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UTM SMILE CAMPAIGN

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The only way you do great work is to love what you do!

Stay hungry!
Stay foolish!

Steve Jobs (2005)
References

INTRODUCTION

- Aims of investigation - clear
- Choice and test method
- Extent and location of tests
- Results
- Liaison of all parties
- Careful planning of test programme
- In-situ testing - maximum amount of worthwhile information with minimum cost and disruption
AIMS OF IN-SITU TESTING

● (i) Control Testing: to ensure an acceptable supplied material - contractor or concrete producer/- test on standard hardened specimen also in-situ, integrity of repair.

● (ii) Compliance Testing: to judge compliance with specification - by or for engineer/- (as above)

● (iii) Secondary Testing: doubt about the reliability of control and compliance results, unavailable, inappropriate (old and damage structures).
COMPLIANCE WITH SPECIFICATION

- e.g. additional evidence required in contractual disputes following non-compliance of standard specimens.
- Retrospective checking following deterioration of structure, legal
ASSESSMENT OF IN-SITU QUALITY AND INTEGRITY

Concerned with current adequacy of the existing structures and its future performance. Routine maintenance - lifetime prediction.

(i) proposed change of usage or extension of a structure  
(ii) acceptability of a structure for purchase or insurance  
(iii) assessment of structural integrity (fire, blast, fatigue, overload....)  
(iv) members suspected to contain material doesn’t meet specification or with design faults  
(v) assessment of deterioration as a preliminary to the design of repair or remedial scheme  
(vi) assessment of the quality or integrity of applied repairs  
(vii) monitoring of strength development  
(viii) monitoring long-term changes in material properties and structural performance
● Careful attention - numbers and location of tests and the validity of the safety factors adopted

● Wherever possible aim of testing to compare suspect concrete with similar concrete in other parts of the structure known to be satisfactory
GUIDANCE FROM STANDARDS, ETC

- BS
- ASTM
- ISO
- FIP
- RILEM
- ACI
- etc
Table: Principal test method

<table>
<thead>
<tr>
<th>Property under investigation</th>
<th>Test</th>
<th>Equipment Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion of reinforcement</td>
<td>Half-cell, resistivity, LPR, cover depth, carbonation, chloride concentration</td>
<td></td>
</tr>
<tr>
<td>Concrete quality, durability and deterioration</td>
<td>Surface hardness, UPV, Permeability, absorption, petrographic, sulphate, expansion, cement type/content, abrasion</td>
<td></td>
</tr>
<tr>
<td>Concrete strength</td>
<td>Core, pull-out, pull-off, penetration resistance</td>
<td></td>
</tr>
<tr>
<td>Integrity and performance</td>
<td>Reinforcement location, strain or crack measurement, load test</td>
<td></td>
</tr>
</tbody>
</table>
TEST PROGRAMME PLANNING

- Consider most appropriate test
- Extent or number of test
- Test location
  - General sequential approach: a properly structured programme is essential, with interpretation as an ongoing activity, whatever the cause or nature of an investigation
Stages of test programme
Typical stages of test programme

● **STAGE 1: (Planning)**
  establish aims and information required → documentation survey → preliminary site visit → agree interpretation criteria → systematic visual inspection, initial test selection & costing
Typical stages of test programme (cont.)

● **STAGE 2**: Non-destructive testing
  comparative survey → calibrated assessment →

● **STAGE 3**: Further Testing
  localised investigation (cores, break-out, etc) → load testing
VISUAL INSPECTION:

- provide valuable information.
- Visual features may be related to workmanship, structural serviceability and material deterioration. Able to differentiate between various types of cracking.
  * segregation/ bleeding – concrete mix
  * honeycombing – low standard of construction workmanship
  * deflection/ flexural cracking – lack of structural adequacy
  * material deterioration – surface cracking and spalling
  * reinforcement corrosion – inadequate cover, high chloride concentration
Classification of Cracks

For legend see Table 1

Shear cracks

Cracks at kicker joints

Top of kicker

'Bad', i.e. ineffective joint

Tension bending cracks

Plus rust stains

Durafiber
Some typical type of cracks
a. Corrosion of rebar
b. plastic shrinkage
c. sulphate attack
d. alkali /aggregate reaction

Visual inspection not confined to the surface, also include examination of bearing, expansion joints, drainage channels, post-tensioning ducts and etc.
ASR

Corrosion

Shrinkage

Freeze & Thaw

Crazing

Thermal
ACA gets cracking in flyover

TAKING A CLOSER LOOK: The ACA’s Engineering Forensic Unit officers examining the cracked pillars.
## Diagnosis of defects and deterioration

<table>
<thead>
<tr>
<th>Cause</th>
<th>Symptoms</th>
<th>Age of appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cracking</td>
<td>Spalling</td>
</tr>
<tr>
<td>Structural deficiency</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Reinforcement corrosion</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Chemical attack</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Frost damage</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Fire damage</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Freeze–thaw</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Internal reactions</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Thermal effects</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Shrinkage</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Creep</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Rapid drying</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Plastic settlement</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Physical damage</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>
TEST SELECTION

- Test selection based on a combination of factors such as access, damage, cost, speed and reliability

  - Testing for durability including causes & extent as in Table below
## Durability test – relative features

<table>
<thead>
<tr>
<th>Method</th>
<th>Cost</th>
<th>Speed of test</th>
<th>Damage</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover measurement</td>
<td>Low</td>
<td>Fast</td>
<td>None</td>
<td>Corrosion risk and cause</td>
</tr>
<tr>
<td>Carbonation depth</td>
<td>Low</td>
<td>Fast</td>
<td>Minor</td>
<td>Corrosion risk and cause</td>
</tr>
<tr>
<td>Chloride content</td>
<td>Low</td>
<td>Fast</td>
<td>Minor</td>
<td>Corrosion rate evaluation</td>
</tr>
<tr>
<td>Half-cell potential Resistivity</td>
<td>Moderate</td>
<td>Fast</td>
<td>Minor</td>
<td>Corrosion risk and cause</td>
</tr>
<tr>
<td>Linear polarization resistance</td>
<td>Moderate/high</td>
<td>Moderate</td>
<td>Minor</td>
<td>Corrosion rate evaluation</td>
</tr>
<tr>
<td>AC impedance</td>
<td>Moderate/high</td>
<td>Slow</td>
<td>Minor</td>
<td>Cause and risk of corrosion and concrete deterioration</td>
</tr>
<tr>
<td>Galvanostatic pulse</td>
<td>Moderate/high</td>
<td>Fast</td>
<td>Minor</td>
<td></td>
</tr>
<tr>
<td>Absorption</td>
<td>Moderate</td>
<td>Slow</td>
<td>Moderate/minor</td>
<td></td>
</tr>
<tr>
<td>Permeability</td>
<td>Moderate</td>
<td>Slow</td>
<td>Moderate/minor</td>
<td></td>
</tr>
<tr>
<td>Moisture content</td>
<td>Moderate</td>
<td>Slow</td>
<td>Minor</td>
<td></td>
</tr>
<tr>
<td>Chemical</td>
<td>Moderate/high</td>
<td>Slow</td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>Petrographic</td>
<td>High</td>
<td>Slow</td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>Expansion</td>
<td>High</td>
<td>Slow</td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>Radiography</td>
<td>High</td>
<td>Slow</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>
## Durability tests-relative features

<table>
<thead>
<tr>
<th>Method</th>
<th>Cost</th>
<th>Speed</th>
<th>Damage</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover depth Carbonation</td>
<td>Low</td>
<td>Fast</td>
<td>Minor</td>
<td>Corrosion risk/ cause</td>
</tr>
<tr>
<td>Chloride cont. Half-cell</td>
<td>Moderate/high</td>
<td>Moderate</td>
<td>Minor/none</td>
<td>Corrosion rate</td>
</tr>
<tr>
<td>Resistivity LPR</td>
<td>low</td>
<td>Slow</td>
<td>Moderate/minor</td>
<td>Corrosion rate</td>
</tr>
<tr>
<td>Absorption Permeability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture cont.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Strength tests – relative merits

<table>
<thead>
<tr>
<th>Test method</th>
<th>Cost</th>
<th>Speed of test</th>
<th>Damage</th>
<th>Representativeness</th>
<th>Reliability of absolute strength correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General applications</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cores</td>
<td>High</td>
<td>Slow</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Good</td>
</tr>
<tr>
<td>Pull-out</td>
<td>Moderate</td>
<td>Fast</td>
<td>Minor</td>
<td>Near surface only</td>
<td>Moderate</td>
</tr>
<tr>
<td>Penetration resistance</td>
<td>Moderate</td>
<td>Fast</td>
<td>Minor</td>
<td>Near surface only</td>
<td>Moderate</td>
</tr>
<tr>
<td>Pull-off</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Minor</td>
<td>Near surface only</td>
<td>Moderate</td>
</tr>
<tr>
<td>Break-off</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Minor</td>
<td>Near surface only</td>
<td>Moderate</td>
</tr>
<tr>
<td>Internal fracture</td>
<td>Low</td>
<td>Fast</td>
<td>Minor</td>
<td>Near surface only</td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>Comparative assessment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultrasonic pulse velocity</td>
<td>Low</td>
<td>Fast</td>
<td>None</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td>Surface hardness</td>
<td>Very low</td>
<td>Fast</td>
<td>Unlikely</td>
<td>Surface only</td>
<td>Poor</td>
</tr>
<tr>
<td><strong>Strength development monitoring</strong></td>
<td>Moderate</td>
<td>Continuous</td>
<td>Very minor</td>
<td>Good</td>
<td>Moderate</td>
</tr>
<tr>
<td>Maturity</td>
<td>High</td>
<td>Continuous</td>
<td>Very minor</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Temperature-matched curing</td>
<td>Moderate</td>
<td>Continuous</td>
<td>Very minor</td>
<td>Good</td>
<td>Good</td>
</tr>
</tbody>
</table>
Testing for concrete strength

- core tests provide the most reliable in-situ strength assessment but most damage, slow and expansive
- hammer and UPV good at uniform test but correlation for absolute strength prediction poses many problems
- least destructive suitable method will be used initially, possibly with back-up tests using another method in critical regions
- Table 1.4
# Strength test-relative merits

<table>
<thead>
<tr>
<th>Test method</th>
<th>Cost</th>
<th>Speed</th>
<th>Damage</th>
<th>Representativeness</th>
<th>Reliability of absolute strength correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Cores Penetration resistance Comparative UPV Hammer</td>
<td>High Moderate Low Very low</td>
<td>Slow Fast Fast fast</td>
<td>Moderate Minor None unlikely</td>
<td>Moderate Near surface only</td>
<td>Good Moderate</td>
</tr>
<tr>
<td></td>
<td>Slow Fast Fast fast</td>
<td>Moderate Minor None unlikely</td>
<td>Good Surface only</td>
<td>Poor Poor</td>
<td></td>
</tr>
</tbody>
</table>
Testing for comparative concrete quality, and localized integrity

- comparative testing is the most reliable application of a number of methods for which calibration to give absolute values of a well-defined physical parameter is not easy. eg. (surface hardness, UPV and chain dragging or surface tapping, radar, abrasion resistance and thermoluminescence)
Testing for Structural Performance

- Large scale dynamic response testing is available to monitor structural performance
- Large scale static load tests + monitoring of cracking may be more appropriate
- Static load tests usually incorporate measurement of deflections and cracking.
NUMBER AND LOCATION OF TESTS

● appropriate number of tests is a compromise between accuracy, effort, cost and damage.

● engineering judgement is thus required to determine the number and location of tests, and the relevance of the results to the element or member as a whole
## Relative number of readings recommended for various test methods

<table>
<thead>
<tr>
<th>Test method</th>
<th>No. of individual reading recommended at a location</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Standard’ cores</td>
<td>3</td>
</tr>
<tr>
<td>Small cores</td>
<td>9</td>
</tr>
<tr>
<td>Schmidt hammer</td>
<td>12</td>
</tr>
<tr>
<td>Ultrasonic pulse velocity</td>
<td>1</td>
</tr>
<tr>
<td>Internal fracture</td>
<td>6</td>
</tr>
<tr>
<td>Windsor probe</td>
<td>3</td>
</tr>
<tr>
<td>Pull-out</td>
<td>4</td>
</tr>
<tr>
<td>Pull-off</td>
<td>6</td>
</tr>
<tr>
<td>Break-off</td>
<td>5</td>
</tr>
</tbody>
</table>
(cont.)

- for a survey of concrete within an individual member, at least 40 locations are suggested.
- for comparison of a similar members smaller no. of points should be examined
- Test for material specification compliance must be made on typical concrete
- Test at around mid height is recommended for beams, columns and walls and surface zone tests on slabs must be restricted to soffits.
We know too well that our freedom is incomplete without the freedom of the Palestinians.

- NELSON MANDELA
IN-SITU CONCRETE VARIABILITY

Within member variability:

– variations in concrete supply will be due to differences in materials, batching, transport and handling techniques.
In-situ strength relative to standard specimens:

– measured in-situ values usually less than the strengths of cubes made of same concrete.....

– in-situ compaction and curing will vary widely, and other factors such as mixing, bleeding and susceptibility to impurities are difficult to predict

– Values in Table 1.6 considered typical. Relationship between standard and in-situ strength – Figure 1.7

– cube size, age of test, wet or dry, cement replacement also influenced reading and treated with caution
Variations of concrete quality across a section.
## Comparison of in-situ and ‘standard’ cube strength

<table>
<thead>
<tr>
<th>Member type</th>
<th>Typical 28-day insitu equivalent wet cube strength as % of ‘standard’ cube strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column</td>
<td>Average 65%</td>
</tr>
<tr>
<td>Wall</td>
<td>65%</td>
</tr>
<tr>
<td>Beam</td>
<td>75%</td>
</tr>
<tr>
<td>Slab</td>
<td>50%</td>
</tr>
</tbody>
</table>
f fresh concrete specified

grade 35

g 'standard' cube

mean 40–43 N/mm²

or

mean 32–35 N/mm²

g 'standard' cylinder

top

22–27 N/mm² 18–22 N/mm² 24–29 N/mm² 16–22 N/mm²

g bottom

structural member

30–36 N/mm² 38–46 N/mm² 40–48 N/mm² 24–28 N/mm²

g column wall beam slab

Typical in-situ equivalent 28-day cube strength
INTERPRETATION

- Interpretation of in-situ test results may be considered in three distinct phases leading to the development of conclusions:
  (i) computation
  (ii) examination of variability
  (iii) calibration and/ or application

- Need for comprehensive and detailed recording and reporting of results. Any dispute or litigation smallest detail may be crucial.

- Comprehensive photographs are often of particular value for future reference.
COMPUTATION OF TEST RESULTS:

– vary according to the test method
  • core must be corrected for length, orientation and reinforcement
  • UPV calculated with allowance for reinforcement
  • Penetration resistance and surface hardness must be averaged to give a mean value.
  • load test summarized in the form of load/deflection curves
EXAMINATION OF VARIABILITY:

– Whenever more than one test is carried out, a comparison of the variability of results can provide valuable information.
Graphical Methods

– ‘Contour’ plots showing, for eg. zones of equal strength are valuable in locating areas of concrete which are abnormally high or low in strength relative to the remainder of the member.

– Concrete variability expressed as histogram
Numerical methods:

- calculation of the COV (= sd x 100/mean) of test results may provide valuable information about the construction standards employed
- Table 1.7 contains typical values of coefficients of variation relating to the principal test methods
Typical COV of test results and maximum accuracies of in-situ strength prediction for principal methods

<table>
<thead>
<tr>
<th>Test method</th>
<th>Typical COV for individual member of good quality construction</th>
<th>Best 95% confidence limits on strength estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cores-standard</td>
<td>10%</td>
<td>± 10% (3 specimens)</td>
</tr>
<tr>
<td>- small</td>
<td>15%</td>
<td>±15% (9 specimens)</td>
</tr>
<tr>
<td>Pull-out</td>
<td>8%</td>
<td>20% (4 tests)</td>
</tr>
<tr>
<td>Pull-off</td>
<td>8%</td>
<td>15% (6 tests)</td>
</tr>
<tr>
<td>Windsor probe</td>
<td>4%</td>
<td>20% (3 tests)</td>
</tr>
<tr>
<td>UPV</td>
<td>2.5%</td>
<td>20% (12 tests)</td>
</tr>
<tr>
<td>Rebound Hammer</td>
<td>4%</td>
<td>25% (12 tests)</td>
</tr>
</tbody>
</table>
Figure 1.9 illustrates typical relationships for standard control cubes and in-situ strength.
Typical values of standard deviation of control cubes and in-situ concrete.

<table>
<thead>
<tr>
<th>Material control and construction</th>
<th>Assumed std. dev. of control cube ( (s) ) ( (N/mm^2) )</th>
<th>Estimated std. dev. of in-situ concrete ( (s') ) ( (N/mm^2) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Normal</td>
<td>5.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Low</td>
<td>7.0</td>
<td>8.5</td>
</tr>
</tbody>
</table>
Calibration and application of test results:

– calibration of NDT and partially-destructive strength tests by means of cores may often be possible

– interpretation of strength results requires the use of statistical procedures (not simply to average)
Application to specification:

– it is essential that concrete tested is representative and this will influence the number and location of tests.

– a small proportion marginally below the specified value may be acceptable, but the average for a number of locations should exceed the minimum limit.

– strength, common criterion for the judgement of compliance with specifications and most difficult to resolve in-situ.

– It is better to compare mean in-situ strength estimates with the expected mean standard test specimen result.
the mean ‘standard’ cube strength using British ‘limit state’ design procedures is

\[ f_{\text{mean}} = f_{\text{cu}} + 1.64s \]

where \( f_{\text{cu}} \) = characteristic strength of control cubes and \( s \) = standard deviation of control cubes

The accuracy increase with number of results

Values in Table can be used as a guide
● If number of readings less than 50, equation (below) for 95% confidence limit will thus apply with k given in Table 1.9

\[ f'_{cu} = f'_{mean} - k's \]
where concrete variability is high, as for poor quality control, a ‘log-normal’ distribution more realistic

- \( \log f'_{cu} = \text{mean value of } [\log f'] - k \times \text{standard deviation of } [\log f'] \)
  where \( f' \) is an individual in-situ strength result
Application to design calculations:

– Measured in-situ values can be incorporated into calculations to assess structural adequacy (reinforcement quantities, location or concrete properties such as permeability..). In most instances concrete strength which is relevant

– Accuracy of strength prediction will vary according to method. Factor of safety of 1.2 is recommended by BS 6089
Structural Assessment and Repair
TEST COMBINATIONS

● All in-situ test methods for concrete assessment suffer from limitations, and reliability is open to question

● combining methods may help
INCREASING CONFIDENCE LEVEL OF RESULTS

- Considerably greater weight can be placed on results if corroborative conclusions can be obtained from separate methods.
- If different properties are measured confidence will be much increased by the emergence of similar patterns of results.
- eg. combination of hammer and UPV.
IMPROVEMENT OF CALIBRATION ACCURACY

● It is possible to produce correlations of combinations of measured values with desired properties, to a greater accuracy.

● eg. For strength, UPV (density) or rebound hammer (surface density)
  – In the latter case, appropriate strength correlations must be produced for both methods enabling multiple regression equations to be developed with compressive strength as the dependent variable.
USE OF ONE METHOD AS PRELIMINARY TO ANOTHER:

- Combinations of methods are widely used in situations where one method is regarded as a preliminary to the other – eg. location of reinforcement prior to other form of testing
eg. use of cores or destructive load tests to establish correlations for NDT or partially-destructive methods which relate directly to the concrete under investigation
more than one type of testing will be required to identify the nature and cause of deterioration, and to assess future durability – eg. corrosion: cover measurement + chemical, petrographic and absorption tests.
## DOCUMENTATION AND STANDARDS

<table>
<thead>
<tr>
<th>British Standards</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS 1881: Testing concrete</td>
<td>Methods of testing concrete for other than strength</td>
</tr>
<tr>
<td>Part 5</td>
<td>Method for the determination of water absorption</td>
</tr>
<tr>
<td>Part 122</td>
<td>Chemical analysis of hardened concrete</td>
</tr>
<tr>
<td>Part 124</td>
<td>Temperature matched curing of concrete specimens</td>
</tr>
<tr>
<td>Part 130</td>
<td>Guide to the use of NDT for hardened concrete specimens</td>
</tr>
<tr>
<td>Part 201</td>
<td>The use of electromagnetic covermeters</td>
</tr>
<tr>
<td>Part 204</td>
<td>Radiography of concrete</td>
</tr>
<tr>
<td>Part 205</td>
<td>Determination of strain in concrete</td>
</tr>
<tr>
<td>Part 206</td>
<td>Near to surface test methods for strength</td>
</tr>
<tr>
<td>Part 207</td>
<td>Initial surface absorption test</td>
</tr>
<tr>
<td>Part 208</td>
<td>BS 6089</td>
</tr>
<tr>
<td>BS 8110</td>
<td>Structural use of concrete</td>
</tr>
<tr>
<td>BS 8204</td>
<td>Screeds, bases and insitu floorings</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>European Standards</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS EN 1542</td>
<td>Products and systems for the protection and repair of concrete structures. Test Methods: Measurement of bond strength by pull-off</td>
</tr>
<tr>
<td>BS EN 12504 Testing Concrete in Structures</td>
<td>Cored specimens — Taking, examining and testing in compression</td>
</tr>
<tr>
<td>Part 1</td>
<td>Non-destructive testing — determination of rebound number</td>
</tr>
<tr>
<td>Part 2</td>
<td>Determination of pull-out force</td>
</tr>
<tr>
<td>Part 3</td>
<td>Determination of ultrasonic pulse velocity</td>
</tr>
<tr>
<td>Part 4</td>
<td>BS EN 13554</td>
</tr>
<tr>
<td>BS EN 13894-4</td>
<td>Methods of test for screed materials — Determination of wear resistance — BCA</td>
</tr>
<tr>
<td>*BS prEN 13791 * in preparation</td>
<td>Assessment of concrete compressive strength in structures or in structural elements</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>American Standards ASTM</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C42</td>
<td>Standard method of obtaining and testing drilled cores and sawed beams of concrete</td>
</tr>
<tr>
<td>C85</td>
<td>Cement content of hardened Portland cement concrete</td>
</tr>
<tr>
<td>C457</td>
<td>Air void content in hardened concrete</td>
</tr>
<tr>
<td>C597</td>
<td>Standard test method for pulse velocity through concrete</td>
</tr>
<tr>
<td>C779</td>
<td>Abrasion resistance of horizontal concrete surfaces</td>
</tr>
<tr>
<td>C803</td>
<td>Penetration resistance of hardened concrete</td>
</tr>
<tr>
<td>C805</td>
<td>Rebound number of hardened concrete</td>
</tr>
<tr>
<td>C823</td>
<td>Examining and sampling of hardened concrete in constructions</td>
</tr>
</tbody>
</table>
REASONS FOR STRUCTURAL TESTING

● To determine strength.
● To carry out a comparative quality survey – condition survey.
● To examine localised integrity.
● To assess potential durability.
● To identify causes & extent of deterioration
Basis of Structural Investigation

- Quality control procedure.
- Assessing non-compliance of specimens.
- Uncertainties in quality of workmanship.
- Monitoring strength development.
- Assessing load carrying capacity for upgrading or change of loading.
- Suspected or observed deterioration or distress.
- Regular maintenance inspection.
- Determining cause of failure or defects.
Scope of Assessment *

- **Strength Assessment** – assessment of concrete strength;
- **Durability Assessment** – identifying nature & extent of observed or suspected deterioration including reinforcement corrosion;
- **Integrity Assessment** – determination of localised integrity or generalised assessment of behaviour of whole structure.

Category of NDT Techniques

- **Near-to-Surface**: semi-destructive or destructive. (e.g. surface hardness, penetration resistance, in-situ permeability, corrosion risk, thermography, radar)

- **Internal Testing**: non-destructive. (e.g. pulse velocity, dynamic response, acoustic emission, radioactive methods)
## Types of Testing Methods

<table>
<thead>
<tr>
<th>Property to be investigated</th>
<th>Testing Method</th>
<th>Equipment Type</th>
</tr>
</thead>
</table>
| Corrosion of steel reinforcement | ● Half-cell potential  
● Resistivity measurement  
● Cover depth  
● Carbonation depth  
● Chloride penetration | ● electrical  
● electrical  
● electromagnetic  
● chemical & microscopic  
● chemical & microscopic |
Checking Concrete Cover – The Covermeter

Marking the location of reinforcement bar
Testing for Corrosion

Half Cell Potential Measurement Device

Resistivity Test Device
Durability Test

Phenolphthalein Test for Carbonation

Portable Chloride Test
## Types of Testing Methods

<table>
<thead>
<tr>
<th>Property to be investigated</th>
<th>Testing Method</th>
<th>Equipment Type</th>
</tr>
</thead>
</table>
| Concrete quality, durability and deterioration | ✮ Surface hardness  
✮ UPV  
✮ Radiography  
✮ Radiometry  
✮ Permeability test  
✮ Absorption test  
✮ Moisture test  
✮ Petrographic  
✮ Sulphate content  
✮ Expansion  
✮ Air content  
✮ Cement type & content  
✮ Abrasion resistance | ✮ mechanical  
✮ electronic  
✮ radioactive  
✮ radioactive  
✮ hydraulic  
✮ hydraulic  
✮ chemical & electronic  
✮ microscopic  
✮ chemical  
✮ mechanical  
✮ microscopic  
✮ chemical & microscopic  
✮ mechanical |
The Rebound Hammer

- Conventional Rebound Hammer
- Calibration Anvil
- Digital Rebound Hammer in Use
Petrography
## Types of Testing Methods

<table>
<thead>
<tr>
<th>Property to be investigated</th>
<th>Testing Method</th>
<th>Equipment Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete strength</td>
<td>Core, Pull-out test, Pull-off test, Break-off test, Internal fracture, Penetration resistance, Maturity test, Temperature match curing</td>
<td>mechanical, mechanical, mechanical, mechanical, mechanical, chemical &amp; electrical, electrical</td>
</tr>
</tbody>
</table>
Core Drilling Machine
Windsor Probe Test
Pull Out (Lok Test)

Lok-Test Insert

Removable stem

Failure cone

8.5 mm anchor plate

Reaction ring
Pull-Off Test
# Types of Testing Methods

<table>
<thead>
<tr>
<th>Property to be investigated</th>
<th>Testing Method</th>
<th>Equipment Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrity and Structural Performance</td>
<td>Tapping</td>
<td>mechanical</td>
</tr>
<tr>
<td></td>
<td>Pulse-echo</td>
<td>mechanical &amp; electronic</td>
</tr>
<tr>
<td></td>
<td>Dynamic response</td>
<td>mechanical &amp; electronic</td>
</tr>
<tr>
<td></td>
<td>Thermography</td>
<td>infra-red</td>
</tr>
<tr>
<td></td>
<td>Radar</td>
<td>electromagnetic</td>
</tr>
<tr>
<td></td>
<td>Reinforcement location</td>
<td>electromagnetic</td>
</tr>
<tr>
<td></td>
<td>Strain / crack measurement</td>
<td>Optical / mechanical / electrical</td>
</tr>
<tr>
<td></td>
<td>Load test</td>
<td>mechanical / electronic / electrical</td>
</tr>
</tbody>
</table>
Pulse Echo / Impact Echo

![Image of Pulse Echo / Impact Echo setup](image-url)
Penetration Radar & Radiography

Ground Penetrating Radar system over a defect.

Plot of Ground Penetrating Radar data from a post-tension tendon survey.

High Energy Radiography equipment and operation
Useful Summary of NDT Techniques

- Inspection and Testing Services Inc. provides a useful summary of NDT techniques for concrete structures.
- Summary of NDT ([pdf file](#)) serves as a general guideline and for academic purpose only.
Load Testing on Structures

- Load testing is required when member strength cannot be determined from in-situ material tests;
- Costly & disruptive but psychologically more convincing with positive demonstration of structural capacity;
- Generally for proof of structural capacity;
- Static load tests or dynamic testing for variable loading.
Load Testing on Structures

- Typical load testing methods consist of applying uniformly distributed dead loads to the structure in the form of water weights, sand bags, concrete blocks, or similar materials; steel kentledge, reaction frames or simple hydraulic jacks.

- These techniques provide an indication of a structure's ability to carry a particular load or complying with certain building regulations or standards.
Category of Load Test

● Testing falls into two main categories: Routine Verification or Change of Use.

● When there is a change in use of a building or a building element shows suspect performance, then testing will be required to establish performance;
  – examples of change of use could be refurbishment of warehousing to residential use, the addition of an extra level to an office block or reassignment of storage for heavy items.
Condition Survey: Crack Mapping & Recording Defects

- Crack mapping over a period of time to assess nature, extent & probable causes.
- Use of proformas to record crack locations & directions on grids.
- Simple instrumentation: tell-tale glass, demec gauge points to record movements.
- Live cracks/dead cracks. Structural or non-structural cracks.
- [Recording of Defects.doc]
- [Condition rating] system may also be used to facilitate recording and reporting.
Crack Monitoring (Demec Gauge)
Crack Monitoring (Tell-Tale Glass)
Crack Measurement
Selection of Test Method

- Preliminary comparative surveys using simple NDT methods are useful in investigation related to materials properties condition assessment.
- e.g. The use of rebound hammer & UPV to establish locations for coring or partially-destructive tests.
- The nature of information required & aims of investigation will influence choice of test method as well as interpretation procedures. These must be agreed by all parties before testing commences.
Selection of Test Method – points to consider

- All tests have limitations: repeatability, accuracy level & access requirements.
- Cost factor.
- Localised damage.
- Indirect measurement needs correlation between test results & the measured parameter.
- All test equipment must be calibrated.
- Requires skilled technician to carry out testing.
ADVANTAGE WORKING WITH UTM
Knowledge acquired shared with students, particularly Malaysian (JKR staff included), probably your brother or sister or your sons and daughters

Improve lecturer experience
Good experienced team (friendly Lecturers)
Good experienced team (and Technicians)
Reliable equipments
Good laboratories facilities

Full Scale Testing
Negotiable costs
Stadium larkin, 2010
Maktab Perguruan, Sabah
Stesyen Keretapi Tanjung pagar, Singapura
Bridges - Majlis Perbandaran Melaka
Bridges - Majlis Perbandaran Melaka
Tunnel Segment - Gelang patah, Johor
19 Cross bridge - MPJBT, Skudai, Johor
Rumah kedai, Senai, Johor
Rebranding Key Amal Indicators (KAI)

**Tangible KAIs**
- Publications
- Research
- PG programs
- Education
- Intellectual property
- RU-compliance etc

**Intangible KAIs**
- Teamwork, ukhuwah
- Knowledge culture
- Integrity, passion
- Entrepreneurship
- Taqwa, amal soleh etc

World class university
## new academia?

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>New academia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faculty members</td>
<td>Professors</td>
<td>Professors, inventors, entrepreneurs</td>
</tr>
<tr>
<td>Learning materials</td>
<td>Books, journals</td>
<td>Books, journals, experiences, Internet, internship</td>
</tr>
<tr>
<td>Philosophy</td>
<td>Specialization</td>
<td>Integration</td>
</tr>
<tr>
<td>Funding</td>
<td>Grants, fees</td>
<td>Grants, fees, VC, endowment, REITs</td>
</tr>
<tr>
<td>Students</td>
<td>School leavers, mid-career</td>
<td>School leavers, mid-career, businessmen, early-career, life-long</td>
</tr>
<tr>
<td>Venue</td>
<td>Campus</td>
<td>Campus, Internet, incubators, brands</td>
</tr>
<tr>
<td>Learning modes</td>
<td>Lectures, tutorials, lab, studios</td>
<td>Lectures, tutorials, lab, studios, internship, incubators, experiential learning, 5 minds</td>
</tr>
<tr>
<td>Outcomes</td>
<td>Degrees, expertise</td>
<td>Degrees, expertise, business models, capital, networks, culture</td>
</tr>
</tbody>
</table>
Engineering Assessment Of Structures For Remedial Works

The Need To Understand Concrete Deterioration And Durability
Situations For Engineering Assessment Of Structures

a. Persistent Defects
b. Aging Structure
c. Change Of Use Or Rehabilitation
d. Post-crisis Assessment
e. Statutory Requirement
a. Persistent Defects

**Signs**
- Cracking
- Corrosion
- Rust Stains
- Spalling
- Sagging / Deflection / Settlement

**Objectives Of Assessment**
- Causes And Extent Of Defects
- Present Safety
- Future Safety
- Cost Of Repair
- Futures Maintenance Plan
b. Aging Structure

Objectives Of Assessment

• Load Limitations
• Present Safety
• Future Safety
• Residual Life
c. Change of Use or Rehabilitation

Objectives Of Assessment

● Loading Limits And Safe Loading Zones
● Zones For Restoration / Strengthening
● Residual Life
● Future Maintenance Plan
d. Post-crisis Assessment

Situations
- Fire
- Overloading
- Explosion
- Construction / Design Mistake

Objectives Of Assessment
- Areas For Immediate Strengthening
- Residual Strength
- Future Decline Of Strength
- Option For Remedial Works / Demolition
- Future Maintenance Plan
e. Statutory Requirement (1)

- Street, drainage and building act 1974 (Act 133) Amended 1994 (Act A903)

- Section 85a
  mandatory building inspection once every 10 years for building exceeding 5-storey

- Building Owner
  To appoint approved professional engineer
  To carry out inspection within 60 days from the date of notice from local authority.
Statutory Requirement (2)

To Determine

- Present safety
- Future safety
- Cost of repairs
- Future maintenance plan
- Load limitations
The Assessment Process

- Collation & Review Of Data
- Visual Inspection
- Testing Inspection
- Testing Works
- Engineering Evaluation
- Report & Recommendation
VISUAL INSPECTION

- Knowledge & Experience
- Accessibility
- Health & Safety Considerations

Aims

i. Overall appreciation of structure condition
ii. Identify nature and types of problems
iii. Map out the extent of the problems
VISUAL INSPECTION (Cont.)

- Identify
- Types of defects
- Possible causes
- Follow-up investigation / testing
- **Determine if**
  1. Problem is structural nature or material deficiencies
  2. Present safety level of structure
TESTING WORKS

● Reasons for testing
● Acceptance criteria
● Site condition
● Selection of testing methods
  − quantum
  − locations
  − Effects of damage
  − Size of member
  − Reliability
● Economics & social factors
● Monitoring works.
ENGINEERING EVALUATION

- Interpretation of test results
- Assess significance of problems / deficiencies
- Selected structural analysis
- Determination of load capacity
- Establish safety level
- Estimate useful life
REPORT & RECOMMENDATION

● Conclusion on the Material Condition & Structural Condition
● Options for Remedial & Strengthening Works
● Cost implications of options
● Bill of quantities / specifications
REPORT & RECOMMENDATION (Cont.)

Options

- Full structural rehabilitation
- Restoration of durability through protection
- Partial strengthening
- Monitoring works
- Periodic inspection
- Do nothing
mutiara hadith

Daripada Abu Musa r.a., meriwayatkan bahawa baginda Rasulullah s.a.w. bersabda: Perumpamaan **ilmu dan hidayah** yang dengannya aku diutus oleh Allah SWT adalah seumpama satu **hujan lebat yang menimpa bumi.** (Bumi terbahagi kepada tiga tanah)

- Pertama ialah tanah baik, lembut dan menyerap air yang kerananya tanah menjadi subur, menumbuhkan tumbuh-tumbuhan yang banyak.
- Kedua ialah tanah yang keras tidak menyerap air tetapi dapat mengumpulkan air bagi keperluan manusia, binatang ternak dan tanam-tanaman yang lain.
- Ketiga ialah tanah yang keras yang tidak menyerap dan tidak dapat mengumpulkan air dan tidak menumbuhkan tanam-tanaman.

(Begitulah dengan manusia yang terbahagi kepada tiga golongan):

- Mereka yang diberi faham agama dan mendapat hidayah. Dengan hidayah itu mereka mengenaliku, mendapat manfaat dengan ilmu yang diberikan Allah SWT kepadaku. Mereka belajar dan mengajarkan kepada orang lain.
- (Golongan kedua) ialah yang tidak mengambil manfaat bagi dirinya tetapi orang lain dapat manfaat darinya.
- (Golongan ketiga) ialah orang yang tidak peduli dirinya dan tidak mendapat hidayah Allah SWT apa yang diturunkan melalui aku.

(Hadis Riwayat Bukhari).
PROBLEMS

1. Comment on use of the schmidt hammer on surfaces with different inclination
2. What is meant by repeatability and reproducibility
3. Discuss the possible reasons for a difference between the strength of test cylinders and cores from the same concrete
4. Why is there a difference between the modulus of rupture and the splitting tensile strength of a given concrete?
5. What are advantages and disadvantages of the pull-out test
6. What are advantages and disadvantages of the Windsor probe?
7. What test would you use to determine the age for early striking of soffit formwork?
8. How do you convert the strength of a concrete core to the estimated strength of a test cube
9. What is the influence of cracks on the ultrasonic pulse velocity of concrete?