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Crack Pattern an Indicator and Type of Distress in Concrete Structures: A Compilation of Causes, Measurement and Solution

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Abstract: Crack occurs over time in almost all concrete which indicates distress. It varies in depth, width, direction, pattern, location, and cause. Cracks can be either active or dormant (inactive). Active cracks widen, deepen, or migrate through the concrete. Dormant cracks remain unchanged. Some dormant cracks, such as those caused by shrinkage during the curing process, pose no danger, but if left unrepaired, they can provide convenient channels for moisture penetration, which normally causes further damage. Structural cracks can result from temporary or continued overloads, uneven foundation settling, or original design inadequacies. Structural cracks are active if the overload is continued or if settlement is ongoing; they are dormant if the temporary overloads have been removed, or if differential settlement has stabilized. Thermally-induced cracks result from stresses produced by temperature changes. They frequently occur at the ends or corners of older concrete structures built without expansion joints capable of relieving such stresses. Superficial repairs do not eliminate underlying causes. To aggravate problems, professional consultation is recommended in almost every instance where noticeable crack occurs [1].

I. INTRODUCTION

Cracks on the surface of any concrete structures are very common and provide vital information about the health of the structure. Several factors are responsible for cracks. Some of the common causes of cracks are evaporation of water, corrosion, variation of temperature, freezing and thawing, alkali aggregate reactivity, unable to expand or contract due to stresses, fire, chemical attack etc. Cracks may appear on the structure due to structural design failure, bad workmanship and deterioration over the period due to environmental factor. Broadly cracks are either dormant or active. As the name says dormant cracks do not increase in size and length whereas active cracks change their width and length under load. Dormant cracks typically result from shrinkage, initial movement of support or previous structural overload. Depending on their size and location it may or may not require repair but if left unrepaired, they can provide convenient channels for moisture penetration, which normally causes further damage.

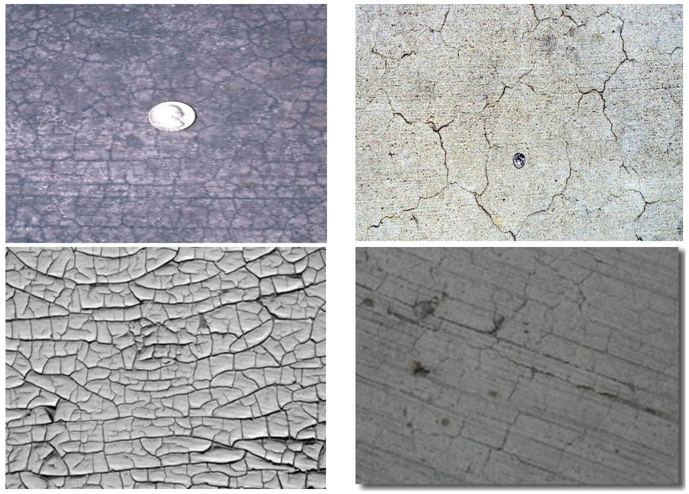
Active cracks on the other hand due to continuous movement of the external force or to present over load. It is difficult to repair. If the underlying cause is not fixed, a new crack will form next to the repaired one. To determine whether a crack is active or dormant, one simple way is to bridge the surface of the crack with rigid but non-shrink materials, such as plaster of Paris or paint, and inspect the patch periodically. The actual magnitude of the movement can be determined by periodically measuring the crack width in a few places. By other definition cracks could be classified as structural or non-structural. Structural cracks are those which are due to incorrect structural design or faulty construction or overloading and these may endanger the safety of the structure. Extensive cracking of an RCC beam is an instance of structural cracking. Nonstructural cracks are mostly due to internally induced stresses in building materials and these generally do not directly result in structural weakening. In course of time, however, sometime non-structural cracks may, because of penetration of moisture through cracks or weathering action, result in corrosion of reinforcement and thus may render the structure unsafe.

II. CRACK PATTERNS

Some of the crack patterns and their consequences are as below:

A. Crazing

It is a pattern of fine cracks that do not penetrate much below the surface and are usually a cosmetic problem only. They are barely visible, except when the concrete is drying after the surface has been wet crazing is the development of craze cracks, a system of fine random cracks in a concrete surface.



B. Plastic Shrinkage Crack

When water evaporates from the surface of freshly placed concrete faster than it is replaced by bleed water, the surface concrete shrinks. Due to the restraint provided by the concrete below the drying surface layer, tensile stresses develop in the weak, stiffening plastic concrete, resulting in shallow cracks of varying depth. These cracks are often fairly wide at the surface, sometimes even extended whole thickness of the slab. These cracks typically run parallel to one another [2].

C. Drying Shrinkage

Drying shrinkage cracks start to form when concrete loses its water, most often these are hairline cracks typically define as less than 0.08 mm wide. These cracks are often straight or ragged, forming at random location, but they can also appear as crazing on the surface of walls and slab. Restraint to shrinkage, provided by the sub grade, reinforcement, or another part of the structure, causes tensile stresses to develop in the hardened concrete. Restraint to drying shrinkage is the most common cause of concrete cracking. In many applications, drying shrinkage cracking is inevitable. Therefore, contraction (control) joints are placed in concrete to predetermine the location of drying shrinkage cracks.

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D. D-cracking

It is a form of freeze-thaw deterioration that has been observed in some pavements after three or more years of service. Due to the natural accumulation of water in the base and sub base of pavements, the aggregate may eventually become saturated. Then with freezing and thawing cycles, cracking of the concrete starts in the saturated aggregate at the bottom of the slab and progresses upward until it reaches the wearing surface. D-cracking usually starts near pavement joints. Zig zag parallel cracks appear near the joints.

E. Alkali-aggregate Reaction

Alkali-aggregate reactivity is a type of concrete deterioration that occurs when the active mineral constituents of some aggregates react with the alkali hydroxides in the concrete. Alkali-aggregate reactivity occurs in two forms—alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR). Pattern of the crack is called map cracking. Indications of the presence of alkali-aggregate reactivity may be a network of cracks, closed or spalling joints, or displacement of different portions of a structure.

F. Thermal Cracks

Temperature rise (especially significant in mass concrete) results from the heat of hydration of cementitious materials. As the interior concrete increases in temperature and expands, the surface concrete may be cooling and contracting. This causes tensile stresses that may result in thermal cracks at the surface if the temperature differential between the surface and center is too great. The width and depth of cracks depends upon the temperature differential, physical properties of the concrete, and the reinforcing steel. It appears on the whole slab quite haphazard but prominent.

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G. *Loss of Support*

Loss of support beneath concrete structures, usually caused by settling or washout of soils and sub base materials, can cause a variety of problems in concrete structures, from cracking and performance problems to structural failure. Loss of support can also occur during construction due to inadequate formwork support or premature removal of forms. Very wide and long crack appears.

H. *Corrosion*

Corrosion of reinforcing steel and other embedded metals is one of the leading causes of deterioration of concrete. When steel corrodes, the resulting rust occupies a greater volume than steel. The expansion creates tensile stresses in the concrete, which can eventually cause cracking and spalling. Generally long crack appears parallel to the edges.

I. *Guideline for Crack Dimension for Harmful Cracks*

The surface width of the cracks should not, in general, exceed 0.3 mm in members where cracking is not harmful and does not have any serious adverse effects upon the preservation of reinforcing steel nor upon the durability of the structures. In members where cracking in the tensile zone is harmful either because they are exposed to the effects of the weather or continuously exposed to moisture or in contact soil or groundwater, an upper limit of 0.2 mm is suggested for the maximum width of cracks. For particularly aggressive environment, such as the 'severe' category, the assessed surface width of cracks should not in general, exceed 0.1 mm [3]. Cracks may appreciably vary in width from very thin hair cracks barely visible to naked eye (about0.01 mm in width) to gaping cracks 5 mm or more in width. A commonly known classification' of cracks, based on their width is: (a) thin - less than1 mm in width, (b) medium- 1 to 2mm in width, and (c) wide- more than 2 mm in width. [4]

J. Guide to Reasonable crack widths, Reinforced Concrete under Service Loads [5]*

Exposure condition	Crack width in. mm
Dry air or protective membrane	0.41
Humidity, moist air, soil	0.30
Deicing chemicals	0.18
Seawater and seawater spray, wetting and drying	0.15
Water-retaining structures	0.10

Note: *It should be expected that a portion of the cracks in the structure will exceed these values. With time, a significant portion can exceed these values. These are general guidelines for design to be used in conjunction with sound engineering judgment.
†Excluding non-pressure pipes.

The threshold limiting crack width has been defined by various code of practice for RCC design vary from 0.1 to 0.3 mm. Any crack in concrete, which is wider than this, is likely to cause durability problems [6].

III. MONITORING AND MEASURING MOVEMENT OF CRACKS [7]

A. Steel Ruler

Steel ruler is simple instrument used to monitor crack width variation. The width of the crack can be measured to the nearest 0.5mm provided that great care is practiced. It should be bear in mind that steel rule measurements are subjective because it is not possible to measure crack width from the same point each time the measurement is taken. That is why steel ruler measurements are used for assessing state of damage at the beginning of investigation.

Fig.1: Steel Ruler

B. Magnified Graticule

Magnified graticule is used to monitor internal crack in smooth finishes. The monitoring is conducted by measuring the offset between two pencil marks utilizing magnified graticule.

The resolution of 0.1mm can be achieved with magnified graticule if necessary cautions are practiced.

Fig.2: Crack Width Measurement Magnifier

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C. Plastic Tell Tale

It is the most famous system used to monitor crack width variation. Plastic tell tale consist of two overlapped plates. The plate with scales marked in millimeter units of measurement is fixed on one side of the crack and the other plate marked with cursor is fixed on opposite side of the crack as it is shown in Figure 3.The instrument is screwed on the wall in such a way that the cursor of one plate and the middle of the scale of opposite plate will be aligned. So, as the crack experiences movement (including shear or normal movement), the variation can be measured to the closet of millimeters by recording the position of the cursor with respect to the scale. It should be known that, the reading can be taken any time by any individual and it does not require initial zero reading.

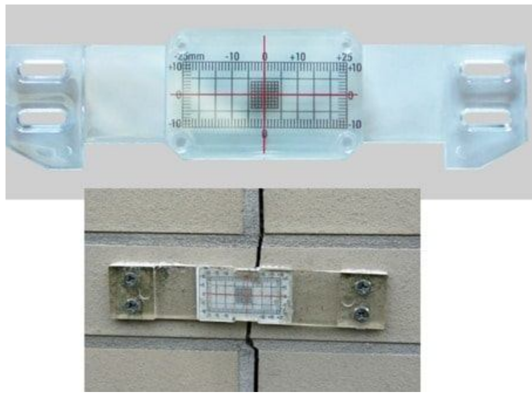

Fig.3: Details and Installation of Plastic Tell Tale

D. Glass Tell Tale

This technique used to measure crack width variation in the past, but it is not popular any more. It basically consists of strip of glass cemented on to the cracked structural element as shown in Figure 4.As it may be observed from the figure, glass tell tale is neither shows the direction of the movement nor the magnitude of the movement. It provides only nature of crack whether it is active or dormant. That is why it is not used any longer.

Fig.4: Glass Tell Tale

E. Brass Screws and Caliper

In this technique of monitoring crack width variation, two screws are fixed on each side of the crack as shown in Figure 5.

Fig.5: Fixing screws on each side of the crack

After that, a caliper will be used to measure the width of the crack as illustrated in Figure 6. As it may be observed, the screws will guarantee the correct measurement of the crack width and prevent errors.

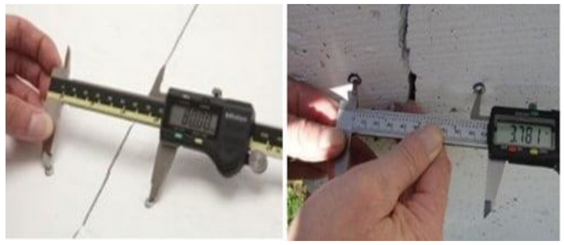

Fig.6: Measuring crack width using caliper by fixing its ends on the installed screws on each side of the crack

Moreover, the caliper can be employed in different modes to measure crack width at corners and other locations with similar difficulty in accessibility. Furthermore, it is possible to measure both normal and shear movements provided that three screws are installed at right angle triangle as shown Figure 7.

Fig.7: Installing three screws at right angle triangle to measure both shear and normal movement

Finally, this technique provides accuracy better than +/-0.1mm and resolution of 0.02mm using digital caliper

F. Displacement Transducer

This instrument is used to continuously monitor the movement of cracks so as to provide warnings when abrupt movement or in the case where the location of the crack is not accessible like railway tunnel.

Linear variable displacement transformer (LVDTs) and potentiometric displacement transducer are the two commonly devices used to continuously monitor crack width variations. Both instruments can be read either manually using hand held unit or automatically employing data logger. This method of monitoring crack width variation is expensive but the requirement for such monitoring would justify the utilization of these devices.

Fig.8: Installation of Linear variable displacement transformer instrument

G. Digital Crack Monitoring Device [8]

The hardware for the new device, named DRS-camera, is a commercial digital camera, attached to a cylindrical tube which allows to realise a constant panchromatic and multi spectral illumination. After thorough calibration and with constant focal length the crack and their immediate surrounding can be captured, i.e. documented objectively. The crack section of interest has to be pre-selected. The field of visibility of the camera has only a diameter of 6 cm to achieve the desired high resolution and to keep the camera size and weight manageable. In Fig. 9 the general idea and elements of this DRS-camera are depicted. The physically defines dots in the ground plate allow to control the stability of the camera parameters.

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Fig 9 New digital crack monitoring device DRS

H. 3D Crack Monitor [9]

3D Crack Monitoris capable of measuring crack deformations in three mutually perpendicular directions as shown in Fig. 10 and 11 developed at Central Soil and Materials Research Station. Usually this is to install for measuring movement of rock, big cavern crown displacement, movement of shear zone etc. X-axis measures the deformation along the crack i.e. the shear movement of the crack. Y-axis measures the deformation across the crack or perpendicular to the crack. The opening and closing of the crack/joint can be measured by Y-axis accurately. Z-axis measures the relative deformation of the two walls of the crack/joint perpendicular to X and Y axes. Thus, the deformations in all the three directions can be measured with the help of the 3-D crack monitor. The crack monitor can also be placed/ fixed in any direction of the crack and the deformations can be measured accordingly. The crack monitor is light weight, portable, compact and is very easy to install. The dimensions of the instrument for measuring the deformation can be changed suiting to the requirements at particular site.

Fig 10 3-D crack monitor (3- dimensional crack monitor)

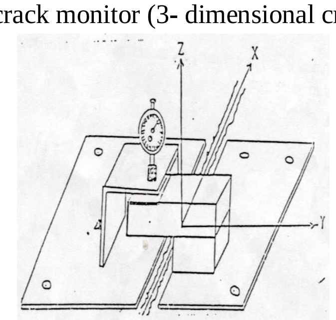

Fig. 11: Axis orientation for monitoring of Crack deformation by 3- D crack monitor

I. Repairing of Crack

Hairline, nonstructural cracks that show no sign of worsening normally need not be repaired. Cracks larger than hairline cracks, but less than approximately one-sixteenth of an inch, can be repaired with a mix of cement and water. If the crack is wider than one-sixteenth of an inch, fine sand should be added to the mix to allow for greater compatibility, and to reduce shrinkage during drying. Field trials will determine whether the crack should be routed (widened and deepened) minimally before patching to allow sufficient penetration of the patching material. To ensure a long-term repair, the patching materials should be carefully selected to be compatible with the existing concrete as well as with subsequent surface treatments such as paint or stucco. When it is desirable to re-establish the structural integrity of a concrete structure involving dormant cracks, epoxy injection repair should be considered. An epoxy injection repair is made by sealing the crack on both sides of a wall, or a structural member, with an epoxy mortar, leaving small holes, or "ports" to receive the epoxy resin. After the surface mortar has hardened, epoxy is pumped into the ports.

Once the epoxy in the crack has hardened, the surface mortar can be ground off, but the repair may be visually noticeable. (It is possible to inject epoxy without leaving noticeable patches but the procedure is much more complex.) Other cracks are active, changing their width and length. Active structural cracks will move as loads are added or removed. Thermal cracks will move as temperatures fluctuate. Thus, expansion-contraction joints may have to be introduced before repair is undertaken. Active cracks should be filled with sealants that will adhere to the sides of the cracks and will compress or expand during crack movement. The design, detailing, and execution of sealant-filled cracks require considerable attention or else they will detract from the appearance of the historic building. Random (map) cracks throughout a structure are difficult to correct, and may be un-repairable. Repair, if undertaken, requires removing the cracked concrete. A compatible concrete patch to replace the removed concrete is then installed. For some buildings without significant historic finishes, an effective and economical repair material is probably a sprayed concrete coating, troweled or brushed smooth. Because the original concrete will ultimately contaminate new concrete, buildings with map cracks will present continuing maintenance problems.

J. Repair of Spalling

Repair of spalling entails removing the loose, deteriorated concrete and installing a compatible patch that dovetails into the existing sound concrete. In order to prevent future crack development after the spall has been patched and to ensure that the patch matches the original concrete, great attention must be paid to the treatment of rebars, the preparation of the existing concrete substrate, the selection of compatible patch material, the development of good contact between patch and substrate, and the curing of the patch.

Once the deteriorated concrete in a spalled area has been removed, rust on the exposed rebar must be removed by wire brush or sandblasting. An epoxy coating applied immediately over the cleaned rebar will diminish the possibility of further corrosion. As a general rule, if the rebars are so corroded that a structural engineer determines they should be replaced, new supplemental reinforcing bars will normally be required, assuming that the rebar is important to the strength of the concrete.

Proper preparation of the substrate will ensure a good bond between the patch and the existing concrete. If a large, clean break or other smooth surface is to be patched, the contact area should be roughened with a hammer and chisel. In all cases, the substrate should be kept moist with wet rags, sponges, or running water for at least an hour before placement of the patch. Bonding between the patch and substrate can be encouraged by scrubbing the substrate with cement paste, or by applying a liquid bonding agent to the surface of the substrate. Admixtures such as epoxy resins, latexes, and acrylics in the patch may also be used to increase bonding.

Compatible matching of patch material to the existing concrete is critical for both appearance and durability. In general, repair material should match the composition of the original material (as revealed by laboratory analysis) as closely as possible so that the properties of the two materials, such as coefficient of thermal expansion and strength, are compatible. Matching the color and texture of the existing concrete requires special care. Several test batches of patching material should be mixed by adding carefully selected mineral pigments that vary slightly in color. After the samples have cured, they can be compared to the historic concrete and the closest match selected. Contact between the patch and the existing concrete can be enhanced through the use of anchors, preferably stainless-steel hooked pins, placed in holes drilled into the structure and secured in place with epoxy. Good compaction of the patch material will encourage the contact. Compaction is difficult when the patch is "laid-up" with a trowel without the use of forms; however, by building up thin layers of concrete, each layer can be worked with a trowel to achieve compaction. Board forms will be necessary for large patches. In cases where the existing concrete has a significant finish, care must be taken to pin the form to the existing concrete without marring the surface. The patch in the form can be consolidated by rodding or vibration.

Because formed concrete surfaces normally develop a sheen that does not match the surface texture of most historic concrete, the forms must be removed before the patch has fully set. The surface of the patch must then be finished to match the historic concrete. A brush or wet sponge is particularly useful in achieving matching textures. It may be difficult to match historic concrete surfaces that were textured, as a result of exposed aggregate for example, but it is important that these visual qualities be matched. Once the forms are removed, holes from the bolts must also be patched and finished to match adjacent surfaces.

Regardless of size, a patch containing cement binder (especially Portland cement) will tend to shrink during drying. Adequate curing of the patch may be achieved by keeping it wet for several days with damp burlap bags. It should be noted that although greater amounts of sand will reduce overall shrinkage, patches with a high sand content normally will not bond well to the substrate.

K. Repair of Deflection

Deflection can indicate significant structural problems and often requires the strengthening or replacement of structural members. Because deflection can lead to structural failure and serious safety hazards, its repair should be left to engineering professionals.

L. Repair of Erosion

Repair of eroded concrete will normally require replacing lost surface material with a compatible patching material. The elimination of water coursing over concrete surfaces should be accomplished to prevent further erosion. If necessary, drip grooves at the underside of overhanging edges of sills, belt courses, cornices, and projecting slabs should be installed.

IV. CONCLUSION

Cracks in any structure are evident where ever stress in the component exceeds its strength. Stresses build in building component could be caused by any of the externally applied forces, such as dead, live, wind or seismic loads, or foundation settlement or it could be induced internally due to thermal movements, moisture changes, chemical action, etc. It has inferred that most of the cracks in the structure are not dangerous. Non-structural cracks, normally do not pose danger and safety to a building, but may look unsightly, or may create an impression of faulty work or may give a feeling of instability. If it is unattended moisture may ingress and further damages the structure which may lead to structural distress. Careful observation of these cracks can correctly diagnose the cause or causes of cracking and adopt appropriate remedial measures.

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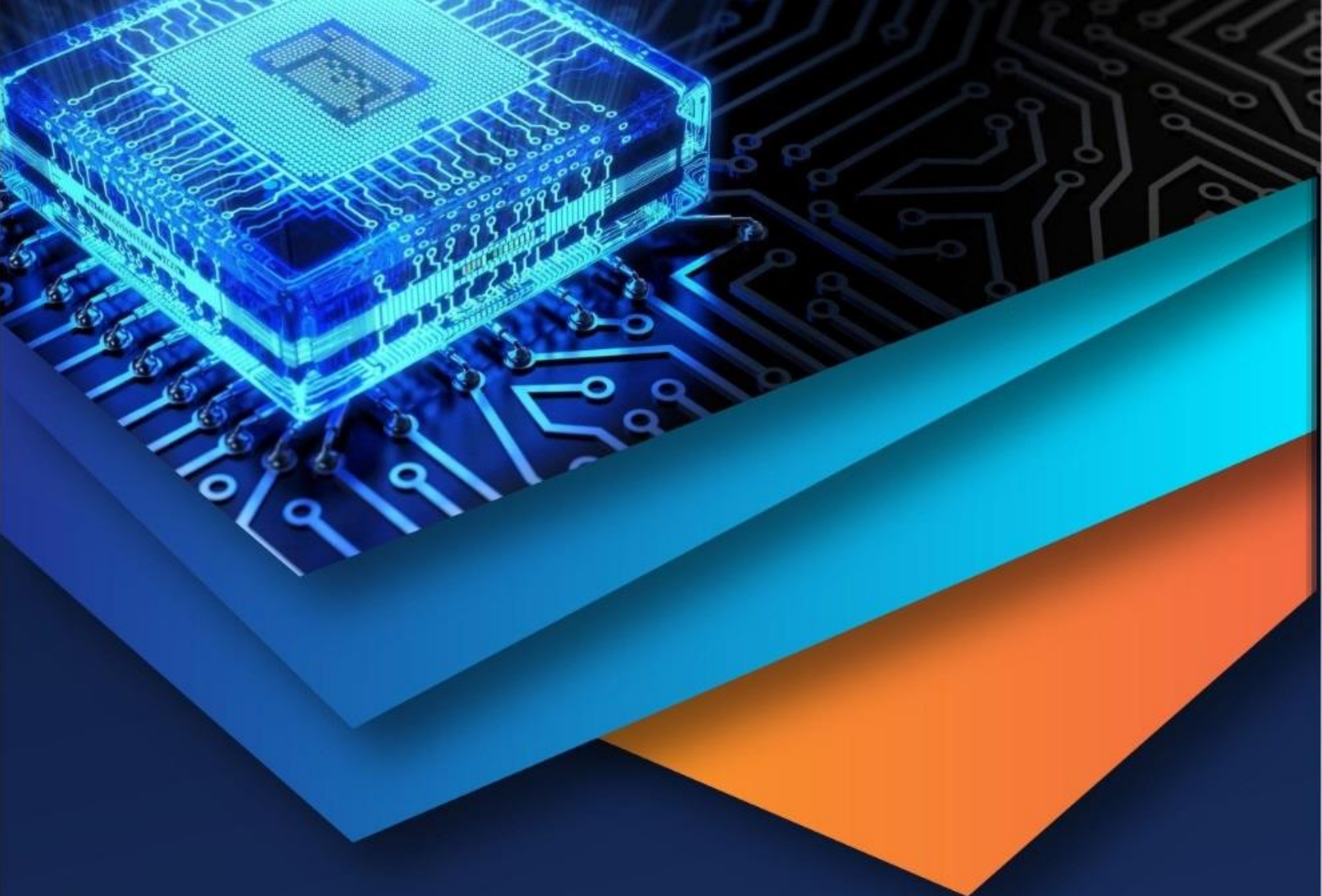

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