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Investigation of Concrete Quality in Old Concrete Dam for its Repair and Rehabilitation

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Abstract: This paper presents the concrete condition assessment of an inspection gallery of old dam works. Few locations of inspection galleries observed slight deterioration and water seepage mostly from the top surface of the gallery. It was carried out for the purpose of obtaining the concrete properties needed for the evaluation of strength and its quality. This was done by sampling the galleries by using non-destructive techniques such as visual inspection, perusal of drawings, ultrasonic pulse velocity (UPV) measurements, and core testing. Core testing gave information about the compression strength, splitting tensile strength, modulus of elasticity, density, and direct ultrasonic pulse velocity. Based on the results, it was recommended for repair and waterproofing of the concrete surface of the inspection gallery.

I. BACKGROUND

The inspection gallery size approximately 1.2 m wide 2.1 m high with inside the dam body. The dam is an earth dam comprising about 110 m wide concrete spillway. The primary purpose of this gallery is to provide access to the interior of the dam for inspection purposes, to monitor the behaviour of the dam in the post-construction period, and to carry out remedial work if required. The sketch of the layout of the dam body consisting of the inspection gallery shown in Figure 1. As per the available details of the construction records, two grades of concrete (Grade A & B) were used for the construction of the inspection gallery. The strength of Grade A and B are around 15 MPa and 18 MPa as per the designs and records of concrete test reports during construction.

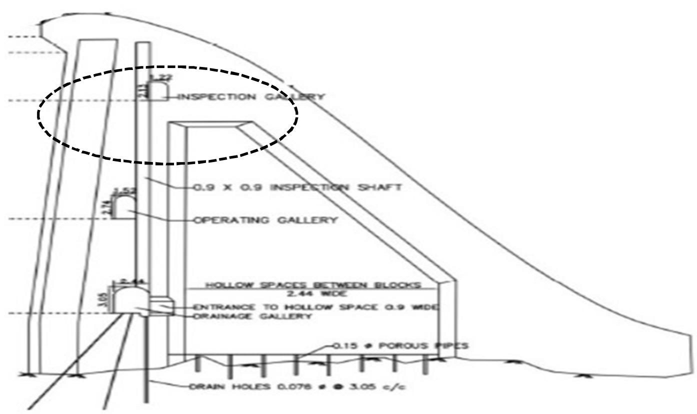

Figure 1. Layout of Dam

II. STRATEGY FOR INVESTIGATION

The board was very particular on the extraction of cores from the gallery due to structural difficulties and hence allowed for extraction as a minimum number of cores as possible. Further, the board was arrived on an opinion to study the complete stability analysis of the dam by mathematical modelling using the evaluated strength parameters such as compressive strength, split tensile strength, and modulus of elasticity of the concrete. To study a total of 29 Nos. of cores taken from the locations that are visually appeared wet due to the seepage in the inspection gallery. Visually these locations were also showed the signs of cracks on a concrete surface. It is also challenging to justify the fewer data obtained. The data collected through testing of cores is validated by using the correlations available in the literature. The size of the cores obtained is around 94 – 104 mm diameter and length varying from 175 – 315 mm. The details of various tests carried on cores is as follows:

Total No. of Cores extracted	Compressive strength (f_{ck})	Splitting Tensile Strength (f_t)	Static Elastic Modulus (E)
29	17	6	6

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III. TESTS ON CORES

As soon as completion of drilling and surface cutting of core work, the cores were dried to the oven temperature 50^o C. After pre-treatment, the UPV measurements on 24 Nos. of cores were carried out by placing the probes (24 kHz) directly on opposite faces of the core, according to IS 516 (Part 5/Sec 1) and ASTM C 597. The illustrative picture of the measurement of pulse velocity carried by using a commercially available PUNDIT 200 Touch Screen (Portable Ultrasonic Non-destructive Digital Indicating Tester) manufactured by M/s Proceq, Switzerland presented in Figure 2.

The length of each core is fed to the UPV machine before measurement, which displays the pulse velocity (v) directly by using the following in-built programmed expression:

$$V = \frac{L}{t} \qquad \text{[Eq.1]}$$

Where V = Pulse Velocity, *km/s*; L = Length of the core in meter and t = Transit time in *seconds*

The statistical summary of pulse velocity of 24 cores is presented in Table 1. Based on the velocity criterion, the approximate concrete quality can be assessed according to Table 2, which is as per the guidelines of IS 516(Part 5/Sec 1). The measured mean pulse velocity of cores observed around 4.72 km/s, which falls under the grading class of "excellent."

Table 1

Statistical Summary of Pulse Velocity in km/sec

Entity	All Cores
Maximum	5.42
Minimum	4.00
Mean	4.72
No. of Cores	24
Standard Deviation	0.373
Coefficient of Variation (COV)	7.90%

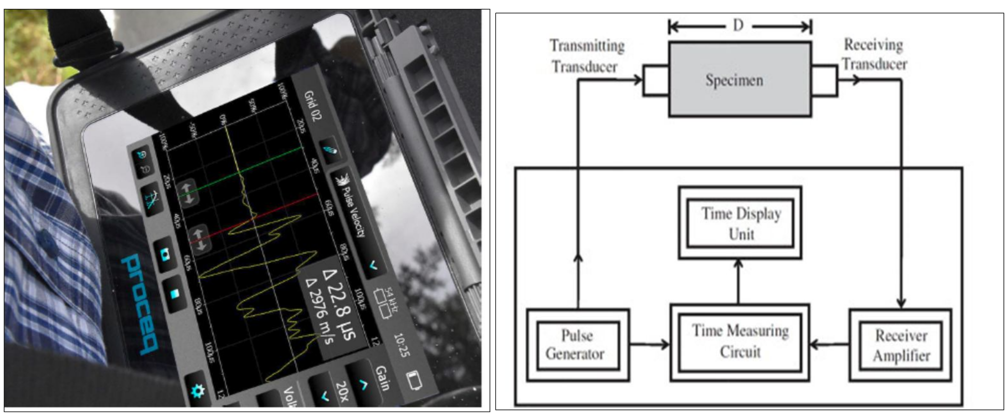

Figure.2 Schematic diagram of pulse velocity test circuit.

Table 2

Velocity Criterion for Concrete Quality Grading

Average Value of Pulse Velocity by Cross Probing in km/s	Concrete Quality Grading
Above 4.40	Excellent
3.75 to 4.40	Good
3.00 to 3.75	Doubtful#
Below 3.00	Poor

In case of "Doubtful it may be necessary to carry out further tests

After USPV testing, cores were tested for density according to IS 516(Part 2/Sec 1). The core dimensions, such as average core diameter and the average length was determined to an accuracy of ± 0.01 mm by measuring three pairs of measurements at right angles, at the half and quarter points of the length of the core. The mass of cores was also measured to an accuracy of 0.1 percent of the mass of the specimen. The density of core was calculated by using below expressed Eq. 2. The statistical Summary of density test results is presented in Table 3. From this test results, it can be observed that the mean density calculated is approximately within the range of normal concrete.

$$Density = \frac{Mass\ in\ kg}{Volume\ in\ m^3} \qquad [Eq.\ 2]$$

Table 3

Statistical Summary of density in kg/m^3

Entity	All Cores
Maximum	2440
Minimum	2260
Mean	2363
No. of Cores	24
Standard Deviation	47.956
Coefficient of Variation (COV)	2.03%

17 No. cores were tested for compressive strength, according to IS 516. Before testing, the load-bearing surfaces of cores were prepared by adopting the grinding method. Flatness, perpendicularity, parallelism, and straightness of prepared surface each core was ensured to an acceptable tolerance limit as specified in IS 516 (Part 4) before conditioning of the cores. These cores were conditioned by soaking in water for 40 - 48 hours at 27 ± 3°C temperature before testing. After removing from water, cores were wiped and brought to the surface saturated condition. These cores were carefully placed central axis of the compression testing machine (confirmed to IS 14858) platen. The rate of loading approximately 14 N.mm^2/min applied continuously on these cores until the core specimen breaks down. The compressive strength of the core specimen was calculated by using the following expressed Eq. 3. The statistical Summary of equivalent cube compressive strength test results is presented in Table 4.

$$f_{ck(Cube)} = 1.25 * (CF)_{l/d} * f_{ck,cylinder} \qquad [Eq.\ 3]$$

Where $f_{ck(Cube)}$ = Equivalent Cube compressive strength in *MPa*

$f_{ck,cylinder} = \frac{P}{A}$ (P = Load at failure in N and A = Area in mm^2)

$(CF)_{l/d}$ = Correction Factor for l/d (l = length of the core in mm and d = diamter in mm)

Table 4

Statistical Summary of Equivalent Cube Compressive Strength in MPa

Entity	All Cores
Maximum	39.39
Minimum	12.29
Mean	27.95
No. of Cores	17
Standard Deviation	7.643
Coefficient of Variation (COV)	27.34%

Cores of 6 No. were tested for splitting tensile strength, according to IS 5816. Before testing, cores were conditioned by soaking in water for 24 hours. After removing from water, cores were wiped and tested at the same time still in wet conditions. The core specimen was carefully placed centrally under the compression testing machine (confirmed to IS 14858) platen. The rate of loading applied within the range of (1.2 – 2.4) * π/4*l*d N/min continuous without shock on these cores until the core specimen breaks down into two halves. The splitting tensile strength of the core specimen was calculated by using the following expressed Eq. 4. Statistical Summary of splitting tensile strength test results are presented in Table 5.

$$f_{spt} = \frac{2P}{\pi * l * d} \quad \text{[Eq. 4]}$$

Where f_{spt} = Splitting tensile strength in MPa

P = Load at failure in N

l = length of the core in mm and

d = diamter in mm

Table 5

Statistical Summary of Splitting Tensile Strength in MPa

Entity	All Cores
Maximum	3.30
Minimum	1.53
Mean	2.62
No. of Cores	6
Standard Deviation	0.622
Coefficient of Variation (COV)	23.77%

Researchers have expressed the empirical formula related (f_{spt}) and $f_{ck(Cylinder)}$ in the following form:

$$f_{spt} = k\,(f_{ck,cylinder})^n \quad \text{[Eq. 5]}$$

Where (k) and (n) are constant coefficients. As per available literature, the value of (n) have been suggested by researchers from 0.5 to 0.85. The ACI 318 – 2014, different values were proposed based on the type of concrete, but for normal concrete, the values of (k) proposed as 0.67 and (n) as 0.5. Therefore, the Eq. 5 modified as follows:

$$f_{spt} = 0.67\,(f_{ck,cylinder})^{0.5} \quad \text{[Eq. 6]}$$

The relationships between the experimental results of splitting tensile strength f_{spt} and cylindrical compressive strength $f_{ck,cylinder}$ are shown in Figure 3. The correlation coefficient (R^2) is 0.7331 for the trend line passing through the origin.

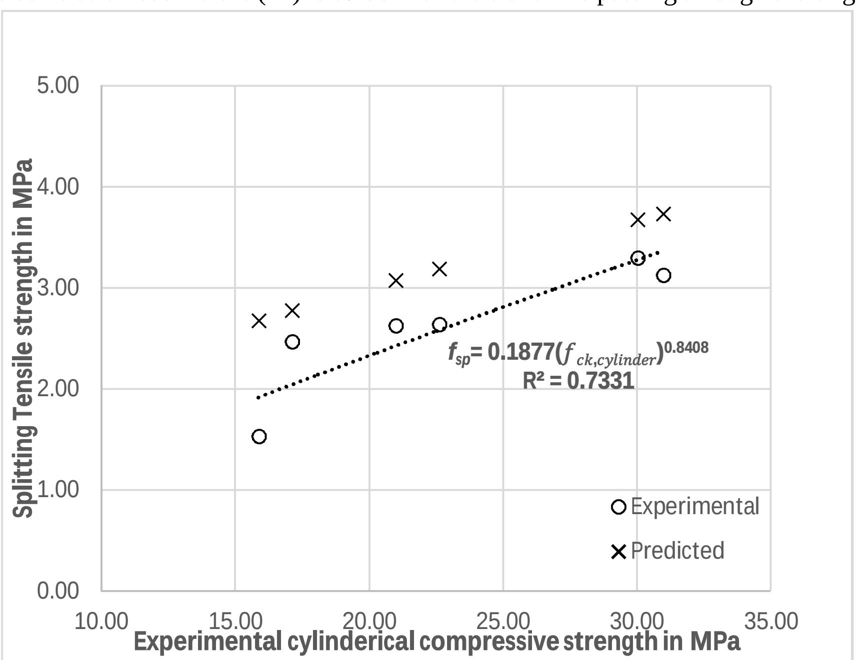

Figure 3: Relation between compressive strength and splitting tensile strength

Predicted splitting tensile strength is based on proposed Eq. 6. The Residual Standard Error (RSE) of the predicted and experimental splitting tensile strength is calculated as:

$$RSE = \sqrt{\frac{RSS}{n-2}} \qquad [Eq.7]$$

Where RSS (Residual Sum Square) = $RSS = \sum_{i=0}^{n}(y_i - \hat{y}_i)^2$

y_i = Measured date ($i = 0 \ldots \ldots n$)

$\hat{y}_i$ = Predicated data ($i = 0 \ldots \ldots n$)

The Residual Standard Error (RSE) of experimental and predicted splitting tensile strength is approximately 0.771. The percentage of deviation around 29.45%, with an average of the experimental splitting tensile strength. Some studies also suggest that ACI 318-2014 coefficients underestimate the splitting tensile strength for high strength concrete and overestimate it for low strength concrete. Cores of 6 No. were tested for modulus of elasticity according to IS 516. Resistance wire type strain gauge for measurement of strains as used instead of extensometers. The strain gauges measures surface strains of the strain gauge attached portion only as in the case of porous materials like concrete. To overcome such shortcomings used four numbers of large size strain gages, which can cover a length of at least three times the maximum size of coarse aggregate on the surface. Outmost care has been taken for preparation of the surface of the core on which strain gauge is to be attached. The application of the rate of loading and unloading cycles was followed as prescribed in IS 516. Statistical Summary of modulus of elasticity test results is presented in Table 6.

Table 6 Statistical Summary of modulus of elasticity in MPa

Entity	All Cores
Maximum	2.37E+04
Minimum	1.95E+04
Mean	2.08E+04
No. of Cores	6
Standard Deviation	1.50E+03
Coefficient of Variation (COV)	7.20%

Predicted modulus of elasticity (E) based on the following proposed expression suggested in IS 456.

$$E = 5000\sqrt{f_{ck,cube}} \qquad [Eq.7]$$

Where E = Modulus of elasticity in MPa

$f_{ck,cube}$ = Equivalent cube compressive Strength in MPa

The correlation between modulus of elasticity and the equivalent cube compressive strength show in Figure 4. The Residual Standard Error (RSE) of experimental and predicted modulus of elasticity is approximately 6.867+E03. The percentage of deviation is around 32.99%, with an average of the experimental modulus of elasticity. IS 456 also suggested that the modulus predicted by using expression 7 may differ by ± 20 % with experimental results.

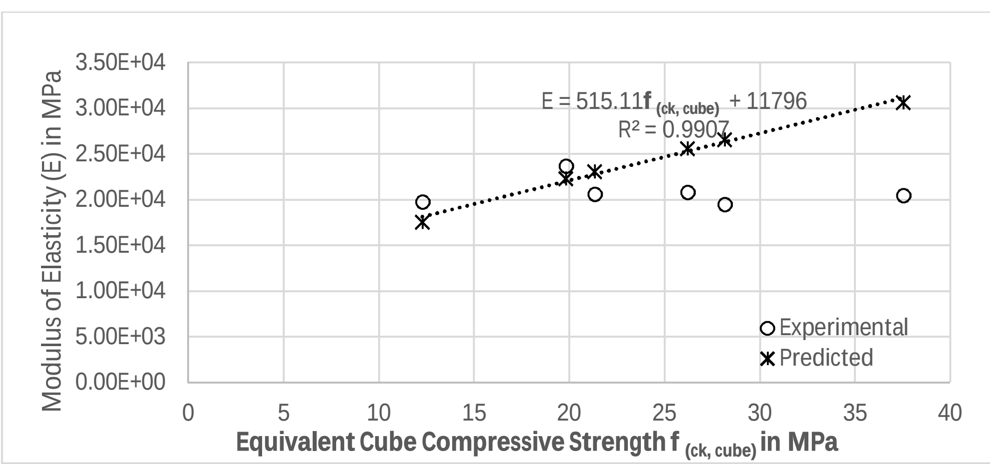

Figure 4: Relation between equivalent cube strength and modulus of elasticity

The Hong[8] (2014) proposed expression for estimation of the ultrasonic pulse velocity in terms of compressive strength as follows:

$$V = 2178.7 f_{ck}^{0.1948} \quad \text{[Eq.8]}$$

Where V = Ultrasonic Pulse Velocity in km/s

f_{ck} = Compressive strength in MPa

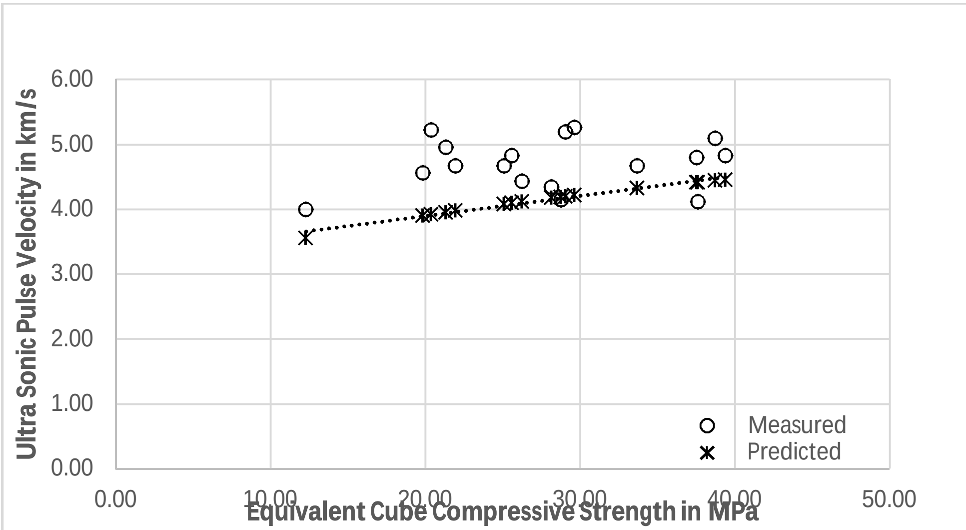

Figure 5: Relation between equivalent cube compressive strength

In comparison with the experimental USPV data with predicted UPV using the Eq 8 of Hong's work, the residual standard error (RSE) approximately 0.772. The percentage of deviation around 15.40%, with an average of the experimental UPV values. It is observed that the expression under estimation may be due to the consideration of a single factor for estimation. The relation between the UPV (predicted and experimental) and equivalent cube compressive strength results are presented in Figure 5.

A. Relationship Between Ultrasonic Pulse Velocity and Compressive Strength

Few researchers proposed the following empirical equations for the estimation of compressive strength and UPV in the literature.

Rouf's et al equation: $f_{ck} = 2.016\exp(0.61V)$ [Eq.8]

Naik and Malhotra equation: $f_{ck} = (-109.6 + 33V)$ [Eq.9]

Considered predicted UPV values in estimating the compressive strength. The Predicted compressive strength presented by using Eq. 8 & Eq. 9 are shown in Figure 6 and 7.

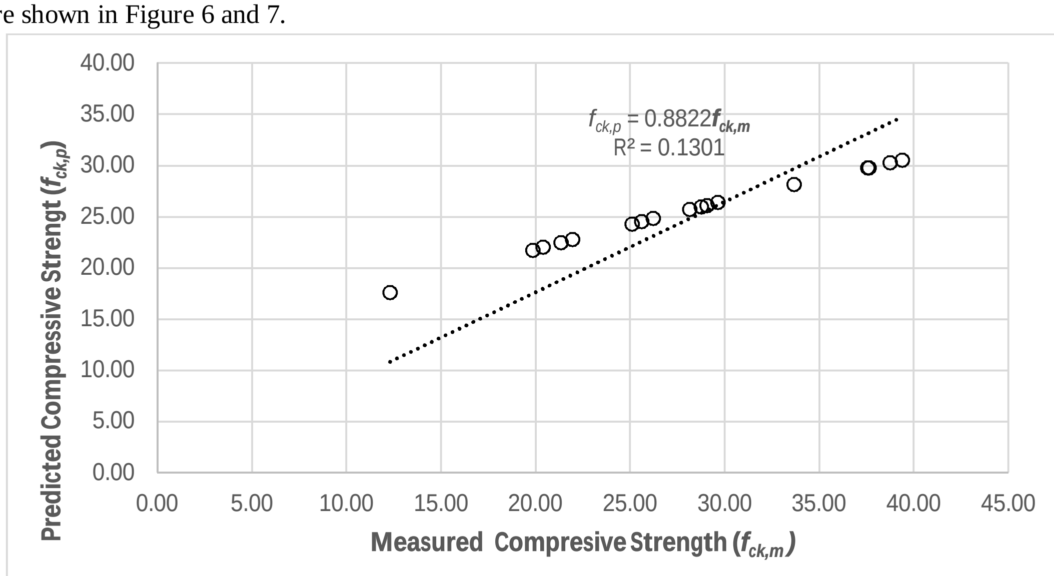

Figure 6: Relation between measured and predicted compressive strength by Rouf's equation

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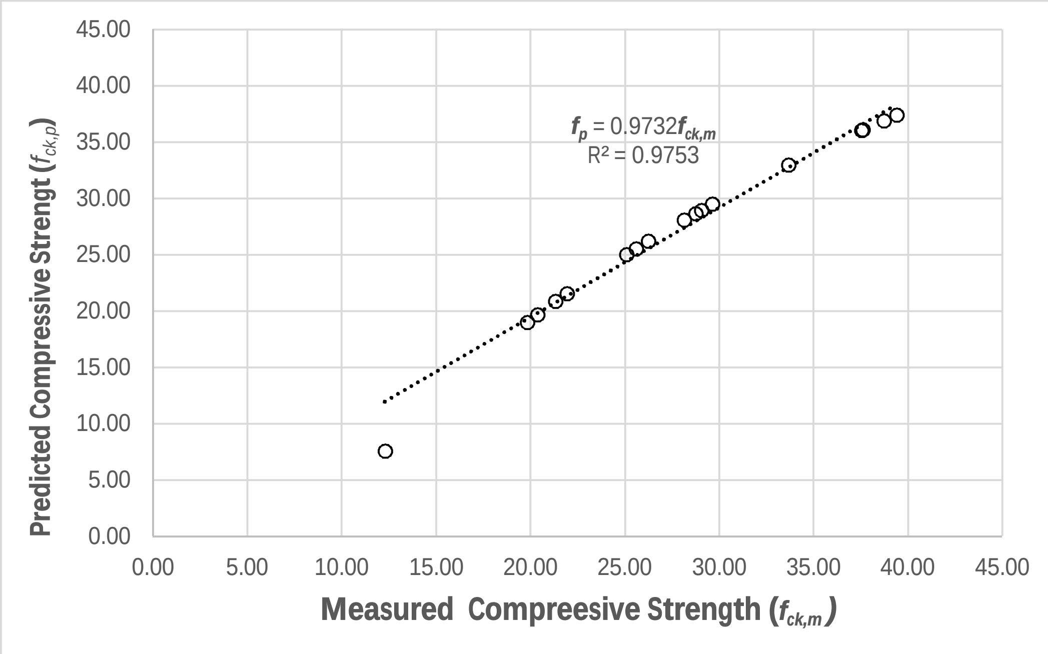

Figure 6: Relation between measured and predicted compressive strength by Naik and Malhotra equation

IV. CONCLUSIONS

A. The mean direct method UPV is around 4.72 km/sec and concrete quality categorized as "excellent." Further, the predicted UPV by proposed Hong's equation showing a 15.40*% deviation with average measured UPV.*

B. The mean density of concrete is observed around 2363 kg/m3, which is approximately the same as regular concrete.

C. The mean compressive strength is around 27.95 MPa, which is above the design target mean strength of the concrete. Predicted compressive strength using Naik and Malhotra equation is fitting best with measured compressive strength.

D. The mean splitting tensile strength and mean modulus of elasticity are around 2.62 MPa and 2.08E+04 MPa, respectively.

E. Obtained properties of concrete, clearly indicate that the quality of concrete reasonably within the acceptable limits of the specifications of the work. The actual reasons for the formation of cracks shall understand only after mathematical modelling studies of the complete dam body by using real measured concrete properties.

F. Thorough investigation which requires few more tests such as permeability test, Rapid chloride penetration test, Alkali Aggregate reaction test, etc. should also be carried out before taking up repair and rehabilitation of the old structures, as huge fund is involved in the work.

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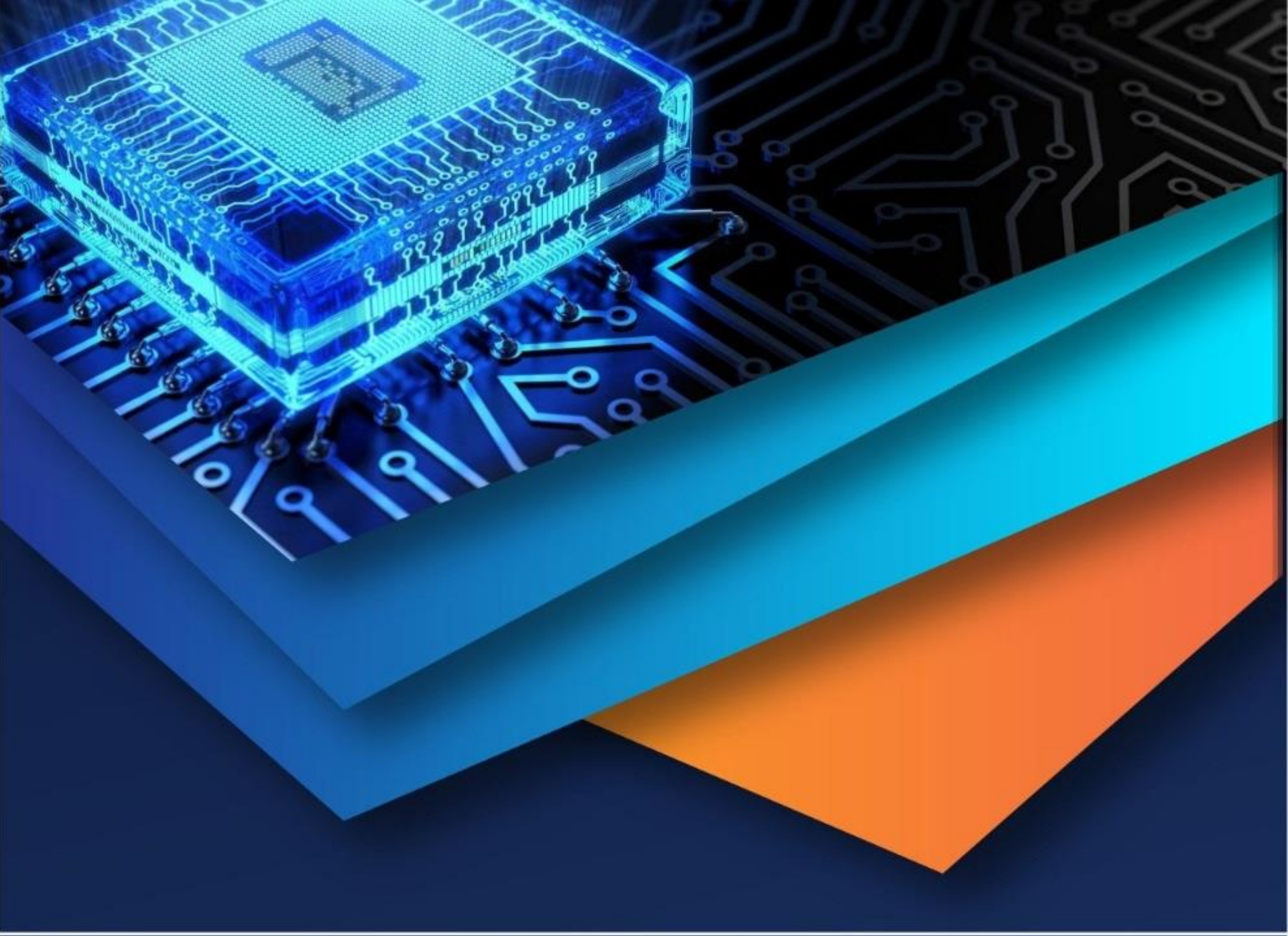

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