Nondestructive Imaging and Diagnosis of Concrete Structures with Ground Penetrating Radar and Infrared Thermography

Ir Dr. Wallace Wai-Lok LAI[1,2] and Dr. Janet Fung-Chu SHAM[1]

[1]The Hong Kong Polytechnic University

[2] Federal Institute of Materials Research and Testing (BAM), Berlin

Medical Imaging for more than 100 years

The Hand of Mrs. Wilhelm Röntgen by X-ray (1895)

A Foot by Magnetic Resonance Imaging (MRI) (2017)

From Medical to Infrastructure Imaging: Are you ready?

- **Why image?**
- What to image?
- How to image?
- How to make use of the images?
- Who can do it in daily basis?

From Medical to Infrastructure Imaging: Are you ready?

- **Why image?**
- What to image?
- How to image?
- How to make use of the images?
- Who can do it in daily basis?

Why image?

1. Introduction

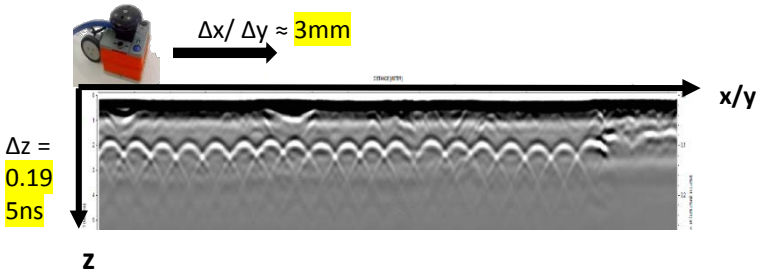
One day, a patient visits a doctor describing a painful wrist. The doctor says "Well! If you are not feeling well, how about we drill a hole in your wrist, have a look and take some samples?" If you were the patient, would you let a doctor do invasive surgery without a scan, like magnetic resonance imaging (an MRI scan) or computer X-ray tomography (a CT scan)? Unfortunately, this happens every day in construction work

Wallace Wai-Lok Lai, Xavier Dérobert, Peter Annan. A review of Ground Penetrating Radar application in civil engineering: A 30-year journey from Locating and Testing to Imaging and Diagnosis. *NDT & E International*, Volume 96, June 2018, Pages 58-78.

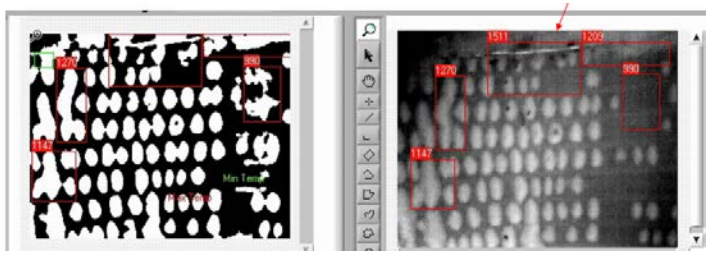
Two Examples for Nondestructive Imaging and Diagnosis of Concrete Structures

- Why image?
- What to image?
- How to image?
- How to make use of the images?
- Who can do it in daily basis?

➢ Corrosion **diagnosis** of concrete structures via Ground Penetrating Radar (GPR) Imaging



➢ Water seepage and delamination **diagnosis** in gravity sewer pipes by active and passive Infrared Thermography (IR) aided with in-house automatic size estimation algorithm



THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

Corrosion diagnosis of ground penetrating radar in Hong Kong-Macau ferry pier

Ir Dr. Wallace Wai-Lok LAI
Ms. Phoebe Tin-Wai Wong
Dr. Janet Fung-Chu Sham
Mr. Ray Kwong-Wai Chang
Prof. C.S. Poon

With the support of
A consultancy project “Non-destructive structural survey and diagnosis of reinforced concrete structures” by CEDD and Chinese National Engineering Research Centre for Steel Construction (CNERC) (Hong Kong Branch)

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Motivation

> The client (CEDD) suspects that a large part of the FRP-wrapped concrete slabs in Hong Kong-Macau Ferry Terminal is delaminated.

>The slab is subject to tide and is constantly exposed to seawater.

>There is no other NDT method….how to diagnose??

Site description (Macau Ferry Terminal, MFT)

Surveyed area: 9m x 4m

Surveyed area: 8m x 1.5m x 0.35m depth

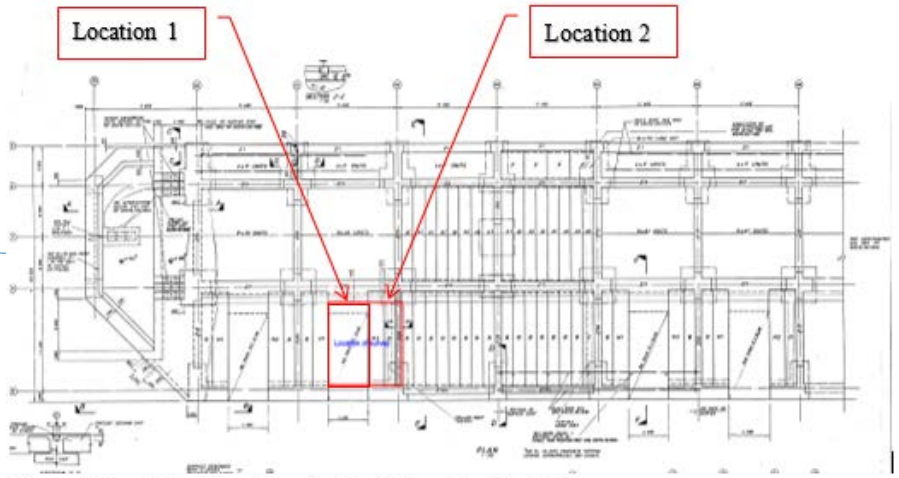


Figure 2: Record drawing of Location 1 and 2 provided by CEDD

Location 1: Slab soffit

Location 2: Beam side and soffit

Method of data collection, processing and presentation

Data collection by GPR (through x-y grid)

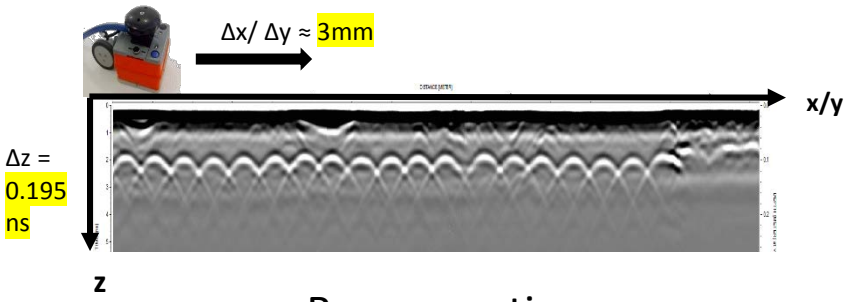
2-D signal processing

Generate 3-D image to illustrate the energy distribution at a user-selected depth

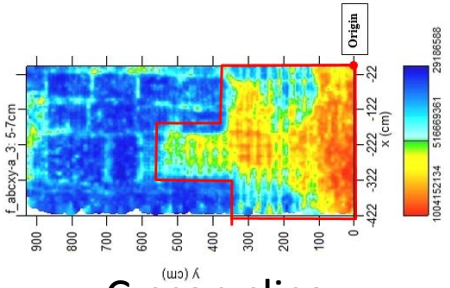
Identify abnormal reflections from C-scans of the collected data

Extract correspond-ing B-scans with abnormal reflections shown at C-scans

Identify areas and propose open-up survey/ coring for validation

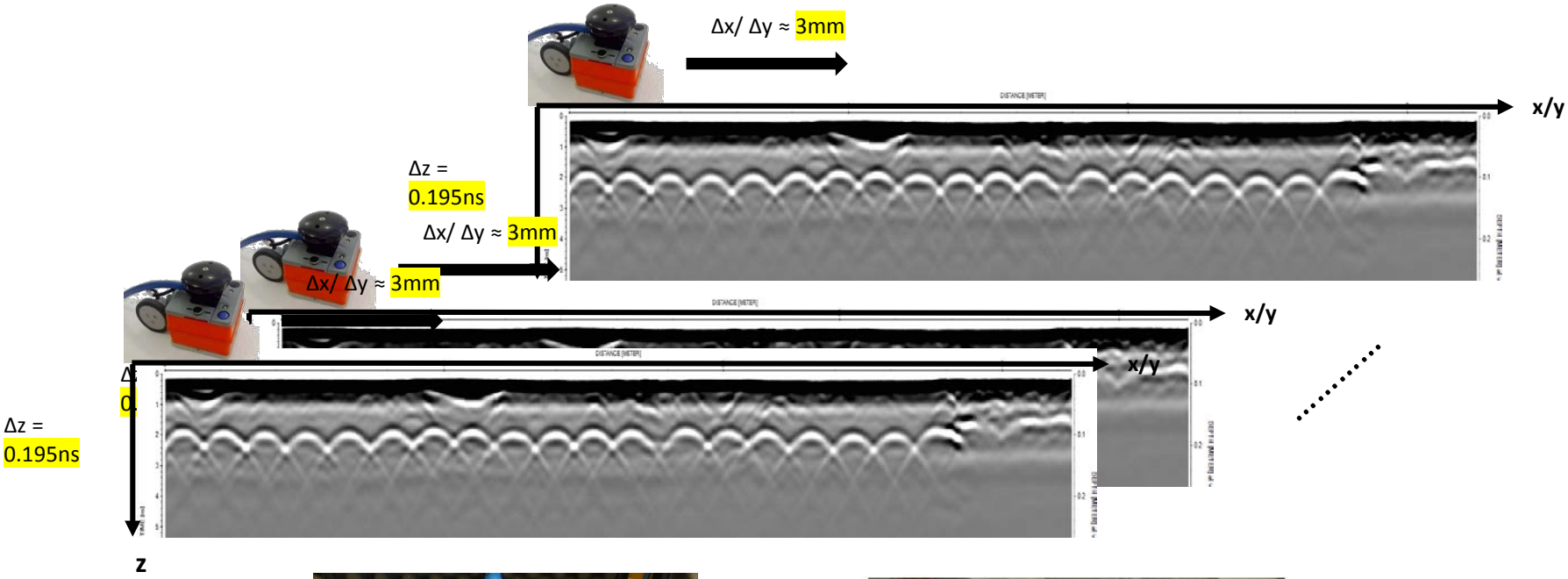


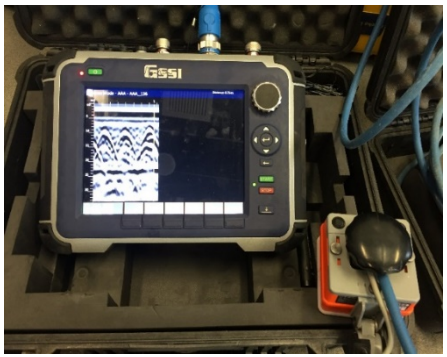
B-scan section



C-scan slice

Data collection





GSSI Control Unit and 2GHz Antenna

MFT

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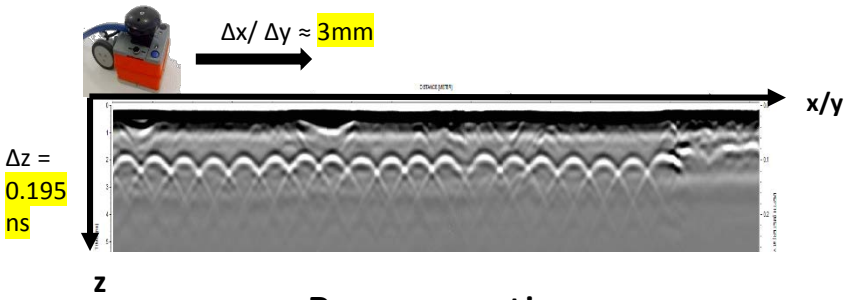
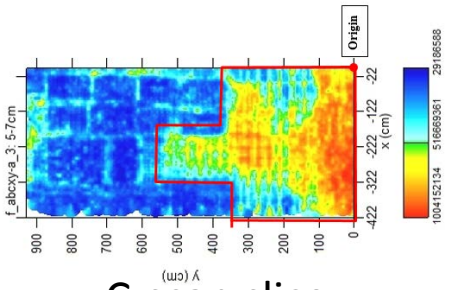
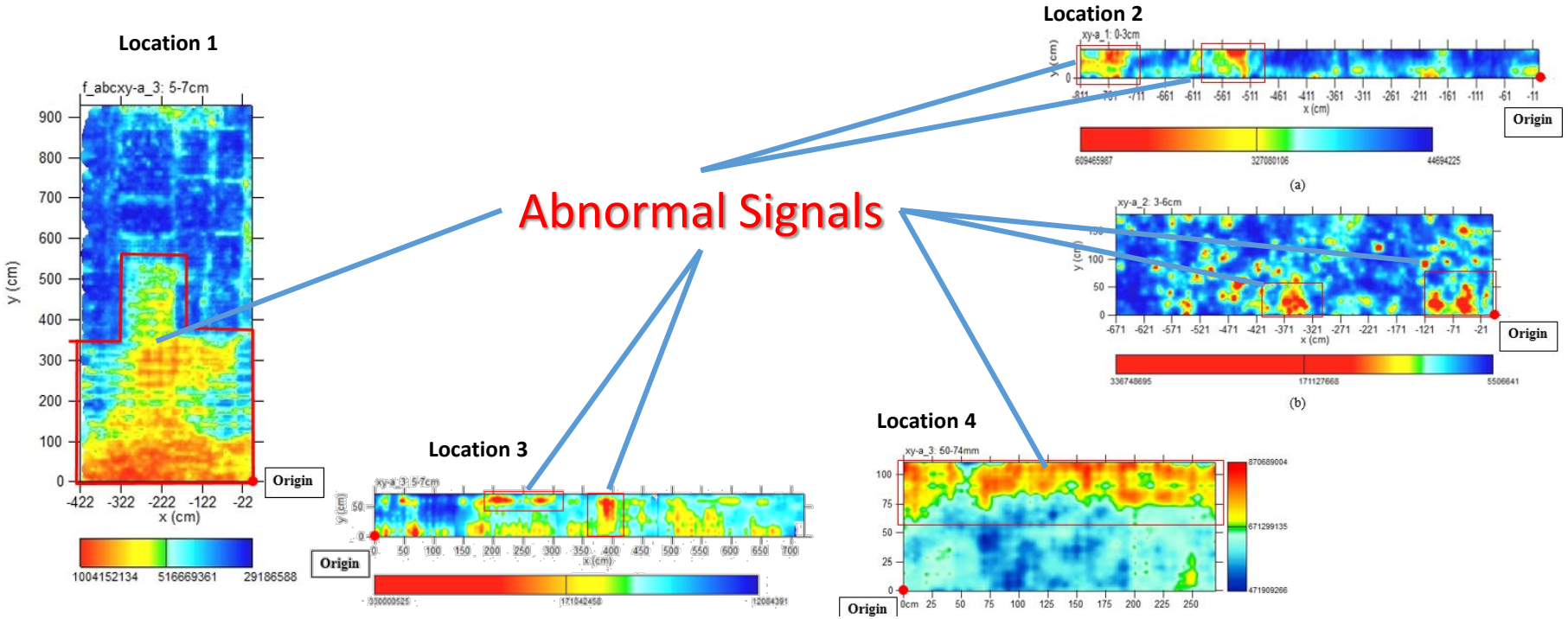


B-scan section



C-scan slice

Findings: Signatures of abnormal GPR signals (C-scan slices)



Method of data collection, processing and presentation

Data collection by GPR (through x-y grid)

2-D signal processing

Generate 3-D image to illustrate the energy distribution at a user-selected depth

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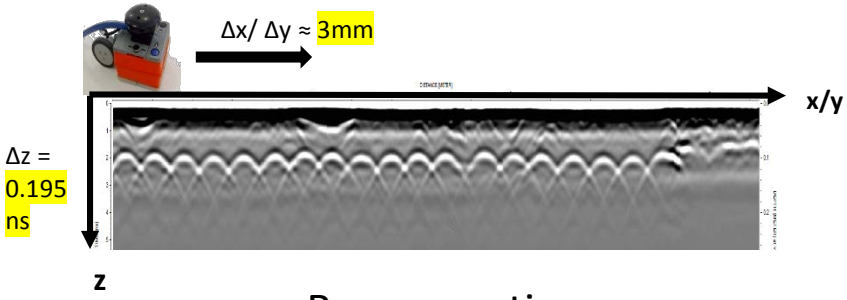
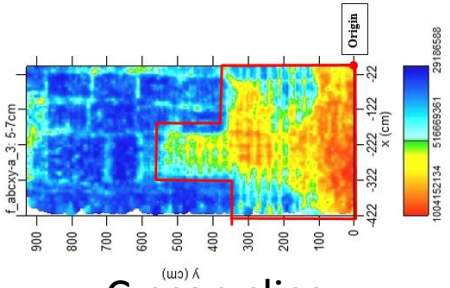
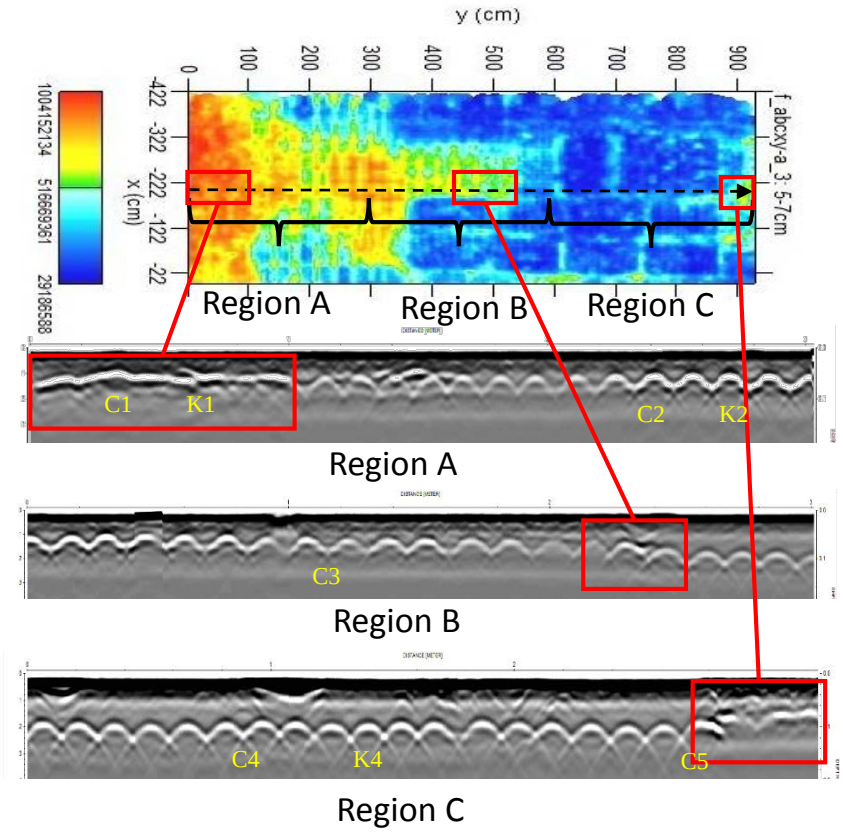


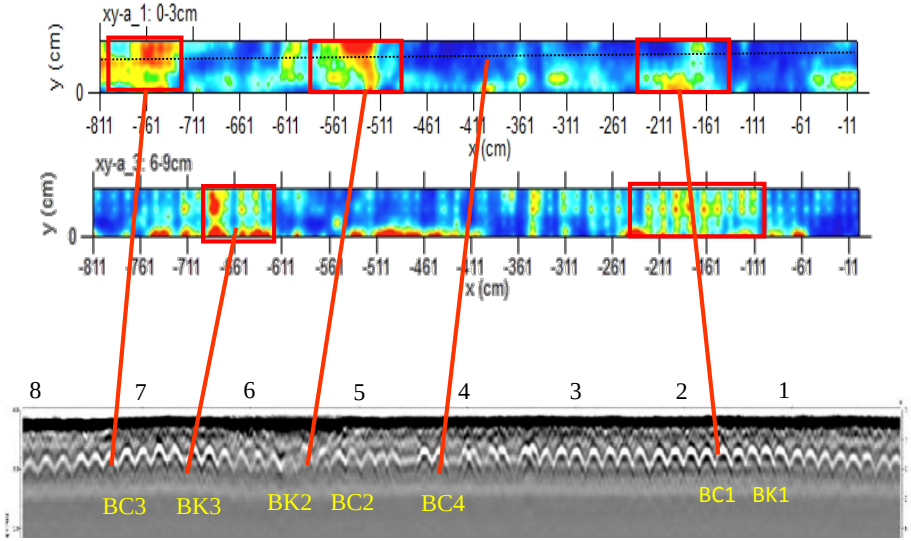
B-scan section



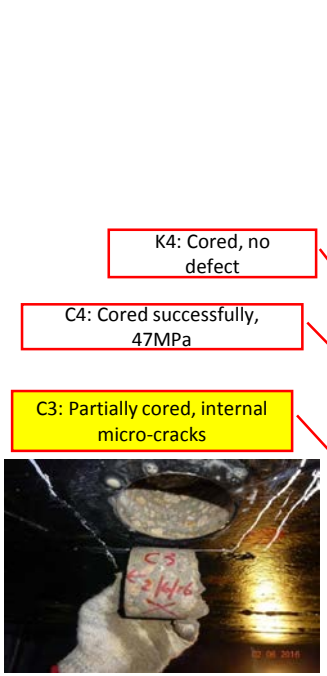
C-scan slice

Findings: Signatures of abnormal GPR signals (B-scans) – Location 1 & 2





Findings: Open-up by coring



K4: Cored, no defect

C5: Cored successfully, 57MPa

BK3: Partially cored, delamination

BK2: Partially cored, delamination between existing and repairing materials

BC4: Partially, cored, internal micro-cracks

C4: Cored successfully, 47MPa

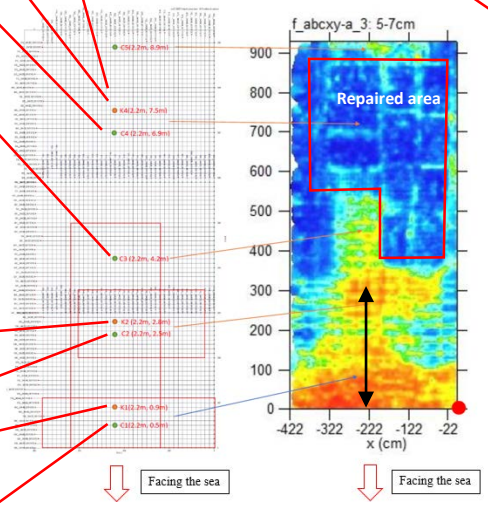
BC3: Partially cored, honeycomb

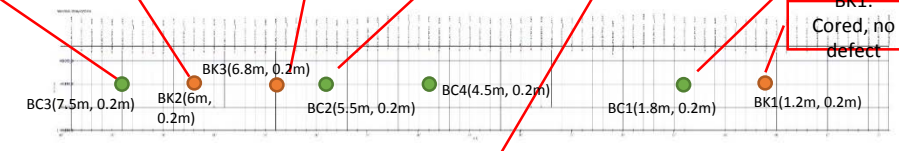
BC2: Failed to core, open-up survey, delamination

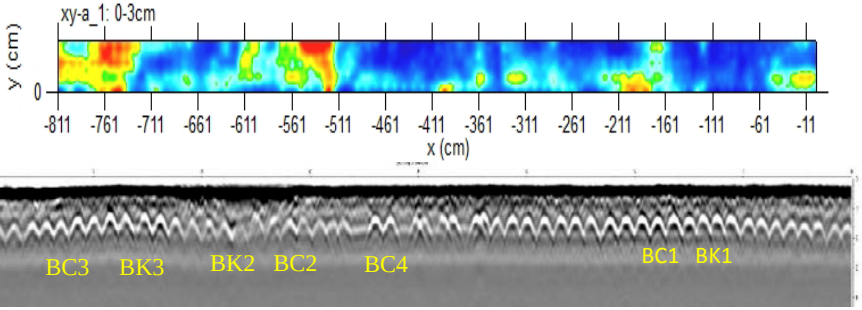
BC1: Cored successfully, 62MPa

C3: Partially cored, internal micro-cracks

BK1: Cored, no defect







K2: Cored, no defect

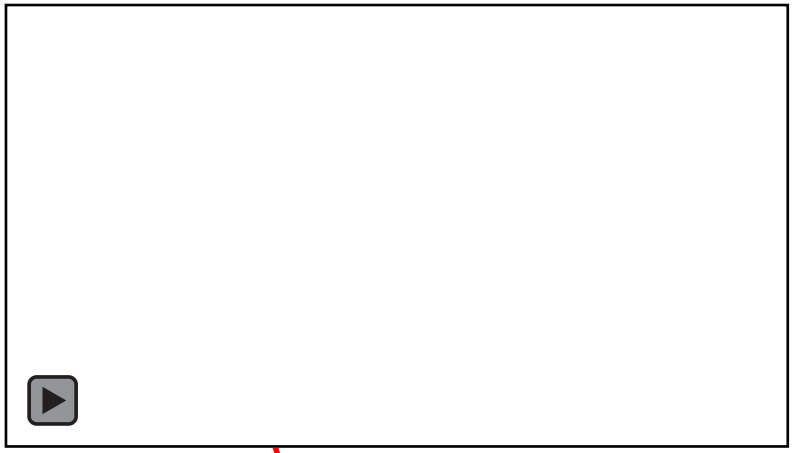
C2: Cored successfully, 53.5MPa

K1: Failed to core, open-up survey, water seepage

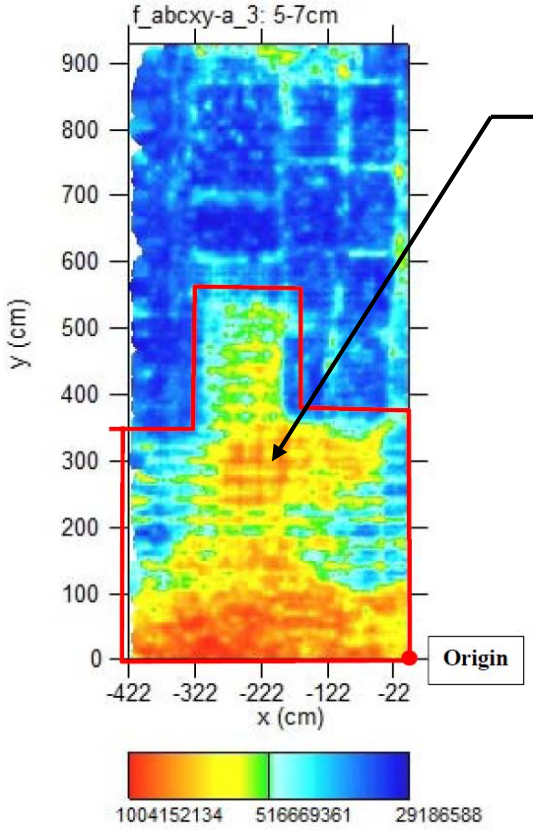
C1: Failed to core, open-up survey, water seepage

Findings: Open-up by hacking off surface concrete

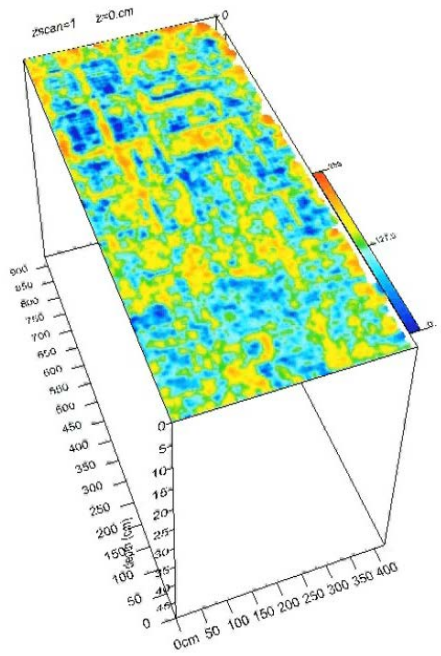
> Reinforced concrete slab



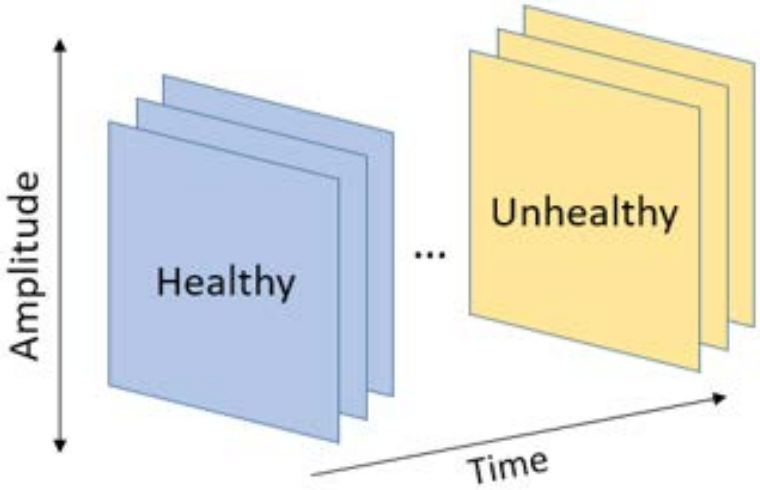
The delamination confirmed by open-up

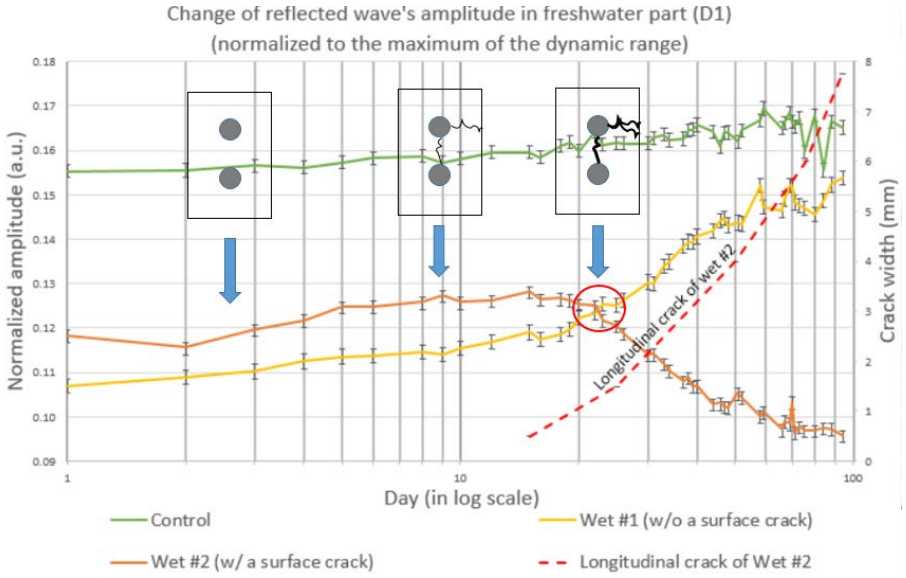


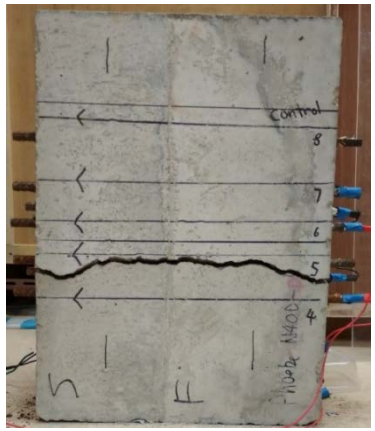
Abnormal high signal amplitude



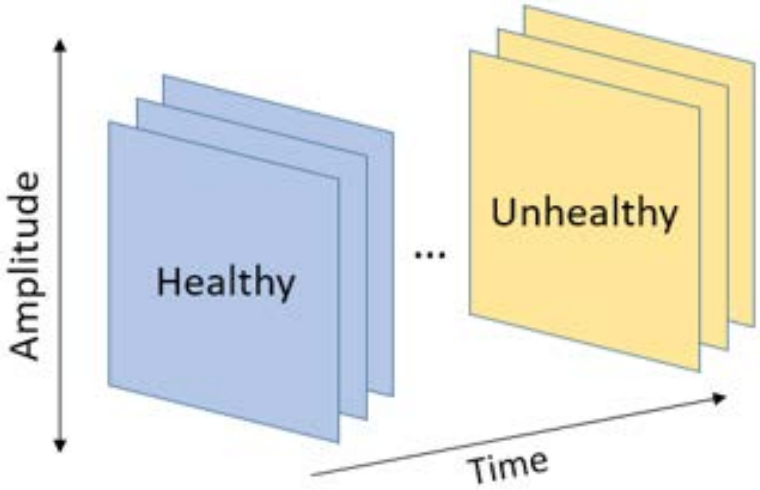
Health model

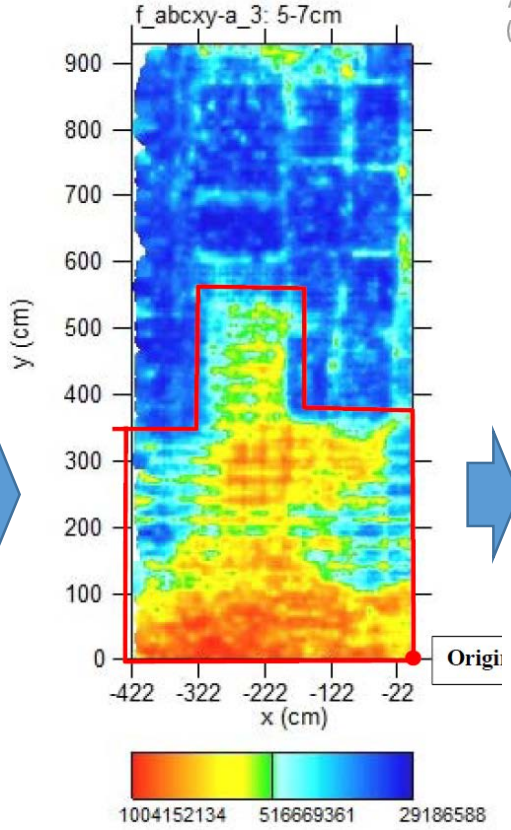




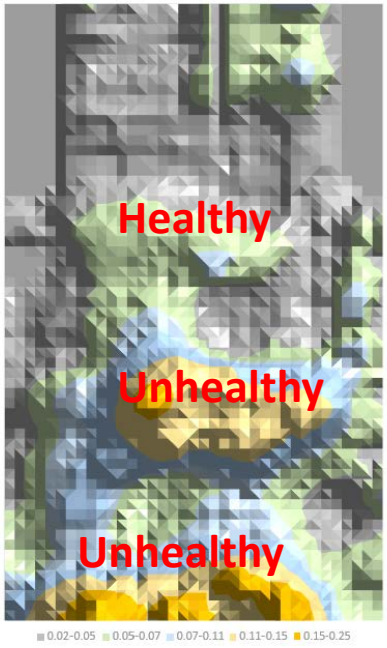


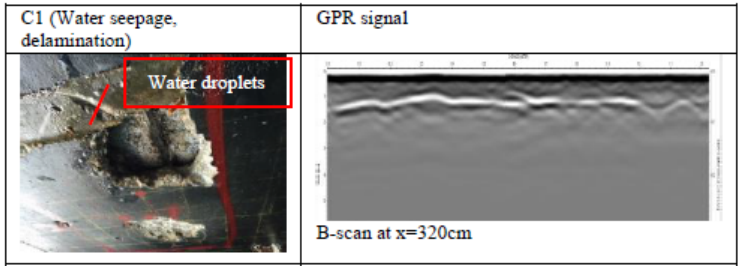
Health model

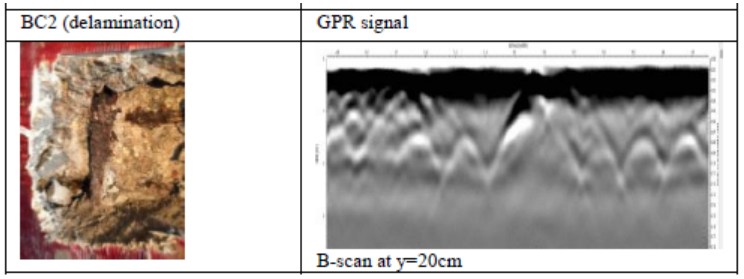




Amplitude map of rebars of the RC slab at HKM
(normalized to the maximum of dynamic range)







Diagnosis of Reinforced Concrete Structures by Ground Penetrating Radar Survey- Case Study

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***Abstract*—In this paper, part of the results extracted from the consultancy project of applying GPR for pier structure diagnosis is presented. GPR survey results on pier structures of: (1) a 9m x 4m slab and (2) the side (8m x0.35m) of a beam located at Macau Ferry Terminal, Hong Kong are discussed. This study is a preliminary study on constructing work flow of defect characterization; and the GPR results has been validated with core/ open up test. Signs of delamination, cracks and damped area are determined after open-up observation. It concluded GPR as decision making tool on concrete rehabilitation scheme. It also helps in conducting rational sampling rather than random sampling for detailed investigation (e.g. coring, open-up survey, chloride and carbonation test etc.) on concrete structure.**

Keywords*— *concrete diagnostic; ground penetrating radar; reinforcement corrosion; delamination

work was carried out on 23rd Feb, 25th Feb, 29th Feb, 3rd Mar, 8th Mar, 22nd Mar, 8th Apr, 2nd Jun, 20th Jun, 2016. In this project, non-destructive surveys of the assigned pier structures were carried out by GPR. The results of GPR survey were validated by open-up survey and had been carried out on 20 June 2016. Major signatures of concrete defects observed by the collected GPR signals from the assigned pier structures at Macau Ferry Terminal (MFT) are presented.

II. CONCRETE DIAGNOSIS BY GPR

A. Principle of GPR

GPR emits electromagnetic pulses into a subsurface and receive the reflected signals. When signal is incident into an object embedded e.g. reinforcement in a medium, e.g. concrete, signals are partially transmitted and reflected. The

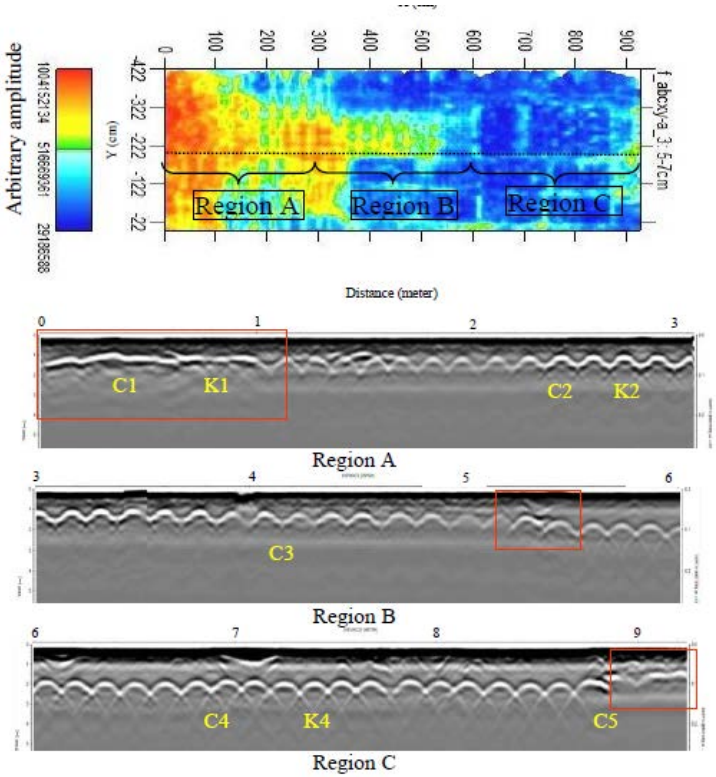

Figure 5: C-scan and the corresponding B-scans at Location 1 (soffit of slab)

Janet F.C. Sham and Wallace W.L. Lai (2017) Diagnosis of Reinforced Concrete Structures by GPR Survey, IWAGPR 2017, Edinburgh.

Extended readings

Structure and Infrastructure Engineering, 2014
http://dx.doi.org/10.1080/15732479.2013.879321

Taylor & Francis
Taylor & Francis Group

Experimental monitoring of chloride-induced reinforcement corrosion and chloride contamination in concrete with ground-penetrating radar

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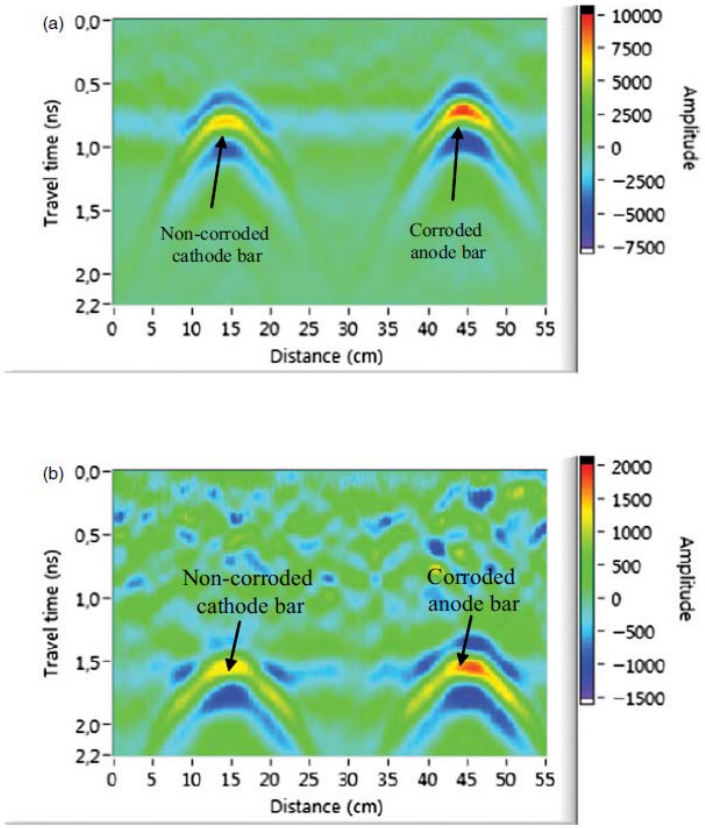
(*Received 26 May 2013; final version received 14 November 2013; accepted 20 December 2013*)

In this article, we present a laboratory experiment to monitor the accelerated corrosion in concrete using ground-penetrating radar (GPR). Four concrete test specimens were cast with rebars of different size and placed at different depths. The lifetime decades of reinforcement corrosion process were accelerated into 18 days by using the impress current technique. The electrochemical corrosion process was periodically monitored with GPR. Two control specimens were also prepared to investigate the influence of chloride contamination on GPR signal. The measured data were analysed both in time and frequency domains. In time domain, the peak-to-peak amplitude of a wave reflected by a rebar was calculated to investigate the relationship between an increase in signal amplitude and the degree of corrosion. In frequency domain, the time–frequency representations of the signal were computed by using S-transform. The results show that reinforce corrosion increased the amplitude of reflected signal in time domain but did not change the peak frequency in frequency domain while chloride contamination attenuates the signal to smaller amplitude and lower peak frequency. Based on the results, a novel process is finally proposed for GPR-based corrosion detection.

Keywords: reinforcement corrosion; GPR; chloride; moisture; S-transform



Some changes

Practice Note No. 1/2017 – Application of Ground Penetrating Radar (GPR) as a Non-destructive Structural Survey for Diagnosis of Reinforced Concrete Structures in Piers

Keywords: Non-destructive Structural Survey, Ground Penetrating Radar (GPR), Hammer Test, Delamination

1. This Practice Note serves to review the use of non-destructive structural survey by Ground Penetrating Radar (GPR) on inspection of reinforced concrete pier. The aim of the Practice Note is to provide maintenance colleagues with basic theories and practical procedures for effective and efficient maintenance services to public.

2. Brief Background of Non-destructive Structural Survey

   2.1 The objectives of a project carried out in year 2016 together with PolyU Technology and Consultancy Company Limited are (1) to carry out non-destructive survey by ground penetrating radar, (2) to present 3D imaging of the surveyed results, (3) to diagnose the pier structures at Macau Ferry Terminal and North Point Vehicular Ferry Pier. Open-up survey had been carried out at some locations for verification after the findings of the concrete condition using GPR.

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

Water seepage and delamination diagnosis of composite materials by Infrared Thermography (IR) aided with in-house automatic size estimation algorithm

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Dr. Janet Fung-Chu Sham

The Hong Kong Polytechnic University

With the support of Lian Shing Construction Co. Pte Ltd.
PASCO Pipeline Assessment and Services Company, and
Public Utilities Board, Singapore.

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Motivation

>**Composite** materials always suffer delamination due to material degradation and/or poor workmanship….how do we know the severity??

>We discuss three cases here:

- liner defects in sewer/drain pipes in Singapore
- external wall debond, and
- water seepage

The airborne and ground-based thermo-camera systems

UAV-IR Integrated System (DJI Phantom 2)

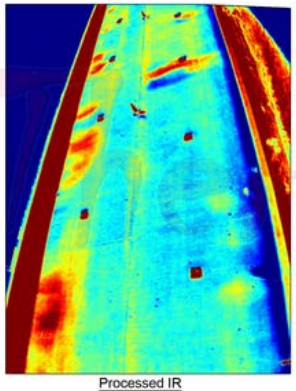
IR images observed by wireless monitor

UAV-IR Integrated System (DJI F450)

UAV/drone system with thermo-camera FLIR Tau 640

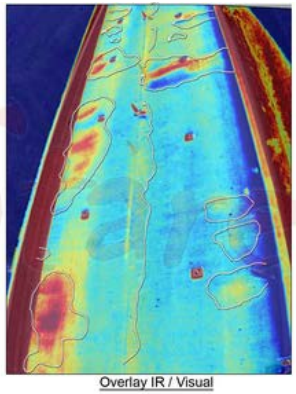
Ground-based IR system with thermo-camera FLIR T630

Applications in Civil Works
Source: Thermalstare, USA

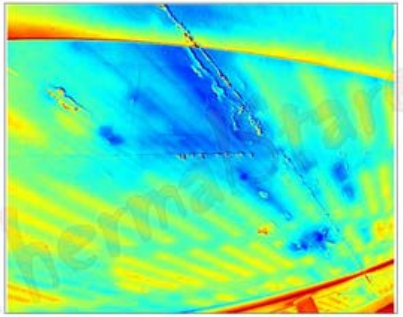


Processed IR

Visual with Sounding Areas Marked

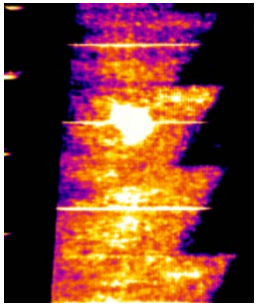


Overlay IR / Visual

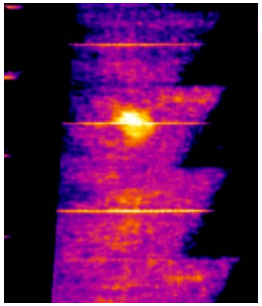


Iowa: Bridge Deck Measurement

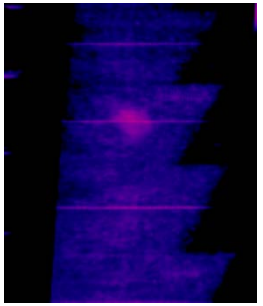
“Professional” judgement an ‘optimum’ color scale?



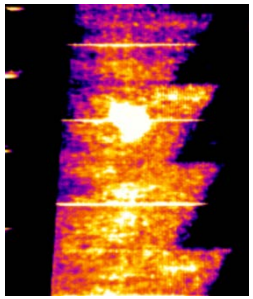
24.5-26.3 degC



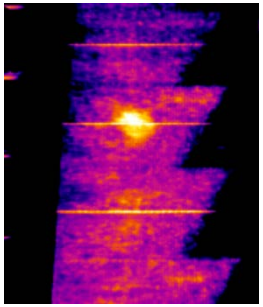
24.5-27.9 degC



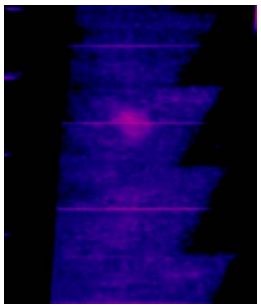
24.7-38.4 degC



Estimated debond = 3.6 m^2

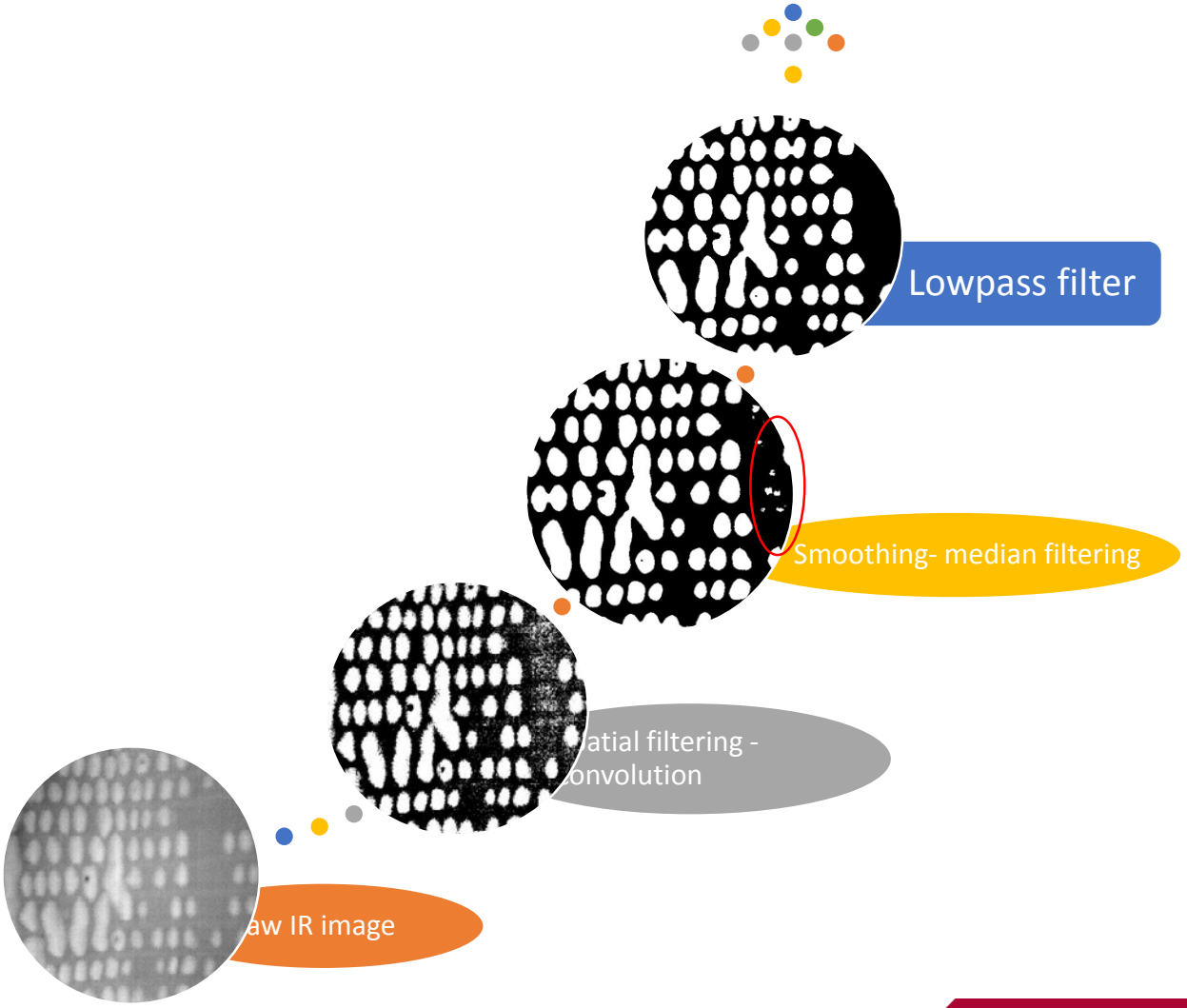


Estimated debond = 1.2 m^2

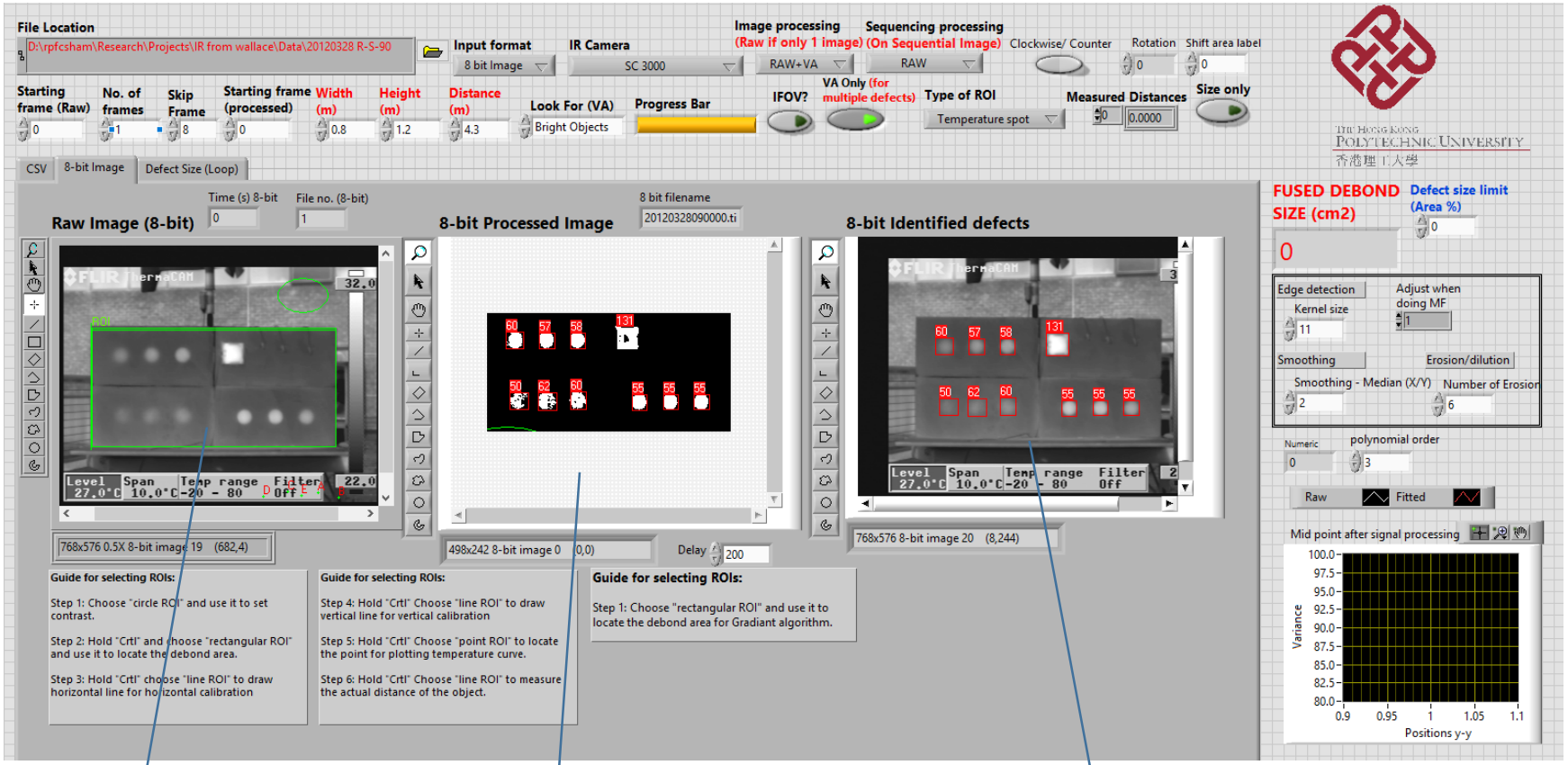


Estimated debond = ??? m^2

Steps for IR image analysis:



In-house program for image analysis

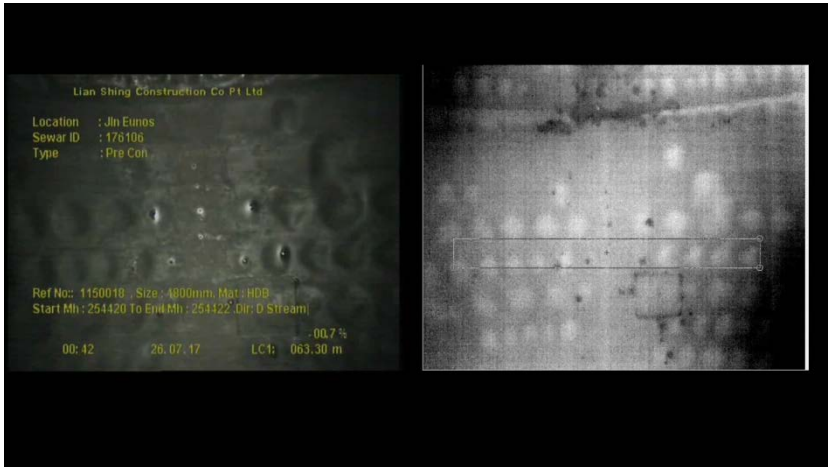


Raw Image
Infrared Image
(CSV)

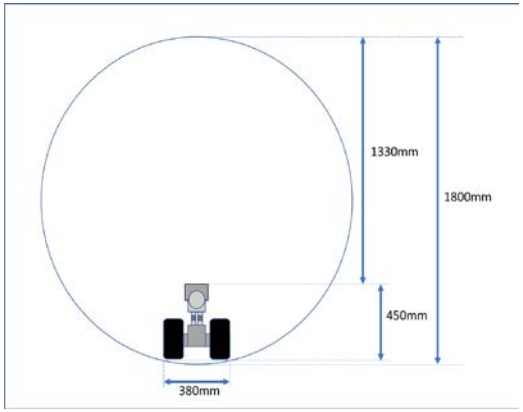
Binary Image
(Post-processing)

Debonds identified by post-processing and indicated on the raw infrared image

Case 1: Size estimation on sewer pipe composite's diagnosis



In-pipe Infrared Thermographic System (IPITS)



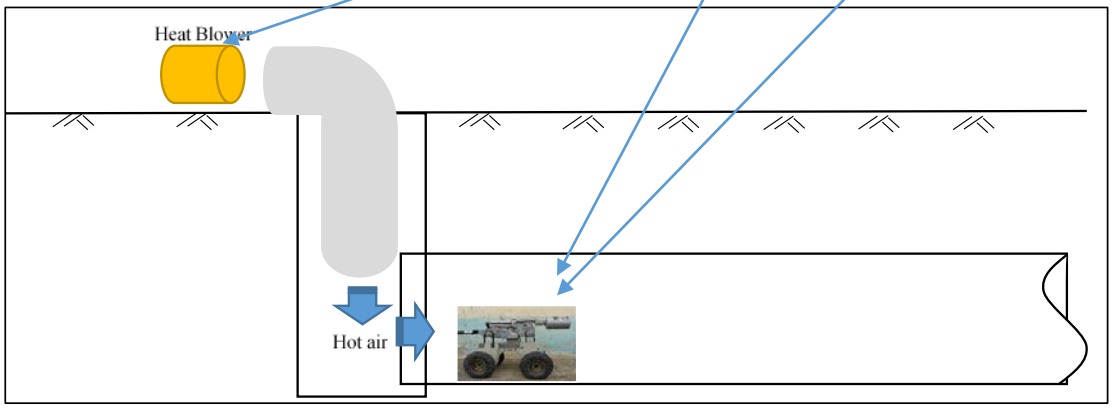
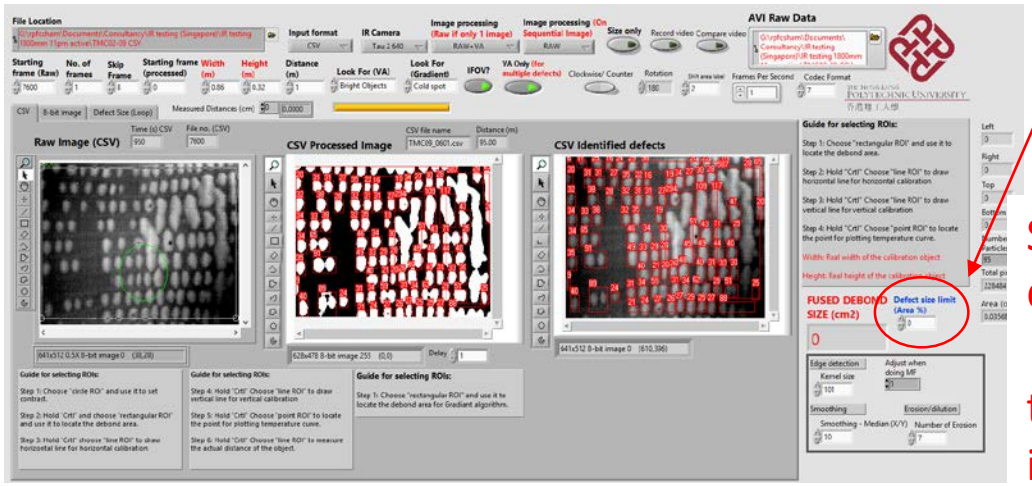


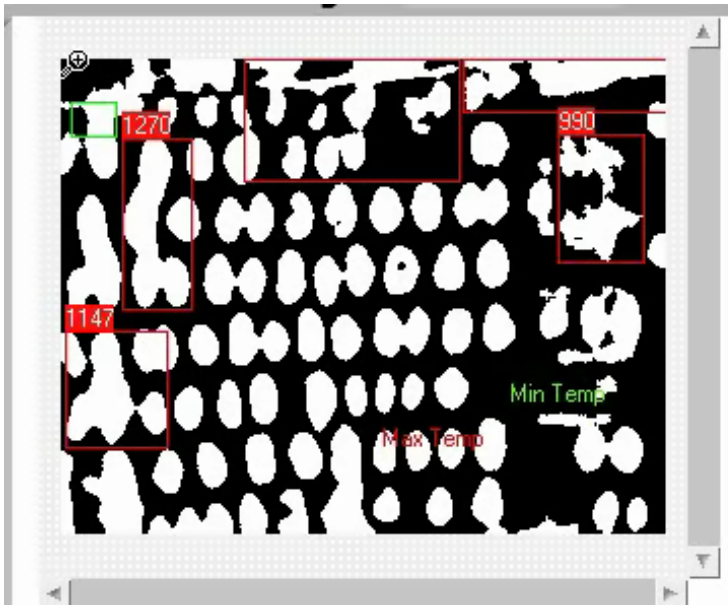
Image analysis

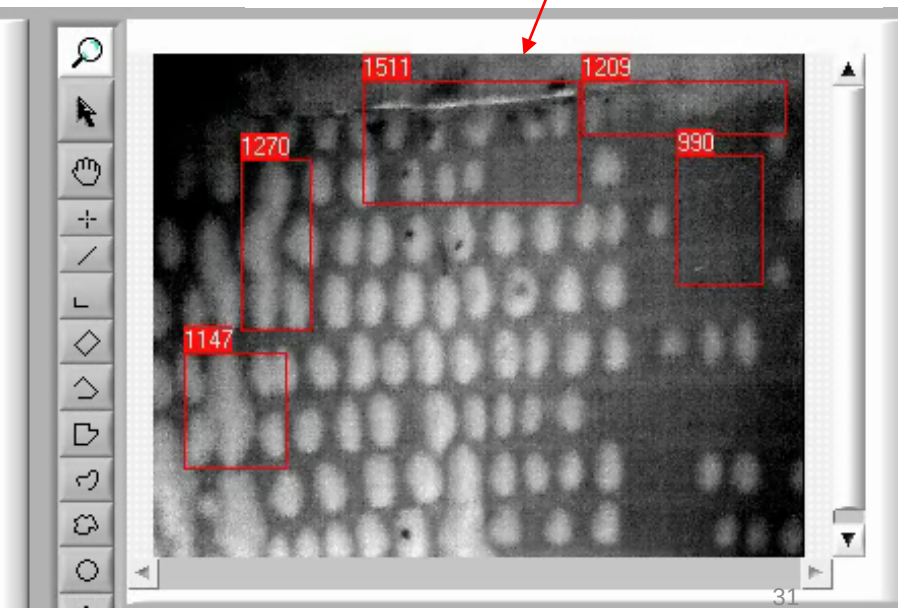


Suspected defects with certain size can be identified automatically by the IPITS program.

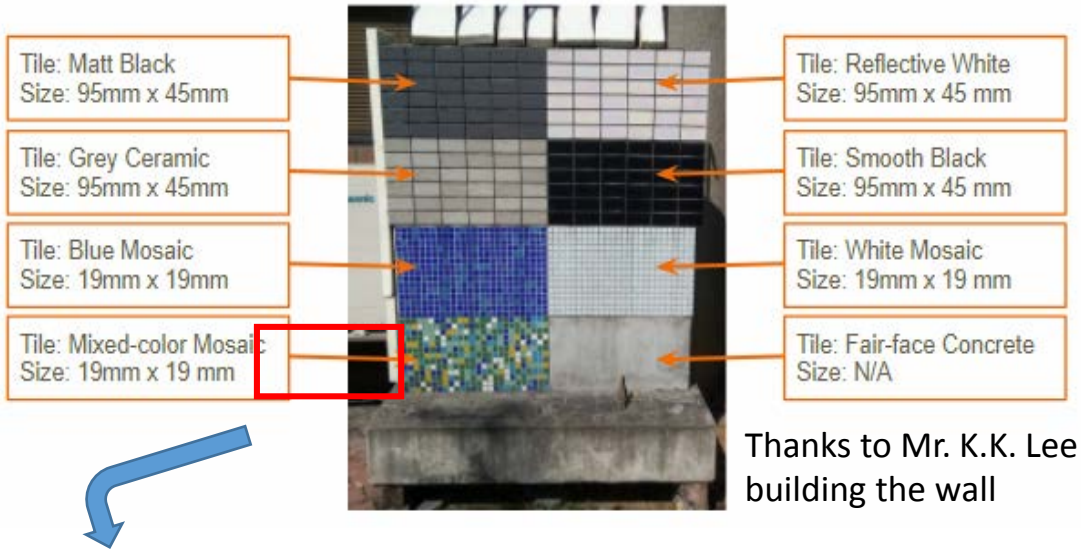
Selection of interested defects:

E.g. defective area > 2% of the overall image size will be identified.

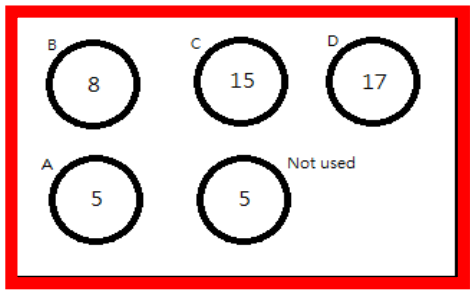




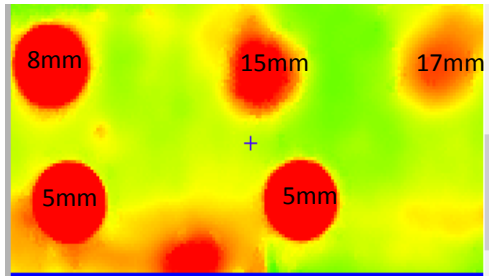
Case 2: Size estimation on external wall debond diagnosis

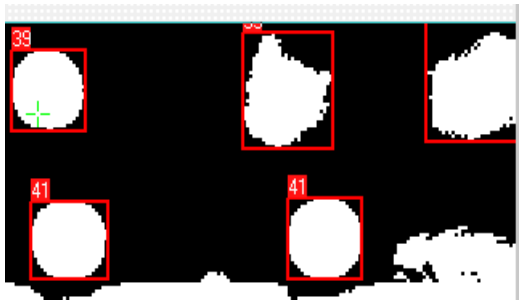


Thanks to Mr. K.K. Lee building the wall



8 demonstrates the depth of debond (in mm)





Case 3: Size estimation of water seepage diagnosis

Specify region of interest (ROI)

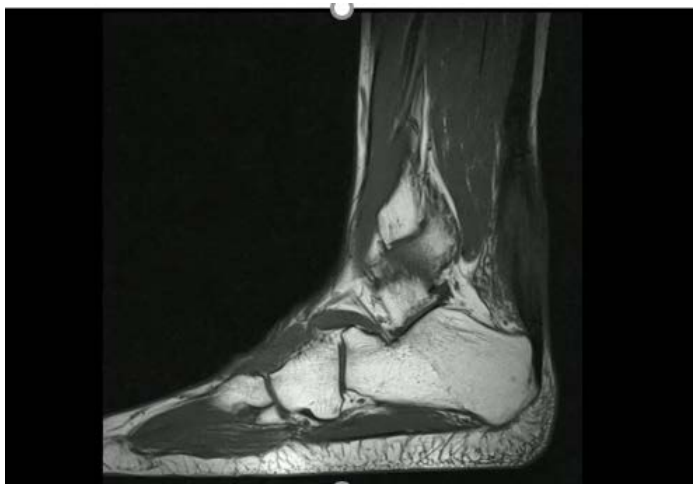
Automatic size estimation by image processing

Suspected water seepage areas and their estimated size are indicated automatically in the IR image

From Medical to Infrastructure Imaging: Are you ready?

- **Why image?**
- What to image?
- How to image?
- How to make use of the images?
- **Who can do it in daily basis?**

Who can do it in daily basis?



- Someone claims they are capable?
- Someone producing ten inches of job reference?
- Someone licensed and company accredited?

The Hong Kong Laboratory Accreditation Scheme (HOKLAS)

HOKLAS Supplementary Criteria No. 19

Construction Materials Test Category – Accreditation of Diagnostic Tests on Concrete

1 Introduction

1.1 This Supplementary Criteria is an amplification and interpretation of the requirements of HKAS 002, HOKLAS 003 and other relevant HKAS and HOKLAS requirements for the accreditation of diagnostic tests on concrete under the Construction Materials Test Category. The diagnostic tests on concrete include, but not limited to, the following methods:

Carbonation test

Chloride content determination

Covermeter survey

Half-cell potential measurement

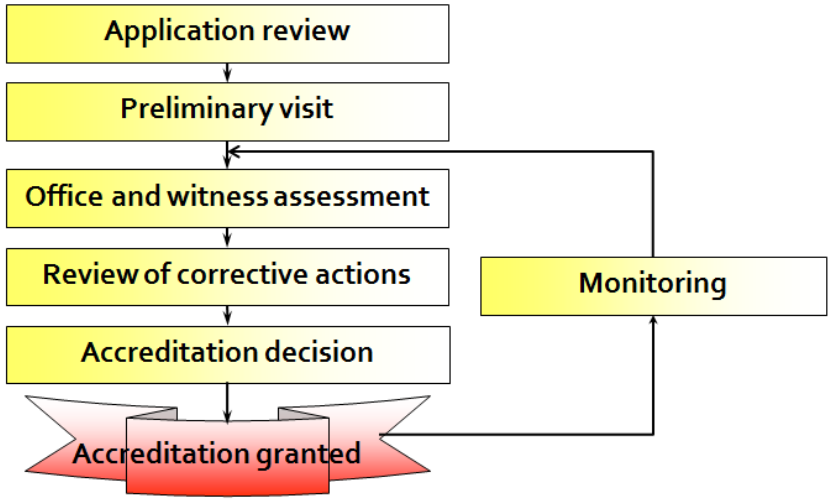
Infrared thermography

Resistivity measurement

Surface hardness measurement

Surface penetration radar survey

Ultrasonic pulse velocity measurement



Source: Hong Kong Accreditation Services, Innovation Technology Commission, HKSARG

Conclusion (Are you ready?)