CONSTRUCTION
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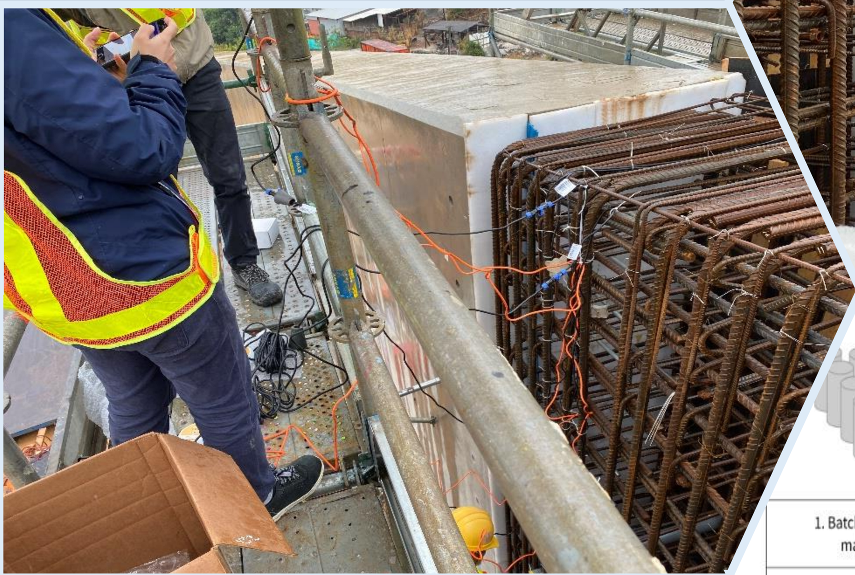
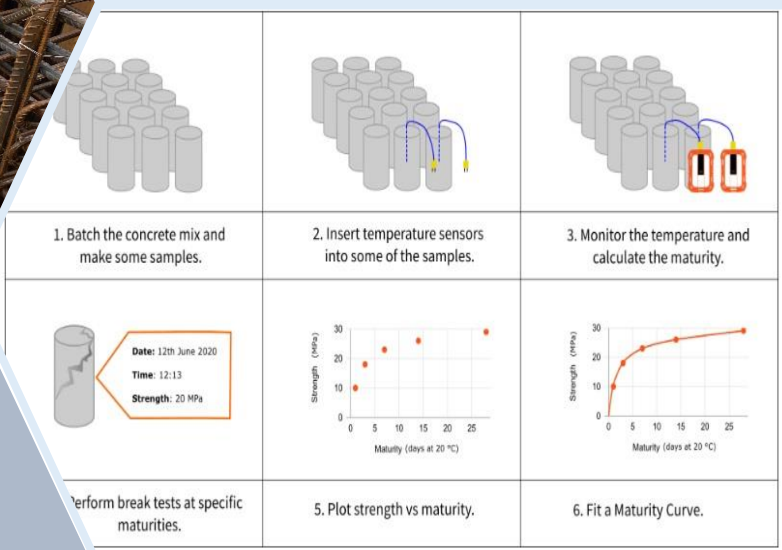
Reference Material





Model Specification for Use of Maturity Method for Estimation of Concrete Strength

www.cic.hk

April 2023

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FOREWORD

This is the seventh of a series of Reference Materials on Sample Specification/ Sample Clauses issued by the Construction Industry Council (CIC) under the theme of Model Specifications for Use of Innovative Technology. Sample Specification/ Clauses for use of (i) Unmanned Aircraft Systems for Image Capturing and Surveying; (ii) a Mobile Mapping System with Laser Scanner for Surveying; (iii) a Global Navigation Satellite System Services for Tracking of Disposal of Construction and Demolition Materials; (iv) Artificial Intelligence for Site Safety Monitoring; (v) the Safety Incentive Payment Scheme; and for (vi) Procurement of MiC Building Projects[1] were issued.

This reference material presents model specification clauses for use of the maturity method for concrete strength estimation. The maturity method is a way of evaluating the concrete in-situ strength by relating time and temperature measurements to actual strength values. The use of the maturity method will reduce the sole reliance on standard test specimens and laboratory testing for establishing concrete strength, and knowing the concrete strength in real time will allow early striking of formwork/falsework, early stressing of tendons, etc. This will enhance construction productivity, quality assurance and environmental sustainability.

The model specification clauses can be modified or added, where necessary, for the preparation of a particular specification, to suit the requirements of each individual project. Selected clauses (e.g. those clauses shown in italics) can be used as Notes on Maturity Method for inclusion on the plans submitted to the Buildings Department or works departments for approval/agreement.

The original version of the sample specification clauses was prepared by ARUP for the CIC[2]. Refinements are made to the specification clauses contained herein in view of the amendments promulgated by the Buildings Department on 23.2.2022 in respect of the Code of Practice for Structural Use of Concrete 2013 (2020 Edition)[3] on use of the maturity method for monitoring early compressive strength of in-situ concrete.

This Reference Material was prepared by Dr Thomas Lam. Mr Thomas Tong has provided very valuable suggestions and comments on this Reference Material in the preparation. There are four products of temperature sensors on the CITF's pre-approved list: Command Center, Converge, LumiCon and SmartRock. Details of the products and specialist service providers are given in Appendix A. Details of the experience sharing session given to the Buildings Department on 18.11.2022 on the use of the maturity method, in particular on the method of determining the maturity functions constants, are given in Appendix B. Messrs Andy Wong (Digital-G) and Antoine Nourisson (Gear-Up Materials Ltd.), Ms Wendy So (Schneider Development Ltd.) and many organizations with knowledge and experience in the use of maturity method, in particular the Development Bureau, Buildings Department, Housing Department and Urban Redevelopment Authority have also provided very useful comments and information in the preparation of this Reference Material. These contributions are gratefully acknowledged.

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[1] https://www.cic.hk/eng/main/aboutcic/publications/reference_materials/

[2] CIC (2021). Practical Guideline on Maturity Method for Estimation of Concrete Strength. https://www.cic.hk/files/page/51/CIC%20Maturity%20Method%20Practical%20Guideline.pdf

[3] BD (2022). Circular Letter dated 23.2.2022 on Amendments to Code of Practice for Structural Use of Concrete 2013 (2020 Edition).

Practitioners are encouraged to comment at any time to the CIC on the contents of this Reference Material, so that improvements can be made to future editions.

Industry Development
Construction Industry Council

ENQUIRIES

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PREFACE

The Construction Industry Council (CIC) is committed to seeking continuous improvement in all aspects of the construction industry in Hong Kong. To achieve this aim, the CIC forms Committees, Task Forces and other forums to review specific areas of work with the intention of producing Alerts, Reference Materials, Guidelines and Codes of Conduct to assist participants in the industry to strive for excellence.

The CIC appreciates that some improvements and practices can be implemented immediately whilst others may take more time for implementation. It is for this reason that four separate categories of publication have been adopted, the purposes of which are as follows:

Alerts	The Alerts are reminders in form of brief leaflets produced quickly to draw the immediate attention of relevant stakeholders to the need to follow some good practices or to implement some preventive measures in relation to the construction industry.
Reference Materials	The Reference Materials provide standards or methodologies generally adopted and regarded by the industry as good practices. The CIC recommends the adoption of the standards or methodologies given in the Reference Materials by industry stakeholders where appropriate.
Guidelines	The Guidelines provide information and guidance on particular topics relevant to the construction industry. The CIC expects all industry stakeholders to adopt the recommendations set out in the Guidelines where applicable.
Codes of Conduct	The Codes of Conduct set out the principles that all relevant industry participants should follow. Under the Construction Industry Council Ordinance (Cap. 587), the CIC is tasked to formulate codes of conduct and enforce such codes. The CIC may take necessary actions to ensure compliance with the codes.

To allow us to further enhnance this publication, we encourage you to share your feedback with us after you have read this publication. Please take a moment to fill out the Feedback Form attached to this publication and send it back to us. With our joint efforts, we believe our construction industry will develop further and continue to prosper in the years to come.

ABBREVIATIONS

AI	Artificial Intelligence
IP Rating	Ingress Protection Rating or International Protection Rating
TMC	Temperature Matched Curing

1. MODEL SPECIFICATION FOR USE OF MATURITY METHOD FOR ESTIMATION OF CONCRETE STRENGTH

1.010 General Requirements

(1) The Contractor shall provide the service of establishing the use of the maturity method for estimation of in-situ concrete strength for the specified concrete structure in the project.

(2) The Contractor shall provide and implement a concrete maturity monitoring system for the specified concrete structure in the project.

(3) The concrete maturity monitoring system shall comprise (i) temperature sensors and devices to retrieve and store the necessary temperature data from the in-situ concrete on-site; and (ii) a cloud-based online digital platform for managing the temperature measurements and viewing the maturity data by relevant stakeholders in the project.

(4) The Contractor shall submit the following to the Architect/Engineer# for approval at least 2 weeks prior to commencement of the laboratory calibration stage of the maturity method used in the project:

(a) *name of the specialist service provider (if a specialist service provider is engaged) (Notes: A list of the specialist service providers who are on the CITF's Pre-approved List is given in Appendix A);*

(b) *planned application for the specified concrete structure in the project;*

(c) *programme of work, covering laboratory calibration, on-site trial and validation, and re-calibration and re-validation;*

(d) *method statement as mentioned in Clause 1.020;*

(e) *name of the engineer responsible for the design and implementation, decision making and supervision of the planned application (the Responsible Engineer) and the concrete technologist;*

(f) *names of the supervision personnel assigned by the Responsible Engineer to carry out the supervision of the implementation of the maturity method, together with their duties, and records of their training and competence assessment by the Responsible Engineer.*

(5) *The maturity method shall be adopted in accordance with the Practical Guideline on Maturity Method for Estimation of Concrete Strength (CIC, 2021)[4] and ASTM C1074-19[5].*

(6) The Contractor shall provide all necessary access and support to the Responsible Engineer and his assigned supervision personnel for them to carry out their duties effectively.

(7) The Contractor shall give authority to the Responsible Engineer in decision making involving application of the maturity method, including the determination of the quantity and locations of the temperature sensors for each application, who should seek advice/endorsement from the Architect/Engineer# in the setup prior to finalising the plan;

(8) The Contractor shall bear all the cost for the application, including but not limited to the concrete maturity monitoring system, laboratory testing and

[4] CIC (2021). Practical Guideline on Maturity Method for Estimation of Concrete Strength. https://www.cic.hk/files/page/51/CIC%20Maturity%20Method%20Practical%20Guideline.pdf

[5] ASTM C1074-19 (2019). Standard Practice for Estimating Concrete Strength by the Maturity Method.

calibrations, staff, precaution and protection works for the equipment and installation of temperature sensors on site and replacement of damaged sensors, and the associated time implication.

1.020 Method Statement

(1) *The following shall be included in the method statement:*

(a) *choice of concrete maturity monitoring system;*

(b) *concrete mix design (the concrete mix used in the structure should be same as that used for deriving the strength-maturity relationship);*

(c) *choice of maturity function (e.g. Nurse-Saul method (Temperature-time Factor) or Arrhenius method (Equivalent Age));*

(d) *procedure for laboratory calibration^, including data acquisition and curing devices (e.g. water-curing tank or air-curing box);*

(e) *procedure for determining the maturity function constants, and establishing the strength-maturity relationship based on the laboratory calibration results;*

(f) *procedure for on-site trial and validation (e.g. using Temperature Matched Curing (TMC));*

(g) *procedure for re-calibration and re-validation (e.g. using TMC);*

(h) *apparatuses and their calibration; and*

(i) *quality assurance and supervision.*

1.030 Concrete Performance Assessment and Submission of Records

(1) *The Contractor/Responsible Engineer shall maintain all records, in a digital database format to be agreed with the Architect/Engineer#, related to the application of the maturity method, including the following:*

(a) *records of the concrete maturity monitoring system used;*

(b) *records of laboratory calibration (including temperature measurements and concrete strength values);*

(c) *results of maturity function constants and strength-maturity relationship obtained;*

(d) *results of on-site trial and validation (including temperature measurements and concrete strength values) and conformity assessment; and*

(e) *results of re-calibration and re-validation (including temperature measurements and concrete strength values) and conformity assessment.*

(Notes: The contents of the conformity assessment should follow those given in Appendix A3.1.3 of the Practical Guideline on Maturity Method for Estimation of Concrete Strength.)

(2) *The Contractor/Responsible Engineer shall submit the concrete temperature measurement records in digital form together with an assessment of the adequacy of the development of concrete strength with time for the specified grade of concrete to the Architect/Engineer# for approval within three days of obtaining the concrete temperature measurements. The Contractor/Responsible Engineer shall highlight the correction factor used and any anomaly in the concrete strength development observed. (Notes: Reference shall be made to the BD's*

Circular Letter dated 23.2.2022 on the correction factor used. Details of the follow-up actions taken to deal with anomaly are given in Appendix A3.2 of the Practical Guideline on Maturity Method for Estimation of Concrete Strength.)

(3) The Responsible Engineer shall submit all records in digital form to the Contractor and the Architect/Engineer# and the Project Client/Employer for the Contract within one month of completion of the planned application.

1.040 Qualification and Experience Requirements

(1) *The Responsible Engineer nominated by the Contractor shall be a Registered Professional Engineer (Structural, Civil or Geotechnical) who shall be supported by a concrete technologist with a degree in civil or structural engineering recognised by the Hong Kong Institution of Engineers. They shall have at least 3 years of post-qualification practical experience in the design of temporary works and quality assurance and quality control of concrete production work.*

(2) *The supervision personnel assigned shall have a higher certificate or higher diploma with a minimum total of 5 years of relevant working experience, or a degree holder with a minimum total of 2 years of relevant working experience in the supervision of works involving in-situ construction of concrete structures (i.e. meeting the qualifications and experience requirements of a Technically Competent Person T3 or higher with experience in the supervision of works involving in-situ construction of concrete structures).*

(3) The Contractor/Responsible Engineer shall provide all necessary training to the assigned supervision personnel in carrying out their supervision duties in the implementation of the maturity method, including the proper and robust installation of temperature sensors and prevention of dislocation and damage to the equipment and installed temperature sensors on site.

1.050 Requirements for Concrete Maturity Monitoring System

(1) All the equipment used for the application of the maturity method shall fulfil the requirements stipulated in the Practical Guideline on Maturity Method for Estimation of Concrete Strength.

(2) Recommended requirements for embedded temperature sensors, non-embedded items and data retrieval and storage system are given below:

(a) The embedded temperature sensors shall be:

(i) able to produce temperature readings with an accuracy of +/- 0.2 ºC at the required interval set;

(ii) provided with rechargeable batteries or a battery lasting for at least 3 months or power connected ;

(iii) able to withstand the temperature of in-situ concrete and transmit the signal to the cloud and produce no detrimental effect to the concrete structure in the long run; and

(iv) water proofed and dust proofed (IP66[6] or above).

[6] An IP Rating (also known as an Ingress Protection Rating or International Protection Rating) is a way of showing the effectiveness of the electrical enclosure protection from foreign bodies, such as dust, moisture, liquids and accidental contact. An IP rating consists of the letters IP (Ingress Protection) and two digits. The first digit indicates the level of the enclosure protection from solid foreign bodies, such as dust, tools or fingers, and the second digit indicates the level of

(b) The non-embedded items (e.g. receivers, hubs, repeaters) shall be:

(i) built with a battery lasting for at least 2 years;

(ii) water proofed and dust proofed (IP66 or above);

(iii) able to withstand the outdoor site harsh environment;

(iv) built without sharp corners; and

(v) light-weight and with QR-code for registration / identification of locations.

(c) The data retrieval and storage system shall be:

(i) able to temporarily store the data for up to 5 days when data connectivity is unavailable (e.g. due to power cut-off at night), and automatically upload the data to the system when connectivity is resumed without any loss and discontinuity of data; and

(ii) able to provide online access of 24/7 data via mobile devices/computers under permission without going to the construction site.

Notes: # The term "Architect/Engineer" may be changed to "Supervising Officer", "Contract Manager", "Appointing Party", etc., as appropriate.

^ The tests shall be carried out by HOKLAS laboratories.

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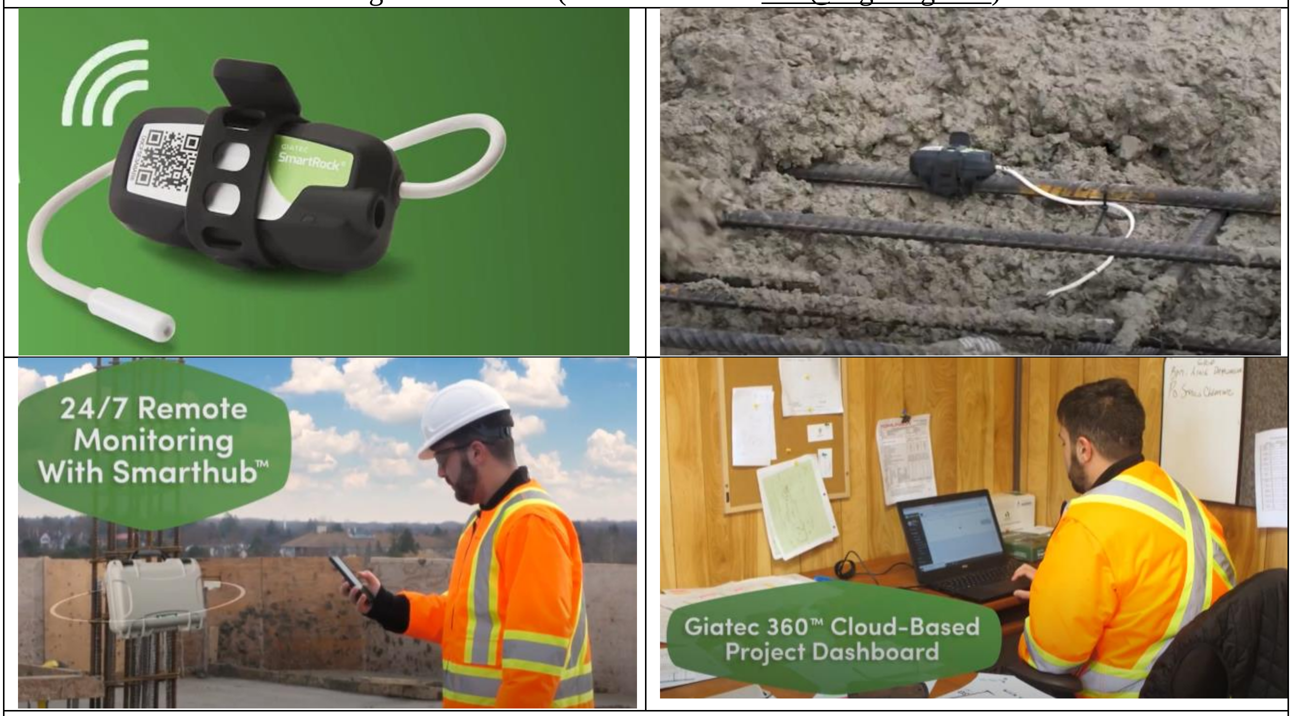
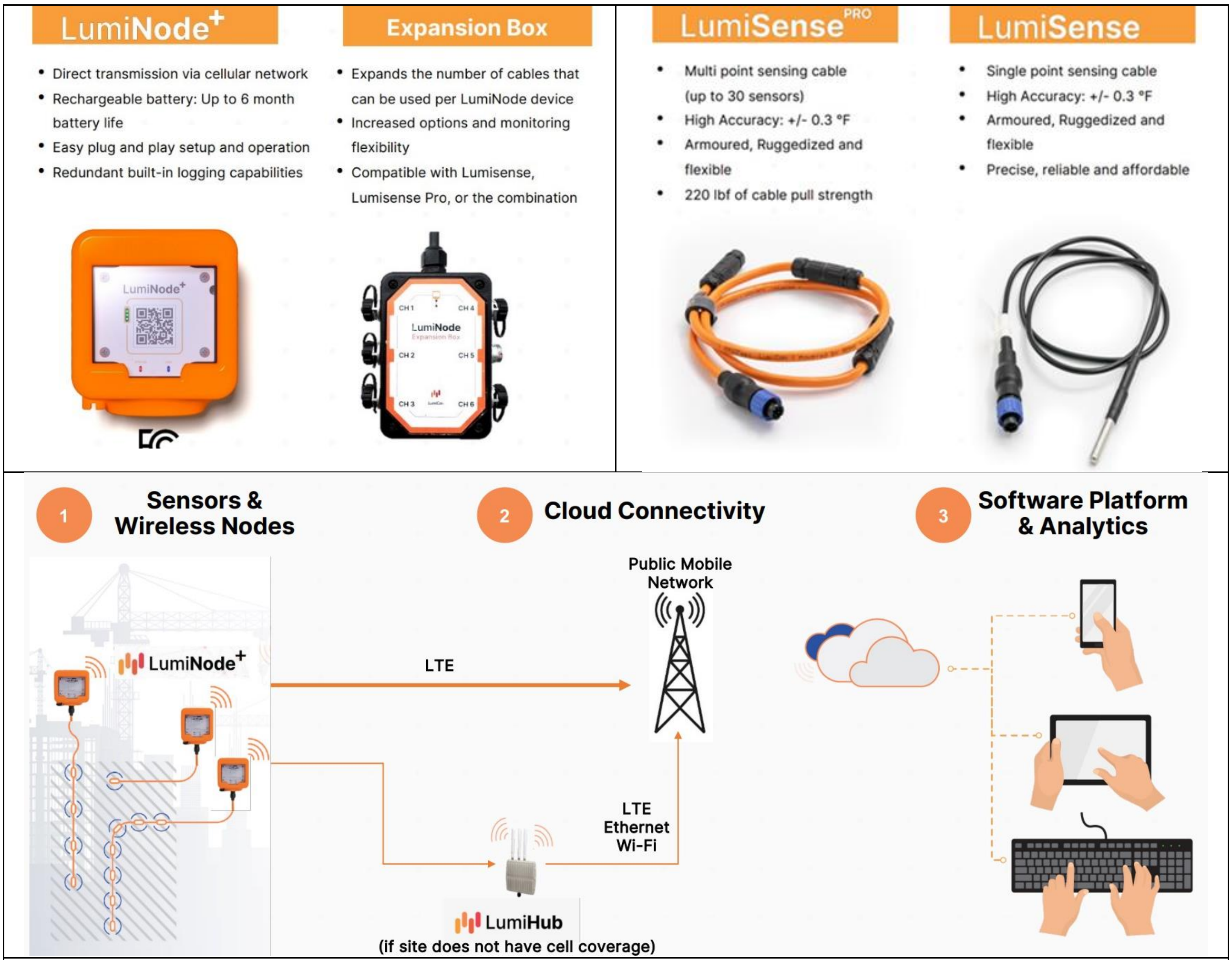
the enclosure protection from moisture (i.e. sprays, drips, submersion, etc.). IP66 indicates that the device is dust-tight and protected from powerful water jets.

APPENDIX A – DETAILS OF CONCRETE TEMPERATURE SENSORS ON THE CITF'S PRE-APPROVED LIST AND SPECIALIST SERVICE PROVIDERS

(a) The Converge System (CITF No. PA18-036)
Digital G Limited (Ms Carter Lam: info@digital-g.tech)



(b) SmartRock (CITF No. PA20-013)
Gear-Up Materials Limited (Antoine Nourisson: anourisson@gearupmaterials.com)



(c) LumiCon (CITF No. PA20-126)
AOMS Technologies (Wendy So: wendy@schneider.com.hk)

(d) COMMAND Center (CITF No. PA21-010)
The Transtec Group Products, LLC (Matt Pittman: matt@thetranstecgroup.com)

APPENDIX B – DETAILS OF EXPERIENCE SHARING SESSION GIVEN TO BUILDINGS DEPARTMENT ON USE OF MATURITY METHOD

CONSTRUCTION INDUSTRY COUNCIL
建造業議會

Use of Maturity Method for Concrete Strength Estimation

Thomas Tong, Thomas Lam & Leo Li, CIC
Andy Wong, Digital-G, Gammon
18 November 2022

Buildings Department Experience Sharing Session

12.11.2022 Version

Work Completed by Arup

- 5 site trials to test the maturity method were carried out.
- A Practical Guideline on Maturity Method for Estimation of Concrete Strength (CIC, 2021) was issued. (*https://www.cic.hk/files/page/51/CIC%20Maturity%20Method%20Practical%20Guideline.pdf*).

Site trial no.	Pour Date	Site Location	Objective – Evaluating early release of	Overseeing Local Department
1	23.04.2021	Central Kowloon Route – Kai Tak West	Soffits to slabs, beams Props to slabs, beams	HyD
2	05.05.2021	Shek Wu Hui – UV System No. 1	Soffits to slabs, beams Props to slabs, beams	DSD
3	15.09.2021	Central Kowloon Route – Kai Tak West	Soffits to slabs, beams Props to slabs, beams Live validation using TMC	HyD
4	05.10.2021	Kai Tak Station Square	Soffits to slabs, beams Props to slabs, beams	ArchSD
5	23.12.2021	Kwu Tung North Retaining Wall	Vertical (non- and profiled) formwork	CEDD

- The materials presented herein are based on ASTM C1074 and the work of Arup.

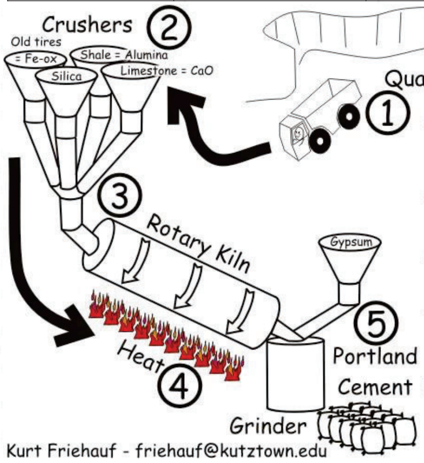
ASTM C1074: Standard Practice for Estimating Concrete Strength by Maturity Method

Composition of Cement

Ingredients	Chemical Name	Source	%
Lime	CaO	Limestone	67%
Silica	SiO_2	Sandstone	22%
Alumina	Al_2O_3	Shale	5%
Iron oxide	Fe_2O_3	Iron	3%
Calcium Sulfate	$CaSO_4.2H_2O$	Gypsum	0.2%
Others			3%





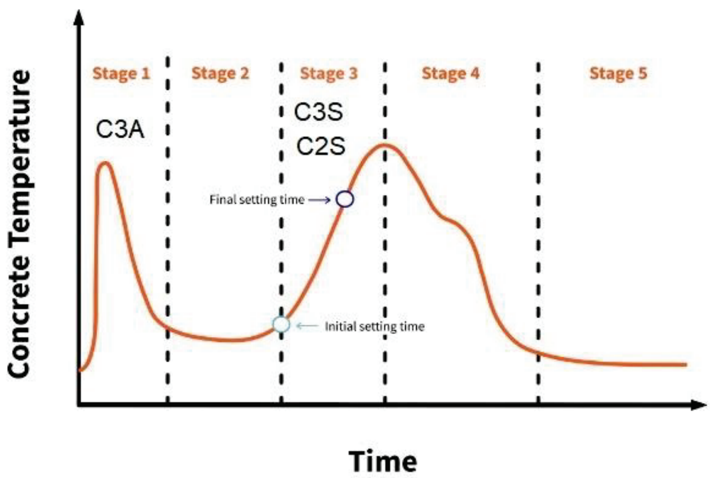


1. Limestone, shale, silica, and iron oxides are quarried from the ground. (Some limestones already contain enough silica).
2. Rock materials are run through a crusher that turns rock into smaller pieces.
3. Crushed limestone + silica + shale + iron oxides are mixed together and run through a rotary kiln.
4. Rotary kiln continuously mixes ingredients and "calcines" limestone so that CO_2 is driven off, forming clinker.
5. Clinker is ground to fine powder and mixed with gypsum (helps moderate how fast the cement "sets), then bagged for sale.

Ordinary Portland Cement (OPC)			
Chemical Properties			%
alite	Ca_3SiO_3	C3S	50-70%
belite	Ca_2SiO_4	C2S	15-30%
aluminate	$Ca_3Al_2O_6$	C3A	5-10%
ferrite	$Ca_4Al_2Fe_2O_{10}$	C4AF	5-15%

Hydration (Setting) Process of Concrete

Stage 1: Initial mixing reaction -> C3A reacts with H_2O to form ettringite (calcium aluminum sulphate) releasing energy.
Stage 2: Dormancy-> coated cement particles formed slowing down reaction (hydration) (Note: This phase is used for transporting and pouring the concrete, as the concrete stays on a fluid level. This phase ends with an initial setting of concrete).
Stage 3: Strength acceleration->C3S and C2S reaction begins producing heat and creating calcium silicate hydrate (CSH), a gel like product.
Stage 4: Speed reduction->maximum temperature reached-> availability of free particles reduced (Note: This phase often ends with the desired strength and the formwork can now be removed).
Stage 5: Steady development->hydration process slows down.



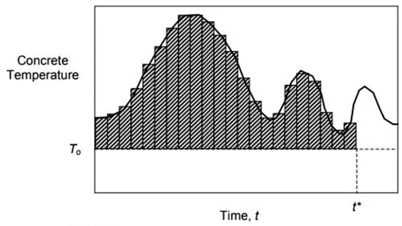
Maturity Method

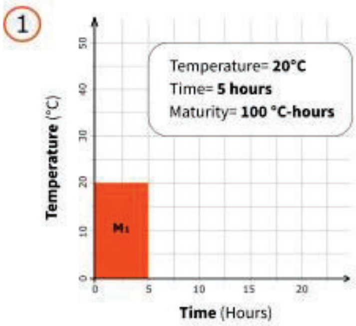
Maturity method is *a technique for estimating concrete strength that is based on the assumption that samples of a given concrete mixture attain equal strengths if they attain equal values of the maturity index.* [ASTMC1074]

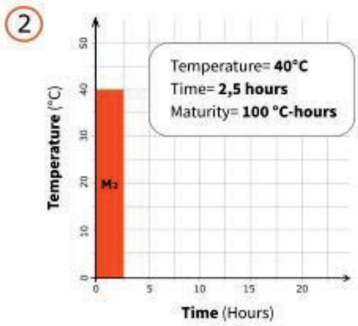
Maturity = Area under curve

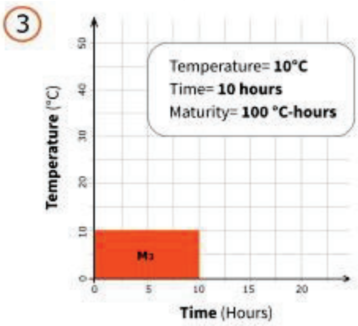
If ${}^1M = {}^2M \Rightarrow {}^1f'_c = {}^2f'_c$

Maturity = time * temperature (°C-hours)









Benefits of Using Maturity Method

The method is simple and highly adaptable for different projects and needs. Some of the benefits are:

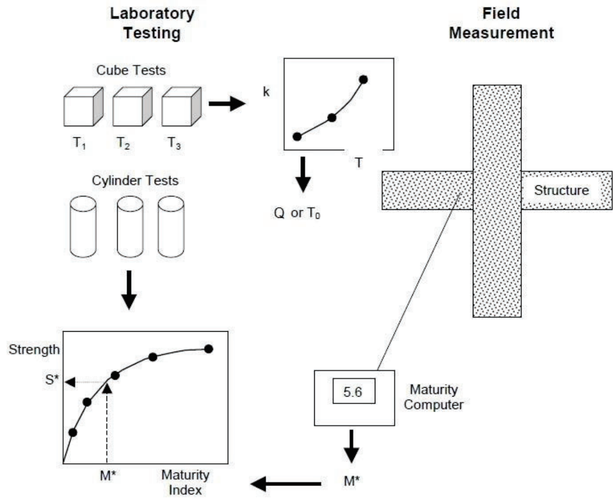
- strength estimation and development in real-time
- better project planning
- automatic documentation

Limitations

- A maturity calibration is required for every concrete
- Limited concrete moisture affects strength development
- High temperatures can affect long term strength estimations
- Inaccurate parameters can affect the strength estimations
- Incorrect use or wrong procedures may affect strength estimations

Maturity Method Steps

1. Select an appropriate maturity function
2. Prepare apparatuses and their calibration
3. Determine maturity function constants and develop strength-maturity relationship
4. Estimate insitu concrete strength
5. Validate insitu concrete strength
6. Re-calibrate and re-validate



BD (2022). BD Circular Letter on Amendments to CoP for Structural Use of Concrete 2013 (2020 Edition) dated 23.2.2022.

Maturity Method Steps

Step 1. Select an appropriate maturity function

"A maturity function is a mathematical expression to account for the combined effects of time and temperature on the strength development of a cementitious mixture. The key feature of a maturity function is the representation of how temperature affects the rate of strength development." (ASTM C1074)

The two functions commonly used are:

1. Temperature-time Factor (or Nurse-Saul) (assuming the rate of strength development is a linear function of temperature)

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

M(t) = temperature-time factor at age t (°C-hrs or °C-days)
Ta = average concrete temperature during time interval Δt (°C)
To = datum temperature (the temperature below which strength development ceases) (°C) (usually taken as -10 to -12°C)
Δt= a time interval (hrs or days)

2. Equivalent Age (or Arrhenius) (assuming the rate of strength development is an exponential function of temperature)

$$t_e = \Sigma \left[e^{-Q\left(\frac{1}{Ta}-\frac{1}{Ts}\right)} \right] \Delta t$$

te = equivalent age at a specified temperature Ts (hrs or days)
Q = activation energy (Ea) divided by gas constant (R) (=Ea/R) (K)
R = gas constant = 8.314 J/mol-K
Ta= average temperature of concrete during time interval Δt (K)
Ts= specified temperature (K)
Δt = time interval (hrs or days)
K= °C+273

Notes: Ea is the minimum energy that a molecule needs before it can take part in the chemical reaction. It depends on several factors like: cement composition, cement fineness, mineral admixtures, water/cement ratio, degree of hydration, etc.

ASTM C1074 recommends a Ea value of 40,000 to 45,000 J/mol for Type I cement without admixtures or additions. This gives a Q value of 5000 K. This value varies between concrete mix and depends on the curing temperature. This value can be determined experimentally following the procedure given in ASTM C1074, if a more accurate value is needed.

Maturity Method Steps

Step 2. Prepare apparatuses and their calibration

- Temperature sensors (2 types: wired or wireless)
- Data acquisition devices (data loggers or transmitters)
- Equipment for making and curing concrete specimens (temperature control water-curing tank or air-curing box)
- Compression testing machine

Command Center

Converge

Lumicon

SmartRock

Water-curing tank

Air-curing box

Maturity Method Steps

Step 3. Determine maturity function constants and develop strength-maturity relationship

- Prepare at least 48 concrete cube specimens with the same properties to be used for the project (mixture proportions and constituents, slump, etc.).
  (Note: The specimens must be prepared according to standard procedures for making and curing the concrete test cubes in laboratory or in field.)
- Embed temperature sensors in 2 specimens and begin logging of temperature.
- Moisture-cure the specimens in 3 different temperatures (in this case 25°C, 40°C & 55°C) (i.e. 16 in each batch).
- Perform compression tests at 6 hrs, 12 hrs, 1 day, 3 days, 7 days, 14 days & 28 days for the 3 batches of specimens.
- Establish maturity function constants (To and Q), and then M(t) or te.

What are the maturity function constants and how to determine them? (1 of 3)

The maturity function constants are To for M(t), and Q for te. The constants can be determined using the results of the compression tests on concrete cubes cured at 3 curing temperatures (see Slides 20 and 21):

1. Hyperbolic equation $S = \frac{S_u \cdot k \cdot (t - to)}{1 + k(t - to)}$ (ASTM C1074)

where S= average cube compressive strength at age t (MPa)
t= test age (hr or day)
Su= limiting strength (MPa)
to= age when strength development is assumed to begin (hr or day)
k= rate constant (hr-1 or day-1)

2. Exponential equation $S = S_u e^{-(\frac{\tau}{t})^{\alpha}}$ (Freiesleben Hansen & Pedersen, 1985)

where S= average cube compressive strength at age t (MPa)
t= test age (hr or day)
S_u= limiting strength (MPa)
τ= characteristics time constant (hr or day)
α= shape parameter (taken as 1)

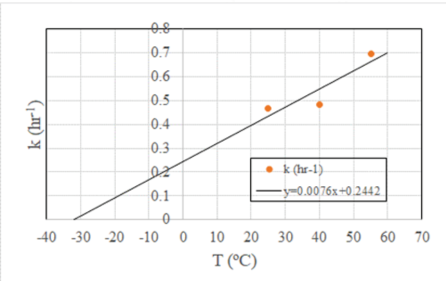
What are the maturity function constants and how to determine them? (2 of 3)

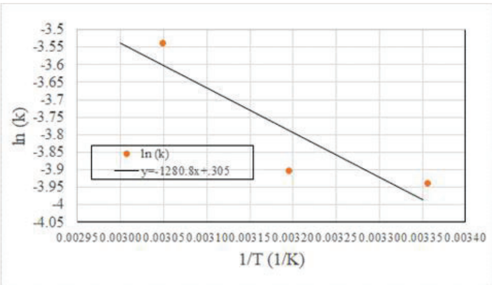
Initial values of to, Su and k for the hyperbolic equation and τ, Su and an α value of 1 for the exponential equation are assumed to compute S. By minimizing the sum of the square of errors (SSE) of the actual and computed S values for the three curing temperatures, the parameters that give the minimum SSE are determined. The solver function in the Microsoft Excel can be used to determine the best fit parameter.

What are the maturity function constants and how to determine them? (3 of 3)

Hyperbolic equation

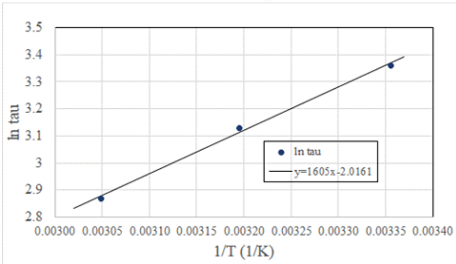
1. Plot k vs curing temperature -> To is given by the x-intercept of the line.
2. Plot ln (k) vs inverse of curing temperature (in 1/K) -> Q is given by the negative gradient of the line.





Exponential equation

1. Plot ln (τ) vs inverse of curing temperature (1/K) -> Q is given by the gradient of the line.



Maturity Method Steps

Step 4. Estimate insitu concrete strength

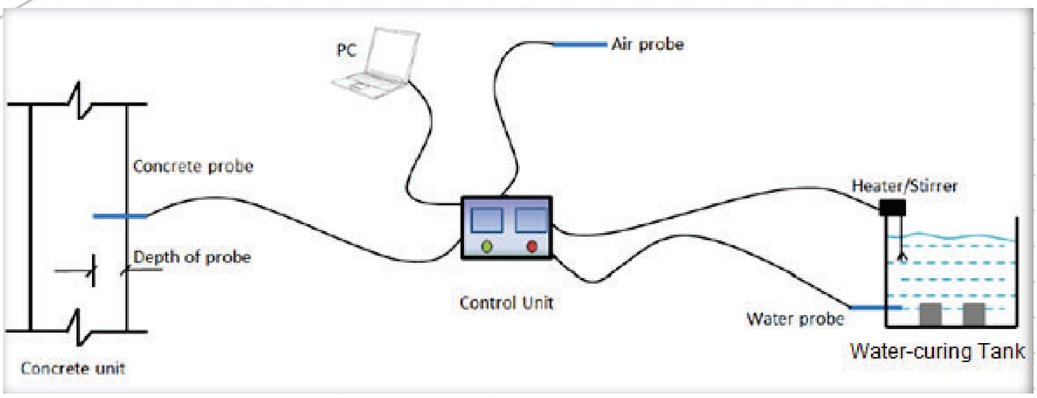
- Install temperature sensors in the structure at critical locations (e.g. at location of highest stress level and /or less temperature development).
- Connect the temperature sensors to data loggers or transmitters and start recording the temperature.
- Pour concrete after the sensors have been properly installed.
- Calculate M(t) or te based on the temperature profile obtained from the temperature sensors.
- Determine concrete strength $S_{M(t)}$ or S_{te} from M(t) or te.

Maturity Method Steps

Step 5. Validate insitu concrete strength

- Prepare at least 14 concrete cube specimens from a concrete batch >3.5m^3 (record concreter mix proportions and constituents, slump, etc.).
- Embed temperature sensors in 2 specimens and subject them to Temperature Matched Curing (TMC); begin logging of temperature
- Perform compression tests at 6 hrs, 12 hrs, 1 day, 2 days, 4 days & 7 days for the specimens to get S_{TMC}.
- Use S_{TMC} to validate the maturity model.

What is Temperature Matched Curing (TMC)?



Temperature Matched Curing (TMC) is a technique that involves matching the temperature of curing specimens with the temperature of the in-situ concrete, to provide a superior measure of early age concrete strength. Water-curing tank or air-curing box is controlled by thermocouples embedded directly in the concrete structure. Temperature readings are read automatically by a battery powered data logging system, which can relay the readings over long distances to a gateway, which can be either hooked up to the Internet or used locally to control the temperature of the curing tank/box.

Maturity Method Steps

Step 6. Re-calibrate and re-validate

The maturity-strength relationship should be reviewed at specific assessment period (typically at least monthly) or when there are changes in the concrete production conditions, such as variations in materials, batching equipment, etc.

Initial Production

- Prepare 12 concrete cube specimens and subject them to TMC.
- Embed temperature sensors in 1 concrete cube specimen and begin logging of temperature.
- Perform compression tests at 6 hrs, 12 hrs, 1 day, 2 days, 4 days & 7 days.
- Use S_{TMC} to validate the maturity model.

Continuous Production

- Prepare 6 concrete cube specimens to be subject to TMC.
- Embed temperature sensors in 2 concrete cube specimens and begin logging of temperature.
- Perform compression tests at 12 hrs, 1 day & 3 days.
- Use S_{TMC} to validate the maturity model.

What are the acceptance criteria (using maturity at all test ages up to 7 days)?

Initial Production

- $(S_{TMC} - S_{maturity\ method}) \leq \pm 20\%$
- If $S_{maturity\ method} > S_{TMC}$, determine correction factor (CF)
- $CF = S_{maturity\ method} / S_{TMC}$
- Min. CF applied = 1.10
- $S^*_{maturity\ method} = S_{maturity\ method} / CF$

Continuous Production

- $(S^*_{maturity\ method} - S_{TMC}) \leq 2$ MPa
- $(S_{TMC} - S^*_{maturity\ method}) > 2$ MPa

Note: $S_{maturity\ method} = S_{M(t)}$ or S_{te}

Case Example

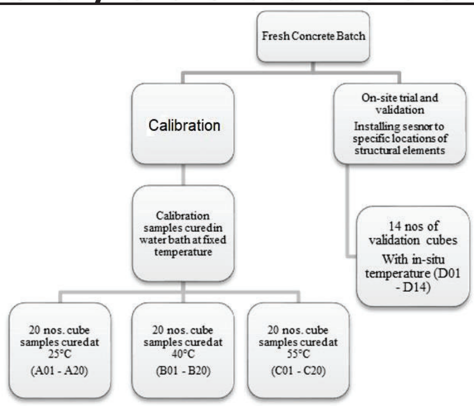
CEDD Kwu Tung North Retaining Wall (Trial No. 5)

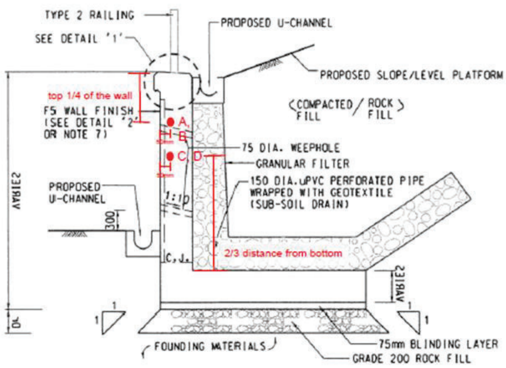
Concrete details

Project	Pour Date	Grade	Slump [mm]	Concrete Supplier	Mix proportions [kg/m^3]							
					w/c	Cement	Fly ash	Water	Coarse agg.	Fine agg.	Admix.
CEDD	23.12.21	30/20D	75	Excel	0.49	285	95	187	952	807	WR&R

Notes: [1]Water reducer and retarder (one chemical admixture)

Laboratory Calibration and Site Validation Approach





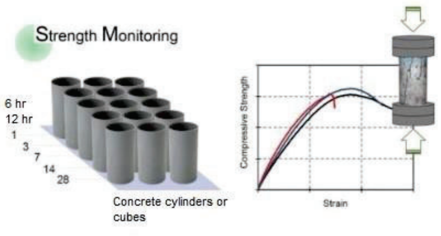
TYPICAL SECTION OF RETAINING WALL

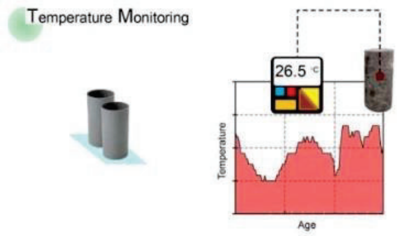
Case Example

Calibration

- Prepare concrete cubes on site (temperature sensors were installed in two concrete cubes) and send them to laboratory for curing in 3 water tanks at 25˚C, 40˚C and 55˚C.
- Carry out compression tests on the concrete cubes taken from the three water tanks at 6 hr, 12 hr, 1 day, 2 days, 3 days, 7 days, 14 days and 28 days.





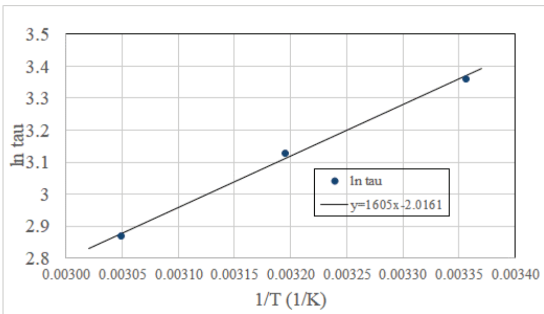
Time of Testing (hr)	Curing Temperature		
	25°C	40°C	55°C
	Strength (MPa)		
6	4	5.2	8.9
12	6.9	14.3	14.3
24	14.6	23.7	24
48	23.8	31.8	31.7
72	29.9	35.9	35.6
168	37.3	45.9	48.2
336	41.7	56.4	51.5
672	47.7	61.4	51.7

Compression test results

How to establish the maturity function (using te in this case)? (1 of 2)

- Use exponential equation $S = S_u e^{-(\frac{\tau}{t})^{\alpha}}$ to determine Q for te. $t_e = \Sigma \left[e^{-Q(\frac{1}{Ta}-\frac{1}{Ts})} \right] \Delta t$
- Assume initial values of τ and Su, and an α value of 1 to compute S.
- Determine τ and Su by minimising the sum of the square of errors (SSE) of the actual and computed S values for the three curing temperatures (using the solver function in the Microsoft Excel)
- Plot ln τ vs 1/T (1/K) to determine Q (=1605 K).

Curing temperature	Su	τ	α
25°C	46.27	28.83	1
40°C	57.26	22.85	1
55°C	51.42	17.60	1



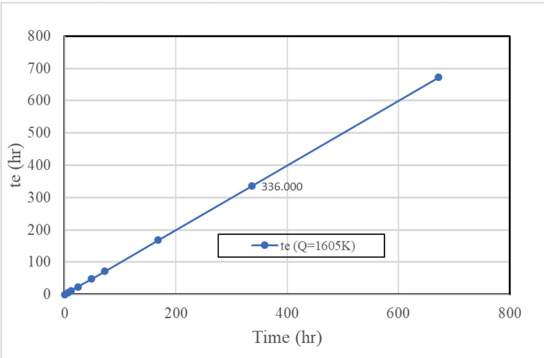
How to establish the maturity function (using te in this case)? (2 of 2)

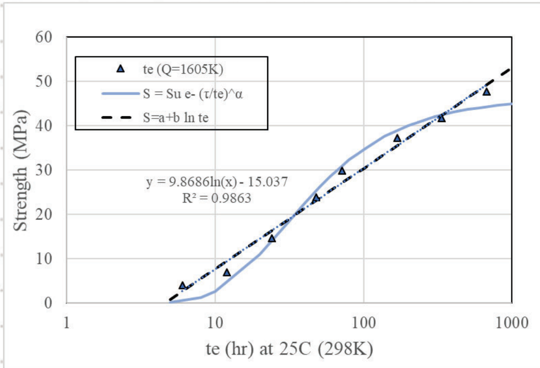
- Compute te for the curing temperature of 25 °C.
- Plot S_{te} vs te for the curing temperature of 25 °C.
- Establish the relationship between S_{te} and te.

$$t_e = \sum \left[e^{-1605\left(\frac{1}{T_a}-\frac{1}{298}\right)}\right]\Delta t$$

$$S_{te} = -15.037 + 9.8686 \ln (t_e)$$

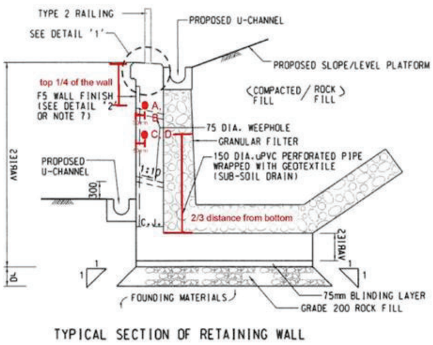
Note: The specified temperature is taken as 25 °C (298K) because this is close to the curing temperature in field.

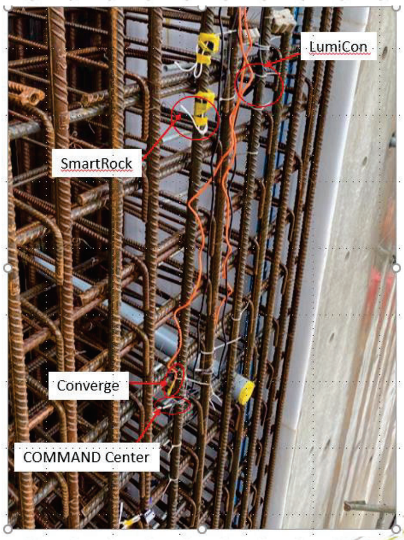




On-site Trial and Validation

- Install temperature sensors at locations A and C (locations of highest stress level and less temperature development) and B and D (redundant locations) in the retaining wall.





How to estimate and validate in-situ concrete strength? (1 of 2)

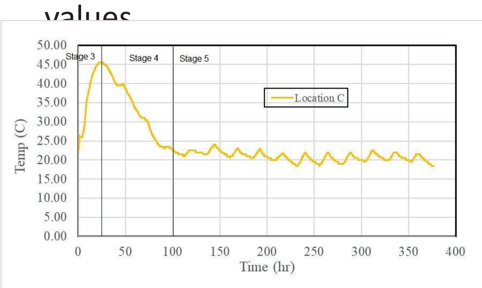
- Review the temperature data collected at Location C by Command Center, as an example, based on te.
- Compute te based on the temperature profile.

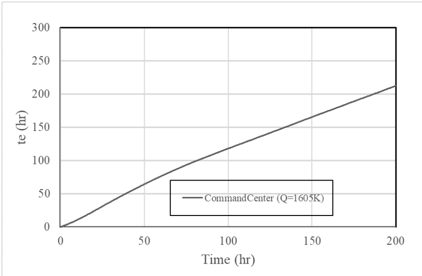
$$t_e = \sum \left[e^{-1605\left(\frac{1}{T_a}-\frac{1}{298}\right)} \right] \Delta t$$

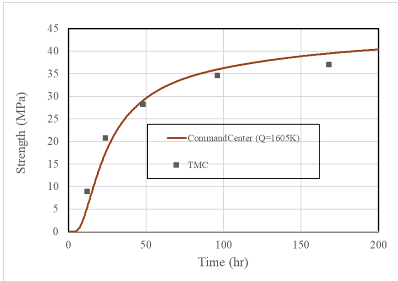
- Compute S_{te} based on te (using the Su, τ and α values established before for the curing temperature of 25°C).

$$S_{te} = S_u \, e^{-\left(\frac{\tau}{te}\right)^{\alpha}}$$

- Carry out compression tests on the TMC concrete cubes, and compare S_{TMC} with the S_{te} values







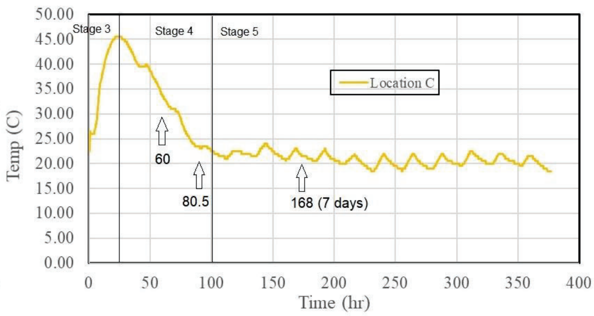
Note: In most systems, te and S_{te} can be calculated automatically, based on the maturity function selected and the constants provided. The strength information can be stored in cloud, and accessed remotely from any device.

How to estimate and validate in-situ concrete strength? (2 of 2)

- Since $S_{te} > S_{TMC}$, determine correction factor (CF)
- Correction factor (CF) = 1.05; use min. 1.1.

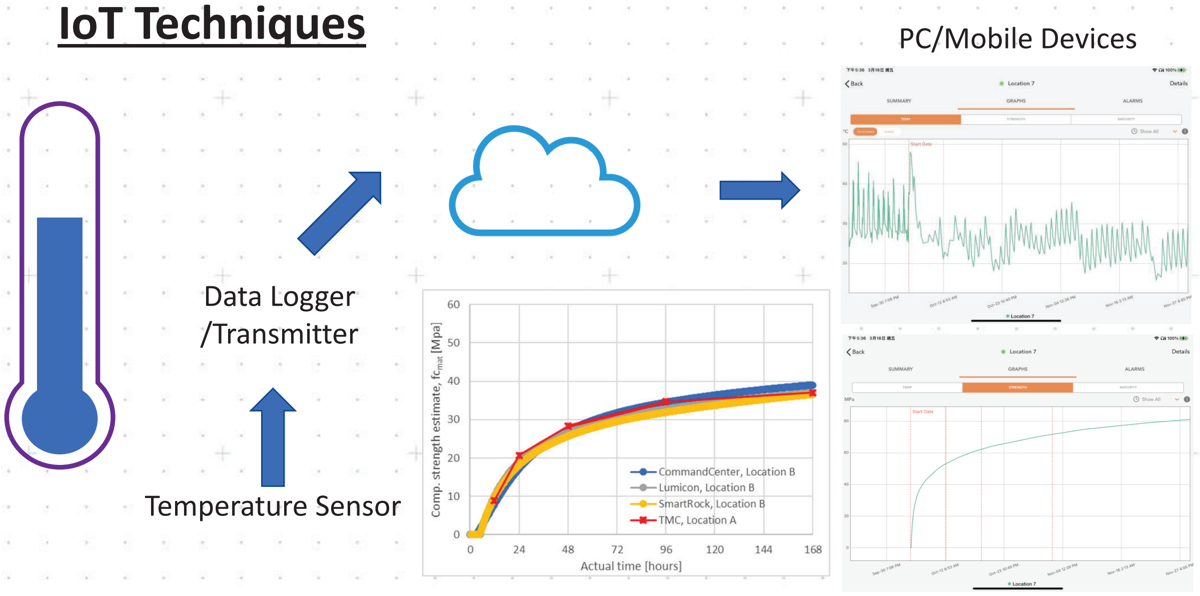
$$CF = \frac{S_{te}}{S_{TMC}}$$

t (hr)	S_{TMC} (MPa)	S_{te} (MPa)	(S_{TMC} - S_{te}) (MPa)	% Range	Correcion Factor (CF)	$S_{corrected}$ (MPa)
12	8.93	8.19	0.74	9%	0.92	7.45
24	20.73	17.51	3.22	18%	0.84	15.92
48	28.27	27.31	0.96	4%	0.97	24.83
96	34.66	34.51	0.15	0%	1.00	31.37
168	37.01	38.91	-1.9	-5%	1.05	35.37
			Max CF		1.05	
			Use min		1.10	



Findings: The criterion for removal of formwork is the attainment of concrete strength of 30 MPa. The time allowed to remove the formwork was found to be 60 hrs (2.5 days), if no CF is applied. The time of removal would become 80.5 hrs (3.35 days), when a CF of 1.1 is applied, as compared with the 7 day requirement as specified in the CoP for Structural Use of Concrete 2013 (BD, 2020).

IoT Techniques



Discussions

1. Correction Factor

a. BD Circular Letter dated 23.2.2022 on Amendments to Code of Practice for Structural Use of Concrete 2013 (2020 Edition).

b. CIC (2021) - A minimum correction factor of 1.1 should be applied to the early age strength estimate (when $S_{te} > S_{TMC}$) (i.e. correction factor≈0.9).

Type of concrete mix	≤ 48 hours after concrete casting	> 48 hours after concrete casting
Concrete mix containing pfa or ggbs	0.7	0.8
Other concrete mix	0.8	0.8

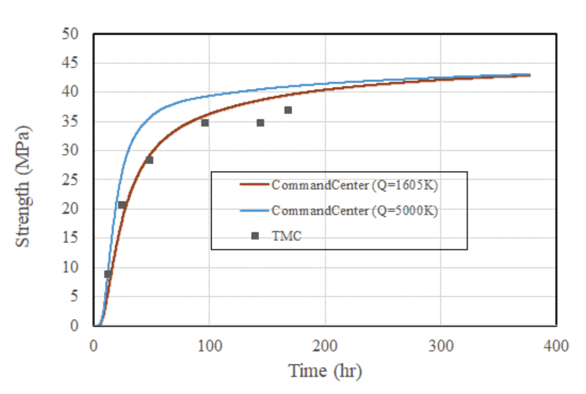
Table 11.2 – Correction factor applied to the estimated insitu concrete compressive strength

1 Due to the rapid rate of concrete strength development within 24 hours after concrete casting, the maturity method is not suitable for use in justifying minimum periods before striking formwork and falsework of less than 24 hours.

Discussions

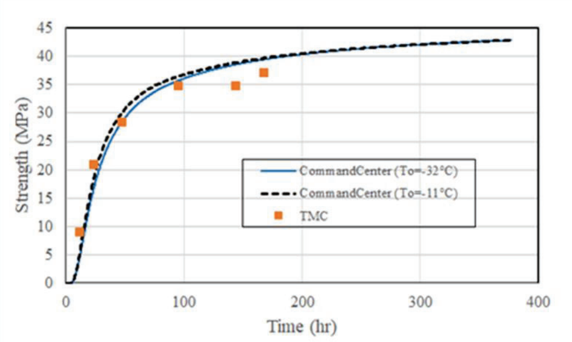
2. Q=5000 K vs Q=1605K using te

A Q value of 5000 K was proposed for type 1 cement without admixtures. Using a Q value of 5000 K, the departure of S_{TMC} from S_{te} is more marked. It is evident that the discrepancy would increase when an inappropriate Q value is used. The best Q value for a given concrete mix should be determined experimentally.



3. To=-32°C vs -11°C using M(t)

-32°C was established and -11°C was usually used in using M(t). The difference between using -32°C and -11°C on the time taken for the concrete to achieve 30 MPa is small.



Discussions

4. APP-167: Quality of In-situ Reinforced Concrete Works at an Early Age

As an alternative to RHT, the quality of in-situ concrete at early age may be assessed by the maturity method on the 7th day after they are cast.

Requirements on RHT

5. Structural concrete elements that require the carrying out of RHT between the seventh and tenth day after they are cast, and the corresponding testing frequency are given in the table below:

Structural Concrete Element subject to RHT[@]	Minimum Testing Frequency
1. Vertical elements[#] of higher concrete grade than the immediate supports at the base provided by pile cap/footing/raft foundation/transfer plate/transfer beam	50%
2. Vertical elements of higher concrete grade than adjoining beams/slabs at the top	10%
3. Transfer beams	50%
4. Beams of higher concrete grade than adjoining beams/slabs on the same floor	10%

Feedback Form

Model Specification for Use of Maturity Method for Estimation of Concrete Strength (April 2023)

Thank you for reading this publication. To help us improve our future versions, we would appreciate your suggestions/feedback on the publication.

(Please put a " ✓ " in the appropriate box)

1. As a whole, I feel that this publication is:	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Informative	❑	❑	❑	❑	❑
Comprehensive	❑	❑	❑	❑	❑
Useful	❑	❑	❑	❑	❑
Practical	❑	❑	❑	❑	❑

2. Does this publication give you useful information on the specification clauses for use of maturty method for estimation of concrete strength?	Yes	No	No Comment
	❑	❑	❑

3. Have you made reference to this publication in your work?	Quite Often	Sometimes	Never
	❑	❑	❑

4. To what extent have you applied the specification clauses made in this publication to your work?	Most	Some	None
	❑	❑	❑

5. Overall, how would you rate this publication?	Excellent	Very Good	Satisfactory	Fair	Poor
	❑	❑	❑	❑	❑

6. Other comments and suggestions (please specify and use separate sheets if necessary).

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