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Retrofitting of Damaged Crumb Rubber Concrete Frame Using Fiber Reinforced Polymers

Muhammad Sulaiman
Department of Civil Engineering, University of Engineering & Technology, Peshawar, (091) Pakistan

Abstract: The research work is focused on the retrofitting of damaged crumb rubber concrete frame. The retrofitting of these frames was carried out using Carbon Fiber Reinforced Polymers (CFRP) wrapping technique accompanied with beam weakening technique, carried out at certain locations to achieve the desired failure mechanism. Two previously tested 1/3rd reduced scale models Crumb rubber concrete (CRC) and Normal concrete (NC) were CFRP retrofitted along with beam weakening and then tested dynamically. From the as-built testing strong-beam weak-column effect was observed, for that purpose beams weakening through cores removal away from the face of the column equal to two times depth of the beam, so as to shift the damage from the brittle failure mechanism of column and joint damage to more ductile damage in the beam. In addition to beam weakening the damaged beam column joints were CFRP retrofitted. A comparative study between the retrofitted and as-built models was done. The results obtained from testing has recovered the ductility up to 82% and response modification factor up to 90% for normal concrete while in case of crumb rubber concrete frame the ductility is recovered up to 76% and its response modification factor up to 81%. As intended, a much-distributed damage behavior/cracking pattern as compared to the reference models, especially in the case of normal concrete model. The intended purpose of the retrofitting in recovering seismic properties and a comparatively distributed damage/cracking pattern was achieved. The purpose of beam-weakening through core removal for shifting the damage from columns and joints towards the beams for achieving a more ductile failure mechanism was achieved to some extent.
Keywords: Retrofitting, Carbon Fiber Reinforced Polymers, Shake Table, Crumb Rubber, Beam Weakening.

I. INTRODUCTION

A very rapid increase in the number of road vehicles in the recent times is observed all over the world. Only in Pakistan as-per its economic survey of 2015-16, during 2000-2015, there is an increase in the number of vehicles by 268%. A total of 17.32 million vehicles were registered in Pakistan by 2015 [1]. Although due to a huge and abrupt increase in the number of road vehicles, many problems can be related to, one that is largely ignored is the great numbers of scrap or used tyers that are disposed without any proper consideration. Due to their non-biodegradable nature, these tyres are seen as a major and sophisticated source of garbage in contemporary countries. As the number of cars on the road rises, so does the amount of scrap rubber tyres that are discarded annually. Even more worrisome is the fact that if these tyres catch fire, they could release toxic gases into the atmosphere [2].

Earthquakes are among the most lethal natural disasters, causing widespread destruction and loss of life. Earthquakes cause an annual average of 10,000 deaths and yearly economic damages in the billions of dollars, which may amount to a significant portion of the total production of the country [Javed et al., 2008] shown in Figure 1.1 to 1.3.

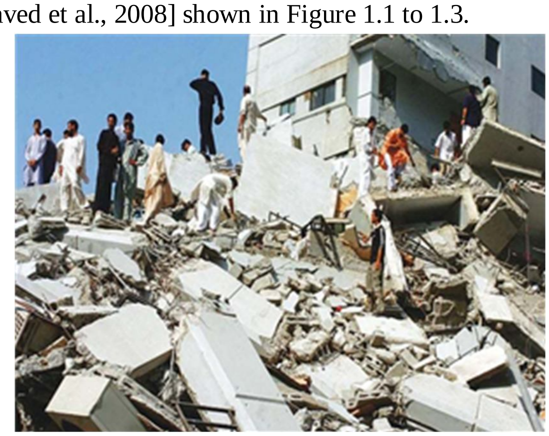

Figure 1.1:Collapse of Reinforced Concrete Structure in past earthquakes

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II. LITERATURE REVIEW

As a recent and alternative/cleaner solution, as compared to disposing, is to use these very large number of scrap rubber tyres, concrete fine aggregates can be replaced in part with crumb rubber. This new/modified concrete is normally named as crumb rubber concrete (CRC) or rubberized concrete. Although a great amount has been recently been made on study such concrete but it has largely been just limited to concrete cubes, cylinders, columns, beams and its joints to find its dynamic and mechanical properties. Largely, the addition/replacement of other fine aggregates with the crumb rubber within a certain limit as a percentage of the total weight or volume content it is helpful in the increase in the hysteretic damping ratio, energy dissipation, ductility and impact resistance of the so-called modified crumb rubber concrete [4, 5, 6]. While on the negatively impacting side it leads to a decrease in its workability, concrete compressive and flexural strength[7].

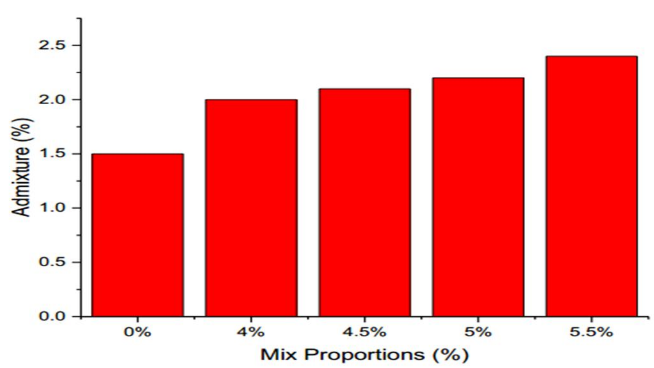
Already mentioned the addition of crumb. rubber inplace of the conventional fine aggregates leaded to an improvement in some of the important properties e.g., damping ratio, energy dissipation and ductility of concrete, when it comes to dynamic response of a concrete structures. But as although the importance of such properties to be realistically evaluated is clearly understood it were not evaluated in case of a more realistic three-dimensional structural level [17]. In order to fix this problem Izzat Khan, a Master of Science Student at U.E.T. Peshawar, conducted a study comparing the seismic performance of conventional concrete with crumb rubber concrete by testing two 1/3-scale models. An examination, using shaking table testing, of the seismic resistance of a crumb rubber concrete, three-dimensional, reinforced concrete frame. Based on the results an over-all promising result were obtained but as no retrofitting was done and as a continuation of the research it needed to check the possibility of retrofitting such structures with possibly improved performance in case of damage mechanism etc. as the damage observed in the as-built was mainly concreted at the joints

Tyres made of rubber that have been discarded are a major source of pollution worldwide. Every year, millions of old tyres are thrown away and placed in landfills throughout the globe. Some 1000 million tyres reach the end of their lifespan annually, and it is projected that by 2030, that figure will rise to 1200 million, culminating in a total of 5000 million tyres that were routinely discarded [8]. According to Martinez et al., 2013, one billion waste rubber tyres are dumped annually throughout the globe, or one tyre per person [9]. A further study conducted in 2011 indicated that 4 billion used tyres were accumulating in landfills [10].

The number of automobiles in Pakistan grew by 268 percent between 2000 and 2015, as reported in the country's economic assessment for 2015-16. A large quantity of waste rubber tyres may be generated from Pakistan's total of 17.32 million registered automobiles in 2015 [1]. The US Environmental Protection Agency estimates that in 2003, 290 million rubber tyres were no longer usable but only 45 million were recycled. Plants in the European Union generate 335 million rubber tyres annually. Most of the world's used tyres end up in landfills (Figure 2.1), where they may pose a number of threats to human health, including the release of toxic fumes from the combustion of synthetic rubber compounds and the breeding of pests like mosquitoes [11].

Throughout the globe, discarded rubber tyres are a major contributor to environmental degradation. The United Kingdom manufactured 37 million tyres in 2002 [12]. A total of 100,000 tonnes of discarded rubber tyres are generated annually in Taiwan, according to a 2013 study by Yung et al [13].

Over twenty million tyres were discarded in landfills throughout Australia in 2010 [14]. The annual production of waste rubber tyres in France is around 10 million, which is a similar figure to that in the United States [15].



The purpose of this study is to conduct an experimental investigation of the axial capacity of helical piles. The following goals have been established for this study to accomplish:

1) To assess the effectiveness of helical piles under axial loading
2) To compare the results with the results from traditional piles.

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III. METHODOLOGY

A. Introduction

In this study two models were retrofitted using CFRPs that were previously tested by Izzat Khan (MSc student). 1/3rd reduced scale models of the structures were constructed by Izzat khan, considering the limitations of the shaking table, with prototype full scale model with structural details and geometric configuration as in Figure 3.1. The first frame was constructed with normal concrete, the second, however, was built with CR concrete, which substituted 15% of the fine aggregates with CR particles. It's worth noting that building a model that satisfies all of the prototype criteria is quite difficult [19]. Because of the complexity involved in accurately simulating concrete and reinforcing, achieving a perfect likeness between prototype and model is currently impossible. As a result, in accordance with the basic / distorted model similitude criteria, the compressive strength for concrete and steel reinforcements characteristics utilized in concrete were maintained at the same levels in both the model and prototype constructions.

B. Test Specimen

1) Analyzing Dimensions and Understanding Scaling Laws

Models of the proposed structures were built, loaded, and subjected to experimental testing in accordance with the principles of similitude, and the resulting data was obtained, analyzed, and interpreted according to the laws of proportion. The suggested structural models should be designed and built in accordance with the relationships described by Equation, where.

$$D_p = D_m X \lambda_f$$

Table 3.1:Model Scale Factors (Khan et al., 2019)

Physical Quantity	Equation	Scaling ratio
Linear dimension (L)	$\lambda_L = L_p/L_m$	3
Deformation (D)	$\lambda_D = D_p/D_m = \lambda_L$	3
Strain	$\lambda_\epsilon = \epsilon_p/\epsilon_m$	1
Stress (f)	$\lambda_f = f_p/f_m$	1
Force (F)	$\lambda_F = F_p/F_m = \lambda_L{}^2\lambda_f$	9
Mass per unit volume	$\lambda_\rho = \rho_p/\rho_m$	1
Frequency (ω)	$\lambda_\omega = \omega_p/\omega_m = 1/\lambda_t$	0.33
Time (t)	$\lambda_t = t_p/t_m = \lambda_L \sqrt{(\lambda_\epsilon\lambda_\rho/\lambda_f)}$	3
Acceleration (a)	$\lambda_a = a_p/a_m = \lambda_f/\lambda_L\lambda_\rho$	0.33
Velocity (v)	$\lambda_v = v_p/v_m = \sqrt{(\lambda_\epsilon\lambda_\rho/\lambda_f)}$	1

2) Modeling and Geometry for Experiments

Special Moment Resisting Frame (SMRF) analysis and design were performed on the prototype utilising the Building Code of Pakistan BCP-SP-2007 [22] and the American Concrete Institute's ACI 318-14 [23]. Figure 3.1 depicts the prototype reinforcing details and member measurements.

3) Materials Used in Scale Models: Fundamental Characteristics

All longitudinal reinforcement was made from #2 (6mm) deformed bars with a yield strength of y=60 ksi, while stirrups were made from #1 (6mm) deformed bars with the same yield strength. Using the guidelines provided in Section 3.6 of ACI Standard 211.1 [24], a concrete mix was designed. The following analyses have been carried out on the primary ingredients.

4) Analysis of Fine Aggregates by Grading and Sieving

Fine aggregates have been subjected to a gradation / sieve analysis test, the results of which were used to derive the fineness modulus (FM). Results of sieve analysis tests are provided in Table 3.3.

C. Designing Concrete Mixtures for Use in Scale Modeling

In order to choose and proportion the concrete materials, a concrete mix design was carried out using the American Concrete Institute (ACI) Standard 211.1 [24]. This was done after the fundamental parameters of the concrete ingredients were determined. To achieve a compressive strength of 4000 psi with aggregates no larger than 3/8 inch in size, the ideal cement-to-fine-to-coarse-aggregates-to-water ratio (cement-to-w/c) was calculated to be 1:1.74:1.57.

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Cylinders of normal concrete (NC) and crumb rubber concrete (CRC) were made with the identical proportions as illustrated in Figure 3.3, with the exception that 15% of the volume of the fine aggregates was substituted by CR particles. Table 3.7 provides a summary of the component ratios employed in the two concrete mixes. Universal Testing Machine UTM tests were performed on trial standard concrete cylinders after 7 and 28 days, as specified by ASTM-C39 / C-39M. [25].

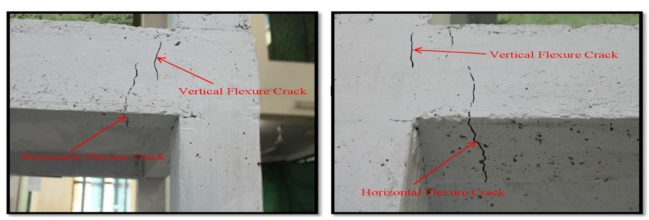
IV. RESULTS AND DISCUSSIONS

A. General

This chapter compares the as-built models with those that have had carbon fiber reinforced plastic (CFRP) added to their frames, as well as testing with shake table findings on ordinary concrete (NC) frame models and CRC frame models. Each computed parameter is explained in detail below.

B. Damage Behavior of a Retrofitted Concrete Frame

During the application of initial loading up-to 50%, no new cracks were observed just the opening of the existing cracks that were just whitewashed was observed



Flexural Cracks in Beam (in-Plane) on Ground Story Flexural Cracks in Beam (in-Plane) on Ground Story
Damages observed at Ground Story at 100% NR

Beam-Column Joint Crack at Ground Story Beam-Column Joint Crack at First Story
Damages observed at Ground and First Story at 140% NR

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C. A Damage Model of a Retrofitted Crumb Rubber Concrete Frame and Its Observed Performance

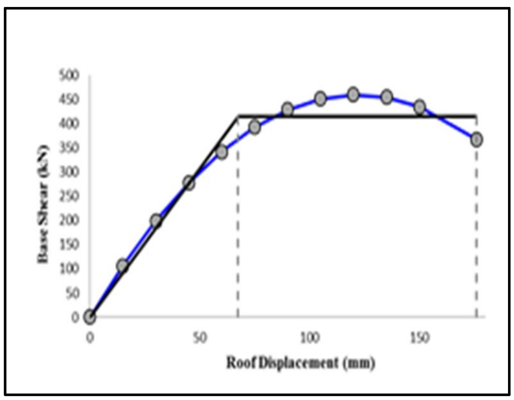
During the application of initial loading up-to 30%, no new cracks were observed just the opening of the existing cracks that were just whitewashed was observed

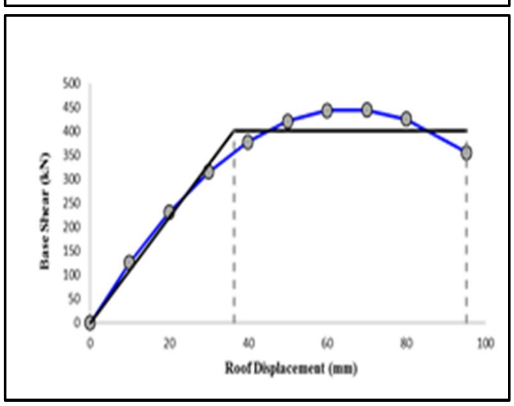
With an increase in loading up-to 80%, further opening of existing and newer shear and flexure cracks in the beam and column were observed (Figure 4.6). At the application of 200% of loading, further opening of the existing cracks and a concentration of shear cracking in the columns ends was observed

In case of both NC and CRC as-built model there were fewer cracks in the beams and nearly all of the joints observed cracking and most of the cracking concentrated in the form of flexural cracking in the column ends. In case of the both retrofitted frames most of the cracking pattern was similar with the joints hidden in FRP layers but no large size additional cracking in the joints was observed. An improved damage behavior as intended due to the retrofitting was observed in the form of relatively more distributed flexure cracking along the height of the columns especially in the case of NC model, with shear cracking concentration at the column ends in case of CRC model.

Curves of lateral force vs. deformation capacity were created for the test model prototype buildings. Shaking table test data was converted into prototypes using different scale factors for various characteristics in accordance with the principles of similarity. By subtracting the minimum from the maximum, we were able to ascertain the utmost roof movement throughout each test run. For each test run, the maximum base shear forces and the maximum story forces were determined, by adding the self-weight of the beam, slab, additional masses of blocks, and half the mass of the column above and below the corresponding floor, and then multiplying that result by the corresponding floor accelerations. There was an assumption that, on the same narrative plane, the inertial masses depicted in these tales would behave similarly to a single, massive inertial mass. The shear forces at the base of each run were then calculated by adding the pressures exerted by the storeys above the base. Plotting the highest value of the base shear force against the maximum roof displacement attained during each test session yielded

Figures 4.9 and 4.10 illustrate the results of bi-linearizing the experimentally acquired capacity curves of both the prototype structure in order to calculate various seismic response parameters utilizing the energy balance. The maximal displacement achieved during these tests was considered the ultimate displacement of the structure. The yield displacement and yield strength of the structure were estimated using an iterative method in order to match the graph of the actual experimental data collected with elasto plastic curve.





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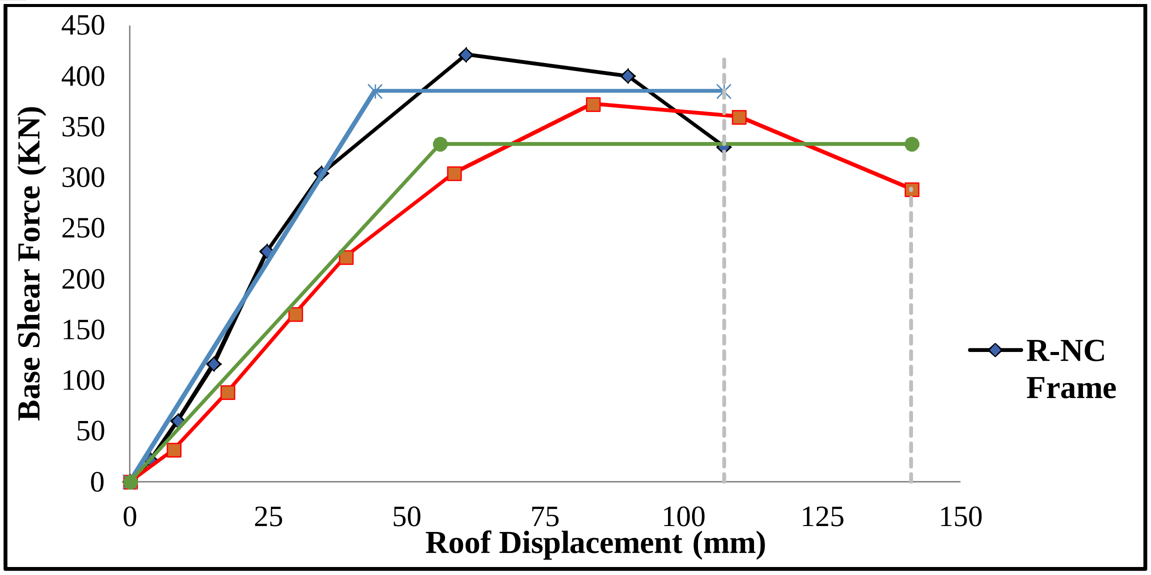

Figure 4.10:Capacity curves for Lateral Force-Deformation (actual model) Using energy balance criterion

The ductility factor was obtained from the maximum allowable displacement divided by the theoretically optimal yield displacement.. Figure 4.9 and Table 4.1 exhibit a contrast between the two models in terms of ductility and response modification factor. Previous authors' method [28] was used to determine the structural response modification factor. It is possible to determine the R factor by solving Equation [28], provided one is familiar with the inelastic lateral force-deformation behaviour of the structure The time period of both the model is above 0.5 sec so the ductility response modification factor is equal to the ductility factor as shown in table above. The ductility factor in case of both NC and CRC are recovered significantly. The ductility-based response modification factor for NC and CRC has recovered up to 83% and 76% respectively. The result shows that the retrofitting technique achieved the desired result in both cases but specifically in NC the recovery is more than that in CRC

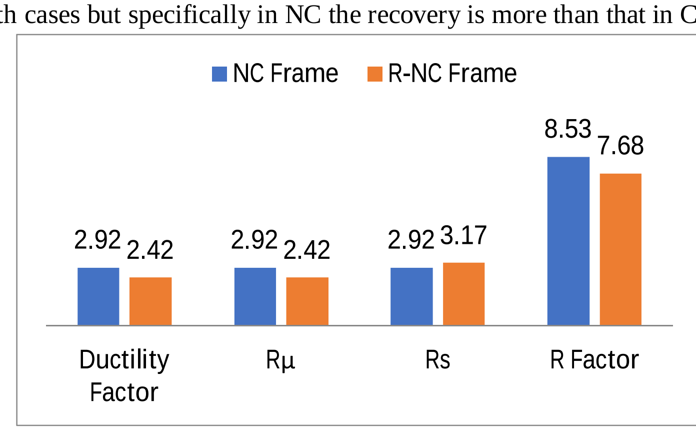

Figure 4.13:Over strength Factor Rs and Response modification factor R (Prototype Structures)

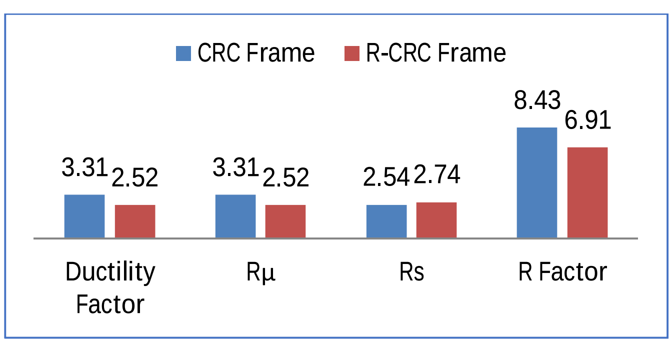

Figure 4.14:Over strength Factor Rs and Response modification factor R (Prototype Structures)

V. CONCLUSIONS AND RECOMMENDATIONS

A. Geenral

The current investigation built upon previous work by Khan et al., 2019 that examined the effect of replacing some of the fine aggregates in reinforced concrete frames with rubber crumb and assessing their seismic performance at a 1:3 scale. One model was casted in normal concrete to serve as a standard of comparison, while the other was casted in crumb rubber concrete, in which 15% of the fine aggregate were substituted with crumb rubber. The purpose of this research was to assess the effectiveness of a CFRP application scheme and core removal from beams (for beam weakening) in regaining and, maybe, increasing certain seismic response characteristics of previously tested models. Results from this investigation led to the following inferences.

B. Conclusions

1) All of the seismic response parameters were largely recovered for both normal and crumb rubber concrete frames.
2) As intended, a much distributed damage behavior/cracking pattern as compared to the reference models, especially in the case of NC model.
3) A lesser distributed cracking or concentration of shear cracking at the ends of the column in case of CRC frame was due to its lesser stiffness and increased deformation of the columns at its bases due to the effect from crumb rubber in the concrete.
4) The load displacement behavior was similar to the reference frames for both of the models with a lesser initial stiffness for the retrofitted models due to the opening of the existing cracks. A higher strength at higher displacements/loading was, as expected, due to the CFRPs contribution at higher deformations.
5) Although the intended purpose of the retrofitting in recovering seismic properties and a comparatively distributed damage/cracking pattern was achieved, the purpose of beam-weakening through core removal for shifting the damage from columns and joints towards the beams for achieving a more ductile failure mechanism was achieved up to some extent.

C. Recommendations

1) Based on this study it is recommended that CFRP retrofitting of both NC and CRC is effective in recovering its seismic response parameters and essentially improving the damage behavior by relatively more distributed cracks along the columns.
2) As beam-weakening through core removal was helpful in shifting damage from column and joint towards beam (ductile failure). It is recommended to properly analyze the situation so that optimum diameter and location of core can be selected depending on the suitability of either depth/length of beam and the amount of weakening required (difference of strength between column/joints and beam of the frames requiring retrofitting).
3) For further improving of the damaged behavior and overall performance of the retrofitted RC structures, filling of existing cracks accompanied with CFRP wrapping should be considered.

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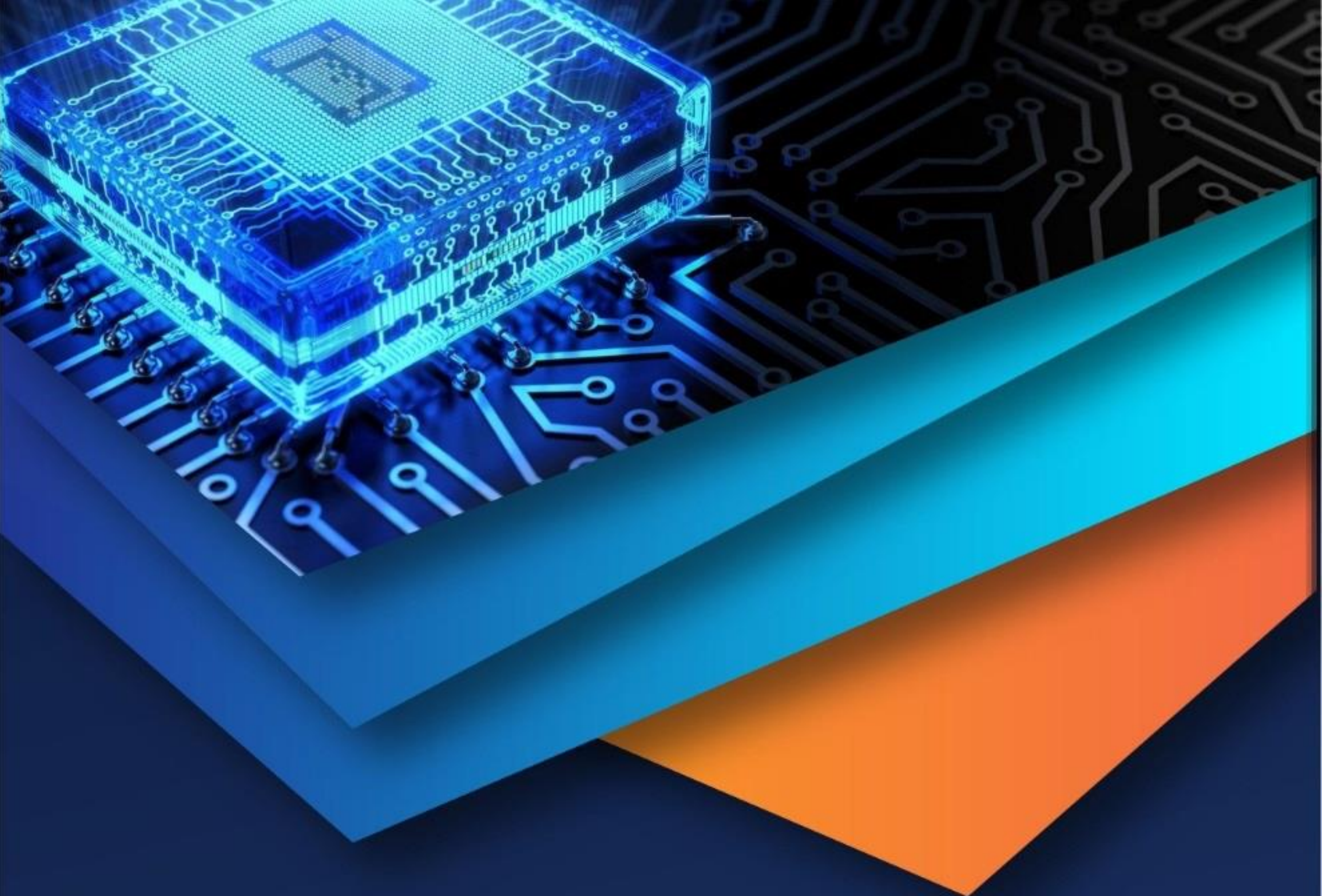

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