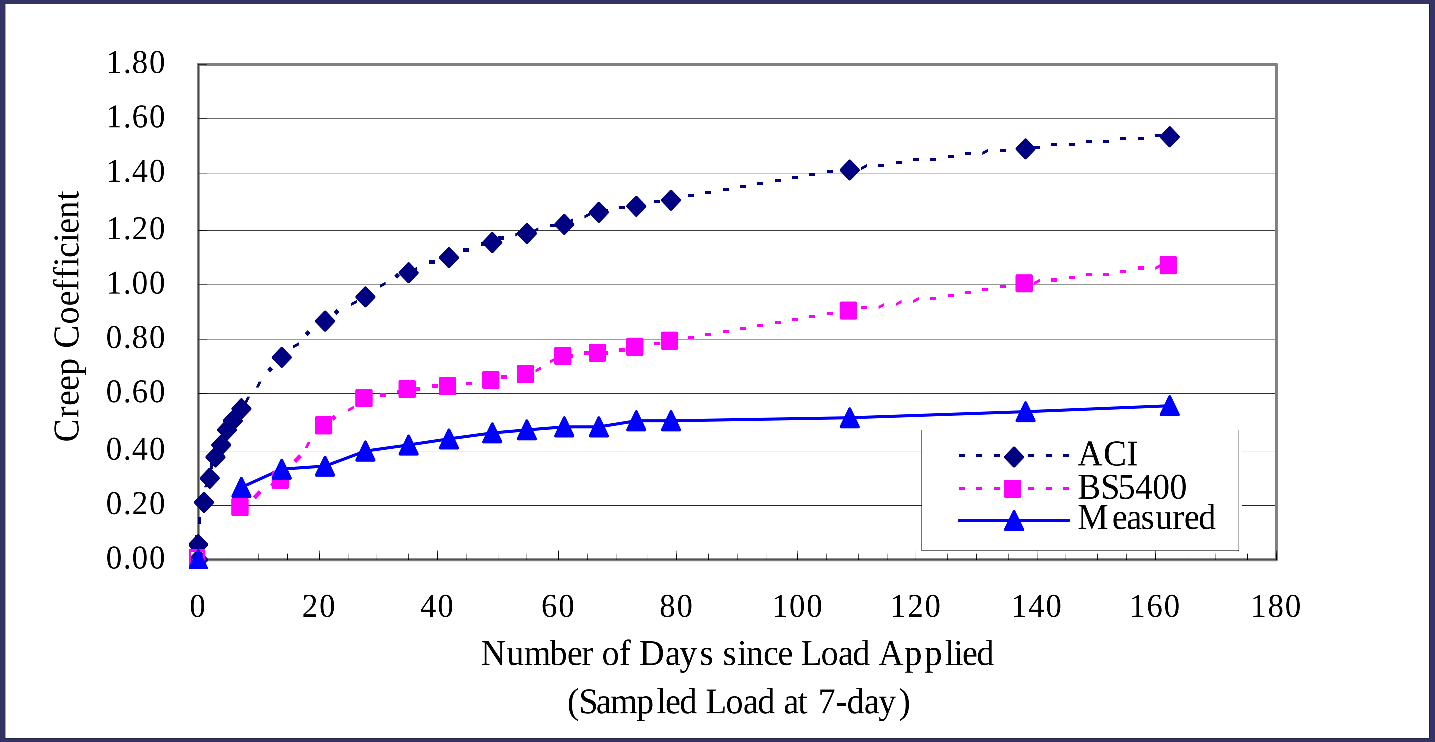
Material	Embodied Energy (MJ/tonne)	Embodied Carbon ($kgCO_2$/tonne)
45/20D PFA concrete	812	129
100/20D high-performance concrete	891	142
Steel bar	36,400	2,680
In equivalent function unit*		
45/20D PFA concrete	81,212,992	51,008
100/20D high-performance concrete	67,003,200	45,120

* Excluding reinforcement steel

Benefits to reduce further processing energy

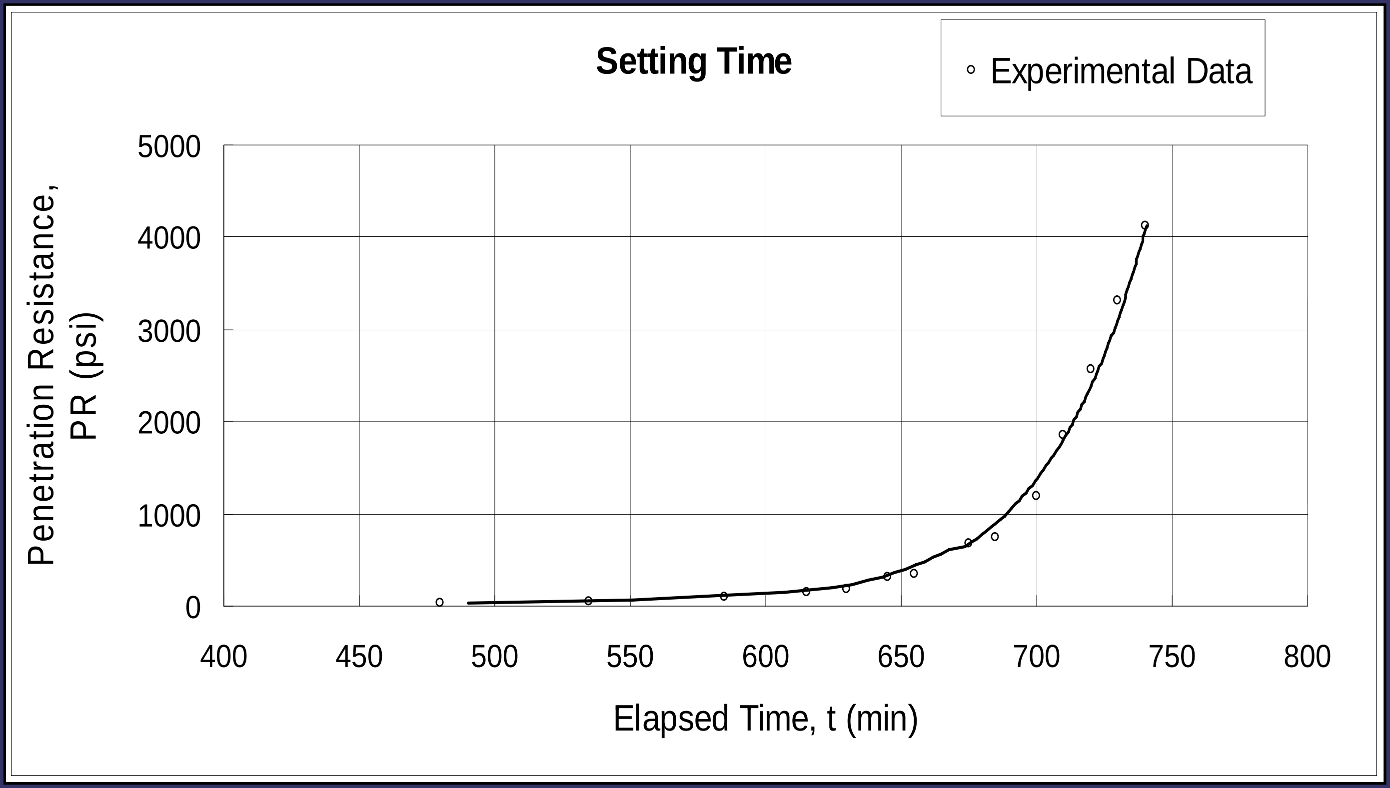
Properties	100/20D HPC Performance
Slump flow (mm)	≥ 650
Workability retention (hours)	≥ 4
Segregation resistance	Satisfactory
Early strength (MPa)	≥ 18 (at 18 hours)
28 days grade strength (MPa)	≥ 100
Modulus of elasticity (GPa)	≥ 40
3 days tensile splitting str. (MPa)	≥ 4.0
Shrinkage (10^{-6})	≤ 250
Chloride penetration (coulombs)	≤ 200

Creep and Shrinkage



Creep coefficient

Setting Time



Final setting time: 12 hours **No bleeding**

Comparison of workability

45/20D normal PFA concrete

100/20D high-performance concrete

Self-compacting after pumping

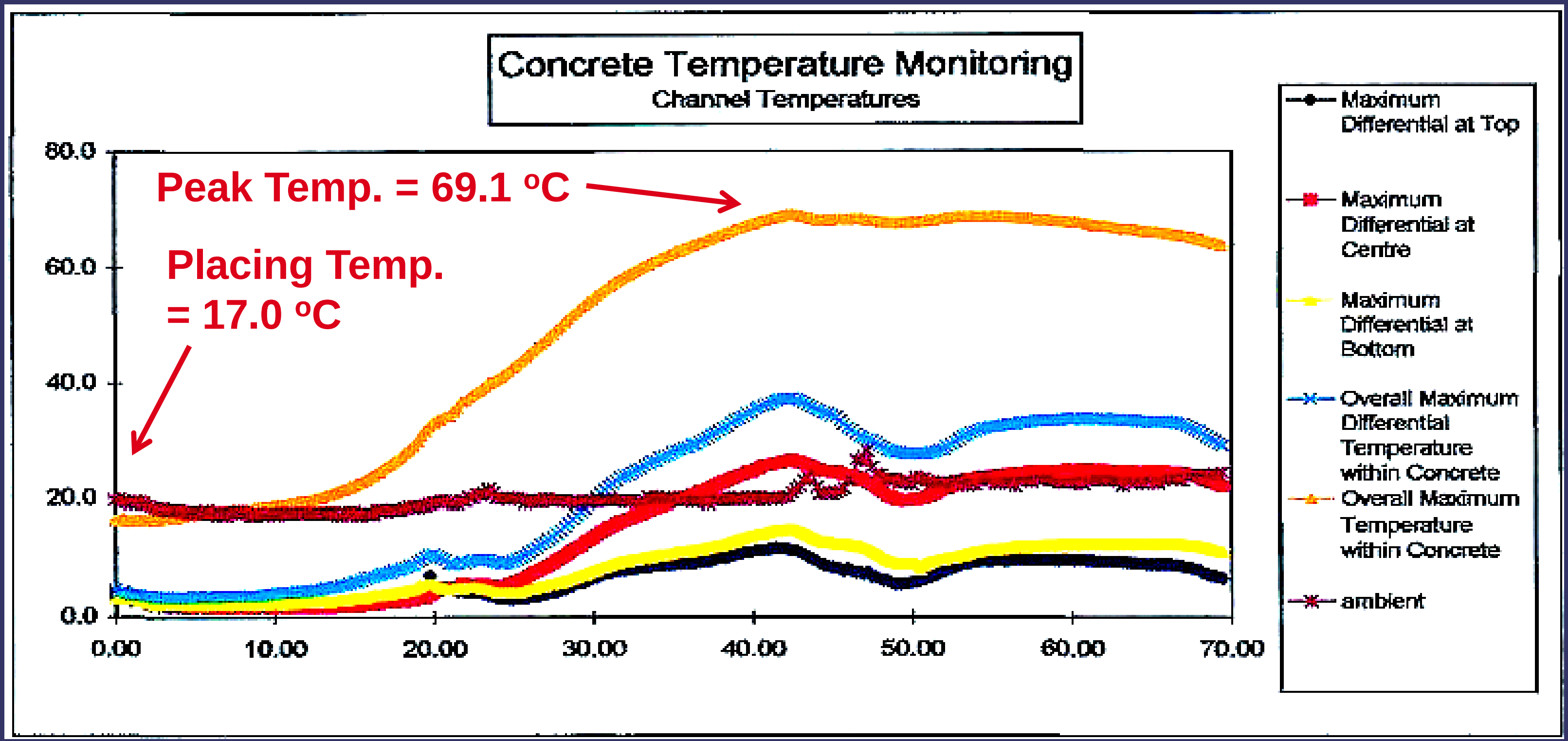
45/20D normal PFA concrete

(Ground level)

100/20D high-performance concrete

(180m above ground)

Temperature rise



Temperature rise: 52 ^{o}C

(Equivalent peak temperature = 80 ^{o}C

when concrete placing temperature = 28 ^{o}C)

Temperature control in mass concrete construction

100/20D high-performance concrete column

80/20D high-strength concrete column

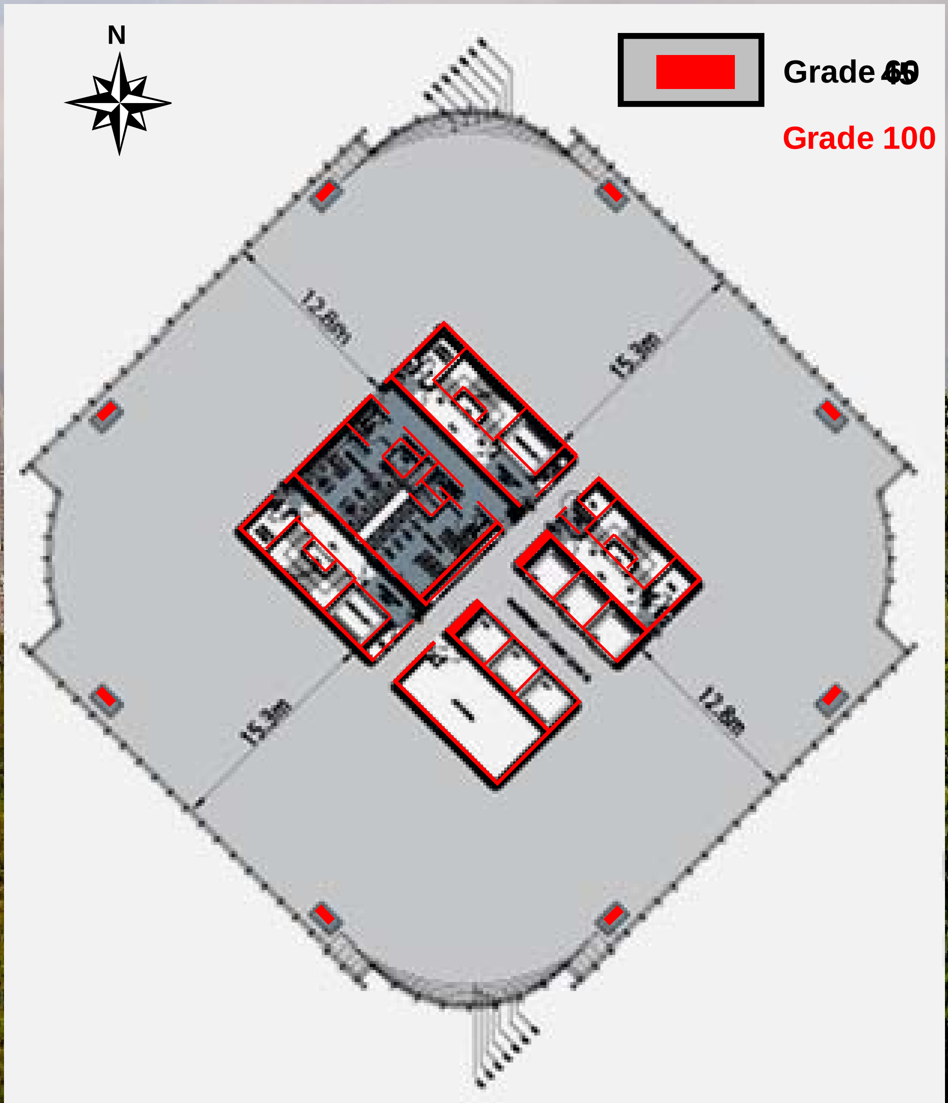
Other indirect benefits

- Less resources required compared with lower grades
  - formwork, rebar, concrete volume, workers
- Less vibration required for compaction
  - safer for workers
  - less noise
- More reliable quality in areas of high density reinforcement
- Shortened floor cycles

More floor area …

Saved about 4.5% rentable area per floor from basement to 39/F

- More rentable floor area
- Higher floor efficiency
- Lower construction cost
- Shorter construction period
- Earlier & higher rental income



100MPa HPC in Buildings (2006)

Very Early Strength Concrete

Route 8 Nam Wan Tunnel and West Tsing Yi Viaduct, January 2006

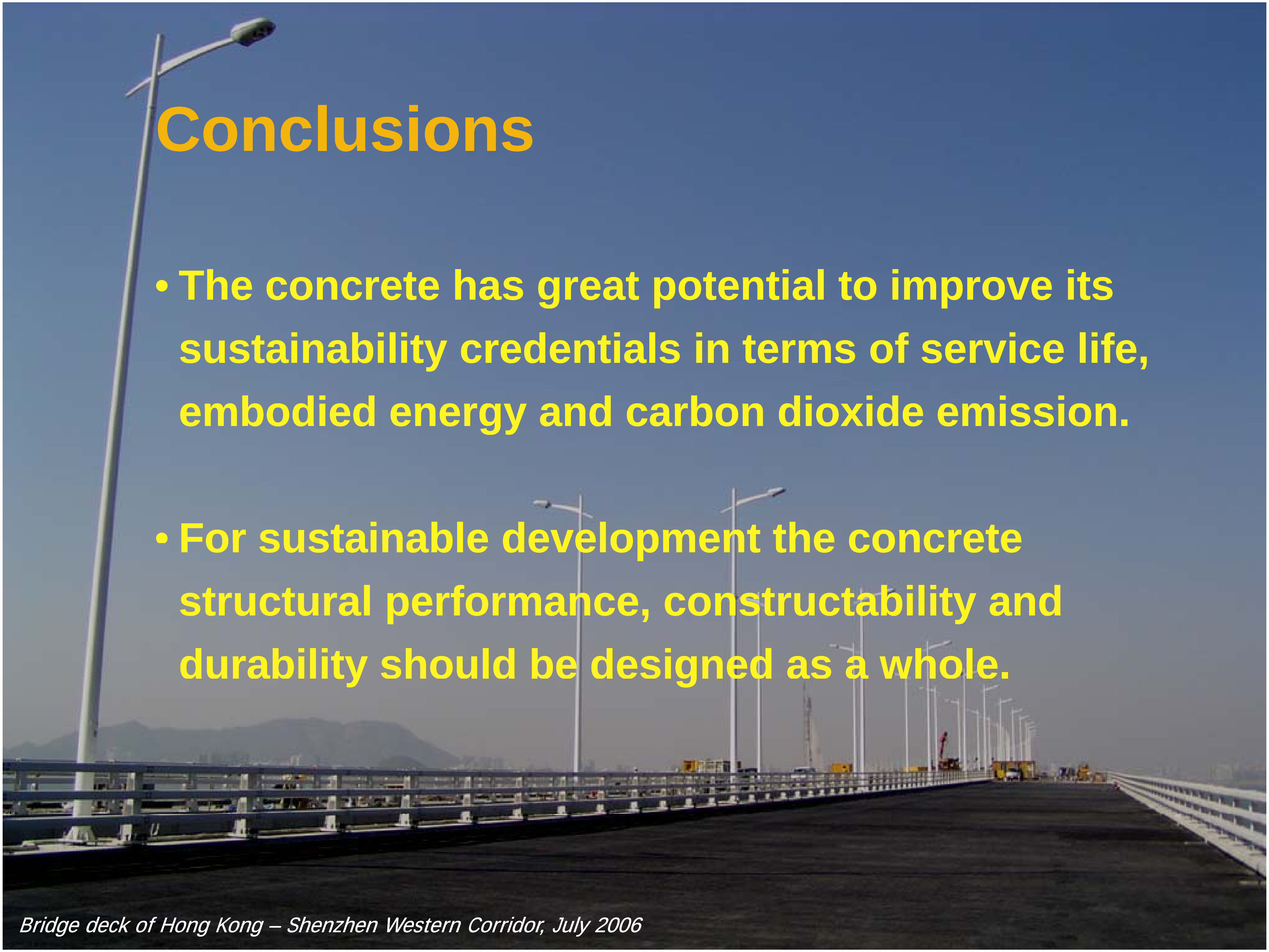
Very early strength concrete (2006)

Concluding Remarks

Conclusions

- **The concrete has great potential to improve its sustainability credentials in terms of service life, embodied energy and carbon dioxide emission.**

- **For sustainable development the concrete structural performance, constructability and durability should be designed as a whole.**



Bridge deck of Hong Kong – Shenzhen Western Corridor, July 2006

A vision for sustainable construction with concrete

"The vision of the North American concrete industry is to transform the built environment by improving the way concrete is designed, specified, produced, transported, installed, maintained, and recycled to ensure an optimum balance between environmental, social, and economic conditions for the industry and the world."

– The Strategic Development Council of American Concrete Institute, 14 Nov. 2008

"Business as usual" is not a viable option for the industry.

– *Ir. Thomas Ho, 15 January 2009 at HKIE conference on "Engineers' Responses to Climate Change"*

Concrete delivery for marine bored pile construction at Hong Kong – Shenzhen Western Corridor project, 2004