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Comparative Study on Damage Index of RCC Frame Considering Fiber Discretization Technique

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***Abstract:** Damage indices which take into account both maximum deformation and cyclic effects were developed by Park and Ang. In the field of structural engineering, it's observed that the Park and Ang damage index is mostly used for RCC structure. The damage index parameter assessed based on plastic hinge approach which is not effective to consider the coupled response between axial force and flexural moment especially in nonlinear domain. The accurate damage evaluations of structure are depending on other parameter such as, accurate modelling of frame, selection ground motion records. Masonry infill walls are widely used as partitions all over the world. Commonly masonry walls are not considered in the damage evaluation process because they are supposed to act as non-structural members or elements. Fiber discretization technique is used to consider inelastic behaviors of member. Single strut is model as infill wall in multidirectional. Results obtained from this study show that the accuracy of damage index totally depends on damage parameter consideration and modeling of building. The coupled effects give more realistic damage of structure as compared with other damage parameters.*
***Keywords:** Damage Index, Fiber Discretization Technique, coupled axial force , moment*

I. INTRODUCTION

The approach utilized is constant shape plastic moment-curvature curve, which is not capable of varying the shape throughout loading history. For this problem, an improved damage index is available, which is considering couple response between axial force and flexural moment. The couple effects are possible because of fiber discretization strategy. The fiber discretization is not only the stiffness and strength degradation has been characterized more accurately, but also the distribution of plasticity along the plastic zone considered. The selection of ground motion record is very important for accurate damage assessment of building. It is difficult to determine a single parameter that best characterizes earthquake ground motion. The recorded of time histories, even at the same site, shows variations in information. Earthquake ground motion amplitude, duration, frequency and the number of peaks in the time history above certain amplitude are some of the characteristics important for determining structural response and damage. Ground motion amplitude is measured in terms of acceleration, velocity and displacement. The frequency content of an earthquake time history is important in identifying the amount of energy imparted at different frequencies. For evaluation purpose various low rise reinforced concrete buildings are designed based on IS 456-2000 Indian codes as test examples. Nonlinear dynamic time-history analysis are performed on these structures. Fiber discretization technique is used to consider inelastic behaviors of member. Single strut is model as infill wall in multidirectional. Results obtained from this study show that the accuracy of damage index totally depends on damage parameter consideration and modeling of building. The coupled effects give more realistic damage of structure as compared with other damage parameters.

II. MODEL DEVELOPEMENT

The Park and Ang damage index is capable of evaluating only ductile failure of member. When the axial load is large and the eccentricity is small, compression prevails over the entire section and neutral axis falls outside of the section . In this case, failuer occur by crushing of concrete when the strain in it reach maximum value. This type of failuer is called as compression failure. It is sudden does not give any warning. The axial load significantly affects deformation and energy terms of damage index and in turn affects the damage index. To take advantage of the Park and Ang damage index model as an index of structural damage, the axial load should be considered in damage terms. Thus, a modification needs to be carried out based on the level of axial load over tension or compression control region of interaction diagram. In compression control region of interaction curve, as soon as the demand exceeds the design strength, damage index is equal to unity and calculation of damage index does not make any sense.The improvement in damage index for a general RC beam-column member is introduced as follows .

$$\text{If } P < P_b \qquad DI_1 = \frac{\theta_m - \theta_r}{\theta_u - \theta_r} + \frac{\beta}{M_y}\int dE_h \qquad (3.3)$$

$$\text{If } P > P_b \qquad DI_2 = 0, \quad - \quad \text{If } M < M_y \qquad (3.4)$$

$$DI_2 = 1, \quad - \quad \text{If } M > M_y$$

Where,
P = maximum axial load in loading history,
P_b = axial load related to balanced point in interaction diagram,
θ_m = maximum rotation during the loading history,
θ_u = ultimate rotation capacity of section,
θ_r = recoverable rotation while unloading,
M_y = yield moment of section
β = non negative parameters (0.1-0.15),
dE_h = incremental dissipated energy.
The damage index is consider as maximum of the values DI_1 ,DI_2

A. *Ground Motion Characterization*

The selection of ground motion record is very important for accurate damage evaluation of building. It is difficult to determine a single parameter that best characterizes earthquake ground motion. The recorded of time histories, even at the same site, shows variations in information. Earthquake ground motion amplitude, duration, frequency and the number of peaks in the time history above certain amplitude are some of the characteristics important for determining structural response and damage. Ground motion amplitude is measured in terms of acceleration, velocity and displacement. The frequency content of an earthquake time history is important in identifying the amount of energy imparted at different frequencies. The strong motion duration of an earthquake time history is the time interval during which most of the energy of that time history contained. Peak ground acceleration (PGA) has frequently been used as a parameter to characterize ground motion. Other parameters included Arias intensity, ratio of PGA to PGV.

Table 1: Ground Motion Records and Parameters

S.No	Earthquake	Date	Recorded Station	PGA (a_{max}) m/s^2	PGV (v_{max}) m/s	PGD (d_{max}) m	T sec
1	N.E. INDIA	06-May-95	Khliehriat	0.22	0.01	0.001	3.72
2	CHAMBOLI	29-Mar-99	Himalaya	0.45	0.03	0.01	6.56
3	N.E. INDIA	08-May-97	Shilling	0.71	0.04	0.00	14.14
4	BHUJ	26-Jan-01	Ahmedabad	1.03	0.11	0.09	46.94
5	H.P. EARTHQUAKE	26-Apr-86	Dharmsala	1.72	0.07	0.01	2.20
6	UTTARKASHI	20-Oct-91	Uttarkashi	2.37	0.17	0.02	6.22
7	IMPERICAL VALLEY	19-May-40	El-Centro	0.31	0.033	0.01	40
8	KOBE	16-Jan-95	Takatori	0.68	0.12	0.012	48

III. ANALYSIS RESULT

The procedure used for the damage evaluation of structure using SAP 2000 is validated with referred literature [12]. A two dimensional model of G+4 RCC frame were considered. The model specification and the loading data are given in Table 2.

Table.2 : Computational Model Specification

Single bay G+3 RCC frame	Span of beam = 6 m, Column Height= 3 m
Material properties	ASTM Standards
Design as per	ACI (2005) code
Distribution of dead load on 2 first beam	38 N/mm
Distribution of dead load on 2 second beam	36 N/mm
Live load on beam	30 N/mm
Seismic mass consider	Dead load +0.25 Live load
Ground motion	Kobe 01/16/95

The geometrical configuration, element description, dimensions and reinforcement details are shown in Figure 1 the structure designed is based on ACI code. The damage was evaluated by using Seismo Struct software.

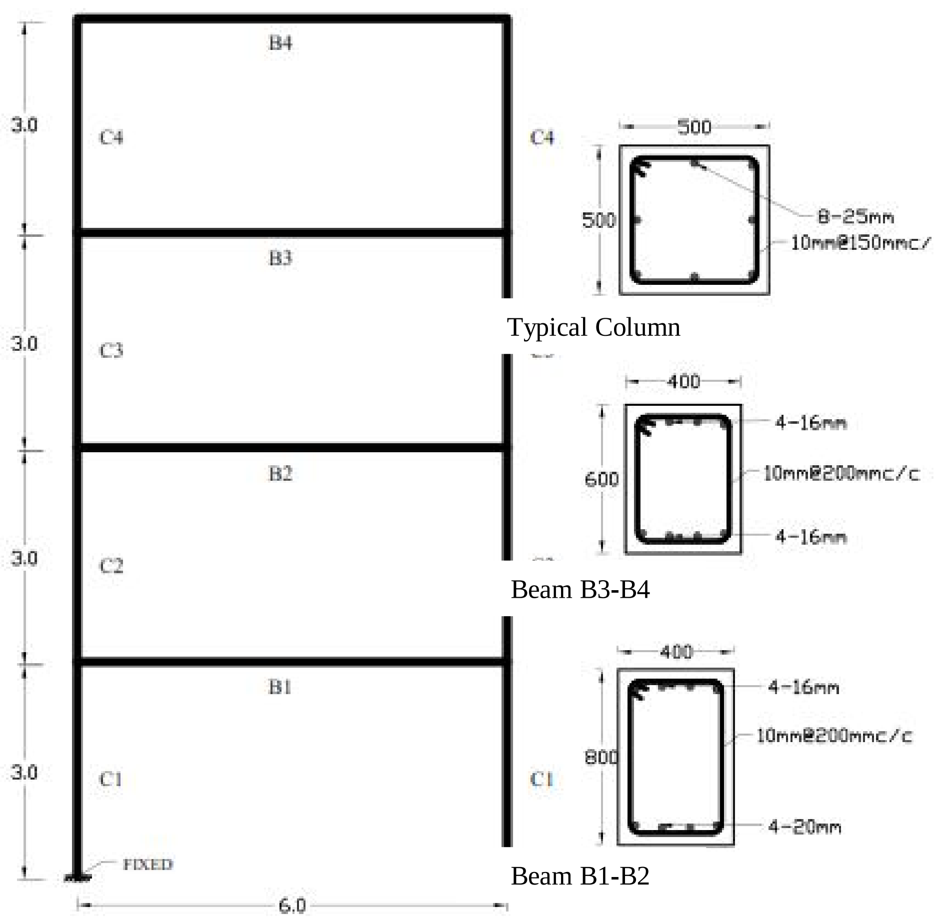

Figure 1: Geometry and design of 4-storey frame

The various local damage index obtained from analysis are shown in Table. with comparison of results between the SAP analysis and reference case. [12].

Table 3: Comparison of Results between the SAP 2000 Analysis and Ref. [12]

Results	SAP Analysis		Reference Paper	
Element ID	Bottom	Top	Bottom	Top
C1	1.740	0.490	2.210	0.080
C2	0.321	0.240	0.450	0.240
C3	0.321	0.241	0.450	0.240
B1	0.530	0.500	0.510	0.150
B2	0.395	0.394	0.300	0.160

From the results obtained it is observed that most of damage belongs to bottom storey columns. The damage in C1 column has reached collapse state for both cases, analysis performed and reference literature. Also the damage obtained from analysis is approximately equal to damage evaluated in Ref. [12] but there is some variation in results because of insufficient material properties available in Ref. [12].

A. Description of the Structure

As an example the damage analysis is performed for typical ground+3 storey reinforced concrete building. The building is designed according to the IS 456-2000 code. The plan area of building is 12 x 12 m with 3.2 m as height of each typical storey. The foundation considered as fixed support. The sectional properties of various elements are obtained based on gravity loading. The building plan and computational model of the building as shown in Figure 2

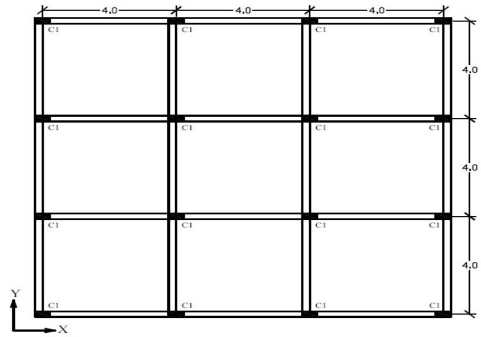

Figure2: Plan of Ground+3 RCC Building

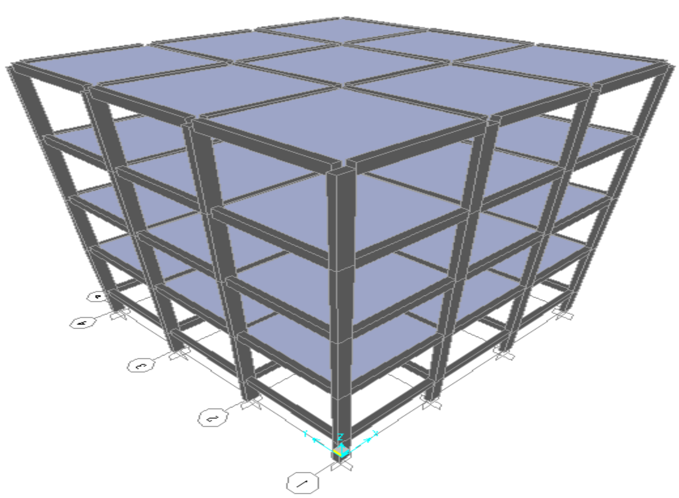

Figure 3: Computer Generated Model of Ground + 3 Storey RCC Building in SAP 2000

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The building is design for gravity loading data as shown in Table 4

Table4 : Numerical Data for Ground + 3 Storey RCC Building

Live load	3 kN/m^2
Floor finish	1 kN/m^2
Earthquake load	El-Centro ground motion 0.31g
Depth of foundation below GL	1.5 m (consider as fixed)
Storey height	3.2 m
Wall	230 mm thick brick masonry walls only at periphery, 115 mm thick brick masonry Wall at internal
Slab	120 mm thick as rigid diaphragm
Material Properties	Concrete- M20 HYSD reinforcement of grade Fe 415

The design data for beams and columns are as shown in Table 5

Table 5: Reinforcement Details of Section

	Floor	Dimension (mm)	Bottom	Top
Beam	Ground	230 x 380	12ϕ-2 No	12ϕ-2 No
	1st to 3rd	230 x 380	12ϕ-3 No	12ϕ-4 No
	Top	230 x 380	12ϕ-2 No	12ϕ-2 No
Column	All floor	230 x 450	12ϕ-8 No	6ϕ@150mmc/c

Analysis Results for ground+3 Storey Building considering couple effect of axial force and flexure. The local damage indices of various elements are obtained from analysis as shown in Table 6

Table 6: Local Damage Index of Elements

Element ID	Axial force (P) kN	Moment (M) kN	Local Damage Index (DI_{PK})	Damage State
25H1	177	61.32	0.46	Minor
26H1	271	41	0.19	Slight
24H1	464	101	0.47	Moderate
27H1	651	106	0.35	Moderate
23H1	712	124	0.53	Severe
22H1	937	132	0.68	Severe
28H1	982	139	0.89	Collapse
21H1	1100	65	0.46	Moderate
30H2	1454	78	0.06	No damage

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IV. RESULTS

A. Analysis Results for ground+4 Storey Building considering couple and uncoupled effect of axial force and moment.

The hysteretic energy distribution over storey height in both cases for constant and fiber hinge approach are shown in Figure 3

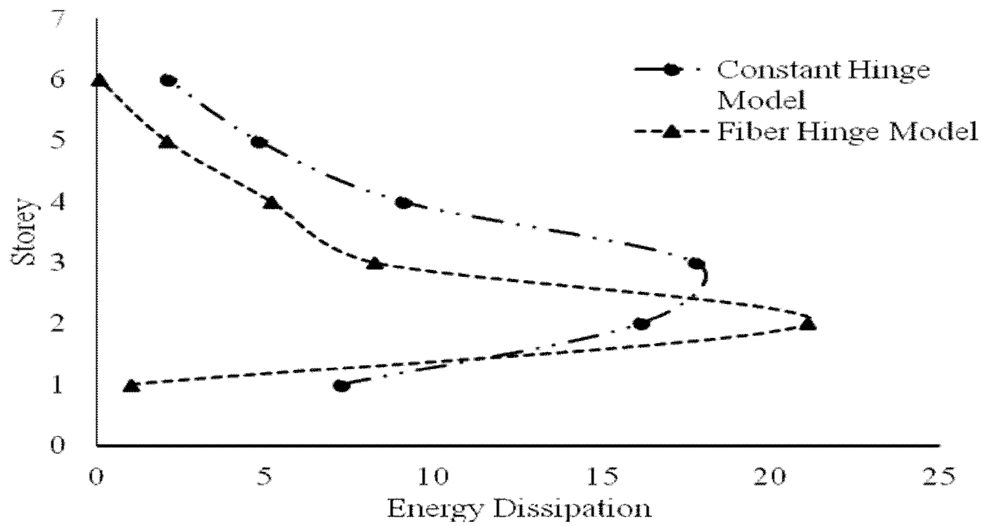

Figure.3: Comparison of Energy Dissipation over Storey Height

At the top storey less energy dissipation shows in fiber hinge than the constant hinge, this occur because fiber hinged consider axial force and moment interaction, at 5^{th},4^{th},3^{rd} storey the axial force is less than the balance axial force in tension region. It is produced confinement effect to member. Hence due to confinement increased moment resistance.

In case of uncoupled effect of axial force and flexure moment, axial force cross the design ultimate value at the bottom storey column (i.e. column had reached collapse damage state). The comparison for energy dissipation in both cases the fiber hinge gives realistic energy dissipation at bottom storey than the constant hinge. When the member had cross collapse state value then perfect plastic hinge formation occurs.

Figure 4 shows the comparison of storey damage index considering coupled and uncoupled effect of axial force and flexure moment under the El-Centro motion.

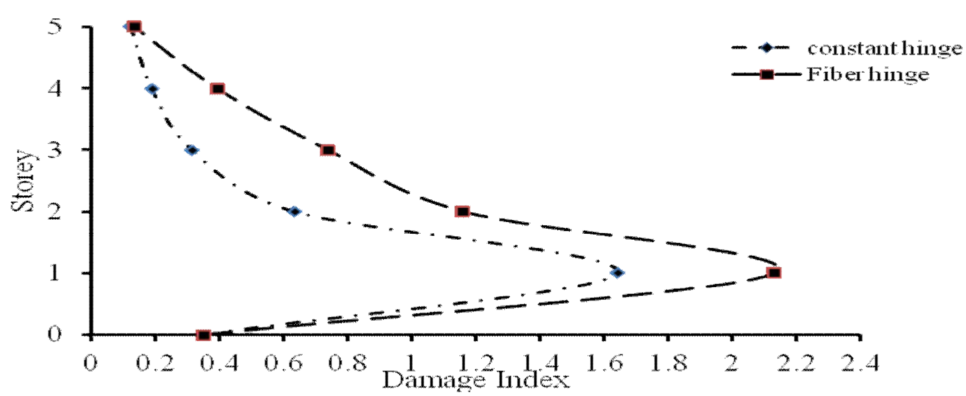

Figure.4: Comparison of Storey Index for El-Centro Ground Motion

In the above Figur 4 by comparing damage distribution of storey index, the fiber hinge shows more damage than constant hinge and is increasing gradually with bottom storey axial force up to failure occur. The maximum axial forces are inducing in bottom storey column still softening damage index does not progress to any damages.

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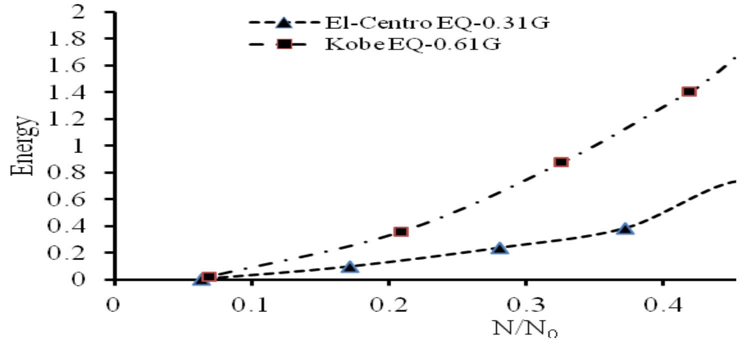
B. Analysis Results for G+4 Storey Building considering couple effect of axial force and moment.



N – Maximum axial force under the loading history
N_0- Balance axial force

Figure.5: Influence of Axial Load on Energy Dissipation

The plot of energy dissipated in element verses ratio of axial force in element to ultimate capacity of element is as shown in Figure 4 when axial load is beyond the axial load ratio of 0.45(balance axial load to maximum axial load capacity of section) element does not exhibit ductile behaviour. In compression control region of interaction diagram due to brittle behaviour, sudden failure is expected. In addition, the brittle failure is so immediate that the computation of damage index is not possible.

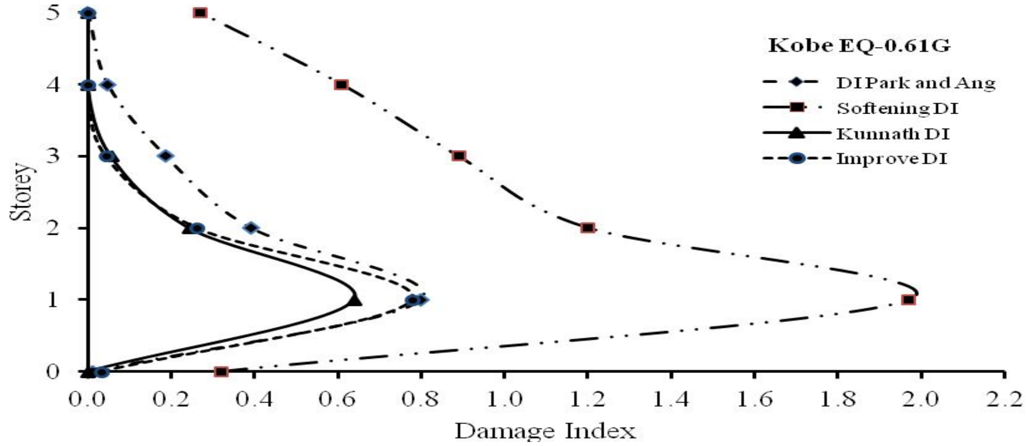


Figure.6: Comparisons of Storey Damage Index for Kobe EQ

The plot of different storey damage index over the storey height is as shown in Figure 6. The softening storey damage index are obtained from ratio of inter storey drift .By comparing softening DI with other damage index, it is observed that overestimation damage. The Kunnath and Improved damage index have same distribution of damage over the storey height.

V. CONCLUSIONS

1) Results shows that if the axial force of column goes beyond ultimate value, the Park and Ang damage index give undamaged state of structure. This is because DI_{PA} does not capture failure in compression.
2) By comparing DI_{PA}, DI_{KUN}, the DI_{PA} gives more damage index than DI_{KUN}. This is because DI_{PA} is considered linear deformation relationship.
3) The axial force and moment interaction is captured in fiber hinged approach
4) By comparing different damage indices it is concluded that damage indices shall be defined limitation of axial force and moment.

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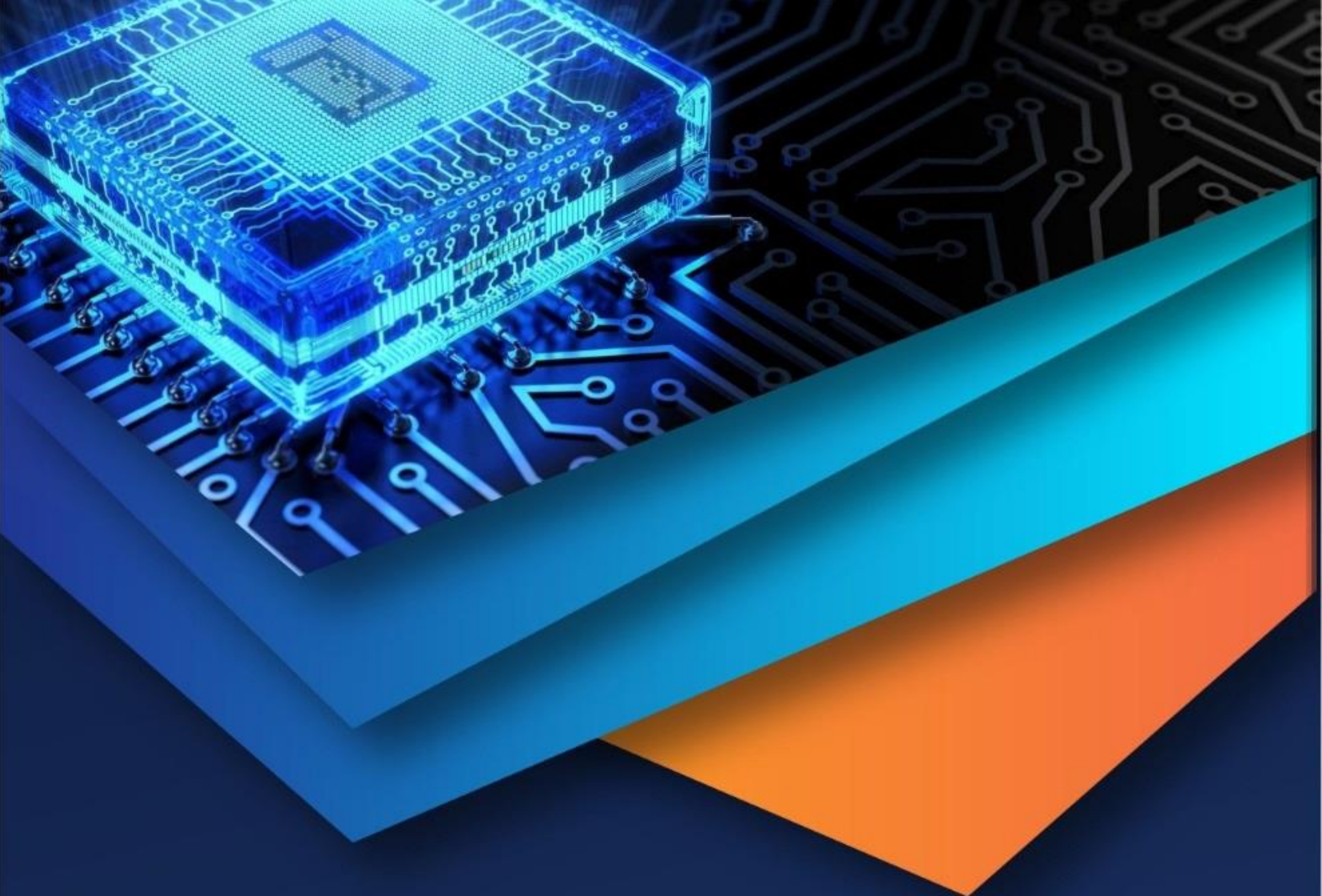

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