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Maturity Method for Estimation of Concrete Strength

Annual Concrete Seminar 2022 - Low-Carbon Concrete on the Move

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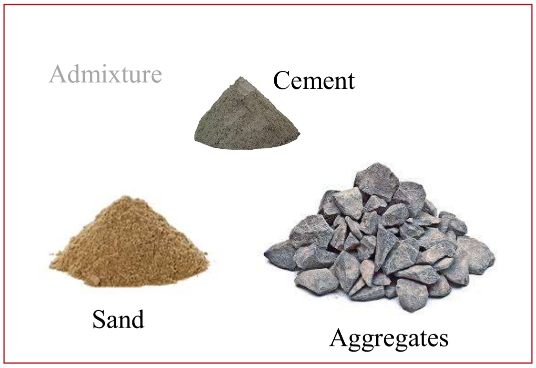
Introduction

What is concrete?

Water



Hydration

↑ Temperature : accelerating hydration speed/the rate of hardening

↓ Temperature : reduce hydration speed/the rate of hardening;

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Agenda

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Removal of Formwork

Removal of formwork and falsework *HKCoP – cl 10.3.8.2*

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Formwork supporting cast insitu concrete in flexure may normally be struck when the strength of the concrete in the element is 10 N/mm^2 or twice the stress to which it will be subjected, ….

Elements	Time to strike formwork
vertical formwork for sides of beams, columns, walls and similar locations	12 hrs
soffit formwork of slabs with props left in;	4 days
soffit formwork of beams with props left in;	7 days
props for slabs	10 days
props to beams	14 days
props to cantilevers	14 days

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ACI 347 & ACI 2-28

GUIDE TO FORMWORK FOR CONCRETE (ACI 374R-14) 17

Table 5.7.2.3—Guidance for stripping time when contract documents do not specify stripping time or stripping strength required

Structural element supported	Structural live load not greater than structural dead load	Structural live load greater than structural dead load
Walls*	12 hours	12 hours
Columns*	12 hours	12 hours
Sides of beams and girder*	12 hours	12 hours
Pan joist forms†		
30 in. (760 mm) wide or less	3 days	3 days
Over 30 in. (760 mm) wide	4 days	4 days
Arch centers	14 days	7 days
Joist, beam or girder soffits		
Under 10 ft (3 m) clear span between structural supports	7 days‡	4 days
10 to 20 ft (3 to 6 m) clear span between structural supports	14 days‡	7 days
Over 20 ft (6 m) clear span between structural supports	21 days‡	14 days
One-way floor slabs		
Under 10 ft (3 m) clear span between structural supports	4 days‡	3 days
10 to 20 ft (3 to 6 m) clear span between structural supports	7 days‡	4 days
Over 20 ft (6 m) clear span between structural supports	10 days‡	7 days
Two-way slab systems§	Removal times are contingent on placement of reshores where required. Reshores should be placed as soon as practicable after stripping operations are complete but not later than the end of the working day in which stripping occurs. Where reshores are required to implement early stripping while minimizing sag or creep (rather than for distribution of superimposed construction loads as covered in 5.8), capacity and spacing of such reshores should be designed by the formwork engineer/contractor and reviewed by the engineer/architect.	
Post tensioned slab system§	As soon as post-tensioning operations have been completed and approved	

*Where such forms also support formwork for slab or beam soffits, the removal times of the latter should govern.

†Of the type that can be removed without disturbing forming or shoring.

‡Where forms can be removed without disturbing shores, use half of values shown but not less than 3 days.

§Refer to Section 5.8 for special conditions affecting the number of floors to remain shored or reshored.

ACI 347

Table 5.1—Recommendations for slabs, shearwalls, and core walls*

Test method	Number of test locations provided: First 75 m^3 (100 yd^3)	Number of test locations provided: Each additional 15 m^3 (20 yd^3)	Number of locations to test: First 75 m^3 (100 yd^3)	Number of locations to test: Each additional 15 m^3 (20 yd^3)
Rebound number	20	2	10	1
Probe penetration	8	1	6	1
Pin penetration	15	2	10	1
Pullout	15	2	10	1
Ultrasonic pulse velocity	15	2	10	1
Break-off	10	2	8	1
Maturity	5	2	5	1
Cast-in-place cylinder†	5	1	5	1

*Core walls that typically surround elevator shafts are usually located at the center of a building and form the structural backbone of the building.

†For slabs only.

ACI 2-28

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《結構混凝土施工規範》 - TaiWan

4.7.6使用第I型水泥且不摻卜作嵐材料或其他摻料之混凝土，其拆模時間除依第4.7.5節之規定外不得少於表4.7.1之規定。

表4.7.1 最少拆模時間

構件名稱	最少拆模時間	
柱、牆、及梁之不做支撐側模	12 小時	
雙向 柵版不影響支撐之盤模*		
75 cm以下	3 天	
大於75 cm	4 天	
	活載重不大於靜載重	活載重大於靜載重
單向版		
淨跨距小於3 m	4 天	3 天
淨跨距3 m至6 m	7 天	4 天
淨跨距大於6 m	10 天	7 天
拱模	14 天	7 天
柵肋梁、小梁及大梁底模		
淨跨距小於3 m	7 天	4 天
淨跨距3 m至6 m	14 天	7 天
淨跨距大於6 m	21 天	14 天
雙向版	依據第4.8節之規定	
後拉預力版系統	全部預力施加完成後	

經驗值 - 跨度小於等於8米的梁板底模及小於等於2米跨的懸樑拆模時間為:

1） 日平均溫度為5度時，拆模時間為20天;
2） 日平均溫度為10度時，拆模時間為14天;
3） 日平均溫度為15度時，拆模時間為11天;
4） 日平均溫度為20度時，拆模時間為8天;
5） 日平均溫度為25度時，拆模時間為7天；日平均溫度為30度時，拆模時間為6天。

那有養護與沒有養護,
又有何分別?
Is there any difference in time if we have curing?

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Current Practice to Obtain the in-situ Strength

Break Tests

- Making cubes to be tested
- Curing cubes in water (usually 25º C)
- Test cubes at or day *X,* …, 7 and 14 days

Are you sure the in-situ concrete are also 25º C?

What happen if the temperature is > 25º C or < 25º C ?

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What is Maturity Method

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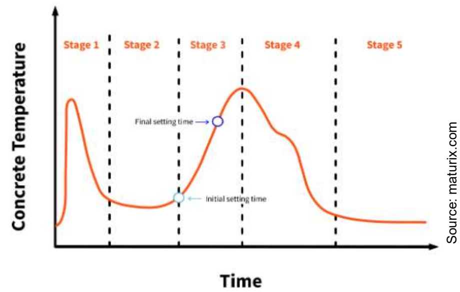
Maturity Method

1. Non-destructive method to estimate early-age strength development of concrete
2. Direct measurement of the strength – temperature history of concrete
3. Measuring the concrete temperature over time enables you to know how far the concrete is in the hydration process (Concrete Maturity) and thereby also an estimated concrete strength.
4. Underlying principle is that concrete cured with different temperatures but with the same maturity index will have an equal concrete strength
5. Ultimately used to ascertain formwork removal time



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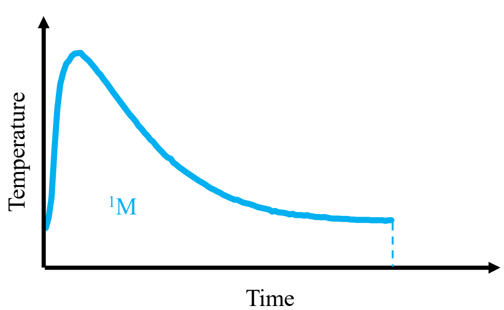
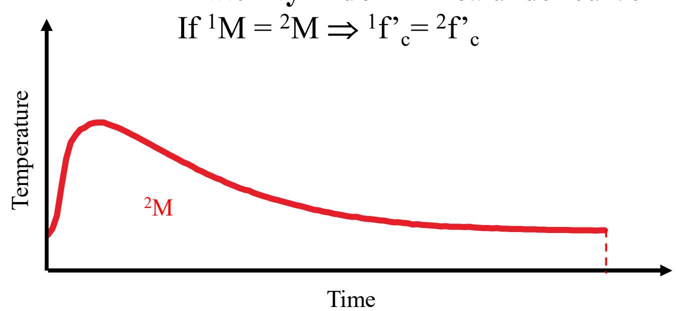
What is Maturity Method?

Maturity method is *a technique for estimating concrete strength that is based on the assumption that samples of a given concrete mixture attain equal strengths if they attain equal values of the maturity index*. [ASTMC1074]

Maturity Index = Area under curve

If $^{1}M = {}^{2}M \Rightarrow {}^{1}f'_c = {}^{2}f'_c$





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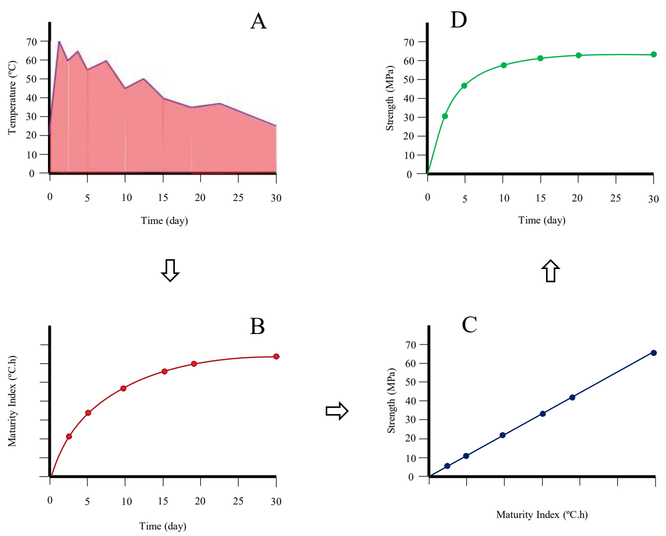
Maturity Method



- Maturity Method : A⇨B⇨C⇨D
- To use Maturity method, we need to determine the parameters for maturity function. (i.e. temperature, time, strength relationship)
- To do so, we need to carry out Pre-Calibration Test: A⇨D ⇨C&B

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Maturity Specifications

- ASTM C1074: Standard Practice for Estimating Concrete Strength by the Maturity Method
- ASTM C918: Standard Test Method for Measuring Early-Age Compressive Strength and Projecting Later-Age Strength
- ACI 228.1R (Section 2.7): In-Place Methods to Estimate Concrete Strength
- ACI 306R: Cold Weather Concreting
- ACI 318: Building Code Requirements for Structural Concrete

- BS EN 13670:2009 Execution of Concrete Structures. BSI
- NMN5970 Determination of strength of fresh concrete with the method of weighted maturity

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Maturity Functions

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Maturity Functions

There are many maturity model functions are available such as:

1. Nurse-Saul
2. Arrhenius Method

} Most Common and adopted commercially

3. Weaver and Sadgrove
4. Freiesleben Hansen and Pedersen
5. The Dutch Weighted Matruity etc

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Nurse-Saul Method

It is knowns as the **Temperature Time Factor (TTF)** and commonly used in maturity method. It assumes that the rate of strength development is a linear function of temperature as

$$M(t) = \sum (T_a - T_0)\Delta t$$

Where:
$M(t)$ = the temperature-time factor at age t, degree-days or degree-hours,
Δt = a time interval, days or hours,
T_a = average concrete temperature during time interval, Δt, ºC, and
T_0 = datum temperature, ºC.

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Arrhenius Method

This maturity function is used to compute **equivalent age** at a specific temperature. It assumes that the rate of strength development obeys the Arrhenius equation, equivalent age at a specified temperature.

$$t_e = \sum \left[e^{-Q\left(\frac{1}{T_a} - \frac{1}{T_s}\right)} \right] \Delta t$$

Where:
t_e = equivalent age at a specified temperature
Q= activation energy divided by the gas constant, K,
T_a= average temperature of concrete during time interval Δt, K,
T_s = specified temperature. K, and
Δt= time interval, days or h

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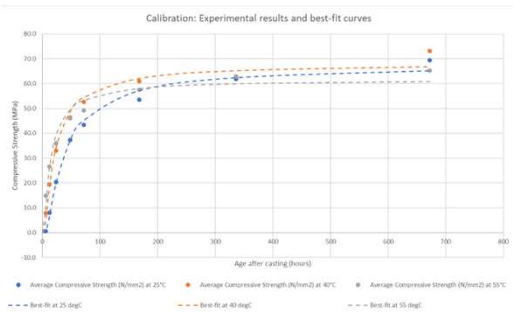
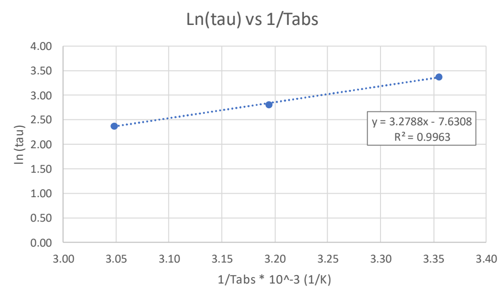
Calibration

Nurse-Saul Method



Temperature (degC)	Su (MPa)	tau (hours)	tau (C.hours)	a (-)
25	68.1	29.6	740	1
40	68.5	16.5	660	1
55	61.8	10.8	540	1

Arrhenius Method



Temperature (degC)	tau (hours)	ln tau	1/Tabs
25	29.63	3.39	3.36
40	16.59	2.81	3.19
55	10.85	2.38	3.05

Activation energy (Ea) = 27.26161539 kJ/mol K

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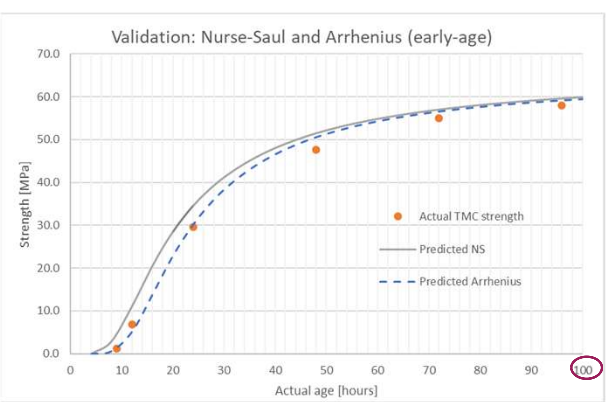
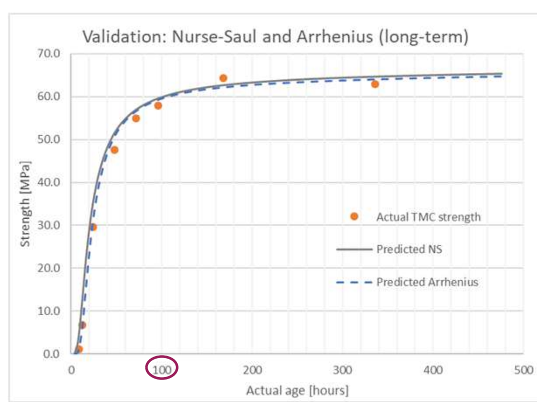
Nurse-Saul Vs Arrhenius Method

Similar prediction for both functions





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Calibration

Casting/Curing/Testong

Casting specimens with concrete mix utilized for calibration process

Curing at 3 different temperatures as required to extract maturity model parameters

Determination of compressive strengths at pre-established times and for each curing temperature

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Type of Sensors

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Sensors

Old Thermal Sensors

New IoT

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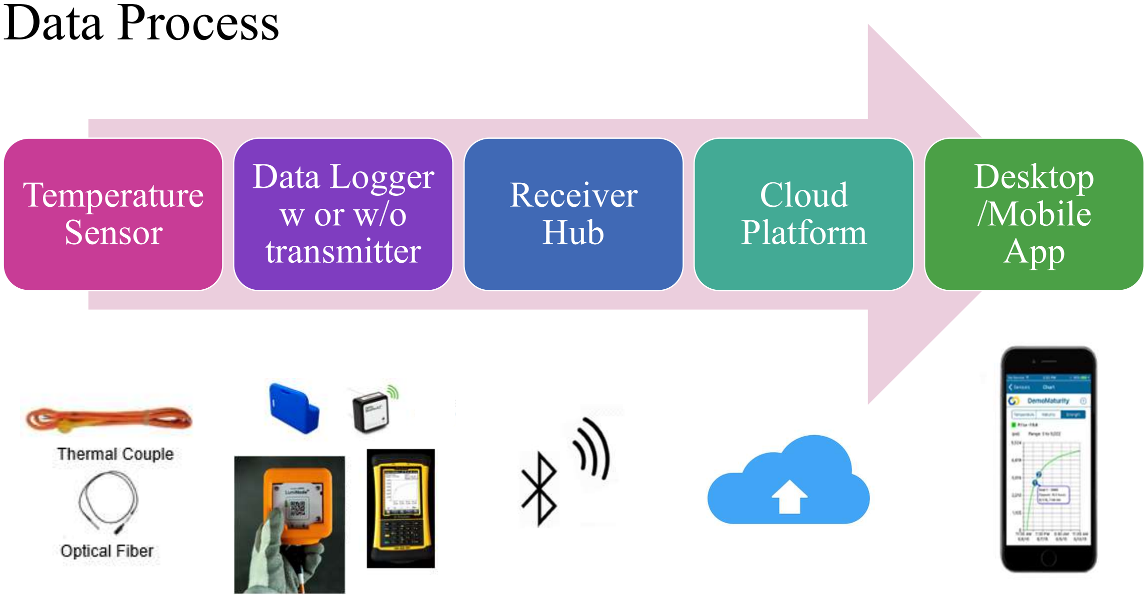
Data Process



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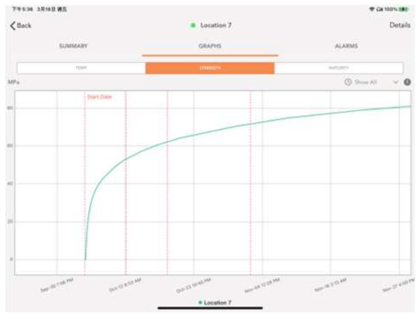
Desktop/Mobile Device

Mobile App by LumiCon

Temperature



Strength

Maturity Index

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Formwork Striking

Removal of formwork and falsework HKCoP – *cl 10.3.8.2*

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那有養護與沒有養護,
又有何分別?
Is there any difference in time if we have curing?

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Teperature Match Curing

Temperature Match Curing

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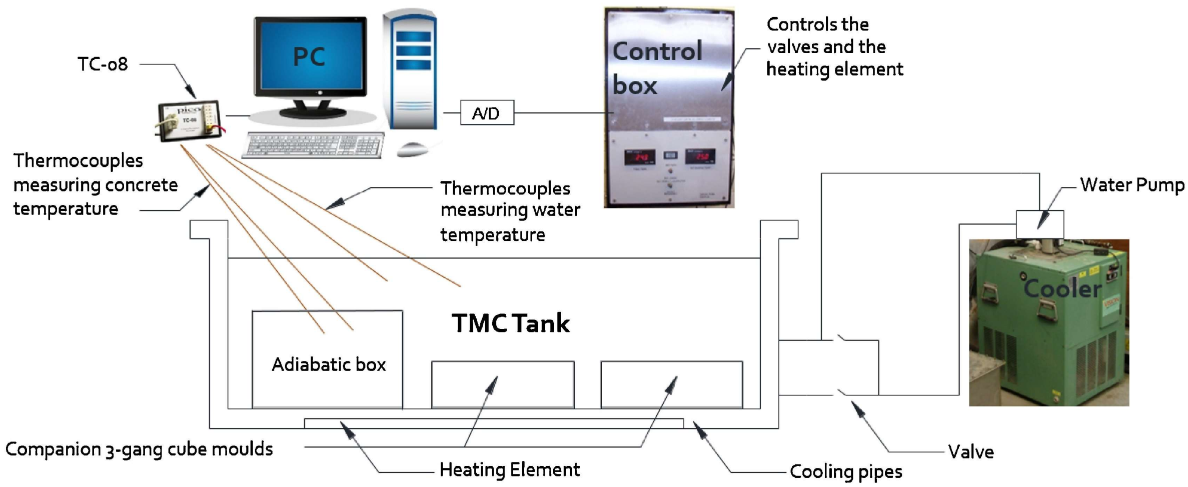
Computer Controlled TMC tank



Source: Soutsos et al, **Critical analysis of strength estimates from maturity functions,** https://doi.org/10.1016/j.cscm.2018.e00183

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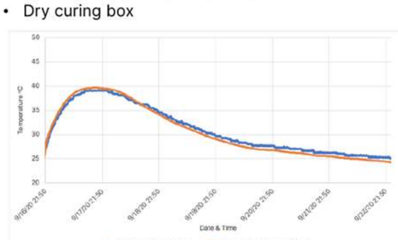
Temperature Matched Curing (TMC)

Temperature Matched Curing (TMC) is a method which simulated the cubes to be cured as the temperature as in-situ concrete.

- Matching the curing box temperature with the concrete temperature
- Premium control design with multiple reference temperature sensors to ensure the uniformity of temperature distribution inside the box
- Temperature control capabilities are within +/- 0.8 degC
- Dry curing box



Source: AMOS_LumiCon

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Site Trial in HK

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Case Studies/ HK Trials

CIC provided the Arup team with access to the following on-going construction projects.

Projects	Structural Element	Concrete Strength	Cement replacement
HyD Central Kowloon Route (Trial no. 1 and 4)	Roof slab	45/20D	35% Fly ash
DSD Shek Wu Hui Effluent (Trial no. 2)	Slab and Beam	50/20D	25% Fly ash
ArchSD Kai Tak Rain Garden (Trial no. 3)	Slab	40/20D	No. CEM 1 only!
CEDD Kwu Tung North (Trial no. 5)	**Retaining Wall**	**30/20D**	**25% Fly ash**

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Case Studies/ HK Trials

SITE TRIAL NO. 5: CEDD Kwu Tung North, Retaining Wall

Key Activity	Date/ Period
Sensor Installation	21 December 2021
Site Trial	23 Dec 2021 – 20 Jan 2022

Sensor System	Data Logger	Temperature Sensor
Command Center	1 No.	4x Surf.
Converge	4 No.	4x Surf.
Lumicon	4 No.	4x Surf.
SmartRock	N/A (fully wireless)	4x Surf.

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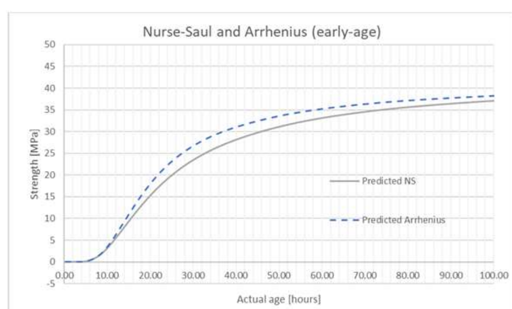
Case Studies/ HK Trials

SITE TRIAL NO. 5: CEDD Kwu Tung North, Retaining Wall

Grade strength: **30/20D** Water/cement: **0.49** Slump: **75 mm**	
Batching plant: **Lam Tei Plant – Excel Concrete Limited**	

Mixture proportions	Mass [kg/m^3]	Origin
Cement	285	Conch [Chak Fung/ Wang Kwong]
PFA	95 (25%)	The Hong Kong Electric Co., Ltd
20 mm agg. (crushed rock)	671	Lam Tei Querry [Grandeur Building Material(Holidays) Limited]
10 mm agg. (crushed rock)	281	Lam Tei Querry [Grandeur Building Material(Holidays) Limited]
Stone fines (crushed rock)	807	Lam Tei Querry [Grandeur Building Material(Holidays) Limited]
Water	187	Water Suppliers Dept.
Admixture	3.31	KFDN-100 [Vast Hill Development Ltd.]



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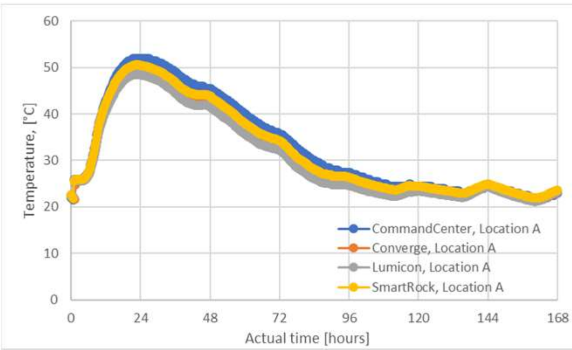
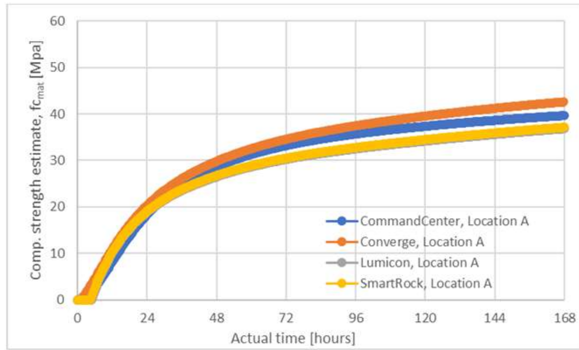
Case Studies/ HK Trials

SITE TRIAL NO. 5: CEDD Kwu Tung North, Retaining Wall





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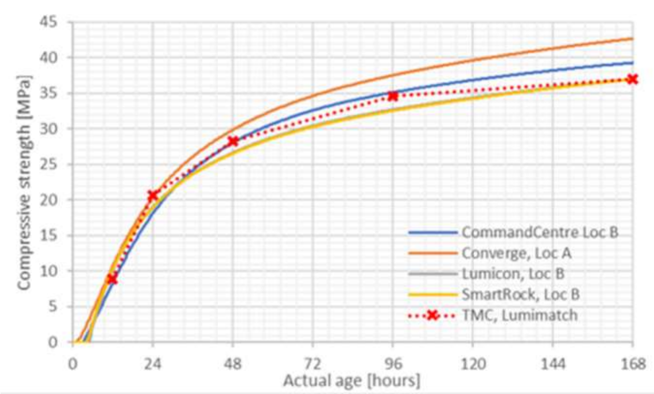
Case Studies/ HK Trials - TMC

SITE TRIAL NO. 5: CEDD Kwu Tung North, Retaining Wall

12 specimens were used to serve the purpose of initial conformity check.



Air curing "Matchbox"

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Applications of Maturity Method

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Applications

Construction Type	Applications
Buildings	• stripping forms of vertical elements • removing falsework in 1-way/2-way slabs once required strength is obtained
Infrastructures	• stripping forms and removing falsework safely in cast-in-situ tunnel liners • apply post-tension in bridge decks or beams when required strength is achieved • determining the actual temperature differential allowed in order to prevent cracking in mass concrete
Precast yards	• early stressing of tendons in pre- or post-tensioned precast elements • early lifting & staking of tunnel segments or other precast products
Pavements	• appropriate time for opening a pavement to traffic (construction or public) • for sawing joints • ceasing special concreting
Others	• estimating modulus of elasticity at very early ages in deformation sensitive members • correct estimate of strength properties to avoid damages during the lifting process of tilt-up members • estimate strength in sprayed concrete sections

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Summary

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Summary of Maturity Method

1. Ability to predict the strength of portland cement concrete and fly ash concrete with good accuracy and applicable to HK.
2. The deviation between maturity estimate and real in-situ strength (temperature matched curing) is within 10%
3. A correction factor system that avoids over/under estimation and keeps the maturity model in check.
4. The method demonstrated reduction in formwork removal time of at least 60% (60 ~ 90%) from code specified striking times e.g. potential to reduce cycle times from as low as 2.8 days to as much as 13 days
5. Maturity method now accepted by BD - incorporated in BD Circular Letter – Amendments to the COP SUC 2013 clause 11.7.5.4 and Table 11.2

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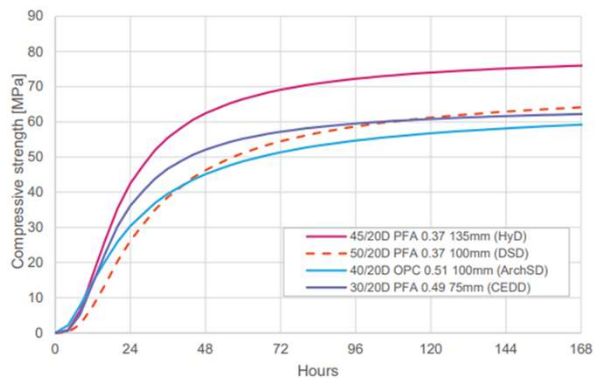
Further Opportunities

1. Promote characterization of new concrete mixes, particularly those involving high replacement levels (low carbon concretes)
2. It is still required to analyze the effects of varying cement contents, w/c ratio or level of fly ash or GBBS replacements
3. Possibility to drive carbon reduction - the maturity method offers the potential to explore reduction in the binder intensity of the concretes



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Acknowledgment

Maturity Method for Estimation of Concrete Strength Practical Guideline

We would like to thank CIC to fund this research project (CICR/04/20) and the support from DevB to arrange site trials in this research.

RESEARCH TEAM

- Principal Investigator: Goman HO
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- Expert Advice: Frag KANAVARIS (UK)
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