AN EXPERIMENTAL STUDY AND REGRESSION ANALYSIS ON EFFECT OF CARBONATION AND pH IN AGED CONCRETE STRUCTURES.

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Abstract- *An experimental study was performed to evaluate regression equations on pH and carbonation depth of concrete samples collected from different ages of structures. Field tests that are conducted on structural elements are rebound hammer test and ultrasonic pulse velocity test methods and carbonation depth. Laboratory test that conducted on collected concrete samples is pH. So all these four different types of tests like pH and carbonation depth and rebound hammer test and ultrasonic pulse velocity test methods are conducted on different type of structures like residential buildings , pylons , water resource structures and cement concrete roads. In residential buildings the age of structures are is also different like t=50,45,30 and 25 years. Similarly the pylons of different age like t=30 and 25 years and water resource structures of different age like t= 25 and 20 years and cement concrete roads of age t= 20 and 15 years. carbonation depth test was conducted by using chemical phenolphthalene and drilling machine. Similarly ultrasonic pulse velocity test methods and rebound hammer test methods are conducted as per is : 13311 part1 and part2. So p^h of concrete samples are decreased as carbonation depth increases and for more strength of concrete samples carbonation depth propagation was less. Quality of concrete is more for greater strength of* concrete samples. As strength is going to increases the p^h value of sample increases.

***Key Words*: carbonation depth, pH, rebound hammer test, ultra sonic pulse velocity test.**

1 .INTRODUCTION

1.1 General

Concrete is the most widely used construction material. It is prepared together mixing cementing materials, aggregates, water and sometimes admixtures in required proportions. Admixtures are ingredients other than water, aggregate and cement that are added to concrete mixture prior to or during mixing. Concrete occupies unique position among the modern construction materials.

The Carbonation, which is one of the major causes for structure deterioration. It happens when carbon dioxide from atmosphere comes in contact with hydration product of cement ,it changes the physical and chemical properties of concrete. It is process of formation of $Ca(OH)_2$ turns into $CaCO_3$.The carbonation depends on different factors that are water cement ratio, atmosphere concentration of co_2, relative humidity and ambient temperature. pH is an important parameter to indicate the alkalinity level of concrete. The most severe concrete damages are caused or accompanied by dropping of the alkalinity level and consequently, decrease of the pH value of concrete. Therefore, it is crucial to measure the pH of concrete by an accurate and reliable method. The methods that have been developed for measuring the pH of fresh and hardened concrete.

pH of concrete depends on different parameters like water cement ratio , atmosphere concentration of co_2, relative humidity and ambient temperature. Ultrasonic pulse is generated by an electro acoustical transducer. A complex system of stress waves is developed which includes longitudinal (compression), shear (transverse) and surface (rayleigh)waves. higher velocities are obtained when the quality of concrete is good. In case of poorer quality, lower velocities are obtained. ultrasonic pulse depends on different properties like Surface Conditions and Moisture Content of Concrete, Path Length, Shape and Size of the Concrete Member ,Temperature of Concrete ,Stress ,Reinforcing Bars. Rebound hammer is pressed against the surface of the concrete, the spring- controlled mass rebounds and the extent of such rebound depends upon the surface hardness of concrete. The surface hardness and therefore the rebound is taken to be related to the compressive strength of the concrete. The rebound is read off along a graduated scale and is designated as the rebound number or rebound index.

Rebound hammer index depends on different parameters like Type of Cement , Type of Aggregate , Surface Condition and Moisture Content of Concrete , Curing and Age of Concrete

2. EXPERIMENTAL WORK

1. Ultrasonic pulse velocity test (IS 13311:part1).

2. Rebound hammer test (IS 13311:part2).

3. p^H test method.

4. Carbonation test method

2.1 Ultrasonic pulse velocity test (IS 13311:part1).

The ultrasonic pulse velocity method could be used to establish the homogeneity of the concrete, changes in the structure of the concrete which may occur with time, the quality of the concrete in relation to standard requirements, the quality of one element of concrete in relation to another. The apparatus for ultrasonic pulse velocity measurement shall consist of the following Equipment :

a) Electrical pulse generator

b) Transducer - one pair

c) Amplifier

d) Electronic timing device

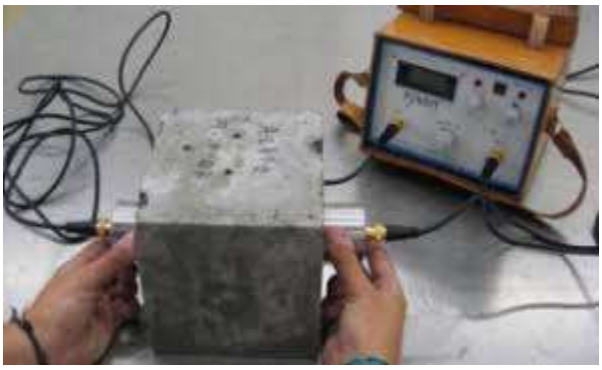

Fig1: Ultrasonic pulse velocity test apparatus

Calculations:

The pulse velocity (V) is given by:

V = L/T

L = Wave traversing path length.

T = Transit time of the pulse.

Table 1: Velocity Criterion for Concrete Quality Grading

S.NO	Pulse velocity by cross probing (Km/sec)	Concrete quality grading
1.	Above 4.5	Excellent
2.	3.5 to 4.5	Good
3.	3.0 to 3.5	Medium
4.	Below 3.0	Doubtful

2.2. Rebound hammer test (IS 13311:part2)

The rebound hammer method could be used for assessing the likely compressive strength of concrete with the help of suitable co relations between rebound index and compressive strength, assessing the uniformity of concrete, assessing the quality of the concrete in relation to standard requirements, and assessing the quality of one element of concrete in relation to another. The Rebound Hammer consists of a spring controlled mass that slides on a plunger within a tubular housing. The impact energy required for rebound hammers for different applications is given.

Table: Impact Energy for Rebound Hammers for Different Applications

s.no	Application	Impact Energy Required for the Rebound Hammers (Nm)
1.	For testing normal weight concrete	2.25
2.	For light-weight concrete or small and impact sensitive parts of concrete	0.75
3.	For testing mass concrete for example in roads, air-fields pavements and hydraulic structures.	30

PROCEDURE: For testing, smooth, clean and dry surface is to be selected. If loosely adhering scale is present, this should be rubbed of with a grinding wheel or stone. Rough surfaces resulting from incomplete compaction, loss of grout, spalled or tooled surfaces do not give reliable results and should be avoided. The point of impact should be at least 20 mm away from any edge or shape discontinuity. For taking a measurement, the rebound hammer should be held at right angles to the surface of the concrete member. The test can thus be conducted horizontally on vertical surfaces or vertically upwards or downwards on horizontal surfaces. If the situation demands, the rebound hammer can be held at intermediate angles also, but in each case, the rebound number will be different for the same concrete. Rebound hammer test is conducted around all the points of observation on all accessible faces of the structural element.

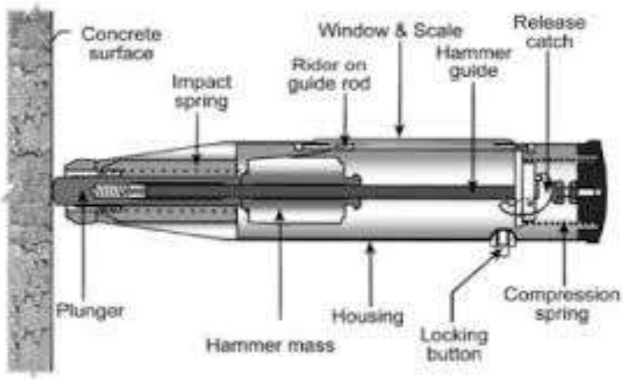

Fig 2: Rebound hammer test apparatus

Calculations and interpretation of results:

The Rebound hammer method provides a convenient and rapid indication of the compressive strength of concrete by means of establishing a suitable correlation between the rebound index and the compressive strength of concrete. Only the vertical faces of the cube as cast should be tested. At least nine readings should be taken on each of the two vertical faces accessible in the compression testing machine when using the rebound hammers. The points of impact on the specimen must not be nearer an edge than 20 mm and should be not less than 20 mm from each other. The same points must not be impacted more than once.

2.3 p^H test method:

Finding out p^H for concrete sample is bewildering process to understand the factors that are influencing the the p^H .There are so major variables such as the type of concrete, sample size, dilution ratio, soaking time, sample gradation, and temperature. After rigorous searching for perfect procedure for finding out p^H of concrete samples, the trusted procedure based on ASTM standards are followed.

Equipment

1)p^H meter.
2)Pipete.
3)100 ml glass water beaker.
4)Glass stirring rod.

Fig 3 : p^H meter electrode test apparatus

Procedure:

a) Calibrate the p^H meter using the manufacturer's directions and appropriate buffer solutions.
b) Collect concrete powder at the required depth using a drill.
c) Use a glass stirrer to mix the concrete powder with of fresh distilled water with diluton ratio of 1:2 at a temperature of 22 ± 1 °C.
d) Wait, until the soaking period 30 minutes ends.
e) Insert the p^H electrode into the mixture. Read the pH to one decimal place.

2.4. Carbonation test method:

Carbonation test method is used to find the depth in measurement of up to carbonation happened in the concrete. When carbon dioxide (CO_2) from atmosphere comes in contact with the hydration products of cement, it changes the physical and chemical properties of the concrete . It is process of formation of $CaCO_3$ from $Ca(OH)_2$ in the presence of carbon dioxide.

Equipment

1) Drilling machine
2)Test element of structure
3) Phenolphthalene
4) Steel rule
5) Specimen collection packets

Procedure:

a) Select the structural element that should be tested.
b) First clear of the surface without any spalling and dirt.
c) Mark on the needle of the drilling machine minimum up to 3cm and after mark for everyone centimeter.
d) First drill the structural element up to minimum depth of 3 cm and collect the the sample on sample collection packets.
e) Then pass the phenolphthalene indicator in the hole of structural element, and observe if there is any colour changing in the liquid.
f) If suppose there is no change of colour in phenolphthalene indicator extend the experiment and drill the structural element with one centimeter proceeding.
g) Similarly, repeat the experiment upto the colour changing in phenolphthalene indicator and note down the depth of at which phenolphthalene indicator changed the colour.

Carbonation depth is the reading in millimeters exactly at what depth the phenolphthalein indicator changes its colour.

3. RESULTS AND DISCUSSION:

3.1 The results of the experimental investigation are presented in this chapter. The following like rebound hammer test,ultra sonic pulse velocity test, carbonation depth and pH tests are conducted on residential; structures with different ages like 50 years,45 tears,30 years and 25 years, similarly pedestals of plyons with different ages like 30 years and 25 years. The test results are as following.

Table 3: Test results of residential building

s.no	f_{ck} (Mpa)	C_d (mm)	Quality of concrete (Km/sec)	pH	Age (yesrs)
RB1(C)	20	70	2.605(D)	8.95	50
RB1(B)	28	60	2.8159(D)	9.15	50
RB1(S)	28	50	3.803(M)	9.28	50
RB2(C)	35	50	4.777(E)	9.48	50
RB2(B)	35	40	4.797(E)	9.97	50
RB2(S)	40	40	4.977(E)	10.4	50
RB3(C)	31	70	2.102(D)	8.75	45
RB3(B)	32	70	2.857(D)	8.9	45
RB3(S)	35	60	3.008(M)	9.1	45
RB4(C)	40	50	3.857(G)	9.45	45
RB4(B)	42	40	3.988(G)	9.55	45
RB4(S)	42	30	4.247(G)	9.65	45
RB5(C)	23	60	3.489(G)	9.88	30
RB5(B)	25	60	3.492(G)	9.98	30
RB5(S)	29	50	3.483(G)	10	30
RB6(C)	32	50	4.416(G)	10	30
RB6(B)	35	40	4.658(E)	10.7	30
RB6(S)	44	40	4.477(G)	11	30
RB7(C)	46	50	4.978(E)	11.3	30
RB7(B)	49	30	5.307(E)	11.5	30
RB7(S)	49	30	5.351(E)	11.7	30
RB8(C)	22	50	3.123(M)	10.78	25
RB8(B)	24	50	3.467(M)	10.8	25
RB8(S)	30	40	4.2729G)	11.78	25
RB9(C)	30	40	3.809(M)	11.86	25
RB9(B)	32	30	4.136(G)	11.98	25
RB9(S)	40	30	4.492(E)	12.34	25

In the above table f_{ck} means compressive strength from rebound hammer test results, C_d means carbonation depth in mm. The test results of residential building are discussing by comparing compressive strength vs carbonation depth ,compressive strength vs quality of concrete and strength vs Ph with respect to their ages like t=50years,45 years,30 years and 25 years.

Comparing results of compressive strength vs carbonation depth in residential buildings

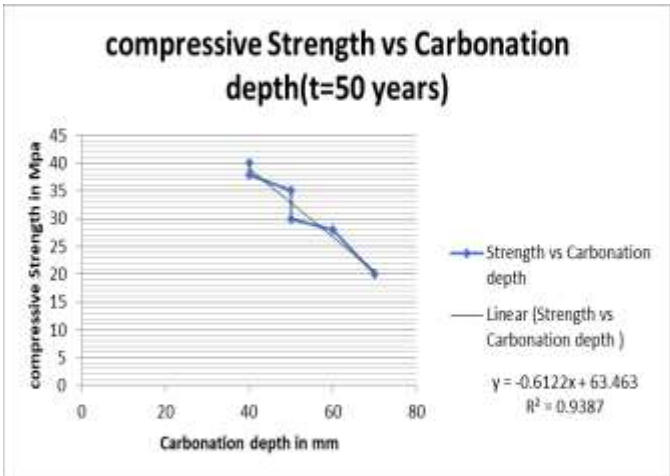

Fig 4: comparing test results of 50 years of residential building

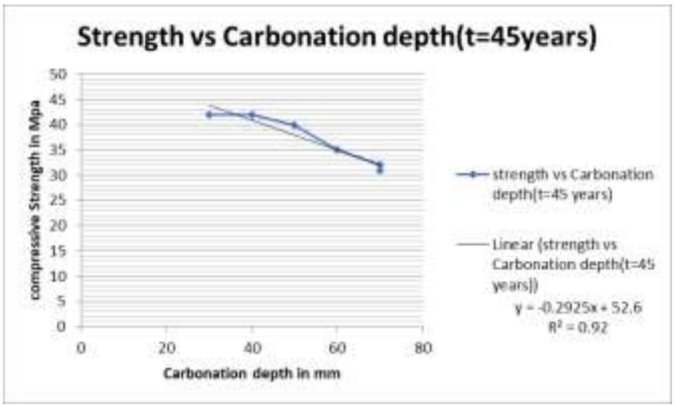

Fig 5: comparing test results of 45 years of residential building

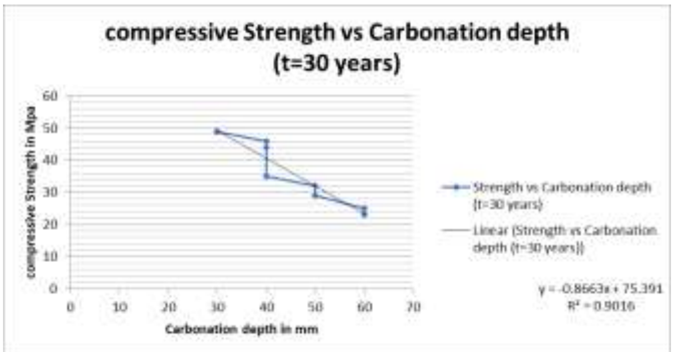

Fig 6: comparing test results of 30 years of residential building

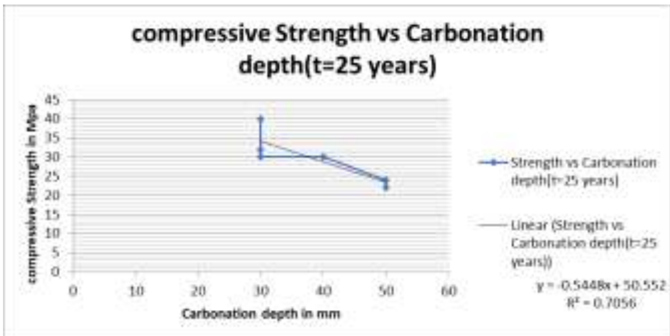

Fig 7: comparing test results of 25 years of residential building

Here, we were compared the results of compressive strength and carbonation depth of chosen old existing concrete structure were. carbonation depth on x-axis and compressive strength on y-axis were taken. It is observed that as carbonation depth increases, compressive strength steadily decreases.

Comparing results of compressive strength vs quality of concrete in residential building.

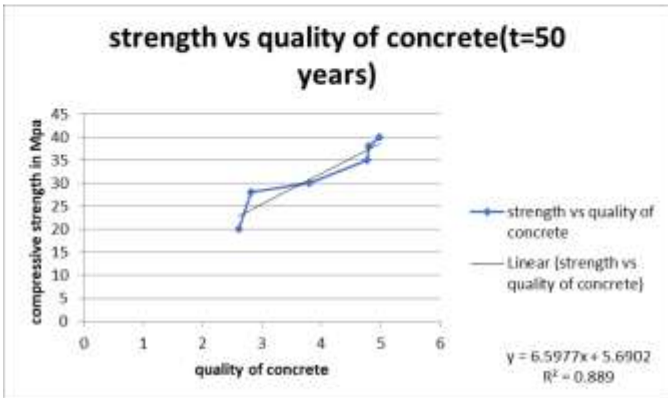

Fig 8: comparing test results of 50 years of residential building

Fig 9: comparing test results of 45 years of residential building

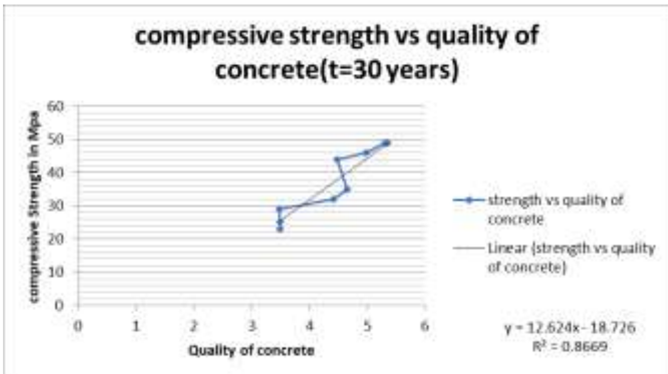

Fig 10: comparing test results of 30 years of residential building

Fig 11: comparing test results of 25 years of residential building

The test results of compressive strength and quality of concrete are compared and analysed by drawing the graph. The x-axis is taken for quality of concrete and y-axis is taken as compressive strength. From the graph it has been observed that compressive strength increases as the quality of concrete assessed by upv increases.

Comparing results of compressive strength vs pH in residential buildings.

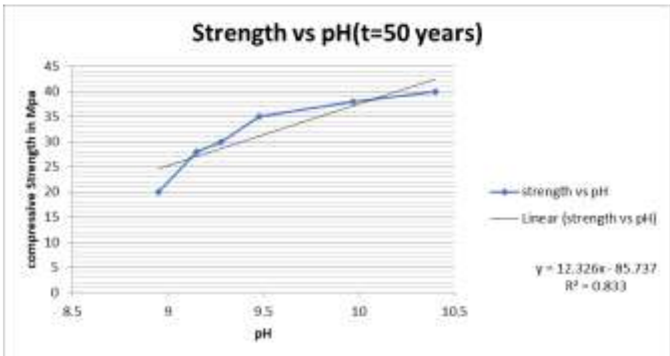

Fig 12: comparing test results of 50 years of residential building

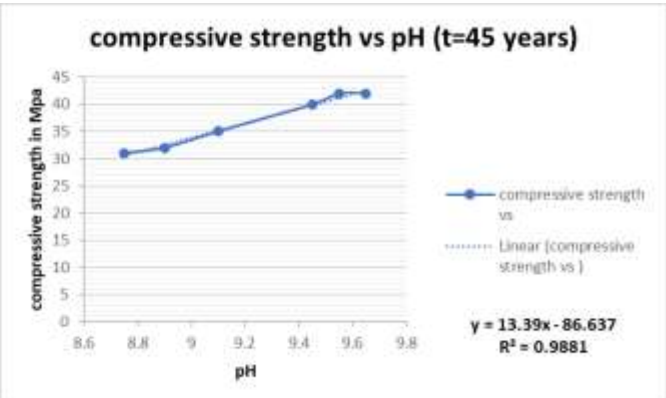

Fig 13: comparing test results of 45 years of residential building

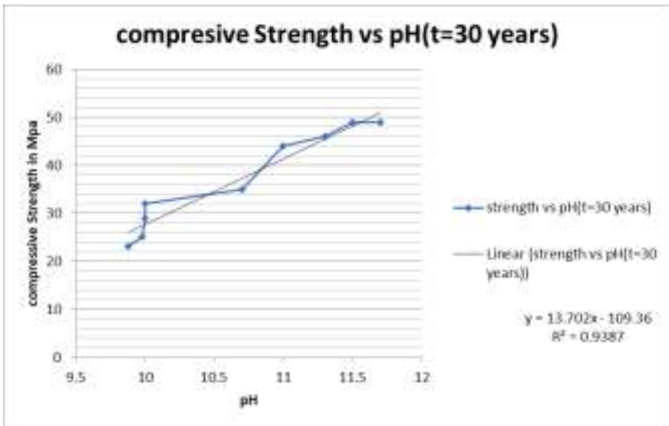

Fig 14: comparing test results of 30 years of residential building

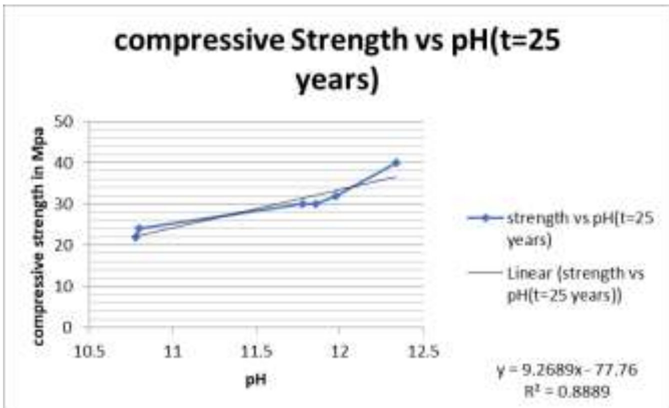

Fig 15: comparing test results of 25 years of residential building

The test results of compressive strength vs pH of concrete, these are compared and analysed by drawing the graph. The x-axis is taken for pH and y-axis is taken for compressive strength. From the results we are observed that compressive strength of concrete increases as pH increases.

3.2

The results of the experimental investigation are presented in this chapter. The following like rebound hammer test, ultrasonic pulse velocity test, carbonation depth and pH tests are conducted on pedestals of pylons with age of 30 years and 25 years.

Table 4: Test results of pylons

s.no	f_{ck} (Mpa)	C_d (mm)	Quality of concrete (Km/sec)	pH	Age (years)
P1	24	70	1.751	8.87	30
P2	24	70	2.156	8.63	30

P3	25	60	2.19	9.13	30
P4	24	70	2.25	8.75	30
P5	25	60	2.396	9.16	30
P6	26	60	2.756	9.22	30
P7	28	50	2.88	10.64	25
P8	28	50	3.018	10.58	25
P9	28	50	3.068	10.88	25
P10	30	40	3.068	11	25
P11	30	40	3.112	11.1	25
P12	32	40	3.13	11.2	25
P13	33	30	3.183	11.51	25
P14	35	30	3.4	11.48	25
P15	35	30	3.5	11.46	25

Comparing test results in pylons:

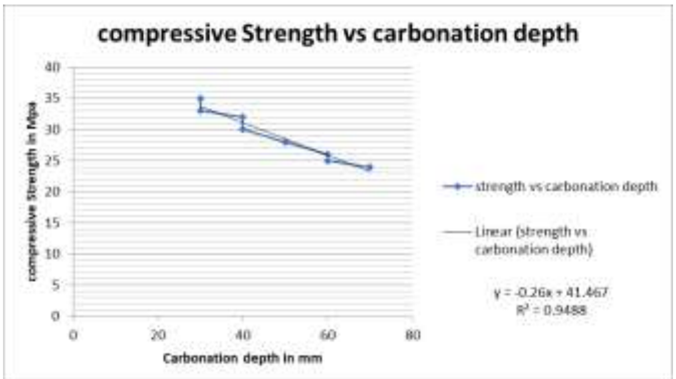

Fig 16: Comparing results of compressive strength vs carbonation depth in plyons.

Here, we were compared the results of compressive strength and carbonation depth of chosen old existing concrete structure were compared. carbonation depth on x-axis and compressive strength on y-axis were taken. It is observed that as carbonation depth increases, compressive strength steadily decreases.

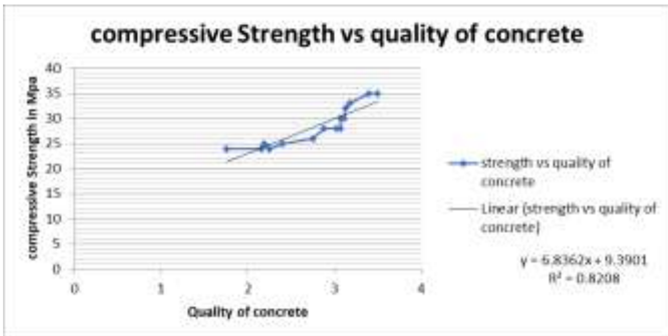

Fig 17: Comparing results of compressive strength vs quality of concrete in plyons.

The test results of compressive strength and quality of concrete are compared and analyzed by drawing the graph. The x-axis is taken for quality of concrete and y-axis is taken as compressive strength. From the graph it has been observed that compressive strength increases as the quality of concrete assessed by up increases.

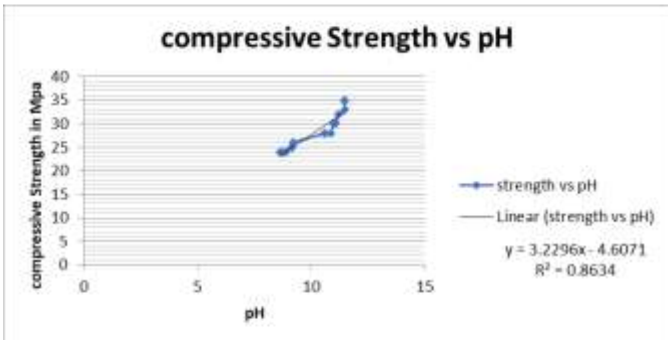

Fig 18: Comparing results of compressive strength vs pH in plyons.

The test results of compressive strength vs pH of concrete, these are compared and analysed by drawing the graph. The x-axis is taken for pH and y-axis is taken for compressive strength. From the results we are observed that compressive strength of concrete increases as pH increases.

4. REGRESSION ANALYSIS

Regression models of carbonation depth and pH are developed for both residential building and plyons are developed based on test results. Here there is both observed results and predicted results.

4.1 Regression models for residential building

Regression equation for carbonation depth in residential building

$C_d = 80.473-(0.395*f_{ck})+(0.396*age)-(8.865*quality)$

Regression equation for carbonation depth in residential building

pH =10.803+(0.012*f_{ck})-(0.076*age)+(0.479*quality)

Here variable f_{ck} represents characteristic compressive strength of cube in Mpa ,age represents the elapse time in years after construction, quality term represents velocity of pulse in Km/sec generated by ultra sonic pulse velocity test.

Comparison of observed results and predicted results

Table 5: Comparison of observed and predicted test results of residential building

s.no	Observed values		Predicted values	
	pH	Cd	pH	Cd
RB1(C)	8.95	70	8.48	69.30
RB1(B)	9.15	60	8.68	64.27
RB1(S)	9.28	50	9.17	54.73
RB2(C)	9.48	50	9.70	44.12
RB2(B)	9.97	40	9.75	42.76
RB2(S)	10.4	40	9.86	40.37
RB3(C)	8.75	70	8.75	67.43
RB3(B)	8.9	70	9.13	60.34
RB3(S)	9.1	60	9.23	57.82
RB4(C)	9.45	50	9.70	48.32
RB4(B)	9.55	40	9.7	46.37
RB4(S)	9.65	30	9.91	44.07
RB5(C)	9.88	60	10.467	52.35
RB5(B)	9.98	60	10.49	51.53
RB5(S)	10	50	10.53	50.03
RB6(C)	10	50	11.01	40.57
RB6(B)	10.7	40	11.17	37.24
RB6(S)	11	40	11.19	35.30
RB7(C)	11.3	40	11.13	35.98
RB7(B)	11.5	30	11.64	25.96
RB7(S)	11.7	30	11.66	25.57
RB8(C)	10.78	50	10.66	54.00
RB8(B)	10.8	50	10.84	50.17
RB8(S)	11.78	40	11.30	40.66
RB9(C)	11.86	30	11.08	44.76
RB9(B)	11.98	30	11.26	41.07
RB9(S)	12.34	30	11.53	34.76

The above observed test results and predicted test results are shown below.

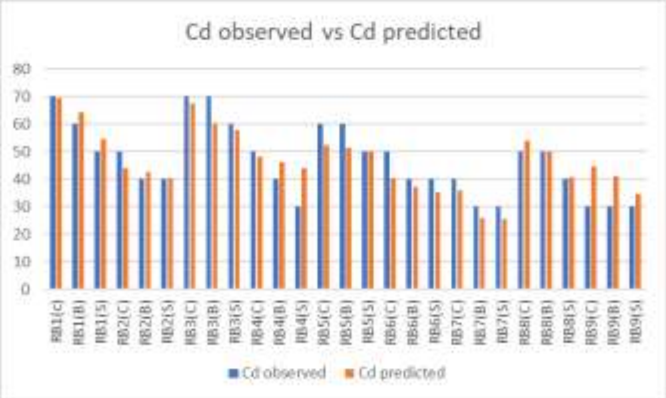

Fig 19: comparison of observed Cd and predicted Cd in residential building.

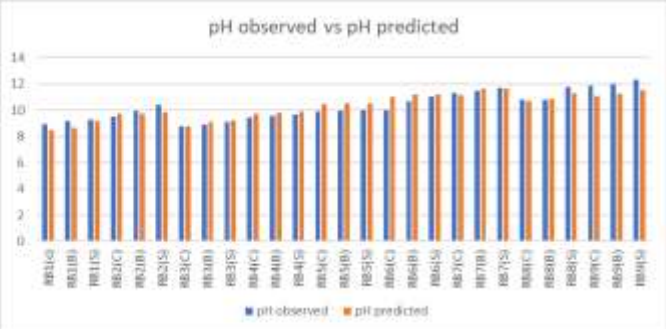

Fig 20: comparison of observed pH and predicted pH in residential building.

4.2 Regression models for pylons

Regression equation for carbonation depth in Pylons

C_d=115.502-(2.769*f_{ck})+(0.857*age)-(3.527*quality)

Regression equation for pH in Pylons

pH =13.755+(0.1135*f_{ck})-(0.262*age)+(0.117*quality)

Here variable f_{ck} represents charachteristic compressive strength of cube, age represents the elapse time of structure after completion of construction, quality term represents velocity of pulse generated by ultra sonic pulse velocity test.

Comparison of observed results and predicted results

Table 6: Comparison of observed and predicted test results of pylons

s.no	Observed values		Predicted values	
	pH	Cd	pH	Cd
P1	8.87	70	8.82	68.60
P2	8.63	70	8.87	67.17
P3	9.13	60	8.99	64.28
P4	8.75	70	8.88	66.84
P5	9.16	60	9.01	63.56
P6	9.22	60	9.17	59.5
P7	10.64	50	10.72	49.26
P8	10.58	50	10.73	48.77
P9	10.88	50	10.74	48.59
P10	11	40	10.97	43.06
P11	11.1	40	10.97	42.92
P12	11.2	40	11.20	37.30
P13	11.51	30	11.32	34.35
P14	11.48	30	11.57	28.04
P15	11.46	30	11.58	27.69

The above observed test results and predicted test results are shown below.

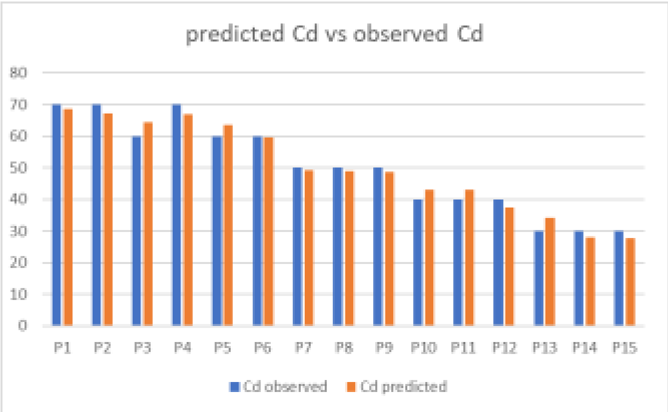

Fig 21: comparison of observed Cd and predicted Cd in pylons.

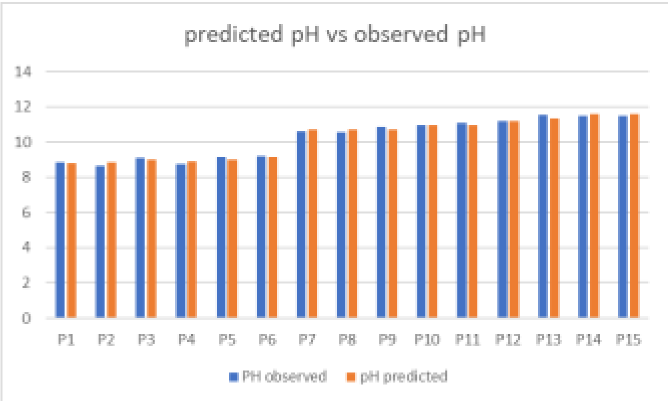

Fig 22: comparison of observed pH and predicted pH in pylons.

7. CONCLUSIONS

Tests were conducted on the four selected dissimilar structures, carbonation depth and pH and quality of concrete and strength of concrete are found out. Similar tests were conducted on four dissimilar structures to analyze the strength variation with varying quality of concrete, pH and carbonation depth and regression models are developed for predicting carbonation depth and pH for different age, compressive strength and quality of concrete.

The following concluding remarks are made based on analysis on test results

- The percentage increase in average carbonation depth for increasing age of residential structure from 25 years to 50 years is 34.7.
- The percentage increase in average carbonation depth for increasing age of pedestal of plyons from 25 years to 30 years is 62.5.
- The percentage decrease in average pH for increasing age of residential structure from 25 years to 50 years is 17.7.
- The percentage decrease in average pH for increasing age of pedestal of plyons from 25 years to 30 years is 19.23.

REFERENCES

1. Jennifer A.Gurb,Hemanth S.Lmaye and Ashok M.Kanade " standard procedure for testing pH of concrete".
2. Antoine Morandeau, Mickaël Thiery, Patrick Dangla - "Investigation of the carbonation mechanism of {CH} and C-S-H in terms of kinetics, microstructure changes and moisture properties"
3. A. Morandeau a,b,⁎, M. Thiérya, P. Danglab - Investigation of carbonation mechanism of CH ansd CSH in terms of kinetics ,micro structure changes and moisture properties .
4. Vagelis G. Papadakis and Costas G. Vayenas – "Experimental Investigation and Mathamatical Modelling Of the Concrete Carbonation Problem".
5. Shaik Hussaina,*, Dipendu Bhuniab, and Shamsher B. Singhc – "An Experimental Investigation of Accelerated Carbonation on Properties of Concrete".
6. Syed S. Rizvi, Saleem Akhtar and Sanjeev K. Verma- "Carbonation induced deterioration of concrete structures".
7. Y. Yuan, J. Shen, Y. Ma, and S. Lai, "Comparison of concrete process under natural condition and high CO2 concentration environments," Journal of Wuhan University of Technology.
8. IS 456-2000: Indian Standard "Plain And Reinforced Concrete" –code of practice.
9. IS 13311:part1: Indian Standard "Non Destructive Testing of Concrete-Method of Test-UltraSonic Pulse Velocity Test"- code of practice.
10. IS 13311:part2: Indian Standard "Non Destructive Testing of Concrete-Method of Test-Rebound Hammer Test"- code of practice.