NON-DESTRUCTIVE TESTING FOR CONCRETE STRUCTURE

UJIAN TANPA MUSNAH TERHADAP STRUKTUR KONKRIT

Tengku Sarah Tengku Amran [1], Noor Azreen Masenwat [2], Mohamad Pauzi Ismail[3]

Kumpulan MSI-NDT, Bahagian Teknologi Industri,
Agensi Nuklear Malaysia
Bangi, 43000 Kajang, Selangor.
Emel : sarah@nm.gov.my

Abstract

Nondestructive testing (NDT) is a technique to determine the integrity of a material, component or structure. It is essential in the inspection of alteration, repair and new construction in the building industry. There are a number of non-destructive testing techniques that can be applied to determine the integrity of concrete in a completed structure. Each has its own advantages and limitations. For concrete, these problems relate to strength, cracking, dimensions, delaminations, and inhomogeneities. NDT is reasonably good and reliable tool to measure the property of concrete which also gives the fair indication of the compressive strength development. This paper discussed the concrete inspection using combined methods of NDT.

Keywords: non-destructive testing, concrete

INTRODUCTION

Non-destructive testing (NDT) evaluates the condition of a structure without damaging it. It can be applied to the whole of a large-scale structure and can efficiently evaluate the degradation condition of the structure (Hiroshi et al. 2008). NDT methods are now considered as powerful tools for evaluating existing concrete structures with regard to their strength and durability. Concrete is a highly nonhomogeneous composite material with varying composition and different raw materials. The increase of hardness of concrete with age and strength has led to the development of test methods to measure this property. These methods consists of penetration tests, rebound tests, ultrasonic method, radioactive methods and many more (Verma et al. 2013). This paper provides comprehensive treatment of nondestructive test methods that are used to evaluate concrete structures by combining methods in which more than one technique are used to estimate strength of concrete.

This paper estimated the concrete strength by combined methods of nondestructive testing. The concrete inspection was done on processing plant in Terengganu at three location namely TRAIN1, TRAIN2 and SILO. The traditional well-known techniques show in Table 1 such as half cell potential measurement, covermeter, carbonation depth measurement and ultrasonic pulse velocity were used in these study. Various chart showing the results are presented. The results were studied and we can predict concrete strength simply and reliaby. The method presented is simple, quick, reliable and cover wide ranges of concrete strengths.

Table 1. The purpose of all technique used in this concrete inspection.

NDT Testing	Purpose
Half-Cell Potential Measurement	The half-cell provides a relatively quick method of assessing reinforcement corrosion over a wide area without the need for wholesale removal of the concrete cover. Quantitative measurements are made so that a structure can be monitored over a period of time and any deterioration can be noted.
Carbonation Depth Measurement	The purpose of Carbonation Depth Measurement is to estimate the age of the building and to seek presence of moisture.

Ultrasonic Instrument Scope	The purpose of Ultrasonic Instrument is to determine the variability and quality of concrete by measuring pulse velocity. Using transmission method, the extent of such defects such as voids, honeycombing, cracks and segregation may be determined. This technique is also useful when examining fire damaged concrete.
Covermeter	The purpose of covermeter inspection is to determine the presence, location and depth of rebars in concrete and masonry components. Advanced versions of covermeter can also indicate bar diameter when cover is known.

PRINCPLE

1) Half Cell Potential Measurement

Electrical potential of steel reinforcement is measured relative to a reference electrode (half-cell). This enables potential contour maps to be plotted. The electrode potential of steel in concrete indicates the probability of corrosion.

2) Carbonation Depth Measurement

To estimate the age of the building, the formula below is being used:

$$Y = \{7.2 / R^2(4.6x - 1.76)^2\}C^2$$

where y is age of building in years,
x is water-to-cement ratio,
C is carbonation depth,
R is a constant ($R = \alpha\beta$).

R varies depending on the surface coating on the concrete (β) and whether the concrete has been in external or internal service (α). This formula is contained in the Japanese Construction Ministry publication "Engineering for improving the durability of reinforced concrete structures." α is 1.7 for indoor concrete and 1.0 for outdoor concrete. β values are shown in Table 2:

Table 2. Values of β

Finished Condition	Indoor	Outdoor
No layer	1.7	1.0
Plaster	0.79	-
Mortar + plaster	0.41	-
Mortar	0.29	0.28
Mortar + paint	0.15	-
Tiles	0.21	0.07
Paint	0.57	0.8

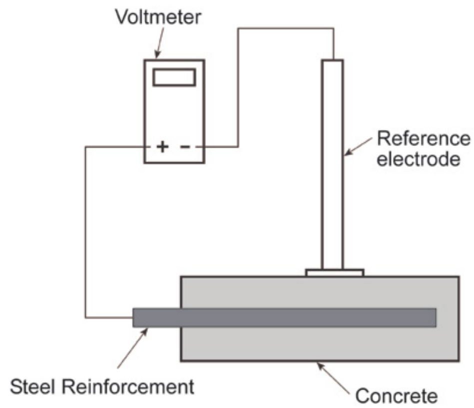

Figure 1. Schematic diagram for Half Cell Potential Measurement

3) Ultrasonic Instrument Scope

Voltage pulses are generated and transformed into wave bursts of mechanical energy by the transmitting transducer (which must be coupled to the specimen surface through a suitable medium). A receiving transducer is coupled to the specimen at a known distance to measure the interval between the transmission and reception of a pulse. There are three practical arrangements for measuring pulse velocity, namely direct, diagonal and surface techniques. The direct approach provides the greatest sensitivity and is therefore superior to the other arrangements.

4) Covermeter

The basic principle is that the presence of steel affects magnetic field. An electromagnetic search probe is swept over the surface of the concrete under test. The presence of reinforcement within the range of the instrument is shown by movement of the indicator needle. When the probe is moved until the deflection of the needle is at a maximum, the bar in question is then parallel to the alignment of the probe and directly beneath it. The needle indicates the cover on the appropriate scale for the diameter of the reinforcing bar.

Figure 2. Calibration of a) Ultrasonic Instrument and b) Covermeter

PROCEDURE

1) Half Cell Potential Measurement

Measurements are made in either a grid or random pattern. The spacing between measurements is generally chosen such that adjacent readings are less than 150 mV with the minimum spacing so that there is at least 100 mV between readings. An area with greater than 150 mV indicates an area of high corrosion activity. A direct electrical connection is made to the reinforcing steel with a compression clamp or by brazing or welding a protruding rod. To get a low electrical resistance connection, the rod should be scraped or brushed before connecting it to the reinforcing bar. It may be necessary to drill into the concrete to expose a reinforcing bar. The bar is connected to the positive terminal of the voltmeter. One end of the lead wire is connected to the half-cell and the other end to the negative terminal of the voltmeter. Table 3 shows the acception criteria for corrosion activity.

Table 3. The acception criteria for corrosion activity

Potential Difference level (mV)	Chance of re-bar being corroded	Main colour
Less than -500	Visible evidence of corrosion	
-350 to -500	95%	Ref 1
-200 to -350	50%	
More than -200	5%	

Ref 1 : 
Increasing probability of corrosion

2) Carbonation Depth Measurement

The 1% of phenolphthalein solution is made by dissolving 1 gm of phenolphthalein in 90 cc of ethanol. The solution is then made up to 100 cc by adding distilled water. On freshly extracted cores the core is sprayed with phenolphthalein solution, the depth of the uncoloured layer (the carbonated layer) from the external surface is measured to the nearest mm at 4 or 8 positions, and the average taken.
If the test is to be done in a drilled hole, the dust is first removed from the hole using an air brush anda again the depth of the uncoloured layer measured at 4 or 8 positions and the average taken. If the concrete still retain its alkaline characteristic, the colour of the concrete will change to purple.

3) Ultrasonic Instrument Scope

Surface condition
The surface condition shall be free from loose scale paint, rust and debris to the extent that adequate ultrasonic coupling is achieved.

Equipment Calibration
The time delay adjustment should be made while the transducers are coupled to the opposite ends of reference bar for which the transit time is accurately known. The time delay adjustment should be made each time the equipment is used to provide a correct zero setting for the apparatus.

Determination of the arrival time of the pulse
Repeated readings at a particular location should be taken until a minimum value is obtained. Readings at any dubious points should be repeated to establish ±1% accuracy.

Accuracy of path length measurement
The accuracy should be better than ±1%. Where direct measurement of path length is not physically possible, the nominal dimension and its tolerance as specified by designer should be used and the fact reported.

Determination of pulse velocity
There are three method of transducer arrangement, namely direct, semi-direct (diagonal) and indirect (Fig. 1) or surface transmissions where possible direct transmission should be used. Surface transmission should be used when only one face of the concrete is accessible, when the depth of a surface crack is to be determined or when the quality of the surface concrete relative to the overall quality is of interest. Recommended number of tests for building appraisal: pulse velocity to 10% of all members or 15 to 20 locations per 1000m^2 floor areas.

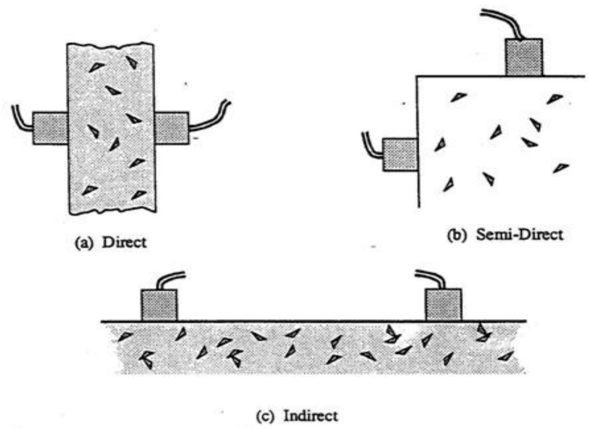

Figure 3. Three method of transducer arrangement

Effect of reinforcement on pulse velocity
For practical purposes where 54 kHz transducers are being used, bars of diameter less than 20mm may be ignored since their influence is negligible.

Estimating of concrete quality/strength

Table 4. The general condition of concrete quality

Pulse velocity (m/s)	**Strength**
Above 4500	Excellent
3600 – 4500	Generally good
3000 – 3600	Questionable
2100 – 3000	Generally poor
below 2100	Very poor

4) Covermeter

The search head is traversed systematically across the concrete until a position of maximum disturbance of the electromagnetic field is indicated by a meter or by an audible signal. In such a position, under ideal conditions, the indicated cover to the nearest piece of reinforcement may be read if the bar size is known. Further, the axis of the reinforcement will then lie in the plane containing the centre line through the poles of the search head.

RESULTS AND DISSCUSSION

1) Half Cell Potential Measurement

Figure 4 shows the half cell measurement result of all the inspect location. Generally, the potential different for half cell at all location is low (>-200mV). This value was given based on the Table 3 where it show no active corrosion activity happened in the inspection area. Therefore there is no need for investigation for corrosion. However, the results still can be used as reference for future inspection.

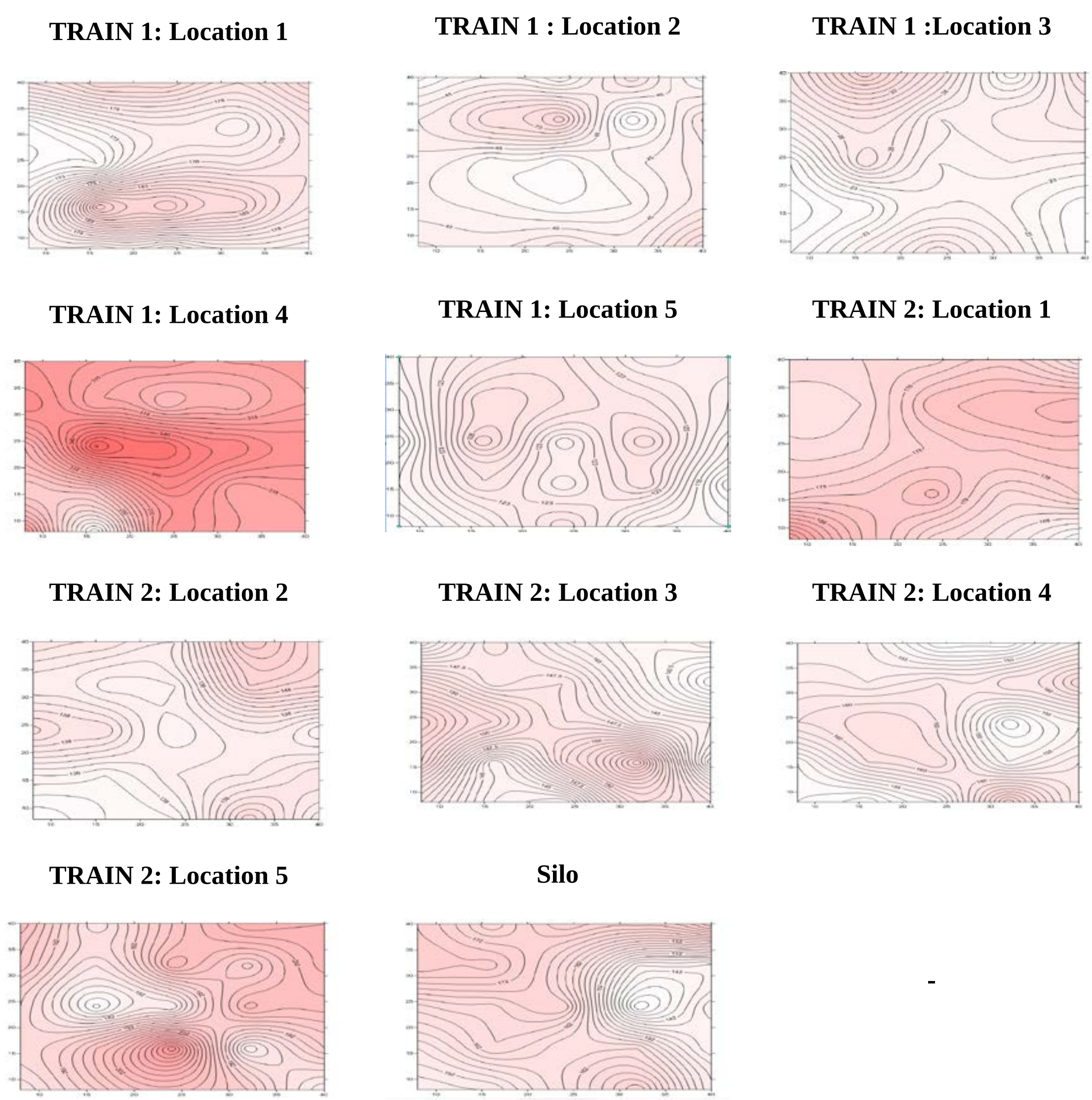

Figure 4. Corrosion Activity in TRAIN 1, TRAIN 2 and SILO

2) Carbonation Depth and Cover Depth Measurement

Carbonation depth and cover depth was measured and the result was presented in Table 5 below. Average reading was taken for six spots for carbonation depth on concrete core. According to the table result below, all points were not reached to the estimate depth 20.7mm. However, the period of carbonation depth to reach 10mm from the cover depth was calculated to prepare suitable action in the future as below equation. . As a result, period of carbonation depth to reach 10mm from the cover depth estimated above of 100 years for all points of samples.

Table 5. Readings for carbonation depth and cover depth

SAMPLE	1^{st} (mm)	2^{nd} (mm)	3^{rd} (mm)	4^{th} (mm)	5^{th} (mm)	6^{th} (mm)	Avg. (mm)	Cover Depth (mm)	Coef. Of b	Period to reach 10mm* (year)
TRAIN 1-1	2	4	2	2	2	2	2.33	96	0.42	42232
TRAIN 1-2	1	2	1	1	2	2	1.5	84	0.27	75447
TRAIN1-3	2	1	0	0	0	0	0.5	81	0.09	625084
TRAIN1-4	1	1	1	0.5	0	0	0.58	41	0.10	88558
TRAIN1-5	1	1	1	2	1	0	1	40	0.18	27900
TRAIN2-1	1	1	1	1	1	1	1	46	0.18	40176
TRAIN2-2	1	2	1	1	2	2	1.5	32	0.27	6668
TRAIN2-3	1	0	0	0	0	0	0.17	79	0.03	5106955
TRAIN2-4	1	2	1	1	2	0	1.17	44	0.21	26178
TRAIN2-5	3	0	0	0	0	0	0.5	73	0.09	492156
SILO S-1	2	2	2	2	2	2	2.0	87	0.36	45949

*Period to reach depth 10mm from the cover depth.

3) Ultrasonic Instrument Scope

Table 6 shows the Ultrasonic pulse velocity (UPV) results taken in TRAIN 1, TRAIN 2 and SILO. Reading for each location was taken at 5 different distances and the average velocity was calculated. The velocity show high velocity appeared at TRAIN 2 (location 3A) with 3679 m/s. Based on Table 4, higher number of pulse velocity indicate the greater strength of the concrete. Concrete quality and uniformity affect the strength of the concrete and it depends on the vibration level. If the vibration was done in shorter time it causes the air void in the concrete when it is harden. Hence, more air void in concrete will contribute to lower compressive strength and strength.

Table 6. Ultrasonic Pulse Velocity (UPV) measurement

LOCATION	UPV MEASUREMENT						VELOCITY (m/s)
TRAIN 1 (drop area) A, B & C	**Distance (m)**	0.08	0.16	0.24	0.32	0.4	3147 m/s
	Time (s)	0.0000164	0.0000516	0.0000896	0.0000917	0.0001144	

	Distance (m)	0.08	0.16	0.24	0.32	0.4	2147 m/s
	Time (s)	0.0000159	0.0000519	0.0000871	0.0001339	0.0001602	
	Distance (m)	0.08	0.16	0.24	0.32	0.4	2815 m/s
	Time (s)	0.0000154	0.0000559	0.0000527	0.0000844	0.0001309	
TRAIN 1 (location 4)	**Distance (m)**	0.08	0.16	0.24	0.32	0.4	2174 m/s
	Time (s)	0.0000149	0.0000574	0.0001042	0.0001252	0.0001624	
TRAIN 1 (location 5)	**Distance (m)**	0.08	0.16	0.24	0.32	0.4	2803 m/s
	Time (s)	0.0000204	0.0000551	0.0000751	0.0001077	0.0001361	
TRAIN 1 (location 2) UPPER	**Distance (m)**	0.08	0.16	0.24	0.32	0.4	2886 m/s
	Time (s)	0.0000169	0.0000446	0.0000666	0.0001142	0.0001124	
TRAIN 1 (location 2) LOWER	**Distance (m)**	0.08	0.16	0.24	0.32	-	2083 m/s
	Time (s)	0.0000304	0.0000587	0.0001216	0.0001269	-	
TRAIN 1 (location 1) UPPER	**Distance (m)**	0.08	0.16	0.24	0.32	-	3137 m/s
	Time (s)	0.0000169	0.0000424	0.0000704	0.0000894	-	
TRAIN 1 (location 1) LOWER	**Distance (m)**	0.08	0.16	0.24	0.32	-	2353 m/s
	Time (s)	0.0000199	0.0000614	0.0000904	0.0001229	-	
TRAIN 2 (location 3) A & B	**Distance (m)**	0.08	0.16	0.24	0.32	0.4	3679 m/s
	Time (s)	0.0000164	0.0000346	0.0000527	0.0000802	0.0001016	
	Distance (m)	0.08	0.16	0.24	0.32	0.4	2312 m/s
	Time (s)	0.0000194	0.0000549	0.0000749	0.0001384	0.0001411	
TRAIN 2 (location 5) A & B	**Distance (m)**	0.08	0.16	0.24	0.32	0.4	2185 m/s
	Time (s)	0.0000219	0.0000579	0.0000784	0.0001296	0.0001711	
	Distance (m)	0.08	0.16	0.24	0.32	0.4	3547 m/s
	Time (s)	0.0000159	0.0000579	0.0000717	0.0000852	0.0001092	
TRAIN 2 (location 1)	**Distance (m)**	0.08	0.16	0.24	0.32	0.4	3586 m/s
	Time (s)	0.0000119	0.0000407	0.0000567	0.0000736	0.0001052	
TRAIN 2 (location 4)	**Distance (m)**	0.08	0.16	0.24	0.32	0.4	2301 m/s
	Time (s)	0.0000199	0.0000504	0.0000769	0.0001232	0.0001559	
TRAIN 2 (location 2)	**Distance (m)**	0.08	0.16	0.24	0.32	0.4	2413 m/s
	Time (s)	0.0000257	0.0000481	0.0000839	0.0001279	0.0001494	
SILO A & B	**Distance (m)**	0.08	0.16	0.24	0.32	0.4	2242 m/s
	Time (s)	0.0000387	0.0000764	0.0001154	0.000154	0.0001769	
	Distance (m)	0.08	0.16	0.24	0.32	0.4	2165 m/s
	Time (s)	0.0000334	0.0000722	0.0001184	0.0001404	0.0001824	

CONCLUSION

The non-destructive testing was used to inspect the concrete condition. Based on the comprehensive experimental investigation involving 4 techniques the main conclusions are:

- The concrete quality and uniformity is very poor at location TRAIN 1 (location 2 – lower) and generally poor at all location except at location TRAIN 2 (location 3A).
- The corrosion activity is low at all location tested. Therefore, there is no need for investigation for corrosion.
- According to the results, all points measured shown slow activity of carbonation where more than 100 years to reach the rebar. All measurements points were taken nearby to the cracks area, however it is not effect to the carbonation activity. This may cause due to the low of carbon dioxide contains in the surround area compare to the normal buildings or structures which near with the roads and vehicles activities. If the current condition of environment will not changes, any repair due to carbonation is not needed.

This study contributes to a better understanding of the non-destructive techniques and enables these techniques to be used with greater confidence.

ACKNOWLEDGEMENTS

The authors wish to thank MOSTI for funding the research as well as the staff of Material and Structure Integrity Group (NDT-MSI) for the support.

REFERENCES

1. H.Irie, Y.Yoshida, Y.Sakurada and T.Ito (2008) Non-destructive testing methods for concrete structures, NTT Technical Review, Vol 6 No 5.
2. S.K.Verma, S.S.Bhadauria and A.Akhtar (2013) Review of Nondestructive Testing Methods for Condition Monitoring of Concrete Structures, Vol 2013, 834572
3. *Annual bridge inspection manual*, Unit Jambatan, Cawangan Jalan, JKR, March 1995.
4. Technical Report No. 54, 2000, *Diagnosis of deterioration in concrete structures*, Concrete Society, UK.
5. *The procedure for maintenance and repair* (for publish on base plate of bridge), Japan Road Public Corporation
6. BS 1881: Part 202, 1986, *Recommendations for surface hardness testing by rebound hammer*, London, BSI.
7. 1996: *private communication* with Mr. Terada K. during his visit to Nuklear Malaysia.
8. Malhotra V.M., 1975, ACI monograph no. 9, *Testing of hardened concrete: Nondestructive methods*, American Concrete Institute.
9. Mohamad Pauzi Ismail, Suhairy Sani and Amry Amin Abas, 2006, *Selection of suitable Nondestructive Testing methods for concrete inspection in structures*, pp 20, MSNT Newsletter, Issue No. 19.
10. TICO instrument manual 2007.
11. BS 1881: Part 203, 1986, *Recommendations for measurement of velocity of ultrasonic pulses in concrete*, London, BSI
12. Mohamad Pauzi Ismail, 2003, *Measurement Of Crack Depth In Concrete By Ultrasonic Methods*, 10^{th} International conference on Structural Faults and Repair 2003, London.
13. Abdul Nassir Ibrahim and Terada K., 1996. *Procedure for Surveying old and damage building*, MINT/II/NDT/BB01, Mac 1996
14. Training course series No. 17, 2002, *Guidebook on Non-destructive Testing of Concrete Structures*, International Atomic Energy Agency, Vienna