Lecture 10

Condition Assessment of Concrete Structures (1/3)

(Exposure conditions, visual inspection, on-site concrete testing)

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NPTEL – MOOC Course on Maintenance and Repair of Concrete Structures

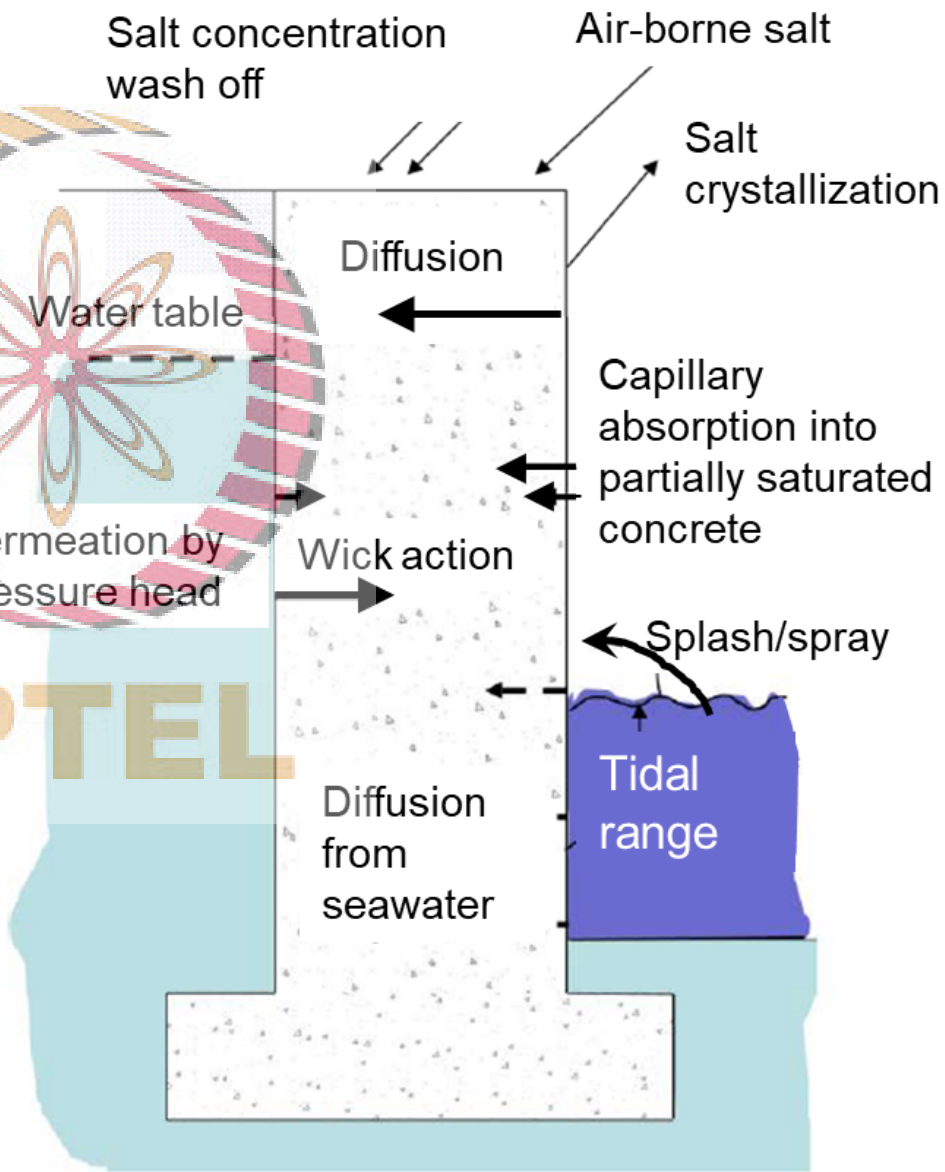
Courtesy: Some images are sourced from the internet for demonstration purposes.

Outline of Module on
Condition assessment of concrete structures

- Service and exposure conditions
- Visual inspection
- Testing of concrete at site
- Testing of concrete in laboratory
- Testing on rebars in field and laboratory

Service and exposure conditions

- Different elements of same structure can experience different exposure conditions
  - Salt crystallization
  - Air-borne chlorides
  - Capillary absorption
  - Permeation
  - Wet-dry/wicking
  - Spray
  - Diffusion

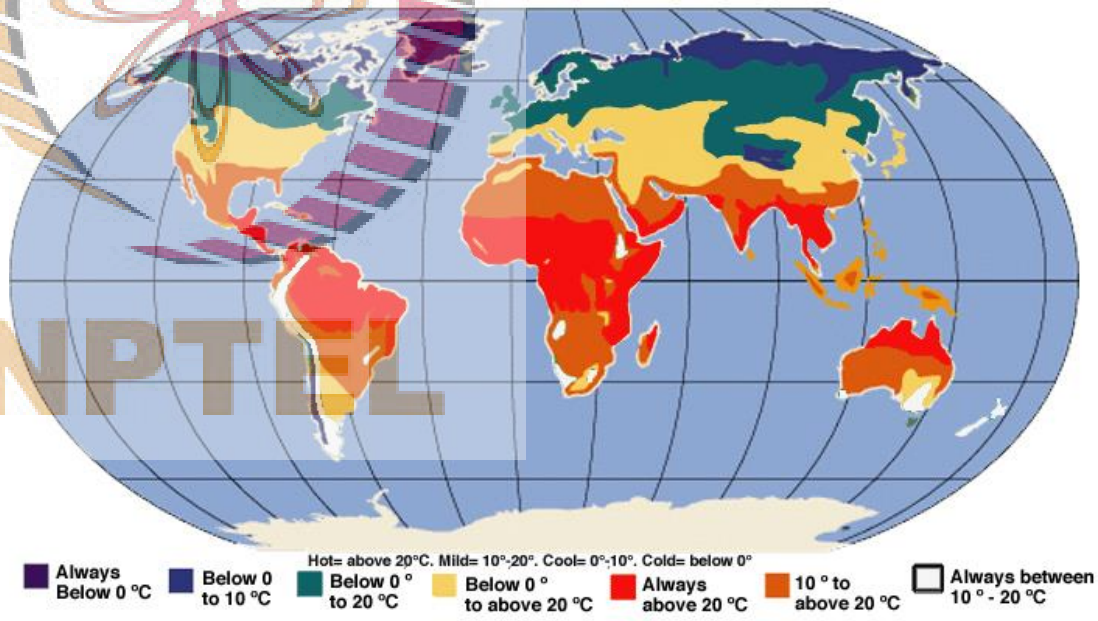


BS 6349 -1 (2000)

Service and exposure conditions

- Temperature
  - High-low
  - Frequency
  - Duration
  - Freeze-thaw cycles
  - Solar exposure

Deterioration due to freeze thaw



Exposure to Hot & cold climate

https://dailyhungama.net/coldest-countries-in-the-world.html; http://earth.rice.edu/mtpe/atmo/atmosphere/hot/anom_99/gsurfacetemp.html; https://www.mti-id.com/blog/freezethaw-protection

Service and exposure conditions

- Moisture
  - Relative humidity range
  - Contact type
    - immersion, runoff, etc.
  - Frequency
  - Duration of exposure

RH sensor

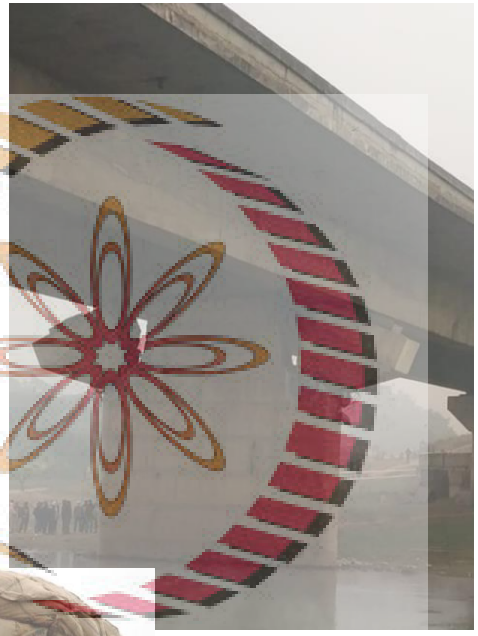
Concrete immersed in sea water

- Chemical
  - Type
  - Form: gas, liquid, solid
  - Concentration
  - Frequency of exposure
  - Duration of exposure

Rain

Service and exposure conditions

- Structural loading
  - Moving/static
  - Impact
  - Vibration
  - Size/magnitude
    - Overloading
    - Frequent/occasional
  - Frequency
  - Duration



https://www.youtube.com/watch?v=LDu_WB9F0Wo; https://www.hindawi.com/journals/mpe/2014/513606/

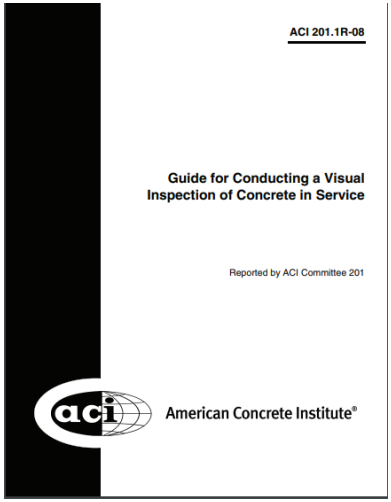
Typical steps for condition assessment of reinforced concrete structures

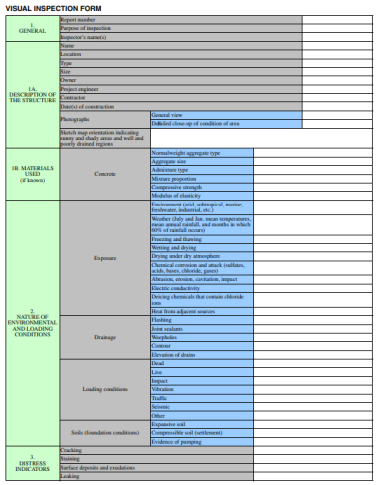
- Visual inspection (walk-through)
- Review of engineering data
  - Drawings/documents
  - Operation/maintenance records
  - Concrete/materials records
  - Previous inspection reports
  - Talking to different site personnel
  - History of loading, repairs etc.
- Condition Survey
  - Mapping, monitoring, joint survey, sampling and testing, NDT, structural analysis
- Final evaluation and recommendations
  - Full/partial repair
  - Replacement

Peter H. Emmons; https://www.canstockphoto.com/four-construction-engineer-working-in-60088558.html; https://www.vectorstock.com/royalty-free-vector/builders-and-engineers-characters-construction-vector-25806011

Visual inspection

- Description of structure
  - Name/location
  - Type/size
  - Owner/engineer/contractor
  - Photographs/identification of shady region
- Materials used
  - Steel – Type, residual
  - Concrete - Aggregate type/size, admixture type, mixture proportion, compressive strength, etc.
  - Others
- Environmental and structural loading conditions
- Distress indicator
  - Cracking, staining, surface deposits,
  - Leaking, alignment of structure

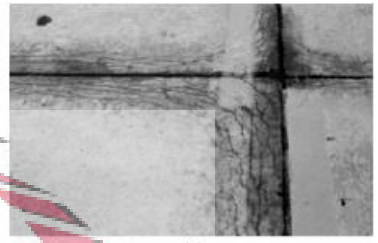



VISUAL INSPECTION FORM

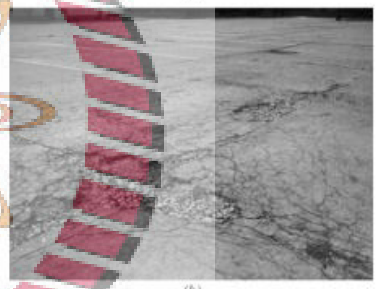
ACI 201.1R-08 Guide for Conducting a Visual Inspection of Concrete in Service

Visual inspection

- Present condition
  - Formed and finished surfaces
  - Cracking/scaling/spall
  - Curling and warping
  - Erosion
  - Others
- Previous repair / history
  - Patch
  - Surface coating
  - Protective system
  - Sealers
  - Others

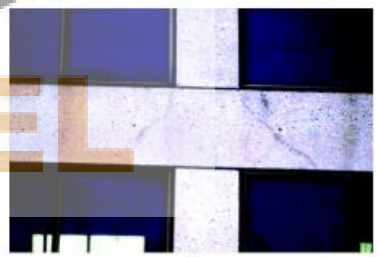


(a)



(b)

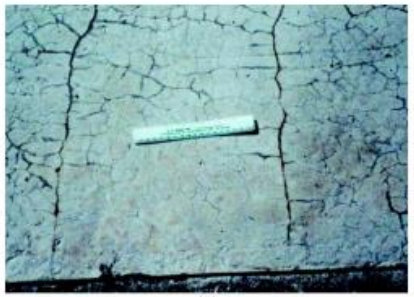
Fig. 2.1.2.3—D-cracks: (a) fine; and (b) severe, with spalling present.



(a)

(b)

Fig. 2.1.2.4—Diagonal cracking.



(a)

(b)

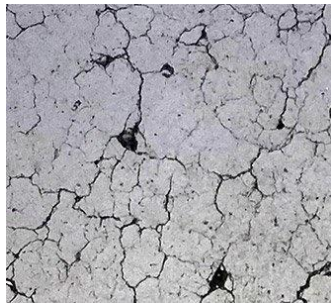
Fig. 2.1.2.7—Map (pattern) cracking.

ACI 201.1R-08

Visual and exploratory investigation - Effects

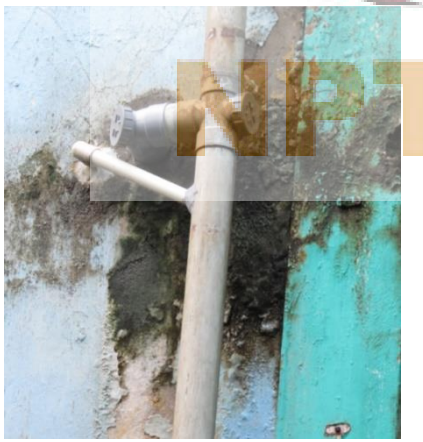
- Cracking and crazing
- Surface distress
  - Spalling, surface disintegration, honeycomb, scaling
- Water leakage
  - Surface dampness, seepage through joints/cracks

Cracking



crazing

Dampness



Seepage

Honeycomb

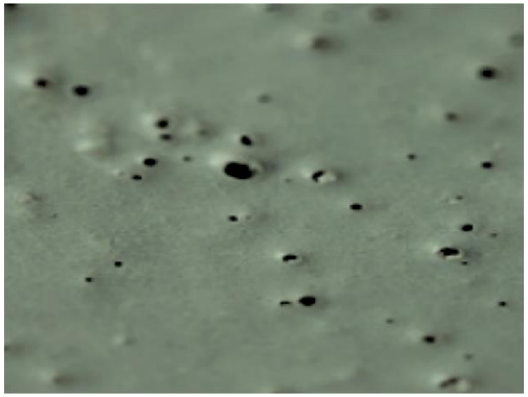
Peter H. Emmons; http://m.engineeringnews.co.za/article/how-to-prevent-craze-cracking-on-concrete-floors-2016-07-07

Visual and exploratory investigation – Effects

- Movements
  - Deflections, heaving, settlement
- Metal corrosion
  - Rust staining, exposed rebars or strands
- Miscellaneous
  - Blistering of coatings/membranes, dislocation

Differential settlement

Corrosion stains



Blistering

Cracking/disintegration

Corroded/exposed rebars

Peter H. Emmons; https://www.flickr.com/photos/136372730@N04/25656773990; https://civildigital.com/effects-corrosion-reinforcement-signs-preventive-measures/; @BoysenTSD; http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-07(307)_FR.pdf

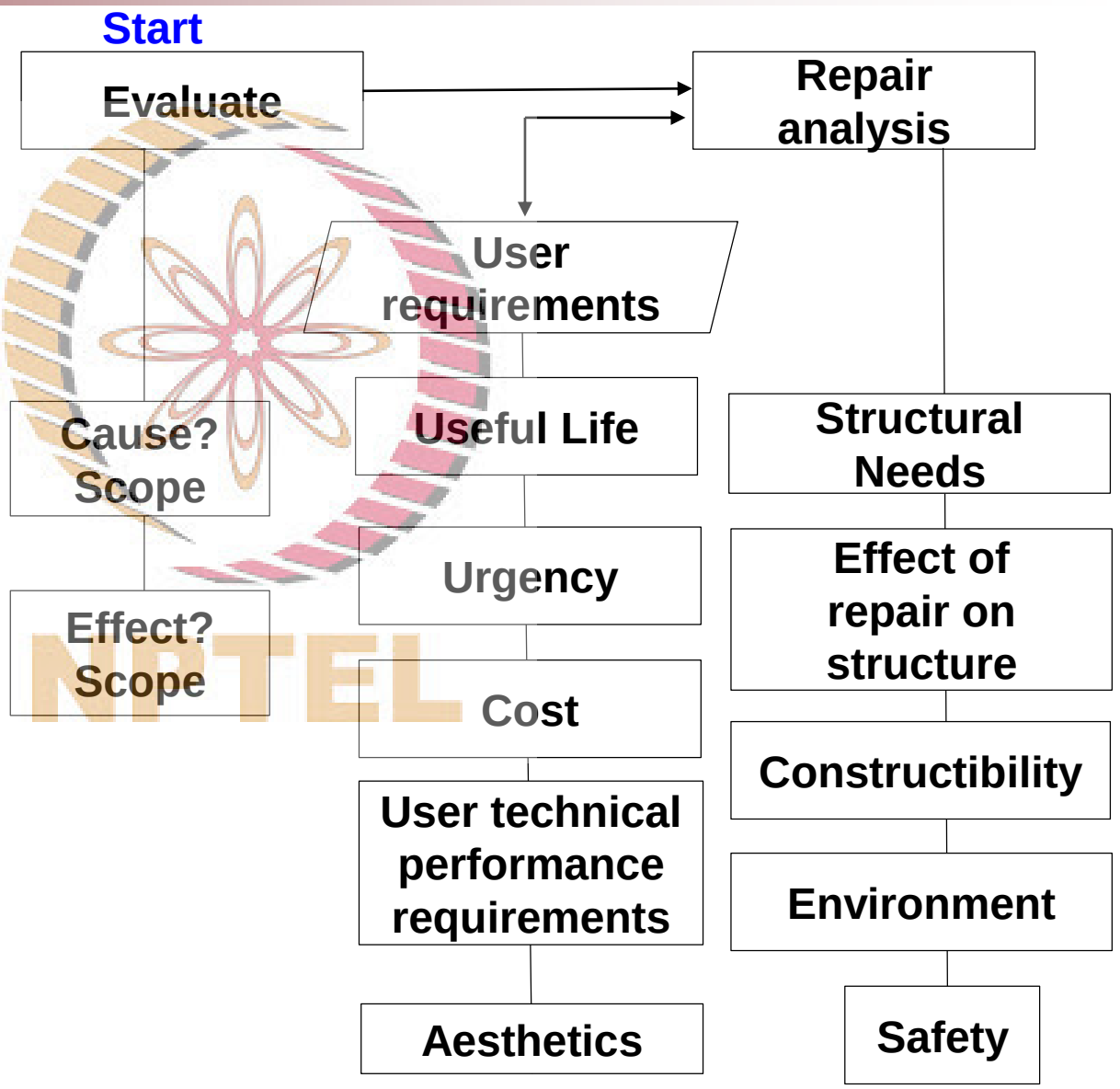
Effects and causes

Effect	Causes	
– Leakage	– Defect	– Deterioration
– Settlement	• Design	• Corrosion of steel
– Deflection	• Material	• Freeze-thaw
– Wear	• Construction	• Erosion
– Spalling	– Damage	• Alkali Aggregate Reaction
– Disintegration	• Overloading	• Sulphate attack
– Cracking	• Chemical spill	
– Delamination	• Earthquake	
– Scaling	• Fire	

Should we preserve, repair, or demolish?

Should we repair or protect?

- Public safety?
- Structural safety?
- Leakage?
- Effects on environment?
- Functionality?
- Aesthetics?



Standard test methods for evaluating concrete/reinforced concrete

Designation	Title
ASTM C42	Obtaining and testing drilled cores and sawed beams of concrete
ASTM C805	Rebound number of hardened concrete
ASTM C803	Penetration resistance of hardened concrete
ASTM C597	Pulse velocity through concrete
ASTM C496	Splitting tensile strength of cylindrical concrete specimens
ASTM C78	Flexural strength of concrete (using simple beam with three-point loading)
ASTM C293	Flexural strength of concrete (using simple beam with center-point loading)
ASTM C418	Abrasion resistance of concrete by sandblasting
ASTM C876	Half-cell potentials of uncoated reinforcing steel in concrete
ASTM D3633	Electrical resistivity of membrane-pavement systems
ASTM C856	Standard practice for petrographic examination of hardened concrete

Standard test methods for evaluating concrete

Designation	Title
AASTHO T259	Resistance of concrete to chloride penetration
AASTHO T260	Sampling and testing for total chloride ion in concrete and concrete raw materials
AASTHO T277	Rapid determination of the chloride permeability of concrete
ASTM C457	Microscopic determination of chloride permeability of concrete
ASTM C666	Resistance of concrete to rapid freezing and thawing
ASTM C671	Critical dilation of concrete specimens subjected to freezing
ASTM C672	Scaling resistance of concrete surfaces exposed to deicing chemicals
ASTM C642	Specific gravity, absorption, and voids in hardened concrete
ASTM G109	Determining Effects of Chemical Admixtures on Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments
ASTM C876	Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete

On-site concrete evaluation

- Visual and Exploratory Investigation
  - Locating delaminated concrete
  - Locating void, crack, honey-comb
  - Remote viewing
  - Locating embedded reinforcing steel
  - In-situ compressive strength
  - Resistivity of concrete
  - Moisture and air permeability of concrete
  - Corrosion activities

Effects and test methods

- Physical Condition
  - Delamination/voids
    - Hammer sounding
    - Chain drag
    - Impact echo
    - Ultrasonic pulse velocity
    - Exploratory removal
    - Remote viewing (TV, Borescope)
    - Infrared thermography
  - Uniformity
    - Ultrasonic pulse velocity
    - Rebound hammer
    - Core testing

https://fhwaapps.fhwa.dot.gov/ndep/DisplayTechnology.aspx?tech_id=16
Peter H. Emmons

Locating delaminated concrete - Hammer sounding ("ping" → "puck")

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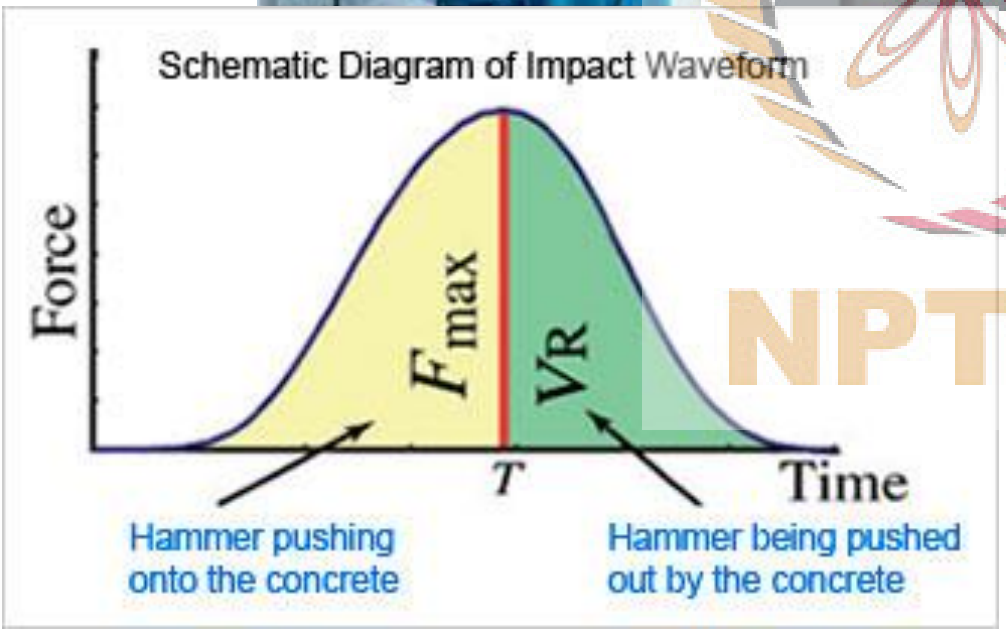
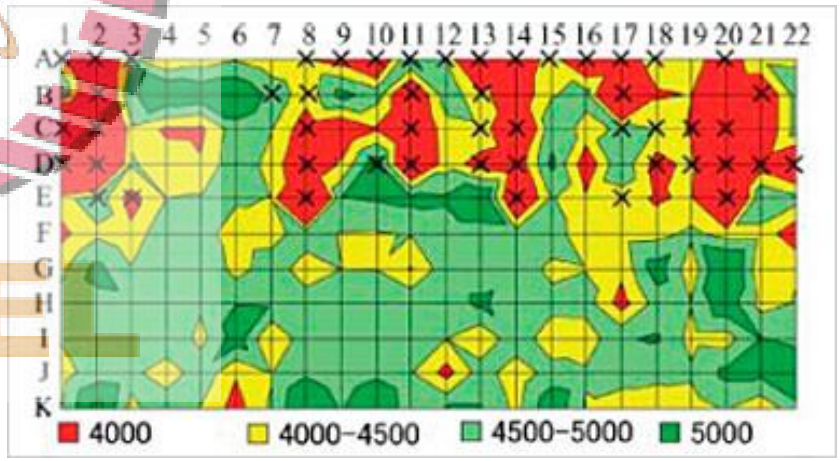
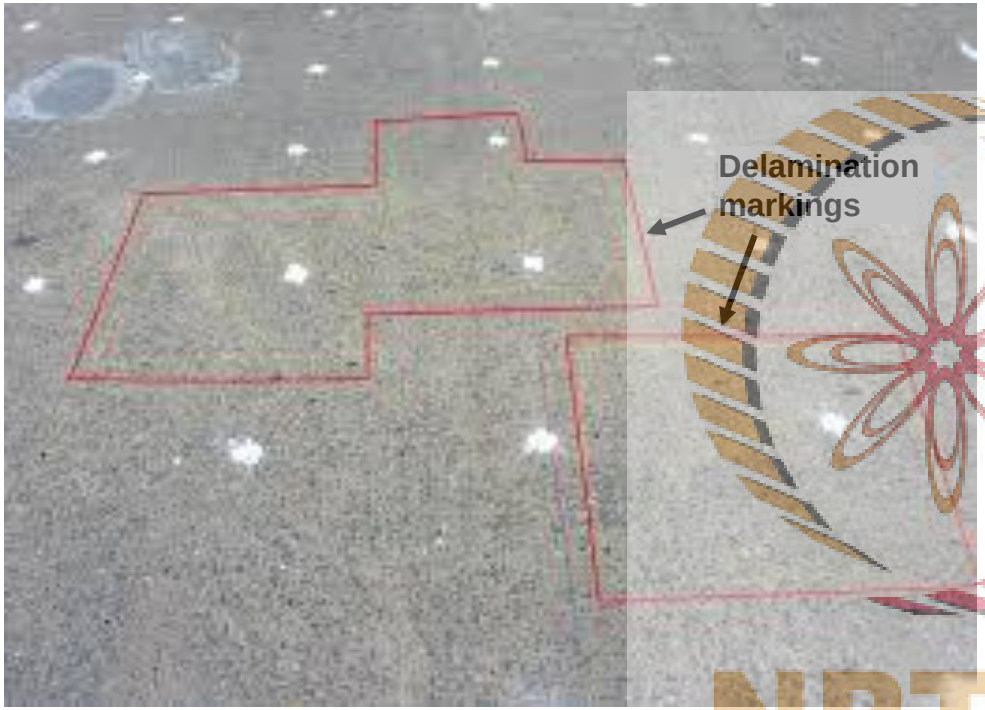


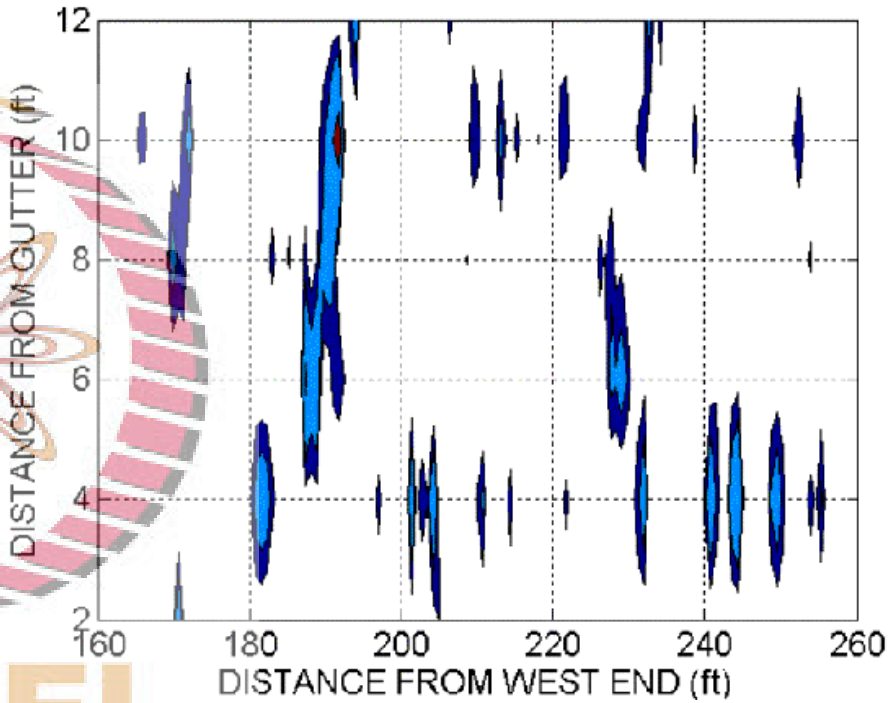


Red – Delaminated
Yellow – Suspected delamination
Green - Intact

http://www.concretetester.com/technology.php

Locating delaminated concrete - Chain drag sounding

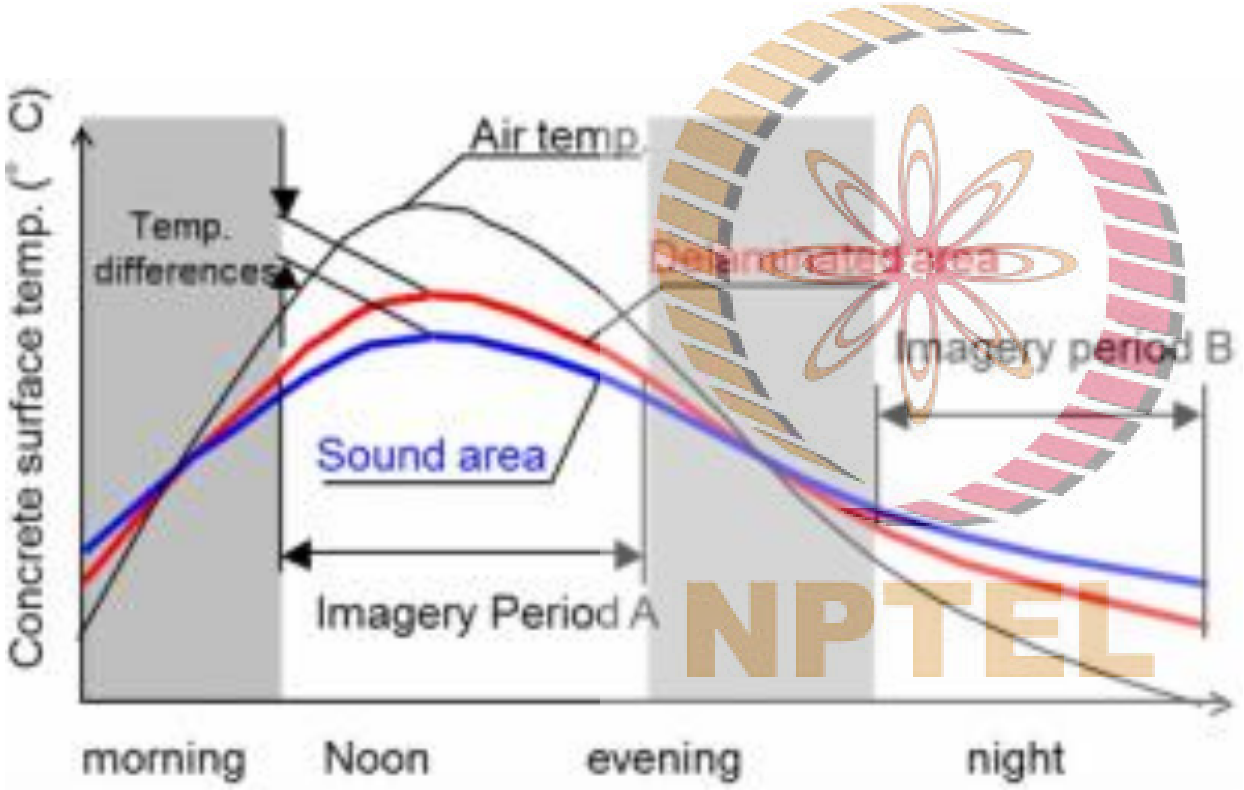


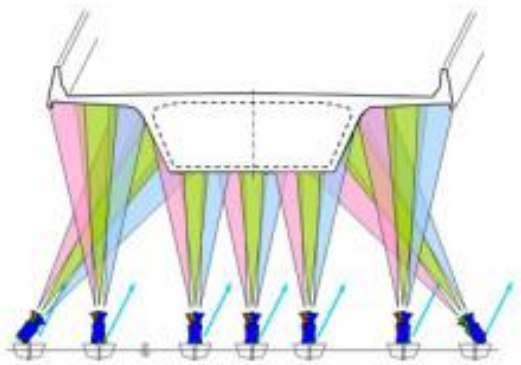


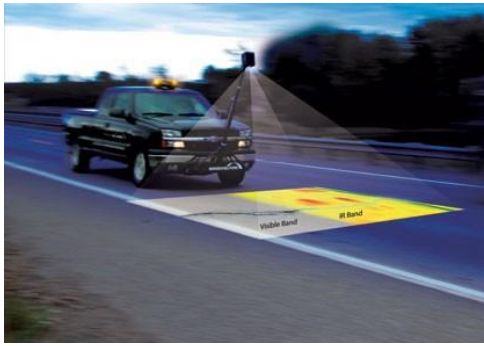
http://www.ndtoolbox.org/content/bridge/cd-description; http://www.acoustics.org/press/146th/Costley.htm;

Locating delaminated concrete - Infrared thermography

- Air layer - poor conductor of heat



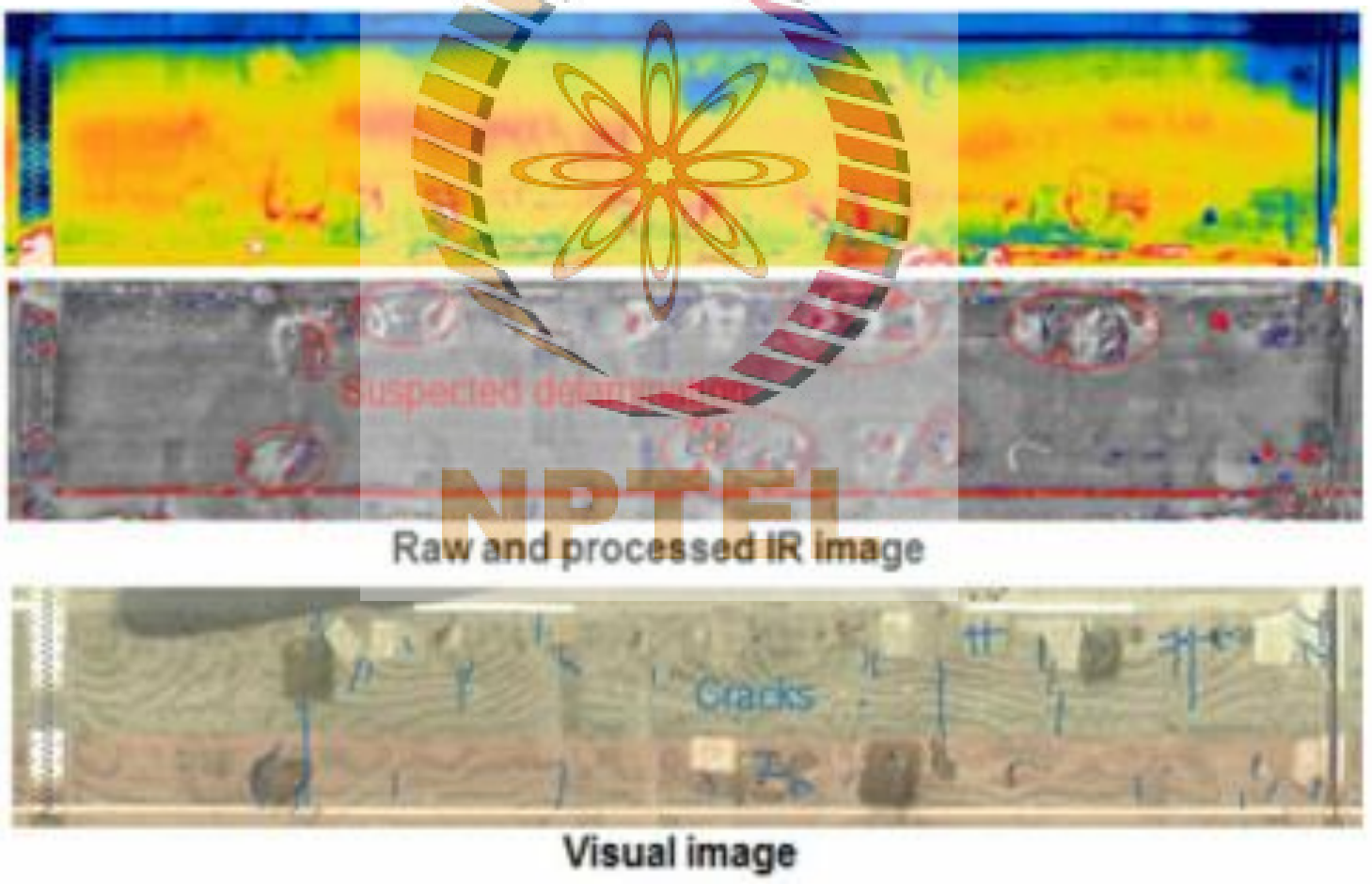




http://www.mcsmag.com/infrared-visible-bridge-scoping/; http://www.w-nexco-usa.com/services.html

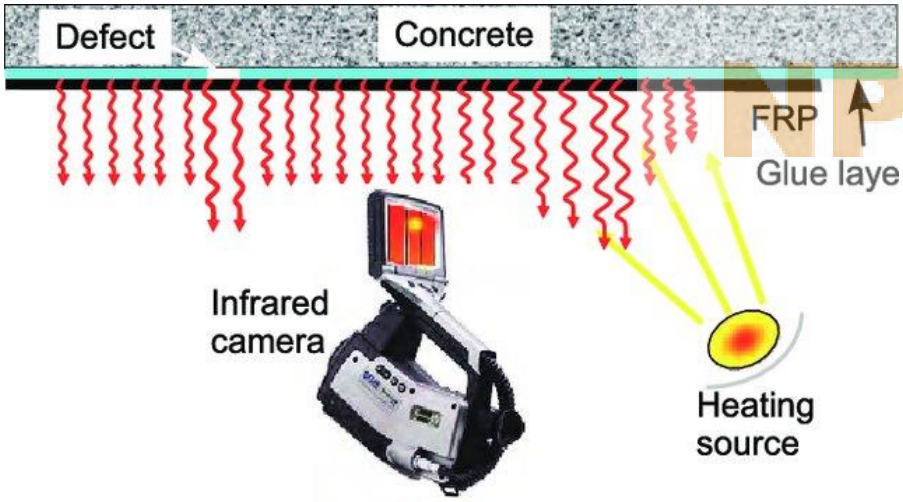
Locating delaminated concrete - Infrared thermography

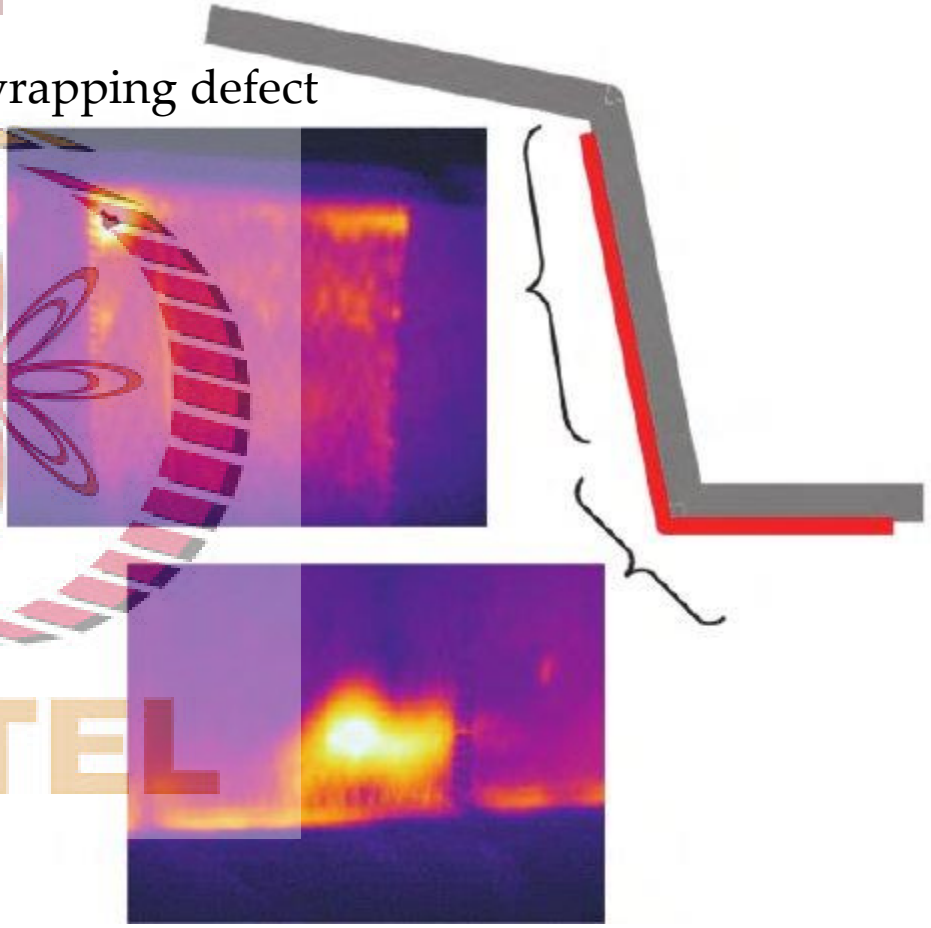
- Example of an infrared thermograph indicating potential regions of delamination and cracks



http://www.mcsmag.com/infrared-visible-bridge-scoping/; http://www.w-nexco-usa.com/services.html

Thermal images showing defect on bonded CFRP wrap.





Taillade et al. (2012)

Locating delaminated concrete
- Ground Penetrating Radar (GPR) systems

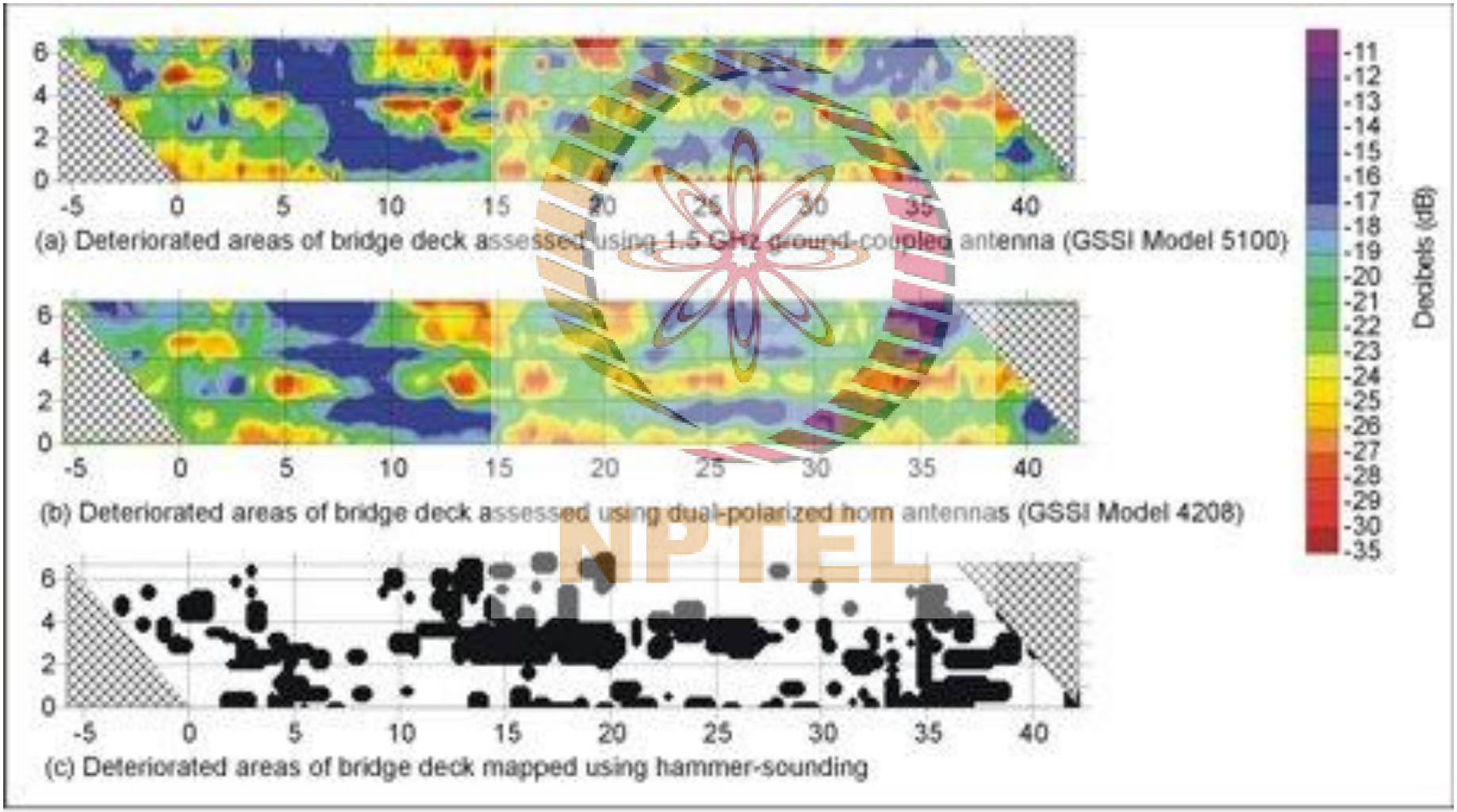
- Ground penetrating Radar systems (radio waves)

High speed, high resolution Dual-Polarization horn antenna method

Low speed, high resolution using four 1.5 GHz antennas spaced equal distance apart

http://www.cflhd.gov/resources/agm/engApplications/BridgeSystemSuperStructure/345VechicleMountedGrdPenRadar.cfm

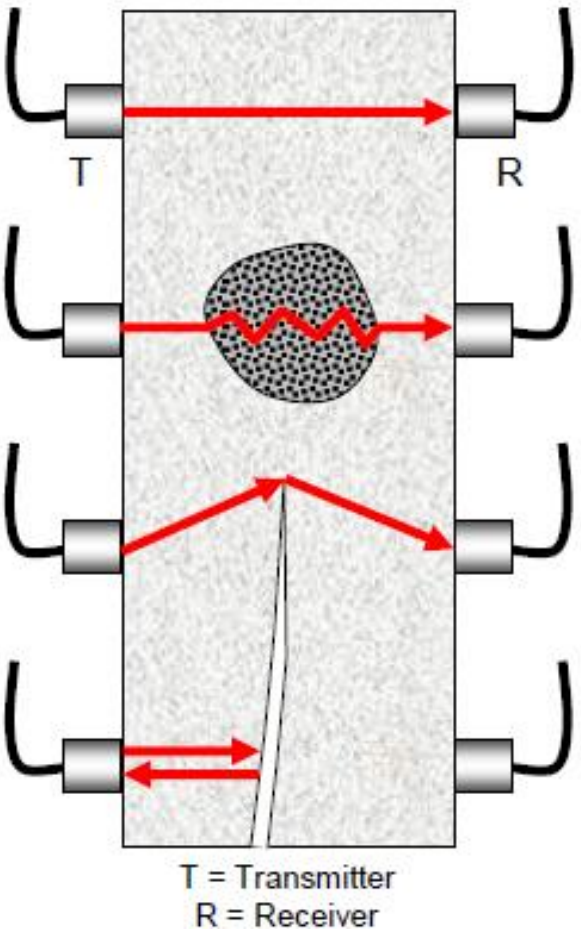
Locating delaminated concrete - Ground Penetrating Radar (GPR) systems



http://www.cflhd.gov/resources/agm/engApplications/BridgeSystemSuperStructure/345VechicleMountedGrdPenRadar.cfm

Locating delaminated/cracked concrete Ultrasonic Pulse Velocity (UPV) test

- The time of travel of an ultrasonic pulse passing through the concrete is measured
- Influencing factors
  - Contact surface
  - Length of the wave path
  - Temperature and moisture content
  - Presence of reinforcing steel



ASTM C597

https://image.slidesharecdn.com/ultrasonicpulsevelocitytestforconcrete-141208113106-conversion-gate02/95/ultrasonic-pulse-velocity-test-for-concrete-17-638.jpg?cb=1418038308

Locating delaminated/cracked concrete Ultrasonic Pulse Velocity (UPV) test

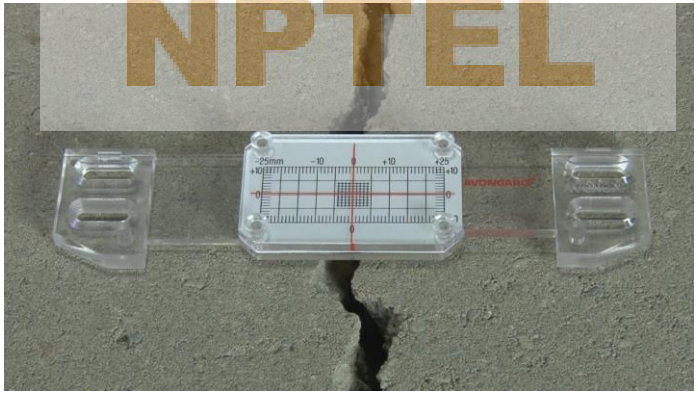
- Pulse velocity is a function of elastic constants
  - *E*, υ, and ρ

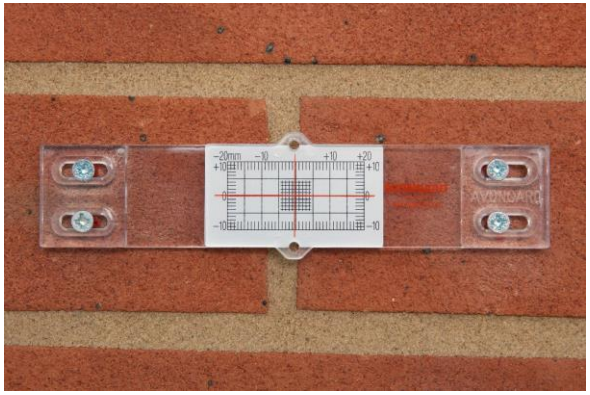
Pulse Velocity (km/second)	Quality (grading)
>4.5	Excellent
3.5 - 4.5	Good
3.0 - 3.5	Medium
<3.0	Doubtful

ASTM C597

Investigation of crack – Live or dead

- Movements
  - Measurement of crack width
  - Monitoring movements (closing/opening of cracks)

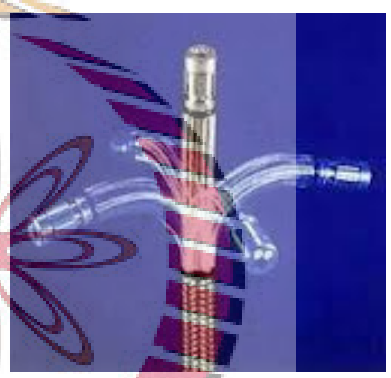




Web; https://theconstructor.org/concrete/crack-width-measurement/21745/; https://www.pearceandpearce.co.uk/services/defects-analysis/

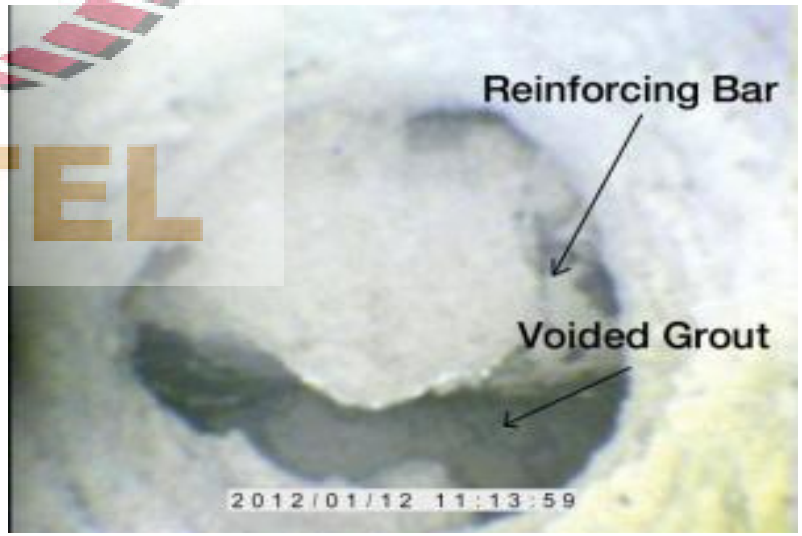
Investigating concrete integrity
Remote viewing - borescope

- Eye piece, objective lens, rigid or flexible fiber optic cable, camera
- Direction of view
  - Straight
  - Perpendicular
  - Any angle in between



Olympus-ims.com

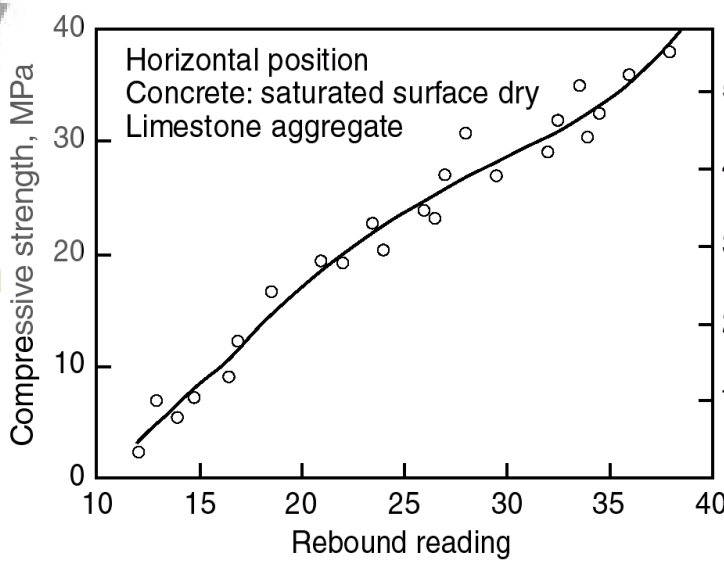
Investigating concrete integrity
Remote viewing - borescope



https://www.fhwa.dot.gov/publications/research/infrastructure/structures/bridge/13028/index.cfm

Rebound hammer/pendulum hammer tests

- The test hammer will hit the concrete at a defined energy.
- The hammer measures the rebound of a spring-loaded mass impacting against the surface of the sample.
- Its rebound is dependent on the hardness of the concrete and is measured by the test equipment
- The rebound reading is correlated to the compressive strength



ASTM C 805

Extraction of concrete cores for preliminary investigation

- Poor handling of coring machines and/or samples during coring and transportation of samples
- Which will have minimum compressive and tensile strengths?

- Do not cut rebars while coring samples from real structures

Effect of internal cracks in cores on both the compressive and tensile strengths

https://theconstructor.org/concrete/types-cracks-concrete-columns/26433/

Correction factor for transverse rebars, if any…

$$C.F\ Rebar = \left\{1 + 1.5\left(\frac{r \times d}{c \times l}\right)\right\}$$

where,

r is the diameter of the reinforcement;

c is the diameter of specimen;

d is the distance of axis of bar from nearer end of specimen;

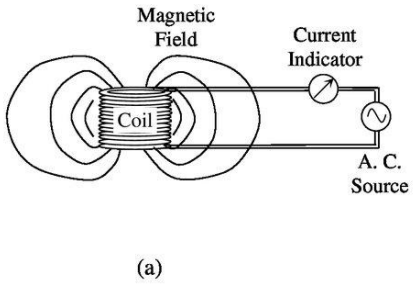
l is the length of the specimen after end preparation by grinding or capping.

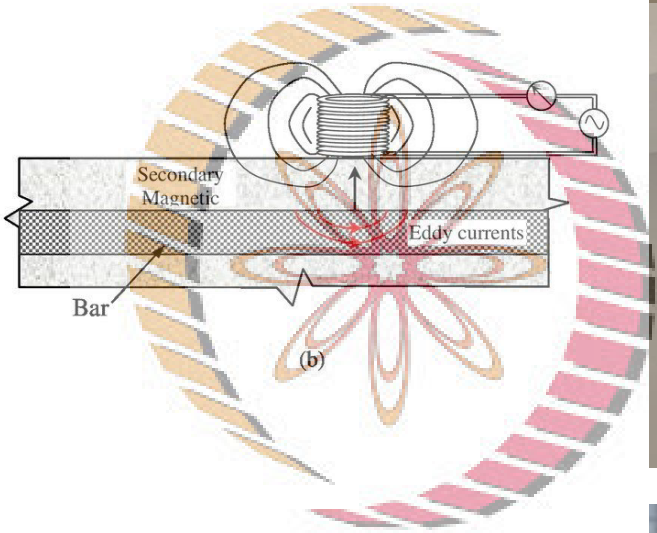
Cutting of rebars must be avoided

ASTM C42 / C42M - 18a

Rebar Locator / Pachometer / Covermeter

- Eddy current principle





- GPR
  - Frequency, depth of rebar

http://www.vertical-access.com/ndt.html; http://www.theconcreteportal.com/nde.html; http://www.avantech.in/testing-consulting-services/concrete-ndt.aspx

Summary

- Service and exposure condition
- Steps for evaluation of reinforced concrete structures
- Visual and exploratory Investigation
- Various test methods to detect delaminated concrete
  - Various test methods are available
  - Should be chosen based on feasibility
- On-site concrete evaluation
  - Various standards and test methods are available
  - Should be chosen based on the requirement

References

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- Andrade, C. (1993), Calculation of chloride diffusion coefficients in concrete from ionic measurements, Cement and Concrete Research, 23, 724-742.
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