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Structural Health Monitoring using Non-Destructive Testing of Concrete

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ABSTRACT

Structures are assemblies of load carrying members capable of safely transferring the superimposed loads to the foundations. Their main and most looked after property is the strength of the material that they are made of. Concrete, as we all know, is an integral material used for construction purposes. Thus, strength of concrete used, is required to be 'known' before starting with any kind of analysis. In the recent past, various methods and techniques, called as Non-Destructive Evaluation (NDE) techniques, are being used for Structural Health Monitoring (SHM).

The concept of nondestructive testing (NDT) is to obtain material properties of in place specimens without the destruction of the specimen nor the structure from which it is taken. However, one problem that has been prevalent within the concrete industry for years is that the true properties of an in-place specimen have never been tested without leaving a certain degree of damage on the structure. For most cast-in-place concrete structures, construction specifications require that test cylinders be cast for 28-day strength determination. Usually, representative test specimens are cast from the same concrete mix as the larger structural elements. Unfortunately, test specimens are not an exact representation of in-situ concrete, and may be affected by variations in specimen type, size, and curing procedures.

The rebound hammer test is classified as a hardness test and is based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. The energy absorbed by the concrete is related to its strength. There is no unique relation between hardness and strength of concrete but experimental data relationships can be obtained from a given concrete. However, this relationship is dependent upon factors affecting the concrete surface such as degree of saturation, carbonation, temperature, surface preparation and location, and type of surface finish. A correlation between rebound number and strength of concrete structure is established, which can be used as well for strength estimation of concrete structures.

Keywords: Non-Destructive Evaluation (NDE), Structural Health Monitoring (SHM)., nondestructive testing (NDT), rebound number and strength of concrete structure

1. INTRODUCTION

To keep a high level of structural safety, durability, and performance of the infrastructure in each country, an efficient system for early and regular structural assessment is urgently required. The quality assurance during and after the construction of new structuresand after reconstruction processes and the characterization of material properties and damage as a function of time and environmental influences is more and more becoming a serious concern. Non-destructive testing (NDT) methods have a large potential to be part of such a system. NDT methods in general are widely used in several industry branches. Aircrafts, nuclear facilities, chemical plants, electronic devices and other safety critical installations are tested regularly with fast and reliable testing technologies. A variety of advanced NDT methods are available for metallic or composite materials.

In recent years, innovative NDT methods, which can be used for the assessment of existing structures, have become available for concrete structures, but are still not established for regular inspections. Therefore, the objective of this project is to study the applicability, performance, availability, complexity, and restrictions of NDT.

The purpose of establishing standard procedures for nondestructive testing (NDT) of concrete structures is to qualify and quantify the material properties of in-situ concrete without intrusively examining the material properties. There are many techniques that are currently being research for the NDT of materials today. This chapter focuses on the NDT methods relevant for the inspection and monitoring of concrete materials.

1.1 Aim Of This Study

The aim of the project was to obtain the Calibration Graphs for Non Destructive Testing Equipment's viz., the Rebound Hammer and Ultrasonic pulse Velocity Tester and to study the effect of reinforcement on the obtained results. These Non-Destructive Instruments were then used to test the columns, beams and slabs of two double storied buildings viz., Hall No.2 and Hall no.7 (a newly constructed)

2. LITERATURE REVIEW

Sundarakumar Kusuma (2015), , The objective of work is to carryout Structural Health Monitoring based on Non Destructive Testing. For this we have considered a 5-storey educational building which is nothing but the R-Block of Usha Rama College of Engineering & Technology. It has an age of 8 years. There is a need for regular monitoring and maintenance of the structure for achieving increased life and service of the structure. In total there are 725 columns in R-Block. Each floor of the 5-floored structure consists of 145 columns. These are divided in to two parts, one as Part-A: 620mm x 260mm (112 no's) and the other as Part-B: 290mm x 290mm (33no's). All the columns were assessed. WTC-Model H Concrete Rebound Test Hammer is used in the present work. The range of compressive strength values measured on small columns vary from 20 to 45 N / mm 2 where as the range of compressive strength values measured on large columns vary from 20 to 50 N / mm 2. Average compressive strengths in Ground floor for large columns and small columns are 43.38 N/mm 2 , 33.60 N/mm 2 respectively. Similar values were obtained for all the floors. The outcome of the project can be used as the basis for repair and maintenance works to be carried out for enhanced life and service of the structure.

Structural health monitoring is at the forefront of structural and materials research. Structural health monitoring systems enable inspectors and engineers to gather material data of structures and structural elements used for analysis. Ultrasonics can be applied to structural monitoring programs to obtain such data, which would be especially valuable since the wave properties could be used to obtain material properties.

This testing approach may be used to assess the uniformity and relative quality of the concrete, to indicate the presence of voids and cracks, and to evaluate the effectiveness of crack repairs. It may also be used to indicate changes in the properties of concrete, and in the survey of structures, to estimate the severity of deterioration or cracking. Decreases in ultrasonic waves speeds over time can reveal the onset of damage before visible deficiencies become evident. This allows inspectors and engineers to implement repair recommendations before minor deficiencies become safety hazards.

3. EXPERIMENTAL STUDY

3.1 Rebound Hammer

The Schmidt rebound hammer is basically a surface hardness test with little apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. Rebound hammers test the surface hardness of concrete, which cannot be converted directly to compressive strength. The method basically measures the modulus ofelasticity of the near surface concrete. The principle is based on the absorption of part of the stored elastic energy of the spring through plastic deformation of the rock surface and the mechanical waves propagating through the stone while the remaining elastic energy causes the actual rebound of the hammer. The distance travelled by the mass, expressed as a percentage of the initial extension of the spring, is called the *Rebound number.* There is a considerable amount of scatter in rebound numbers because of the heterogeneous nature of near surface properties (principally due to near-surface aggregate particles).

There are several factors other than concrete strength that influence rebound hammer test results, including surface smoothness and finish, moisture content, coarse aggregate type, and the presence of carbonation. Although rebound hammers can be used to estimate concrete strength, the rebound numbers must be correlated with the compressive strength of molded specimens or cores taken from the structure.

Figure 1: Rebound Hammer

3.2 **Ultra-sonic pulse velocity test**

This test involves measuring the velocity of sound through concrete for strength determination. Since, concrete is a multi-phase material, speed of sound in concrete depends on the relative concentration of its constituent materials, degree of compacting, moisture content, and the amount of discontinuities present. This technique is applied for measurements of composition (e.g. monitor the mixing materials during construction, to estimatethe depth of damage caused by fire), strength estimation, homogeneity, elastic modulus and age, & to check presence of defects, crack depth and thickness measurement. Generally, high pulse velocity readings in concrete are indicative of concrete of good quality. The drawback is that this test requires large and expensive transducers. In addition, ultrasonic waves cannot be induced at right angles to the surface; hence, they cannot detect transverse cracks.

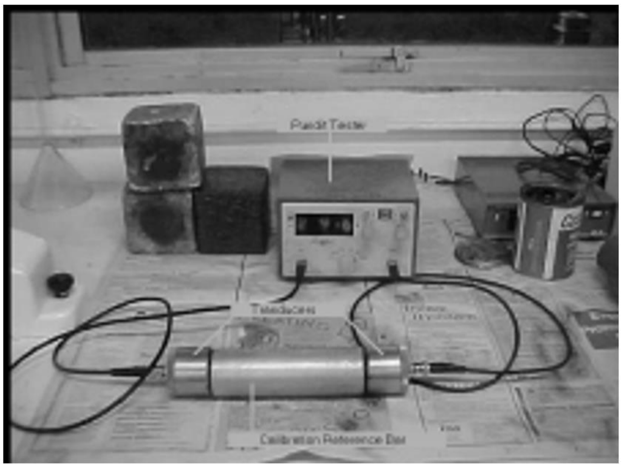

Figure 2: Ultra-sonic pulse velocity test

4. RESULTS AND DISCUSSIONS

4.1 Rebound Hammer

6 cubes were cast, targeting at different mean strengths. Further, the cubes were cured for different number of days to ensure availability of a wide range of compressive strength attained by these cubes. Size of each cube was 150×150×150 mm.

Table 1: Sample 1

SL NO.	R. NO.
1	19
2	25
3	23
4	22
5	23
6	22
7	22
8	22
9	23
10	22
MEAN	22.3
S.D.	1.49

Dead Load	150 KN
Breaking load	247 KN
f (ck) N/mm^2 (Predicted)	14.2 N/mm^2
f (ck) N/mm^2 (Actual)	11.0 N/mm^2

Table 2: Sample 2

SL NO.	R. NO.
1	19
2	20
3	19
4	20
5	19
6	20
7	19
8	20
9	19
10	22
MEAN	19.7
S.D.	0.94

Dead Load	150 KN
Breaking load	311.5 KN
f (ck) N/mm^2 (Predicted)	13.2 N/mm^2
f (ck) N/mm^2 (Actual)	13.8 N/mm^2

Table 3: Sample 3

SL NO.	R. NO.
1	24
2	25
3	26
4	26
5	26
6	25
7	25
8	24
9	25
10	25
MEAN	25.1
S.D.	0.737865

Dead Load	150 KN
Breaking load	346.5 KN
f (ck) N/mm^2 (Predicted)	18.8 N/mm^2
f (ck) N/mm^2 (Actual)	15.3 N/mm^2

The following graph is obtained between the Predicted Compressive Strength by the Rebound Hammer and the Actual Compressive Strength:

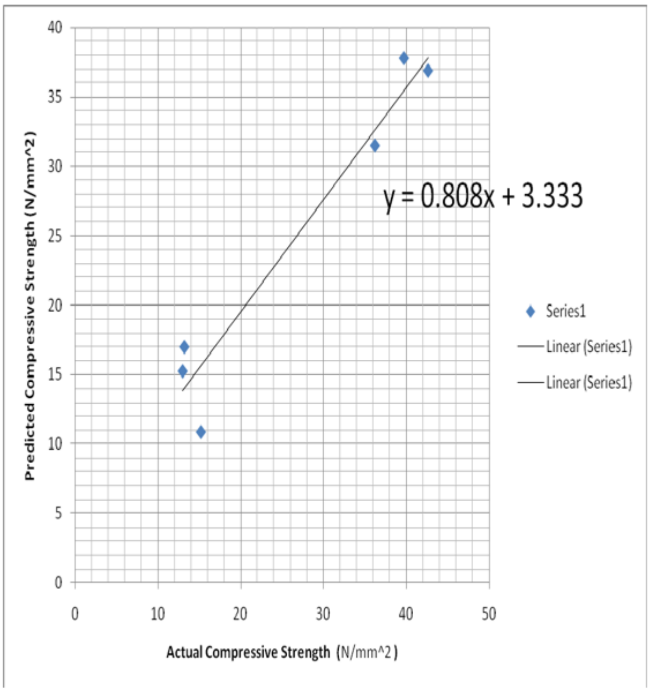

Figure 4: ReboundHammer and the Actual Compressive Strength

4.2 Ultrasonic Velocity Testing Machine

9 cubes were cast, targeting at different mean strengths. Further, the cubes were cured for different number of days to ensure availability of a wide range of compressive strength attained by these cubes. Size of each cube was 150×150×150 mm.

3 readings of Ultrasonic Pulse Velocity (USPV) were obtained for each cube.

The cubes were then given a load of 7 N/mm^2 (as specified by the IS CODE 13311) in the Compression Testing Machine and the USPV were obtained.

The cubes were then loaded up to their ultimate stress and the Breaking Load was obtained.

The following table lists the USPV in each specimen with their mean velocity, the Dead Load, the Breaking Load and the actual Compressive Strength as obtained by the Compression TestingMachine.

Figure 5: USPV

Table 4: Ultrasonic Pulse Velocity (USPV)

SAMPLE NO.	V1	V2	V3	V		BREAKIN G	f (ck) N/mm^2
	(m/sec)	(m/sec)	(m/sec)	(m/sec)	I R LOAD	LOAD	(Actual)
				(Avg)	KN	KN	
1	2825	2916	2913	2884.667	150	562.5	25
2	3350	3585	3218	3384.333	150	669.8	29.77
3	3625	3632	3218	3491.667	150	720	32
4	4219	4213	4007	4146.333	150	841.5	37.4
5	4411	4444	4117	4324	150	875.2	38.9
6	4625	4525	4417	4522.333	150	893.2	39.7

The following graph is obtained between the Compressive Strength and the Ultrasonic PulseVelocity

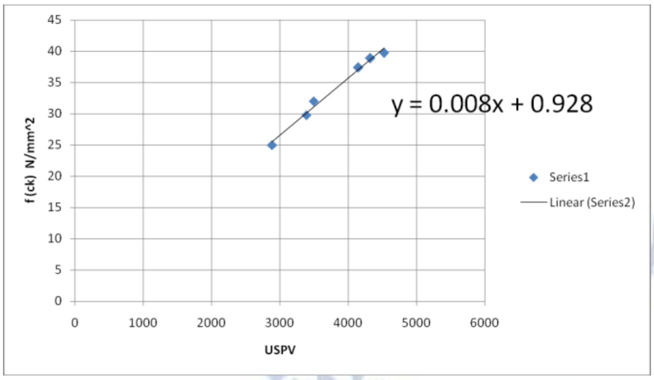

Figure 6: Compressive Strength and the Ultrasonic Pulse Velocity

This graph can now also be used to approximately predict the Compressive Strength of Concrete.
Although it gives fairly approximate results but it should be verified with some other tests like the Rebound Hammer test.

Grade of concrete used M 20

	REBOUND NO.		ULTRASONIC PULSE VELOCITY (m/sec)	
SL NO.	WITHOUT REINF'MENT	WITH REINF'MENT	WITHOUT REINF'MENT	WITH REINF'MENT
1st End	29	30	2861	3155
Quarter Length	28	29	2941	3053
Mid Span	30	31	2991	3075
Three Quarter Length	28	29	2800	2908
2nd End	29	29	2925	3224

Grade of concrete used M 25

	REBOUND NO.		ULTRASONIC PULSE VELOCITY (m/sec)	
SL NO.	WITHOUT REINF'MENT	WITH REINF'MENT	WITHOUT REINF'MENT	WITH REINF'MENT
1st End	36	36	3161	3688
Quarter Length	36	37	3141	3374
Mid Span	35	37	3191	3488
Three Quarter Length	39	41	3322	3778
2nd End	39	39	3257	3722

The maximum variation obtained for Rebound Value 3.6 % whereas in case of
Ultrasonic Pulse Velocity the maximum variation is 16.1 % .Therefore, the variations are well within the tolerable limits.

5. CONCLUSIONS

Considerable engineering judgment is needed to properly evaluate a measurement. Misinterpretation is possible when poor contact is made. For example, in some cases it may not be possible to identify severely corroded reinforcing bar in poor quality concrete. However, it is possible to identify poor quality concrete which could be the cause of reinforcing bar problems. The poor-quality concrete allows the ingress of moisture and oxygen to the reinforcing bars, and hence corrosion occurs. Presently the system is limited to penetration depths of 1 ft. Research is ongoing to develop a system that can penetrate to a depth of 10 ft or more.

When variation in properties of concrete affect the test results, (especially in opposite directions), the use of one method alone would not be sufficient to study and evaluate the required property. Therefore, the use of more than one method yields more reliable results. For example, the increase in moisture content of concrete increases the ultrasonic pulse velocity but decreases the rebound number . Hence, using both methods together will reduce the errors produced by using one method alone to evaluate concrete. Attempts have been done to relate rebound number and ultrasonic pulse velocity to concrete strength. Unfortunately, the equation requires previous knowledge of concrete constituents in order to obtain reliable and predictable results.

The Schmidt hammer provides an inexpensive, simple and quick method of obtaining an indication of concrete strength, but accuracy of ±15 to ±20 per cent is possible only for specimens cast cured and tested under conditions for which calibration curves have been established. The results are affected by factors such as smoothness of surface, size and shape of specimen, moisture condition of the concrete, type of cement and coarse aggregate, and extent ofcarbonation of surface.

The pulse velocity method is an ideal tool for establishing whether concrete is uniform. It can be used on both existing structures and those under construction. Usually, if large differences in pulse velocity are found within a structure for no apparent reason, there is strong reason to presume that defective or deteriorated concrete is present. Fairly good correlation can be obtained between cube compressive strength and pulse velocity. These relations enable the strength of structural concrete to be predicted within ±20 per cent, provided the types of aggregate and mix proportions are constant.

In summary, ultrasonic pulse velocity tests have a great potential for concrete control, particularly for establishing uniformity and detecting cracks or defects. Its use for predicting strength is much more limited, owing to the large number of variables affecting the relation between strength and pulse velocity.

The deviation between actual results and predicted results may be attributed to the fact that samples from existing structures are cores and the crushing compressive cube strength was obtained by using various corrections introduced in the specifications. Also, measurements were not accurate and representative when compared to the cubes used to construct the plots. The use of the combined methods produces results that lie close to the true values when compared with other methods. The method can be extended to test existing structures by taking direct measurements on concrete elements.

Unlike other work, the research ended with two simple chart that requires no previous knowledge of the constituents of the tested concrete. The method presented is simple, quick, reliable, and covers wide ranges of concrete strengths. The method can be easily applied to concrete specimens as well as existing concrete structures. The final results were compared with previous ones from literature and also with actual results obtained from samples extracted from existing structures.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

References

[1] V. Malhotra, Editor, Testing Hardened Concrete: Non-destructive Methods, ACI, Detroit, US (1976) monograph No. 9.

[2] A. Leshchinsky, Non-destructive methods Instead of specimens and cores, quality control of concrete structures. In: L. Taerwe and H. Lambotte, Editors, Proceedings of the International Symposium held by RILEM, Belgium, E&FN SPON, UK (1991), pp. 377–386.

[3] Raju, B. G., & Rao, K. N. S. (2015). Characterization of fibre reinforced bituminous mixes. International Journal of Science and Research (IJSR), 4(12), 802-806.

[4] Kiranmai, Y., & Rao, K. N. S. (2018). Strength permeation and nano studies on fly ash based magnetic water concrete. International Journal of Scientific Engineering and Technology Research, 7(6), 1088-1093.

[5] Pandey, S., Singh, N. K., Rao, K. N. S., Yadav, T. C., Sanghavi, G., Yadav, M., ... & Nayak, J. (2020). Bacterial production of organic acids and subsequent metabolism. Engineering of Microbial Biosynthetic Pathways, 153-173.

[6] SUSHMA, K. V. N., & RAO, K. N. S. Designing Liquid Retaining Frame for Overhead Tank.

[7] KUMAR, M. C. N., & RAO, K. N. S. Moderate Density Fly Ash Blend to Erect Geopolymer Binders.

[8] PRASAD, U., & RAO, K. N. S. AN EXPERIMENTAL INVESTIGATION ON UTILIZATION OF LOW DENSITY TESLON WASTE IN THE MANUFACTURING OF PAVER BRICK.

[9] GOPI, G. V., & RAO, K. N. S. STUDY OF STRENGTH PROPERTIES OF CONCRETE BY PARTIAL REPLACEMENT OF CEMENT WITH SILICAFUME, METAKAOLIN AND GGBS.

[10] Saikrishna, P., & Rao, K. N. S. An Investigational Work on Mechanical Properties of Low Calcium Fly Ash Based Geopolymer Concrete with GGBS.

[11] Srikanth N, et.al, Experimental Investigation on Strength and Toughness Properties of Self Compacting Concrete Mineral Admixtures, Test Engineering Management, March - April 2020 ISSN: 0193-4120 Page No. 17246 – 17253.

[12] ASTM C 805-85, Test for Rebound Number of Hardened Concrete, ASTM, USA (1993).

[13] Srikanth N, et.al, Mechanical and Durability Properties of Flyash Geopolymer Concrete Using Granite Waste, The International journal of analytical and experimental modal analysis, ISSN NO:0886-9367, Volume XII, Issue VII, July/2020, Page No:2223-2230.

[14] BS 1881: Part 202, 1986: Recommendations for Surface Hardness Tests by the Rebound Hammer, BSI, UK (1986).

[15] In Place Methods for Determination of Strength of Concrete; ACI Manual of Concrete Practice, Part 2: Construction Practices and Inspection Pavements, ACI 228.1R-989, Detroit, MI (1994) 25 pp..

[16] N. Srikanth, et.al, Study on Different Internal Curing Agents on Properties Self-Compacting Concrete, The International journal of analytical and experimental modal analysis, ISSN NO: 0886-9367, Volume XV, Issue VI, June/2023, Page No: 254-262

[17] T. Akashi and S. Amasaki, Study of the stress waves in the plunger of a rebound hammer at the time of impact. In: V.M. Malhotra, Editor, In situ/Nondestructive Testing of Concrete, ACI SP-82, Detroit (1984), pp. 19–34.

[18] S. Amasaki, Estimation of strength of concrete structures by the rebound hammer. CAJ Proc Cem Conc 45 (1991), pp. 345–351.

[19] W. Grieb. In: Use of the Swiss Hammer for Estimating the Compressive Strength of Hardened Concrete, FHWA Public Roads 30 (1958), pp. 45–50 Washington, DC, No. 2, June.

[20] C. Willetts. Investigation of Schmidt Concrete Test Hammer, Miscellaneous Paper No. 6-267,

[21] U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS (1958) June.

[22] G. Teodoru, The use of simultaneous nondestructive tests to predict the compressive strength of concrete. In: H.S. Lew, Editor, Nondestructive Testing vol. 1, ACI, Detroit (1988), pp. 137– 148 ACI SP-112.

[23] Dr. K Naga Sreenivasa Rao, et.al, Utilization of fly ash and Baggage ash in light weight concrete, The International journal of Analytical and experimental modal analysis, ISSN 0886-9367, volume XV, Issue VI, June/2023

[24] Dr. K Naga Sreenivasa Rao, et.al, Experimental Investigation on partial replacement of fine aggregate with stone dust in concrete, The International journal of Analytical and experimental modal analysis, ISSN 0886-9367, volume XV, Issue VI, June/2023

[25] Dr. K Naga Sreenivasa Rao, et.al, An investigational work on mechanical properties of low calcium flyash based geopolymer concrete with GGBS, IJAEM, Volume 5, Issue 4, 2023, ISSN 2395-5252, PP 1103-1112.

[26] Dr. K Naga Sreenivasa Rao, et.al, Experimental study on geopolymer concrete by using glass fibre, The International journal of Analytical and experimental modal analysis, ISSN 0886-9367, volume XIV, Issue VI, June/2022

[27] Dr. K Naga Sreenivasa Rao, et.al, Experimental study on strength of concrete by using sand stone dust, IRJET, Volume 09, Issue 12, ISSN 2395-005, Dec-2022, PP-754-760, PP 583-588.

[28] K Naga Sreenivasa Rao, et.al, Strength Peremenation and nano studies an flyash based magnetic water concrete, ISJER, Volume 7, Issue 6 PP 1088-1093, 2018, ISSN 2319-8885

[29] K Naga Sreenivasa Rao, et.al, Impact of strength properties on concrete by relatively replacement of cement with clay and flyash, IJITR, Volume 5, Issue 3, ISSN 2320-5547, PP 6376-6379, 2017

[30] K Naga Sreenivasa Rao, et.al, Moderate density flyash blended to erect geopolymer binders, IJITR, Volume 4, Issue 6, ISSN 2320-5547, PP 4504-4507

[31] K Naga Sreenivasa Rao, et.al, Experimental investigation on the strength properties of eco-friendly concrete, JICR, Volume 12, Issue 7, ISSN 0022-1945, PP 1171-1175

[32] A. Neville. Properties of Concrete, Addison-Wesley Longman, UK (1995).

[33] ASTM C 597-83 (Reapproved 1991), Test for Pulse Velocity Through Concrete, ASTM, USA (1991).

[34] BS 1881: Part 203: 1986: Measurement of Velocity of Ultrasonic Pulses in Concrete, BSI, UK (1986).

[35] A. Nilsen and P. Aitcin, Static modulus of elasticity of high strength concrete from pulse velocity tests. Cem Concr Aggregates 14 1 (1992), pp. 64–66.

[36] R. Philleo, Comparison of results of three methods for determining Young's modulus of elasticity of concrete. J Am Concr Inst 51 (1955), pp. 461–469 January.

[37] M. Sharma and B. Gupta, Sonic modulus as related to strength and static modulus of high strength concrete. Indian Concr J 34 4 (1960), pp. 139–141.

[38] ACI 318-95, Building Code Requirements for Structural Concrete (ACI 318-95) and Commentary-ACI 318R-95, ACI, USA (1995) 369 pp..

[39] E. Whitehurst, Soniscope tests concrete structures. J Am Concr Inst 47 (1951), pp. 433–444 Feb..

[40] R. Jones and E. Gatfield. Testing Concrete by an Ultrasonic Pulse Technique, DSIR Road Research Tech. Paper No. 34, HMSO, London (1955).

[41] C. Yun, K. Choi, S. Kim and Y. Song, Comparative evaluation of nondestructive test methods for in-place strength determination. In: H.S. Lew, Editor, Nondestructive Testing, ACI SP-112, ACI, Detroit (1988), pp. 111–136.