Lining the HATS Sewage Tunnel with High-performance Concrete in Hong Kong

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“*Failure is success in progress.*”

On 20 March, 2014

“There is always a gift in any challenge.”

On 28 March, 2014

Where? - Harbour Area Treatment Scheme (HATS)
The Stage 2A Sewage Conveyance System (SCS)

Contents

A. HATS Stage 2A Sewage Conveyance System

B. Mix characterization and risk prevention framework

C. Long time transportation and crack control

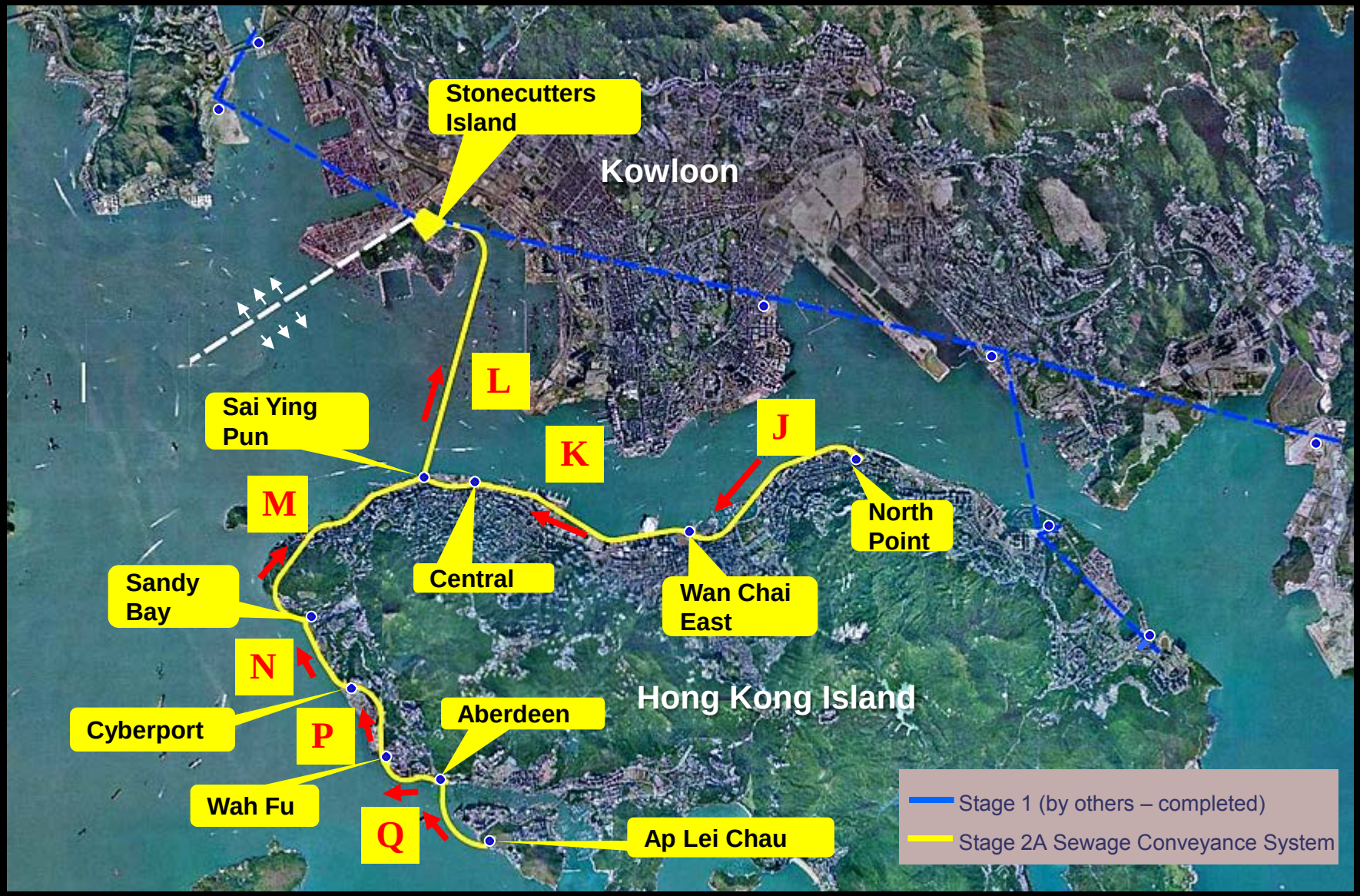
D. High-performance concretes at HATS

E. Conclusions

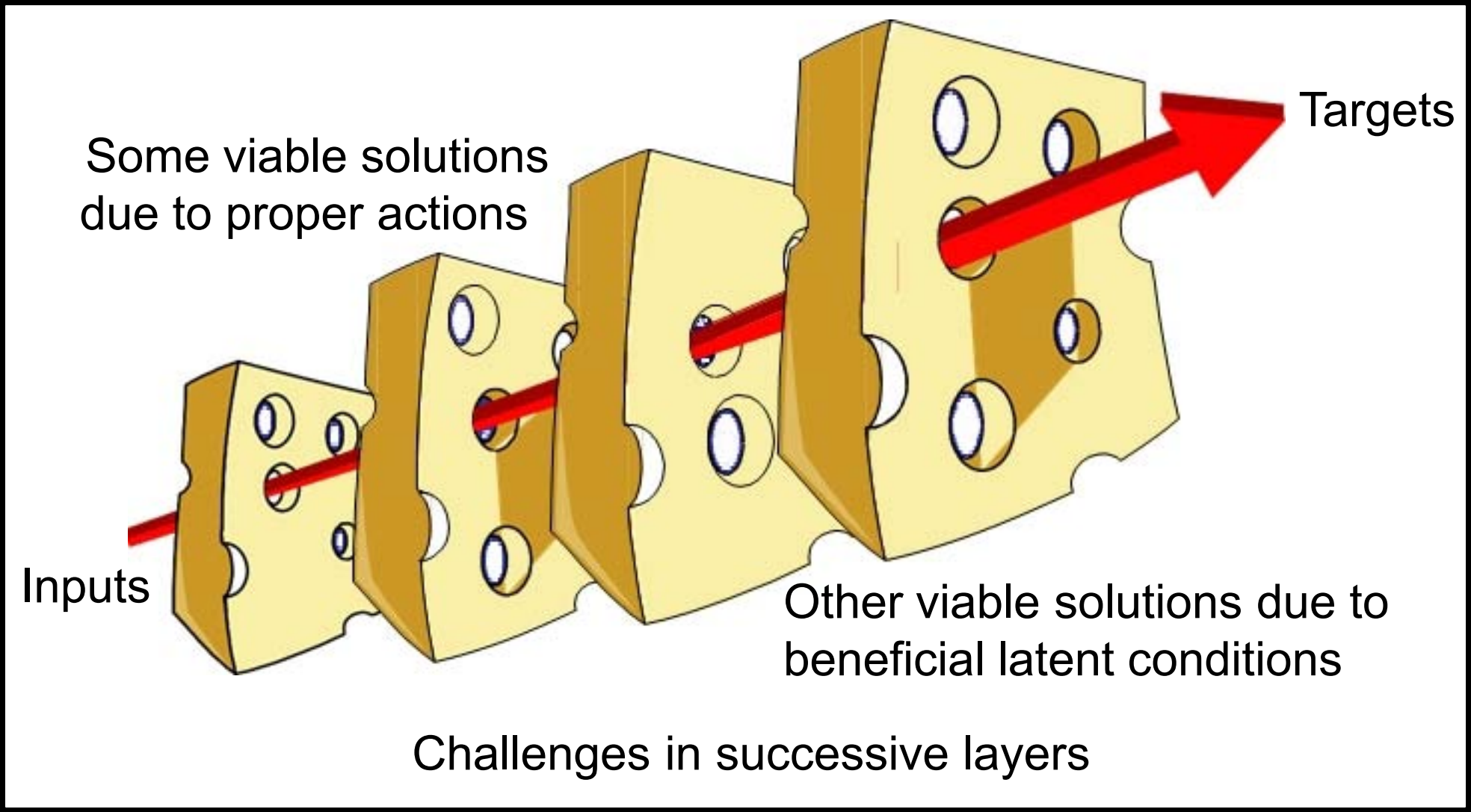
A HATS Stage 2A

Sewage Conveyance System

HATS Stage 2A SCS alignment



Quality assurance and the Swiss Cheese



Modified from J Reason, "Managing the risks of organizational accidents" , NASA Annual Risk Management Conference 2004, Cleveland, US, 26-29 Oct. 2004

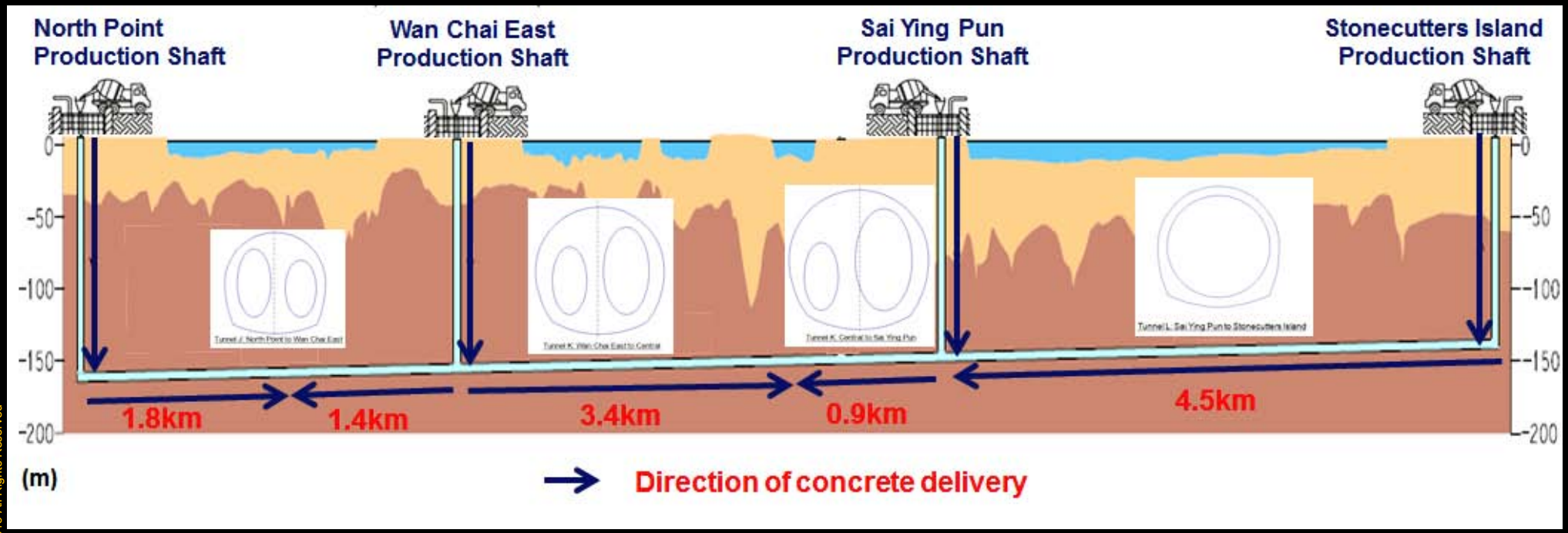
B Mix Characterization and Risk Prevention Framework

Prescribed requirements for structural design

Category	GS (2006) Sections 16 & 21 - Marine Concrete (Grade 45/20D)	DSD HATS (Plain marine concrete Grade 45/20D)
A	**Concrete mix**	
	(1) Min grade: 45 MPa (2) Max 0.38 w/cm ratio (3) Mix design: from 375 to 450 kg/m^3 cementitious materials (cm), with 25-40% PFA with 5-10% condensed silica fume	
	PC, SRPC, PFAC, PBFC, GGBS, CSF	SRPC (Sulphate resisting Portland cement) or equivalent
B	**Concrete Performance**	
Temperature	Placing temperature < 30 ^{O}C	(1) Placing temperature < 32 ^{O}C (2) Peak ≤ 70 ^{O}C (3) Max difference ≤ 20 ^{O}C
Strength	Same as normal concrete	Extra requirements on any consecutive 40 results of 28-day cube strength: ▪ Coefficient of variation ≤ 8% ▪ Average strength ≥ Grade strength + 2 x Standard Deviation
Durability	Not specified	▪ 28-day AASHTO chloride diffusion (6 hour test) ≤ 1,000 coulombs ▪ 28-day Water sorptivity ≤ 0.07 mm/min$^{0.5}$

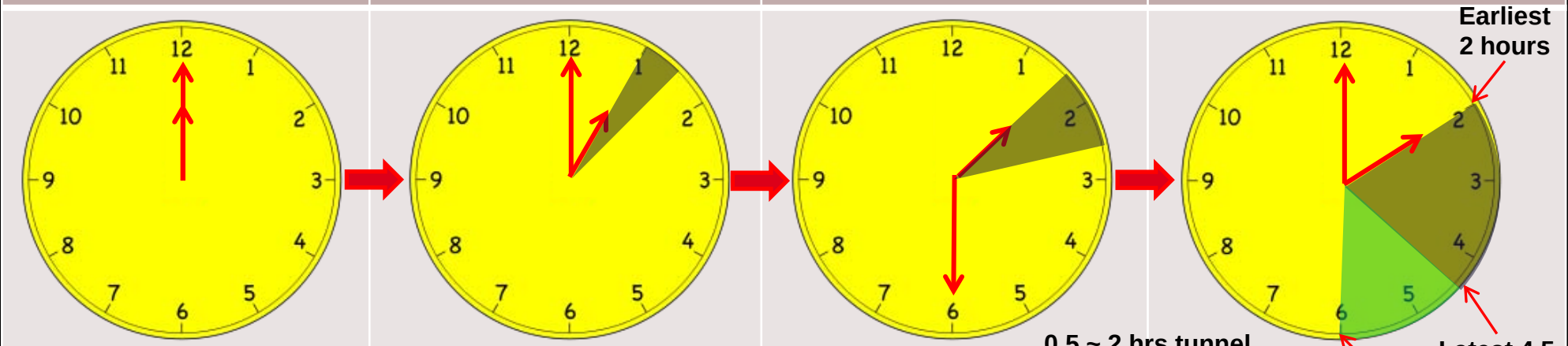
Logistic requirements

- 200,000m^3 Grade 45 and 60 unreinforced high performance concrete, up to Grade 80
- Typical 300m^3 (max. 370m^3) single pour volume (max. length = 22.5m for Tunnel K, 60m for Tunnel L)



Construction requirements for workability & strength

Leave batching plant after mixing	Arrive to site and queuing	Vertical Discharge (over 160m deep)	Placed in final position



1~1.5 hrs in traveling from batching plant

0.5 ~ 1 hr queuing for vertical discharge

0.5 ~ 2 hrs tunnel concrete conveyance by train mixer / pumping

Slump ≤ 240mm at 2.5 hrs after mixing with water

(For special concreting works ≥ 680mm slump flow)

Early Strength ≥ 3MPa in 8 hrs for Tunnel L

Early Strength ≥ 1MPa in 6 hrs for Tunnel J & K

Slump ≥ 200mm at 6 hrs after mixing with water

High-performance concrete (HPC)

*"Concrete meeting **special combinations of performance and uniformity requirements** that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practices."*

- American Concrete Institute, January 2013

Revelation to Construction Industry

The use of high-performance concrete integrates flexibility and control of various time-dependent concrete properties to suit different construction methods so that the overall performance of construction projects and concrete structures is improved significantly.

LESSONS

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

A Vision for Future

- The market needs for, and the use of HPC will increase.
- There will be following changes in the industry:
  - application of performance-based concrete specification;
  - small changes in concrete construction methods;
  - improvements in QA/QC of concrete mix design, production, supply and application;
  - wider acceptance to slightly higher materials cost of construction projects.

LESSONS

Concrete delivery for marine bored pile construction, 2004

The Concrete for Future Hong Kong

- The shelf life of ready-mixed concrete could be tailor-made, either as soon as after mixing or as long as needed.
- The grade strength is achieved in one day after concreting.

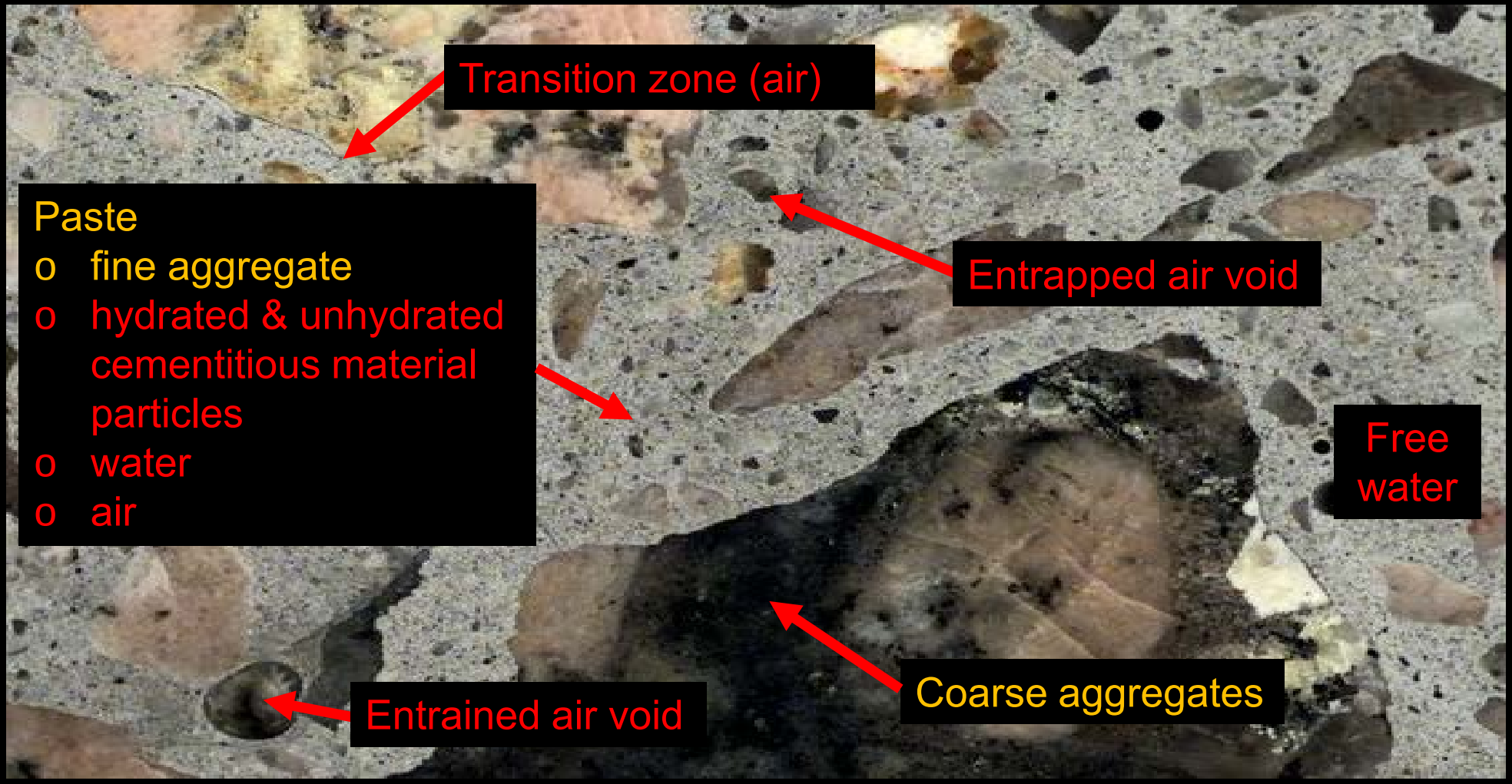
LESSONS

Hong Kong – Shenzhen Western Corridor and Shekou, July 2006

Conclusions at SCCT

Annual Concrete Seminar 2007

Concrete: known and unknown



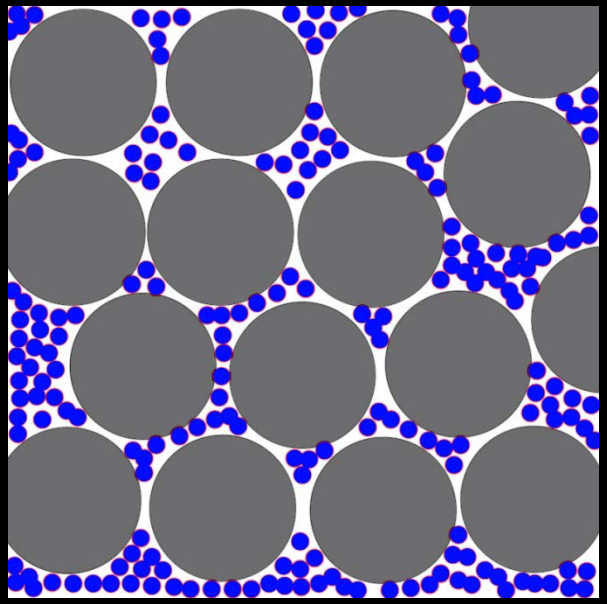
By volume: 68% Aggregate + 32% Cement & Water & Air
By weight: 26% Cement & Water + 74% Aggregates

Concrete properties: time-dependent

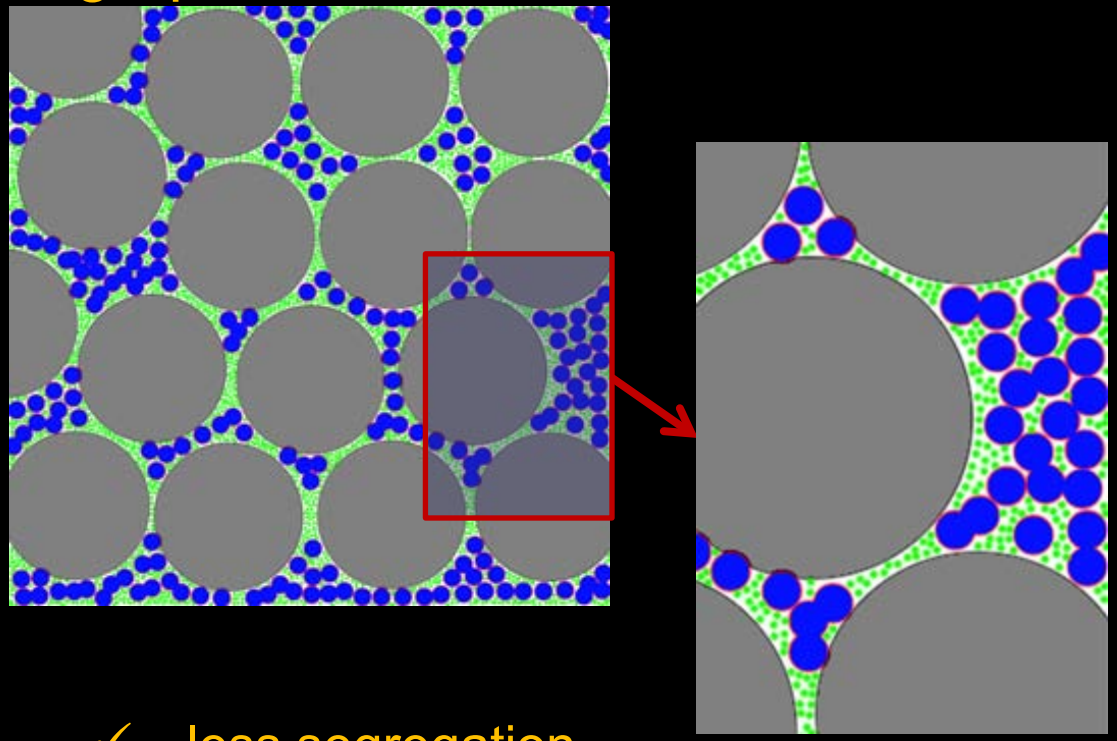
- Workability / consistency
- Volume change:
  - Temperature rise
  - Shrinkage
  - Resistance to environmental loadings
- Mechanical properties: strengths and modulus
- Durability: absorption, permeability and abrasion resistance
- Others: ductility and fire resistance

Mix design and optimal packing

Normal concrete



High-performance concrete

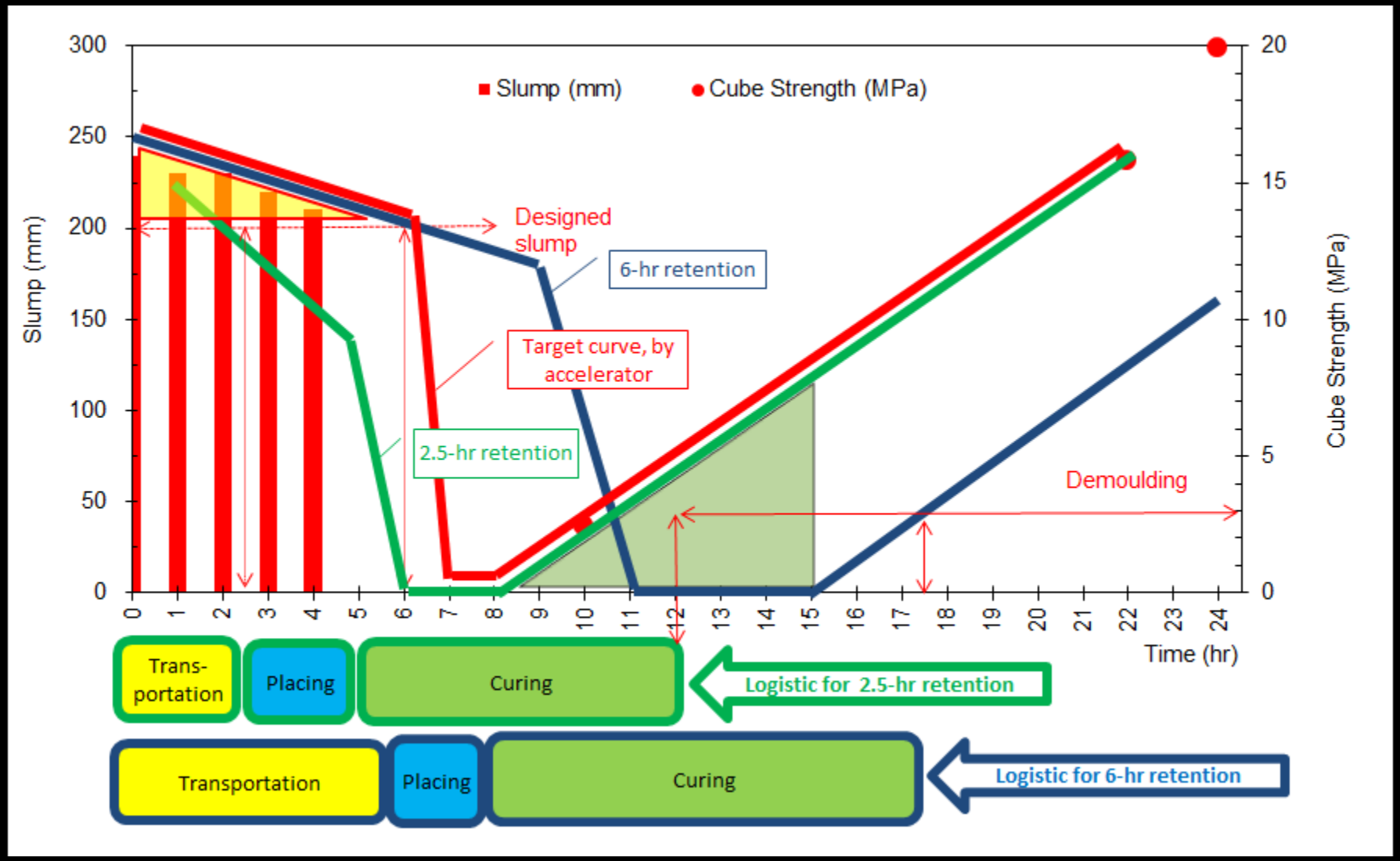


At optimal state:

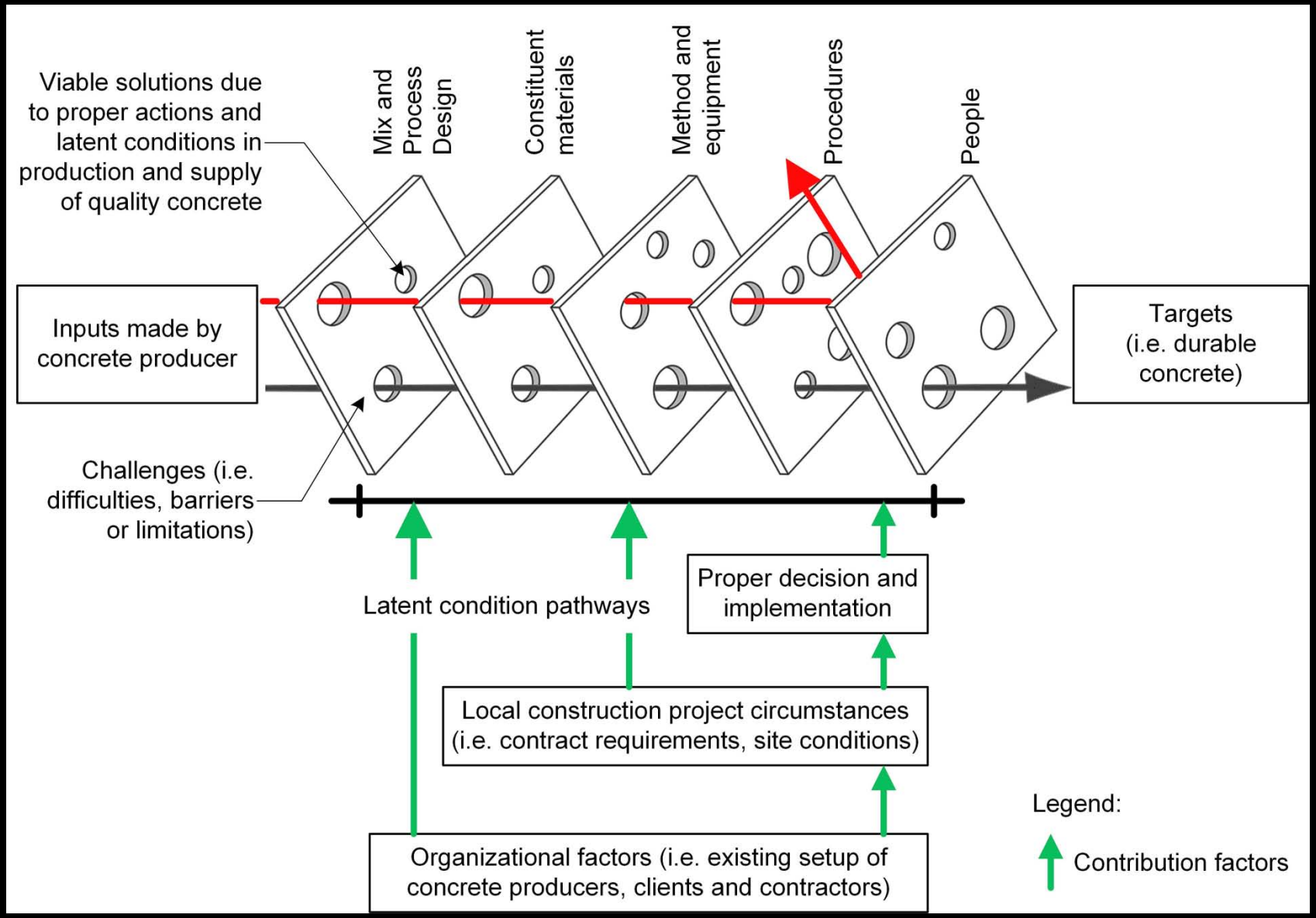
- ✓ denser micro structure
- ✓ higher workability

- ✓ less segregation
- ✓ higher density
- ✓ higher strength

Characteristic curve for concrete performance



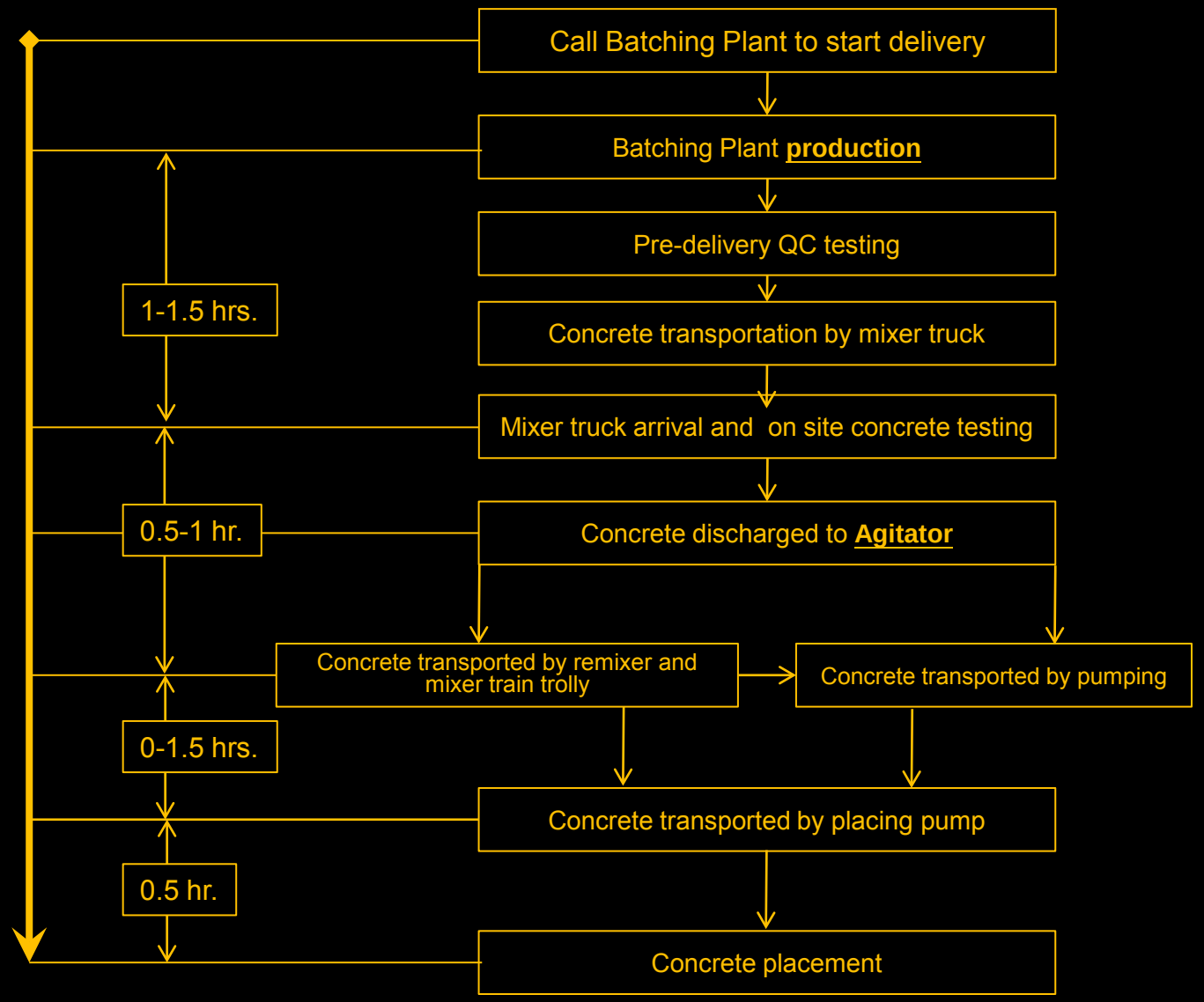
Framework of quality management



C Long Time Transportation and Crack Control

Logistic plan for production, transportation & placing

- Transportation: 4.5 hrs.
- Contingency: 1.5 hrs.
- Total: 6 hrs.



Long distance pumping & train mixer

Concrete discharged from train mixer to pump receiving hopper

Advantages of long-distance pumping

- Rapid transportation and placement of concrete at a rate of more than 35m^3/hour/pump
- Perform concreting where traffic condition is restricted, or access is difficult such as in underground construction
- Maintain concrete supply in line with concrete placement rate to enhance concrete crews' efficiency

Common problems encounted in long distance pumping

- Loss of workability and temperature control
- Insufficient headroom for pump of proper capacity
- Pump or pump line blockage
  - Mix design deficiencies
  - Pipeline and joint deficiencies
  - Operating error
  - Slow reaction in locating and cleaning pipe blockage
  - Lack of contingency plan
- Insufficient risk prevention measures in place

Unexpected loss of workability

Concrete tested after pumping does not achieve deigned performance criteria

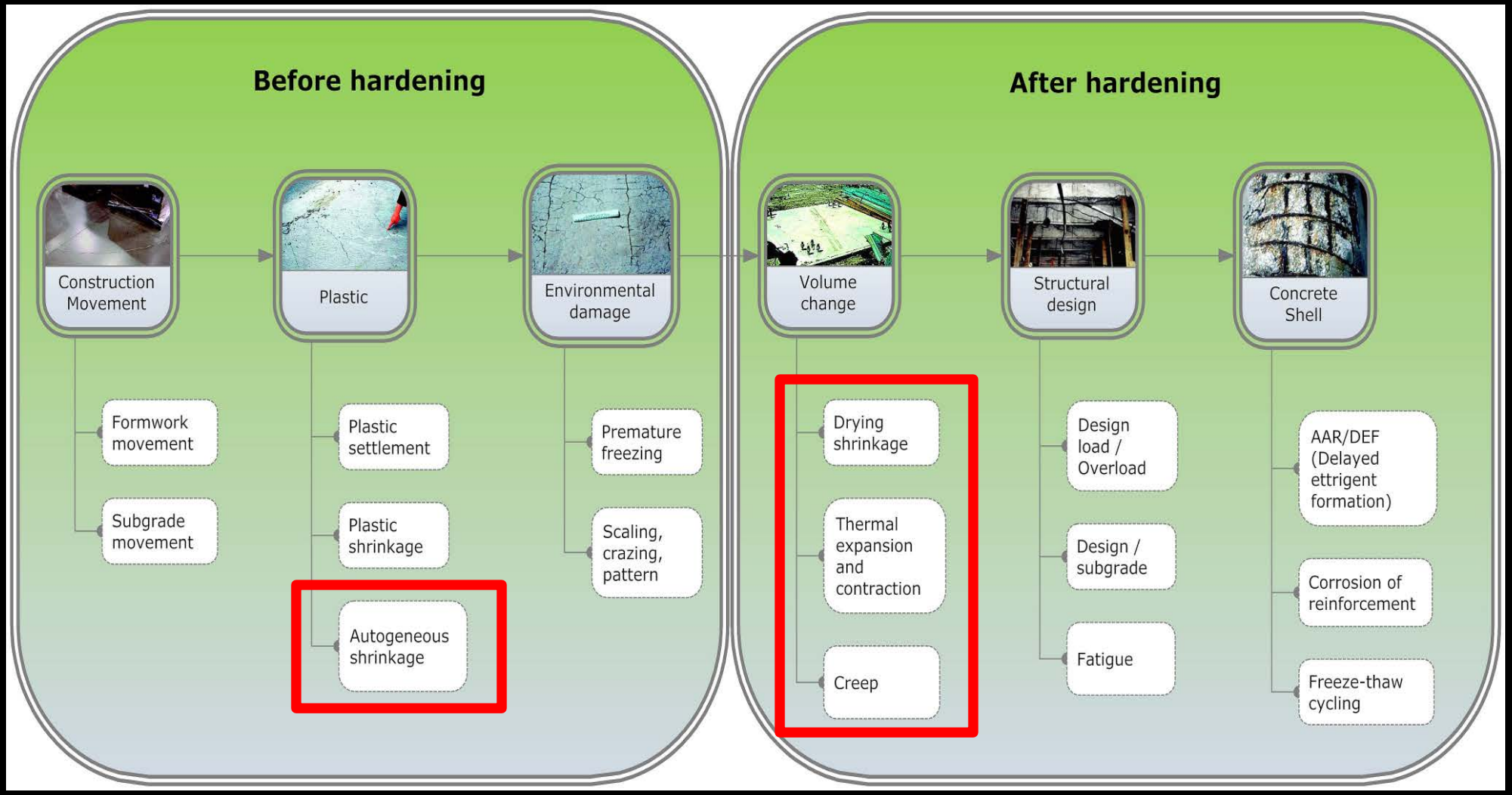
Pump pipe line blocked during pumping, causing delays in concrete construction

Pumpline blockages

Causes of pumping system blockage

- Mix design deficiencies
- Pipeline and joint deficiencies
- Failure to response properly
- Organizational accident

Nature of concrete cracking



Early-age dimension stability

Dimension stability

(or volume change):

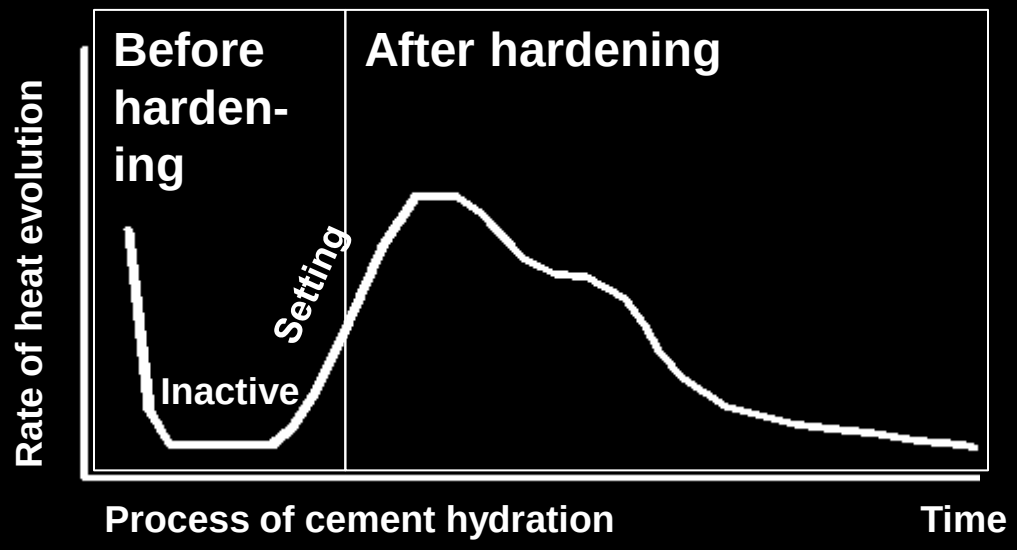
an increase or decrease in volume due to any cause.

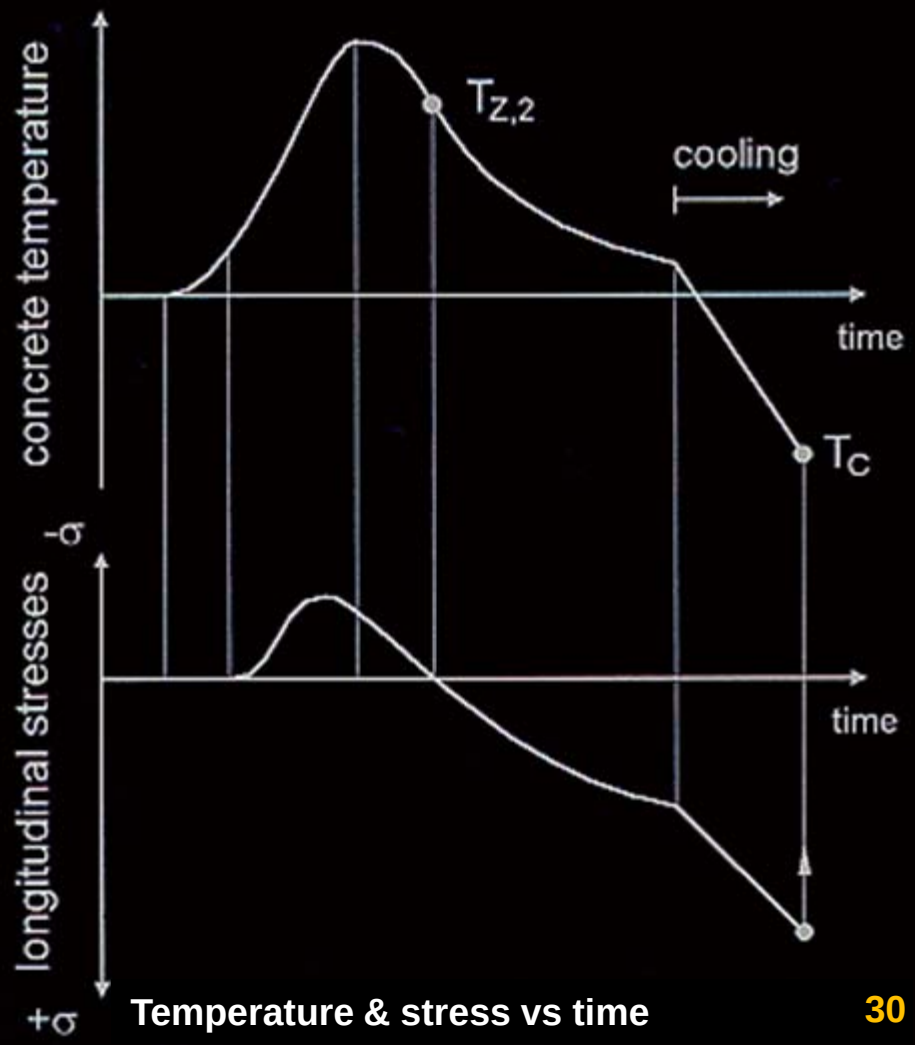
Dimension stability

- Thermal movement
- Shrinkage
- Creep
- Expansion

Thermal expansion and contraction

- Factors affecting concrete thermal movement:
  - Cement hydration
  - Ambient temperature
  - Sunlight & wind exposure
  - Heat dissipation

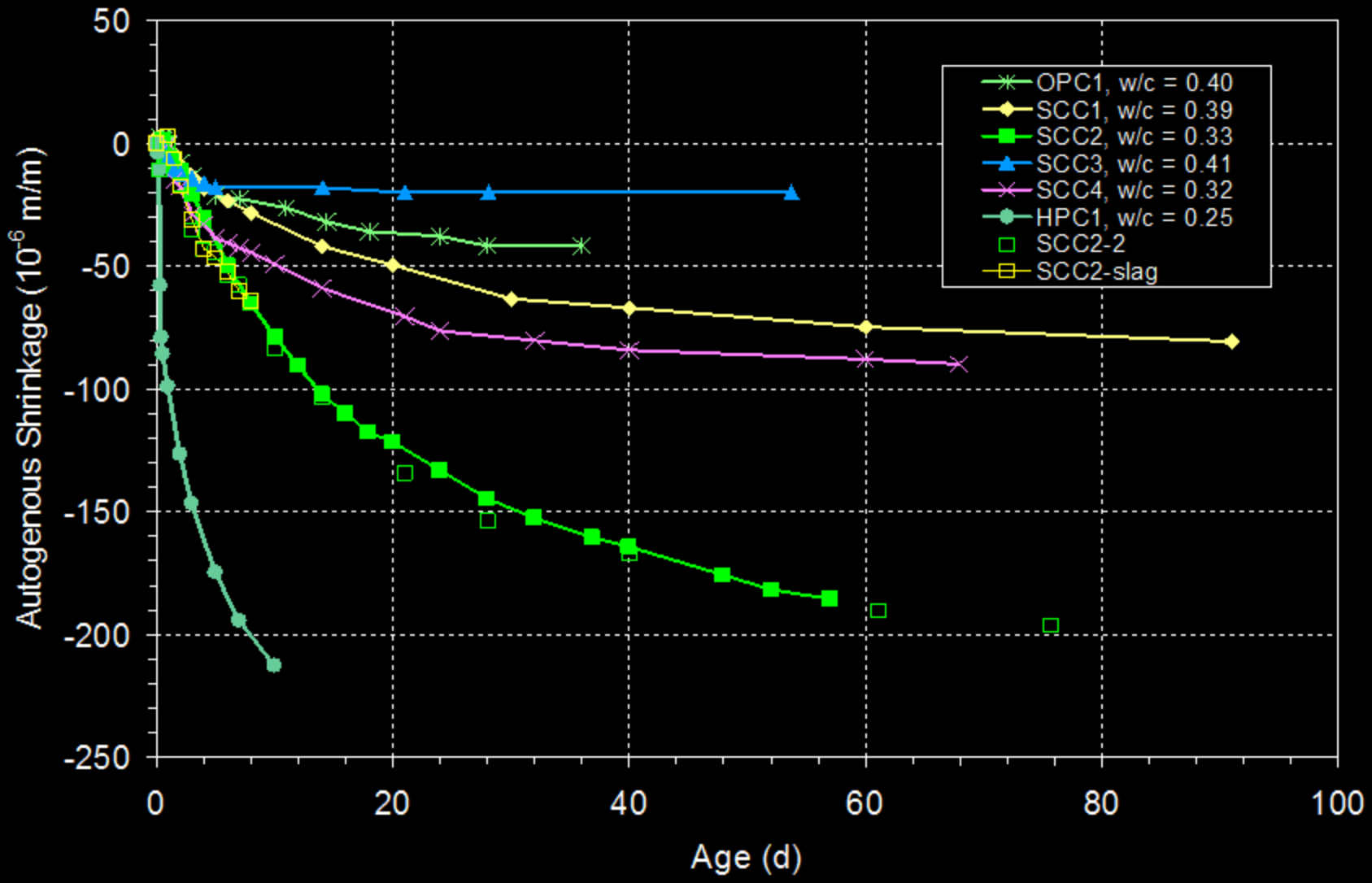




Temperature & stress vs time

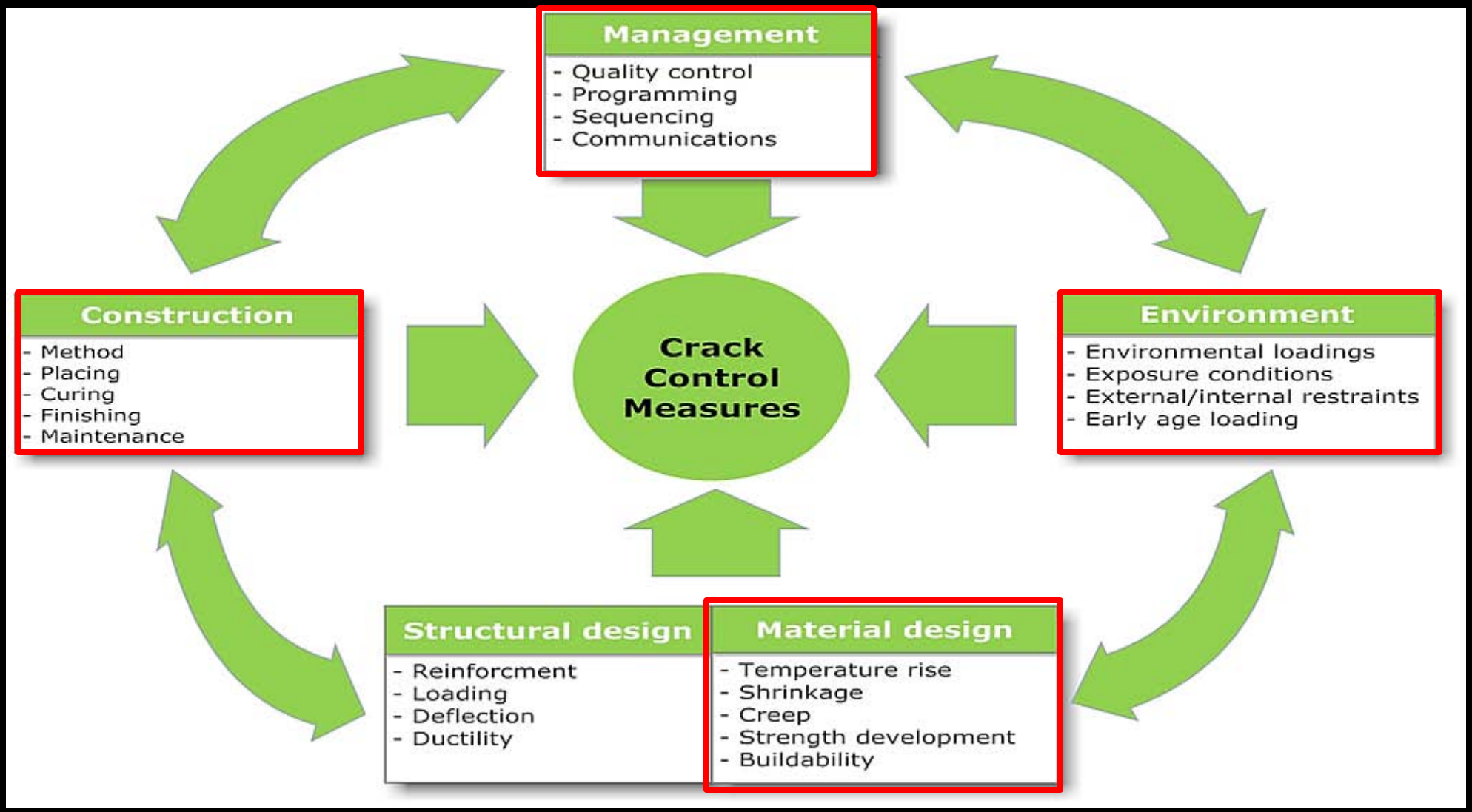
"In Search of Crack-Free Concrete", David A. Lange, 2005

Dimension stability: shrinkage by design



"In Search of Crack-Free Concrete", David A. Lange, 2005

Cracking control by material's approach



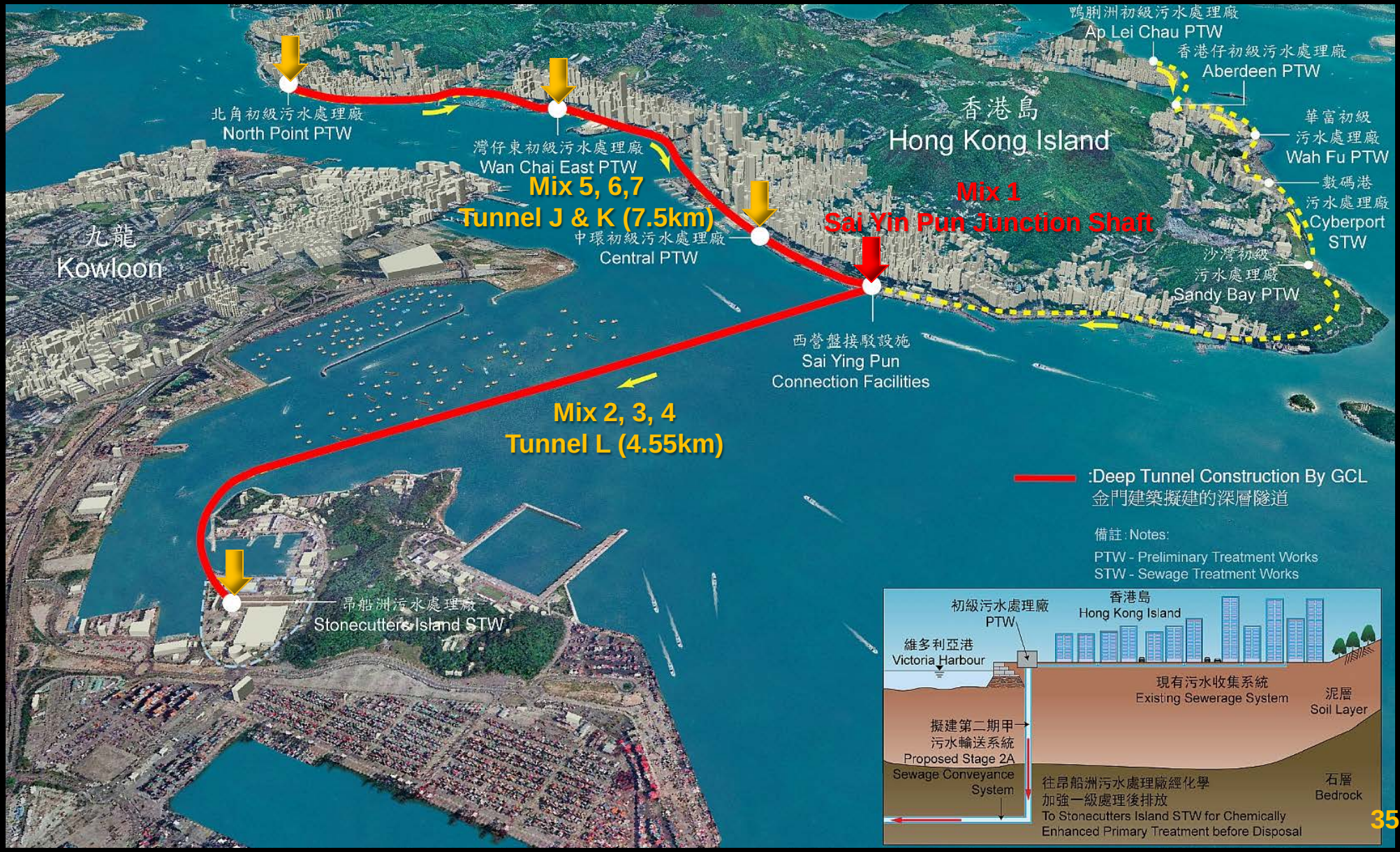
D High-performance Concretes at HATS

List of concrete mixes

Mix ID	Mix Type	Desig-nation	Workability	cm (kg/m^3)	PFA Content	CSF Content	w/cm	Coarse Agg. (kg/m^3)	Fine Agg. (kg/m^3)	Admix-tures (L/m^3)
1	Self-compacting	15/10D	680mm SF	440	58%	0%	0.42	830	820	6
2		45/10D	700mm SF	435	31%	6%	0.37	950	780	8
3	High-performance	45/20D	200mm slump	435	31%	6%	0.38	1000	730	11
4		45/20D		435	31%	6%	0.37	1000	750	11
5		60/20D		450	30%	6%	0.35	1000	765	8
6		60/20D		450	30%	6%	0.35	1000	765	8
7		80/20D		450	25%	5%	0.31	1020	770	11
8	Very early strength	45/20D	225mm slump	435	31%	6%	0.38	950	780	17
9		60/20D		450	28%	6%	0.34	940	810	17

Remarks:
1. cm – Cementitious materials; PFA – Pulverized fly ash; CSF – Condensed silica fume; w/cm – Water to cementitious materials ratio; SF – Slump flow.
2. Mix 1 is used for backfilling at Sai Ying Pun Junction Shaft. Mix 2 is used for Stonecutter adit.
3. Mix 3-7 is used for tunnel lining, while mix 8 and 9 are prepared for contingency use.

Portion of Stage 2A SCS tunnel and shaft network



Placing of lining concrete at Tunnel J, K (Invert)

Placing of lining concrete at Tunnel J, K (Crown)

Lining concrete at Tunnel L

In-situ trial of low strength self-compacting concrete

E Conclusions

2005
Grade 100 high-performance concrete
One Island East

2006
Self-compacting concrete
HKCEC Expansion

2007
Crack controlled concrete
WSD Facilities for the Centennial Campus, HKU

2010
Marine concrete suitable long distance pumping
Habour Area Treatment Scheme

2012
Cast in-situ architectural concrete
HKU Centenial Camps

2013
Low shrinkage concrete and direct pumping
West Kowloon Terminus Station North

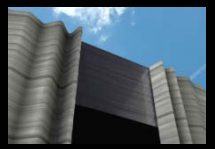
2014
Cast in-situ architectral concrete
Hong Kong Sci. & Tech. Park Ph 3

2003
Various high-Performance concrete
HK-Shenzhen Western Corridor

2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021

2015
Today

WYPIWYG
What You Place Is
What You Get



2004
Predictions for
ACI's next century

2015
CIC Carbon Labelling

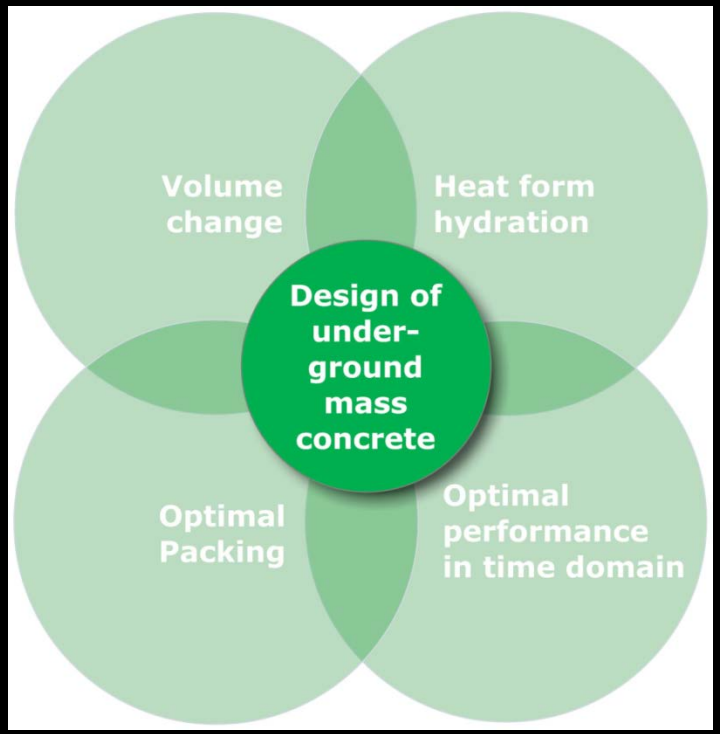
2012
PAS 2050 Certification

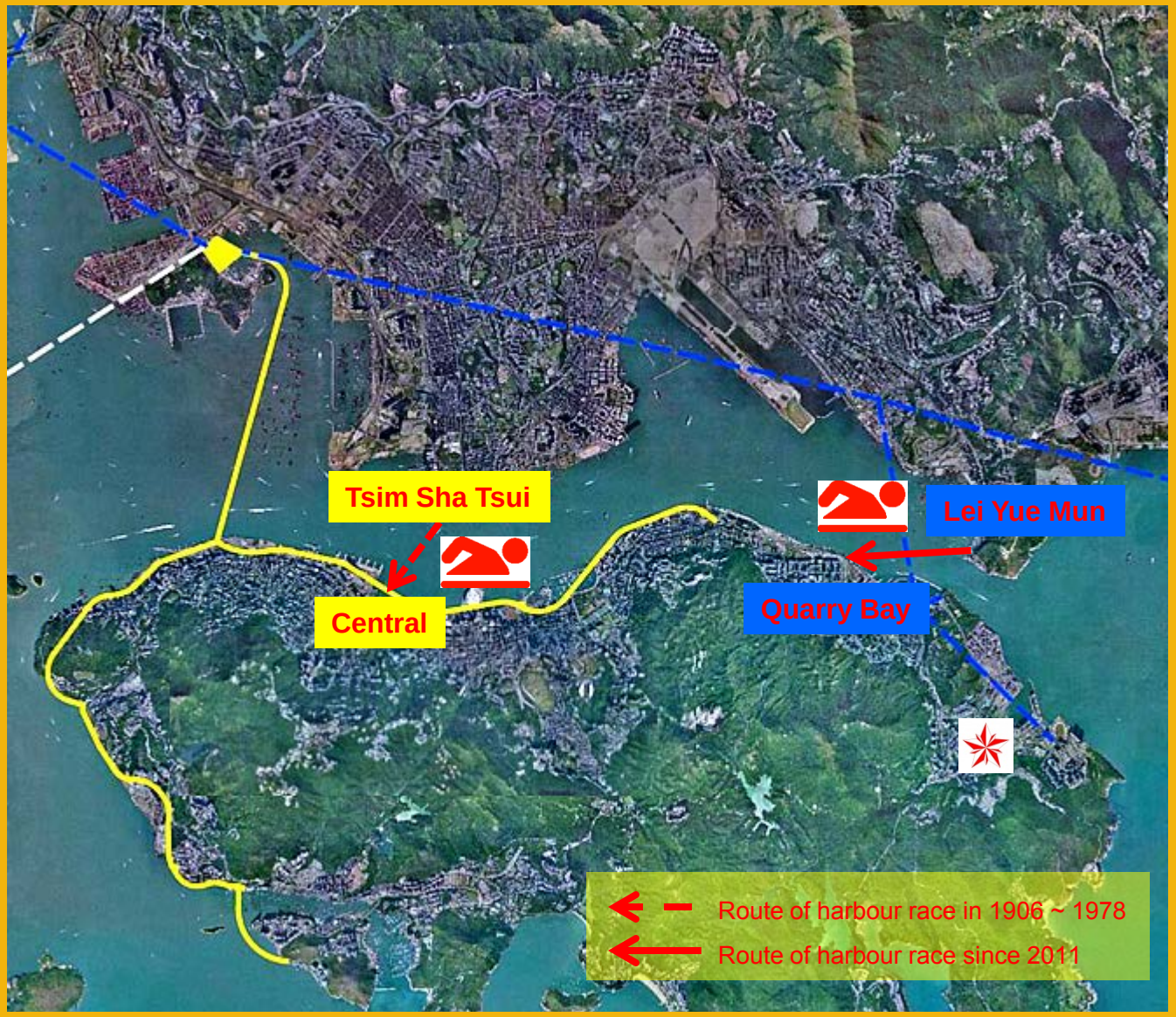
2012
HKAEE Wastewi$e lebel

2007
HK Awards for Industries: Technological Achievement

Conclusions

1. Various high-performance concretes have brought substantial benefits to HATS Stage 2A Sewage Conveyance System project by proper planning and implementation of:
   - Risk prevention based quality management strategy;
   - Technological advancement in design, production, supply and application of HPC.
2. High-performance concrete has significantly facilitated the design and construction of HATS Stage 2A Sewage tunnel lining in aspects of buildability, construction programme and durability.
3. Project applications also show that the potentials of HPC durability, i.e. acid resistance, can be enhanced so that longer design life of sewage concrete structures can be achieved.




Tsim Sha Tsui
Central
Lei Yue Mun
Quarry Bay
Route of harbour race in 1906 ~ 1978
Route of harbour race since 2011

Thank You