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NDT, Ultrasonic Pulse Velocity Test Assessment, Procedure and Limitation

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Abstract: Concrete Quality is one of the most important requirements that can be used to decide the structure is safe or not. Concrete quality directly depends on the homogeneity and voids in the concrete. There are several method used for this purpose, among the mostly used methods are the Ultrasonic pulse velocity, as ultrasonic pulse velocity test detect internal cracking as well as other defects. The present study is done to check the structural homogeneity of concrete structure. The pulse velocity method is an efficient way to find out quality of concrete in terms of homogeneity in structure.
Keywords: Non-destructive Test, Visual Inspection, Homogeneity, Pulse Velocity, UPV Test.

I. INTRODUCTION

A. Aim

To study the structural homogeneity analysis of a college building using the non-destructive testing methods i.e. Ultrasonic Pulse Velocity Test.

B. Objective

1) To study the structural homogeneity of RCC structures.
2) To study factors responsible for voids in RCC structures.
3) To study non-destructive testing method - Ultrasonic Pulse Velocity Test Method.
4) To do preliminary site inspection for NDT survey of structure under consideration.
5) To analyze quality strength of existing RCC structure using Ultrasonic Pulse Velocity Test.

C. Scope

To study Structural Homogeneity Analysis of various RCC component like column, slab and beam of a building of College of Engineering and Technology, Akola by using Ultrasonic Pulse Velocity Test.

D. Need

The quality of new concrete structures is dependent on many factors such as type of cement, type of aggregates, water cement ratio, curing, environmental conditions etc. Besides this, the control exercised during construction also contributes a lot to achieve the desired quality. The present system of checking slump and testing cubes, to assess the strength of concrete, in structure under construction, are not sufficient as the actual strength of the structure depend on many other factors such as proper compaction, effective curing also. If the selection of proper material and compaction is not done then it causes structural inhomogeneity as well as air voids, which directly affects on strength of structure. Considering the above requirements, need of testing of hardened concrete in new structures, is there to asses the actual condition of structures.When old structure are considered , it can be seen that they are subjected to many factors that are responsible for reduction of strength and thus timely testing and quality checkup is important at different stages during the life of a structure.
As during life span of structure various forces like wind force, rain, humidity, atmospheric condition, natural disaster, pollution content in air and other forces acts on structure. So, it becomes necessary to check the stability of structure to avoid damage to lives and structure. To check the stability and suitability of structure non destructive test should be done in interval of year.
Even the importance of determining the existing structures strength is considered under by laws and is specified under clause No.77 of revised Bye-Laws of Cooperative Housing Societies:
The Society should do the Structural Audit of the building if age of building between 15 to 30 years then once in 5 years and building aging above 30 years once in 3 years.
To keep the habitant safe and secure, it is unavoidable to do timely check of the structural member’s strength and durability and thus one such way of determining strength is using NDT, which is considered over here for further study.

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II. LITERATURE REVIEW

Vladimir Guilherme Haach et. al. (1), In this research paper author did the analysis of propagation of ultrasonic waves in a solid which provided a tomographic reconstruction of its interior allowing the detection of cracks, voids and heterogeneity. In This paper author presented a study of tomography reconstruction from results of ultrasonic tests in concrete prisms. Author carried out the measurements of time-of-flight (TOF) of ultrasonic waves in three concrete prisms with different compressive strength and one concrete prism cast with two distinct concrete compositions. Author tested the prisms before and after an imposed damage. Heterogeneity of concrete was evaluated and the tomographic image is obtained using some techniques of image reconstruction implemented in new software. Author showed that ultrasonic tomography may be an interesting tool to evaluate damaged structures. Kaushal Kishore (2), In this research paper author discussed about the Visual Inspection of Concrete Structure. Author discussed various important phases which came under the visual inspection. Author gave brief information about the various types of cracks in a concrete structure, testing concrete by tapping method, visual inspection of fire damage concrete. Under the heading of cracks in a concrete structure author discussed their location, causes of cracking, remedy and time of appearance. Kishor Kunal et. al. (3), In This research paper author discussed about how visual inspection of cracks can be helpful in order to identify and categorize them with respect to various parameters by taking case study of an institutional building. From the case study author concluded that some prevention could be taken care of during the construction process itself. Any lack of attentiveness can lead to a cause for damage in the building in its future, which can also lead to the failure of structure.

Tomasz Gorzelańczyk et. al. (4), In this paper author presented the tests of concrete homogeneity inside a structural element constituting a concrete wall of the hydroelectric power plant suction pipe, carried out using the non-destructive impulse response method. Author carried out test on about 1000 mm thick structural element made up of grade C25/30 concrete with 32 mm maximum aggregate grading, reinforced with smooth rebar's made of A-I St3S steel. On the basis of results of the tests, author showed that the impulse response method can be successfully used to identify concrete zones characterized by inhomogeneity (honeycombing) inside massive structural elements.

Kaushal Kishore (5), discussed the strength of hardened concrete. In this research paper author also discussed various influence factor on test such as moisture content, temperature path length and all other. In a whole day, concreting work cubes are cast in a few batches, the differences (unintentional and intentional) in the composition are not uncommon, their compaction and their hardening conditions always differ more or less from those of the structure. Feras Latef Khlef (6), In this research paper the author developing a mathematical relationship between the Ultrasonic Pulse Velocity (UPV) and the compressive strength for concrete specimens subjected to different amounts of exposure of sulfate attack. The experimental data were collected from a research work by the author using concrete subjected to sulfate exposure and form a literature used an extensive concrete work without sulfate exposure. Author found the UPV technique effective and successful in detecting the strength reduction due to exposure of sulphate.

III.NON-DESTRUCTIVE TESTING

A. Introduction

Non-destructive testing (NDT) methods are techniques used to obtain information about the properties or internal condition of an object without damaging the object. Non-destructive testing is a descriptive term used for examination of material and components in such a way that allows material to be examined without changing or destroying their usefulness. NDT is a quality assurance management tool which can give impressive results when used correctly. It requires an understanding of the various methods available, their capabilities and limitation, knowledge of the relevant standards and specification for performing the test. NDT technique can be used to monitor the integrity of the items or structure throughout its design life.

B. Need and Application of NDT

It is often necessary to test concrete structures after the concrete has hardened to determine whether the structure is suitable for its designed use. Ideally such testing should be done without damaging the concrete. The tests available for testing concrete range from the completely non-destructive, where there is no damage to the concrete, through those where the concrete surface is slightly damaged, to partially destructive tests, such as core tests and pullout and pull off tests, where the surface has to be repaired after the test. The range of properties that can be assessed using non-destructive tests and partially destructive tests is quite large and includes such fundamental parameters as density, elastic modulus and strength as well as surface hardness and surface absorption, and reinforcement location, size and distance from the surface. In some cases it is also possible to check the quality of workmanship and structural integrity by the ability to detect voids, cracking and delamination.

C. Basic Methods for NDT of Concrete Structure

The following methods, with some typical applications, have been used for the NDT of concrete:

1) Visual inspection, which is an essential precursor to any intended non-destructive test. An experienced civil or structural engineer may be able to establish the possible causes of damage to a concrete structure and hence identify which of the various NDT methods available could be most useful for any further investigation of the problem.
2) Ultrasonic pulse velocity testing, mainly used to measure the sound velocity of the concrete and hence the compressive strength of the concrete.
3) Schmidt/rebound hammer test, used to evaluate the surface hardness of concrete.
4) Half-cell electrical potential method, used to detect the corrosion potential of reinforcing bars in concrete.
5) Impact echo testing, used to detect voids, delamination and other anomalies in concrete.
6) Ground penetrating radar or impulse radar testing, used to detect the position of reinforcing bars or stressing ducts.

IV. BASIC STUDY OF CONCRETE STRUCTURE

Types Of Concrete Structure

A. Plain Concrete Structure

Concrete is a mixture of stone and sand held together by a hardened paste of cement and water. When the ingredients are thoroughly mixed they make a plastic mass which can be cast or moulded into a predetermined size and shape. When the cement paste hardens the concrete becomes very hard like a rock. It has great durability and has the ability to carry high loads especially in compression. Now days it is hard to find a plain cement concrete structure.

B. Reinforced Concrete Structure

Reinforced concrete is a combination of concrete and steel. Alone concrete is very strong in compression but very weak in tension. Since concrete bonds firmly to steel reinforcement the combination acts as one material which offers high compressive strength, high tensile strength and high shear strength.

C. Prestressed Concrete Structure

The basic principle of prestressed concrete is that superimposing compressive stresses eliminate tensile stresses in the concrete. This involves the installation of high tensile strength steel as reinforcement, stretching the steel by applying a pre-stressing force, and holding the tension. The pre-stressing force in the steel wire or strand is transferred to the concrete, placing the concrete under compression.

D. Pre Cast Concrete Structure

This type of concrete is cast into the form, shape and size of the structural members like column, beams, girder etc. directly and then these precast members in fully cured and in full development of strength are carried to the site where they are simply assembled together to form the structure.

E. Discontinuities and Defects in Concrete Structures

Most of defects due to improper construction, lack of quality control during construction, over-emphasis on reading cost at the expense of durability and safety, and lack of maintenance. Most of the problems listed below occur even in relatively new building, which require repair within 5 years after construction. Of late, even building which have survived for a long periods have shown problems because change of environment, such as industry or traffic pollution.

F. Cracking of Concrete

Cracking affects the appearance of concrete. In some cases it affects its structural adequacy and durability. In reinforced concrete cracking allows easier access to air and moisture which can cause steel to rust and eventually weaken the concrete. Cracks can occur at any stage

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G. Spalling

The delamination of surface of brick or mortar or plaster is called spalling. Spalling can occur due to internal stresses or due to external actions. Concentrated eccentric load causes highly stressed narrow compression zone which encourages spalling. Spalling also occurs due to freeze thaw effect of entrapped water, chemical effect, efflorescence and repeated wetting drying in coastal area.

H. Staining

Staining of masonry wall is caused by absorption of water containing salts and subsequent efflorescence. Efflorescence is defined as the deposition of water soluble salts on the surface after evaporation of water. In reinforced masonry wall, rust staining may occur due to absorption of water. Because of increase in volume due to the formation of rust, spalling and cracking occur.

I. Honeycombing

This is when too much coarse aggregate appears on the surface with some cavities underneath. It occurs as a result of poor compaction or if a bony mix is used with not enough sand. If it only occurs on the surface it can be repaired with a render (thin layer of sand/cement mortar) or a proprietary cement product. If cavities exist below the surface, it is more appropriate to break out to sound and dense concrete and repair as per spalling above.

J. Moisture Ingress

The moisture ingress depends on several factors such as the porosity of the bricks, the mortar joints, the pointing, cracks in the wall and the plastering. Water seepage causes wetness and encourages the growth of mould, fungi and vegetation. It can degrade the quality of the wall.

K. Corrosion of Reinforcing Bars

Corrosion occurs when the concrete surface cracks allowing water entry, or if water enters the concrete by diffusion during carbonation. The increase in diameter of the reinforcing bars caused by the formation of iron oxide (rust) can cause the concrete above the affected bars to spall off.


Fig 1: Cracks on concrete surface Fig 2: Honeycombing


Fig 3: Spalling of Concrete and corrosion of reinforcing bars Fig 4: Moisture Ingress

V. VISUAL INSPECTION

Visual inspection is very effective method for evaluation of structure condition. It also helps us in evaluating requirement of maintenance required for the structure as well as tells us the health of the building. It is the first steps in the evaluation of a concrete structure. Visual inspection can provide a wealth of information that may lead to positive identification of the cause of observed distress.

A. Tools And Equipment For Visual Inspection

An engineer carrying out a visual survey should be well equipped with tools to facilitate the inspection. These involve a host of common accessories such as human eye and brain, aided with a note book, proforma, measuring tapes or rulers, markers, thermometers, anemometers and others. Binoculars, telescopes, borescopes and endoscopes or the more expensive fibre scopes may be useful where access is difficult.

B. General Procedure Of Visual Inspection

Before any visual test can be made, the engineer must read all relevant structural drawings, plans and elevations to become familiar with the structure. Available documents must also be examined and these include technical specification, past reports of tests or inspection made, construction records, details of materials used, methods and dates of construction, etc. The survey should be carried out systematically and cover the defects present, the current and past use of the structure, the condition of adjacent structures and environmental condition. All defects must be identified, the degree classified, similar to those used for fire damaged concrete and, where possible, the causes identified. The distribution and extent of defects need to be clearly recognized. For example whether the defects are random or appear in a specific pattern and whether the defect is confined to certain locations of members or is present all over the structure. A study of similar structures or other structures in the local area constructed with similar materials can also be helpful in providing 'case study' evidence, particularly if those other structures vary in age from the one under investigation.

Defects that commonly need recording include:

1) Cracking which can vary widely in nature and style depending on the causative mechanism
2) Surface pitting and spalling
3) Surface staining
4) Differential movements or displacements
5) Variation in algal or vegetative growths
6) Surface voids
7) Honeycombing
8) Bleed marks
9) Constructional and lift joints
10) Exudation of efflorescence

VI.ULTRASONIC PULSE VELOCITY TEST

A. Introduction

The ultrasonic pulse velocity method has been used successfully to evaluate the quality of concrete for more than 75 years. This method can be used for detecting internal cracking and other defects as well as changes in concrete such as deterioration due to aggressive chemical environment and freezing and thawing. The pulse velocity method is a truly non-destructive method, as the technique uses mechanical waves resulting in no damage to the concrete element being tested. A test specimen can be tested again and again at the same location, which is useful for monitoring concrete undergoing internal structural changes over a long period of time.

B. Objects

As per the IS 13311 (Part 1):1992, the main objects of the ultrasonic pulse velocity method are to establish

1) The Homogeneity of the Concrete,
2) The Presence of Cracks, Voids and other Imperfections,
3) Changes in the Structure of the Concrete Caused by the Exposure Condition, Corrosion, Wear etc. which may occur with time,
4) The Quality of the Concrete in relation to the Specified Standard Requirements,
5) The Quality of One Element of Concrete in Relation to the Another, and
6) The values of the Dynamic Elastic Modulus of the Concrete.

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C. Fundamental Principle

This is one of the most commonly used method in which the ultrasonic pulses generated by electro-acoustical transducer are transmitted through the concrete. The method is based on the principle that the velocity of an ultrasonic pulse through any material depends upon the density, modulus of elasticity and Poisson's ratio of the material. Comparatively higher velocity is obtained when concrete quality is good in terms of density, uniformity, homogeneity etc.The transducers convert electrical signals into mechanical vibrations (transmit mode) and mechanical vibration into electrical signals (receive mode). The travel time is measured with an accuracy of +/- 0.1 microseconds. Transducers with natural frequencies between 20 kHz to 200 kHz are available, but 50 kHz to 100 kHz transducers are common.

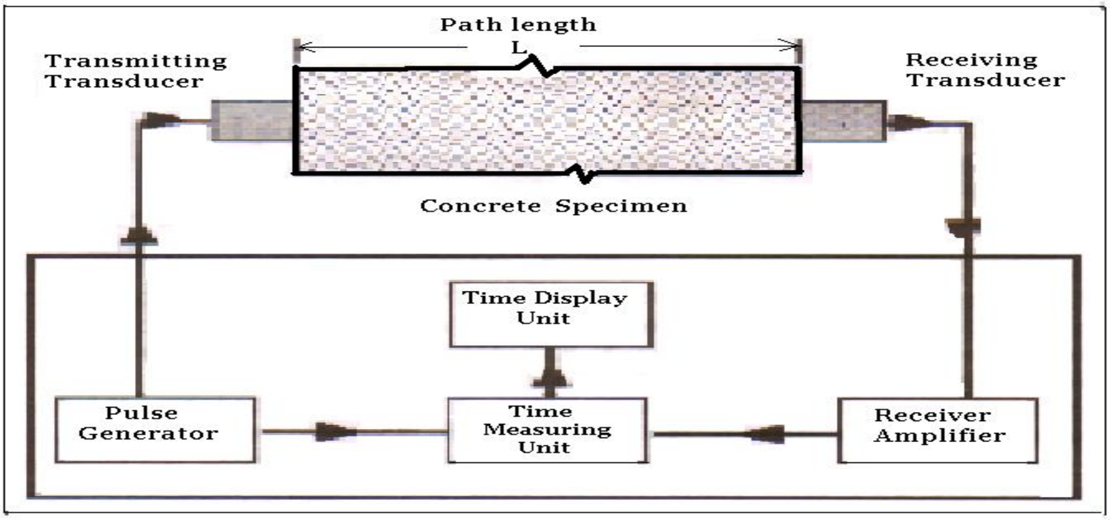

Fig.5: Schematic Diagram of Ultrasonic Pulse Velocity Method

D. Apparatus

As per IS13311 (Part 1):1992, the apparatus for ultrasonic pulse velocity measurement shall consist of the following

1) Electrical pulse generator
2) Amplifier
3) Electronic timing device
4) Transducer-one pair

Fig.6 Ultrasonic Pulse Velocity Testing Instrument

E. Transducers

Piezoelectric and magneto-strictive types of transducers are available in the range of 20 kHz to 150 kHz of natural frequency. Generally, high frequency transducers are preferable for short path length and low frequency transducers for long path lengths. Transducers with a frequency of 50 to 60 kHz are useful for most all-round applications.

Table 1 Natural Frequency Of Transducers For Different Path Length

Path Length (mm)	Natural Frequency Of Transducer (kHz)	Minimum Transverse Dimension Of Member (mm)
Up to 500	$\geq$150	25
500-700	$\geq$60	70
700-1500	$\geq$40	150
Above 1500	$\geq$20	300

F. Procedure for Ultrasonic Pulse Velocity Test

Find out the most suitable test points on the sample to be tested and note down measurement of path length 'L'. Apply couplants to the surface of the transducers and press it hard onto the surface of the material. Do not move the transducers while a reading is being taken, as this can generate noise signals and errors in measurements. Continue holding the transducers onto the surface of the material until a consistent reading appears on the display, which is the time in microsecond for the ultrasonic pulse to travel the distance 'L'. The mean value of the display reading should be taken when the unit digits hunts between two values.

The pulse velocity (V) is given by V = L / T

Where, V = Pulse velocity,

L = Path length,

T = Time taken by the pulse to traverse the path length

Once the velocity is determined, an idea about quality, uniformity, condition and strength of the concrete tested can be attained.

G. Mounting Of Transducers

The direction in which the maximum energy is propagated is normally at right angles to the face of the transmitting transducer, it is also possible to detect pulses which have traveled through the concrete in some other direction i.e., the pulse velocity can be measured by Direct Transmission, Semi-direct Transmission and Indirect or Surface Transmission. Normally, Direct Transmission is preferred being more reliable and standardized. (Various codes gives correlation between concrete quality and pulse velocity for Direct Transmission only) Surface probing is the least satisfactory of the three methods because the pulse velocity measurements indicate the quality of concrete only near the surface and do not give information about deeper layers of concrete. Also in this method path length is less well defined. Surface probing in general gives lower pulse velocity than in the case of cross probing and depending on number of parameters.

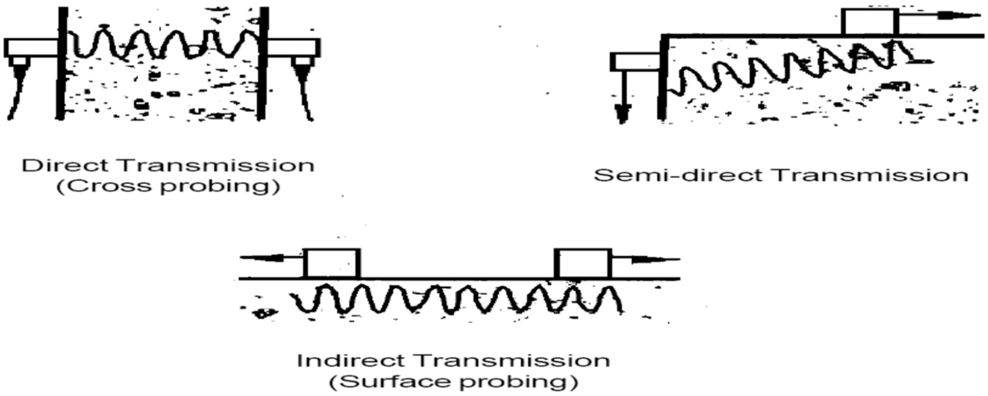

Fig. 7: Different Methods of Propagating Ultrasonic Pulses through Concrete

H. Criterion for Concrete Quality Grading

1) The ultrasonic pulse velocity of concrete can be related to its density and modulus of elasticity. It depends upon the materials and mix proportions used in making concrete as well as the method of placing, compacting and curing of concrete.
2) If the concrete is not compacted thoroughly and having segregation, cracks or flaws, the pulse velocity will be lower as compare to good concrete, although the same materials and mix proportions are used.
3) The quality of concrete in terms of uniformity can be assessed using the Indian Standard code for method of test & specifications of velocity of ultrasonic pulses in concrete. (I.S. 13311-1992: part 1 Table 2) as follows

Table 2: Velocity Criterion For Concrete Quality Grading

Sr. 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	Poor

I. Factors Affecting The Measurements Of Pulse Velocity

It is important that test should be conducted such that the pulse velocity are reproducible and they are affected by only the properties of the concrete under test rather than other factor. Various factors which can influence pulse velocity and its correlation with various physical properties of concrete are as follow:

1) Factor resulting directly from concrete properties
   a) Aggregate size, Grading, Type and water content
   b) Cement type
   c) Water cement ratio
   d) Admixture
   e) Age of concrete
2) Other effects :
   a) Transducers contact
   b) Temperature effects
   c) Moisture and curing condition of concrete
   d) Path length
   e) Size and shape of specimen
   f) Presence of reinforcing bars

J. Detection of Defects

The use of the ultrasonic pulse velocity technique to detect and define the extent of internal defects should be restricted to well-qualified personnel with previous experience in the interpretation of survey results. Attention is drawn to the potential risk of drawing conclusions from single results.

VII. LIMITATIONS

A. The utilization of UPV Tester is highly influenced by weather condition, dampness, the material type and its properties.
B. Any structure consist of open and hidden structural members and thus every time it is not possible to go for direct method thus the observation are combined output of direct, semi-direct and indirect method which influences the result upto 15-20 percent.
C. The thickness as well as path length also plays the important role and thus uniformity for the thickness cannot be set out which result in great variation.

VIII. CONCLUSION

The pulse velocity method is an efficient way to find out quality of concrete in terms of homogeneity in structure. 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.

IX. ACKNOWLEDGMENT

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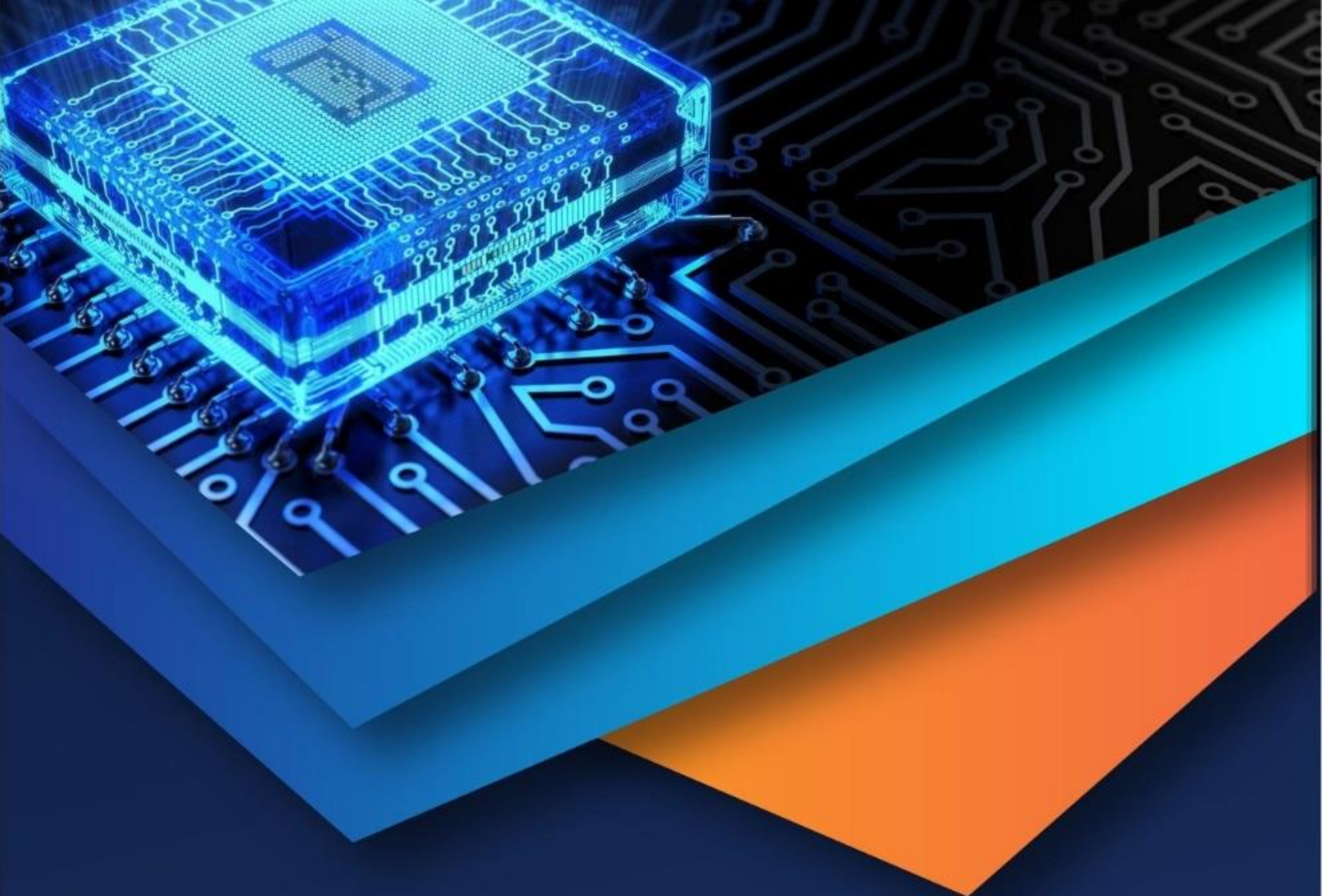

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