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Seismic Assessment of Unreinforced Concrete Block Masonry Buildings Before and After Retrofitting: A Case Study

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***Abstract:** This article presents the results of a case study on the performance of unreinforced concrete block masonry building system. The configuration and materials used for the single-story building are typical of those found in the northern areas of 2005 Kashmir earthquake. The retrofitting of the building was done using Ferro-cement overlay and cement based grout injection. Combined shear and flexure failure was observed during the test before retrofitting. The lateral load capacity of the retrofitted building was significantly improved and the damage mechanism was transformed from mixed compression-flexure-shear to a more stable flexural rocking mode. Damage patterns and deformation behavior of the retrofitted structure are compared to the intact structure to quantify the benefits of retrofitting scheme, which is proposed as an efficient approach for the rehabilitation of the existing buildings. Study data were analyzed and presented in the form of force-deformation loops and envelope curves. Based on the measured data, different performance levels before and after retrofitting of the structure have been established. The results from this study are expected to guide future efforts on development of design recommendations and vulnerability assessment of buildings.*

***Keywords:** Earthquake; Unreinforced Concrete Block Masonry; Retrofitting; Quasi Static Test; Ferro-Cement Overlay; Rehabilitation; Vulnerability assessment;*

I. INTRODUCTION

The 2005 Kashmir earthquake occurred on 8 October in Pakistani-administered Azad Kashmir. It was centred near the city of Muzaffarabad, and also affected nearby Balakot and some areas of Indian-administered Jammu and Kashmir. It registered a moment magnitude of 7.6 and had a maximum Mercalli intensity of XI (Extreme). The earthquake also affected countries in the surrounding region in Afghanistan, Tajikistan, India and the Xinjiang region. The severity of the damage caused by the earthquake is attributed to severe up thrust. Over 86,000 people died, a similar number were injured, and millions were displaced. It is considered the deadliest earthquake in South Asia, surpassing the 1935 Quetta earthquake. Kashmir lies in the area of collision of the Eurasian and Indian tectonic plates. The geological activity born out of this collision, also responsible for the birth of the Himalayan mountain range, is the cause of unstable seismicity in the region.

The maximum intensity in India was VIII (Destructive) on the Medvedev–Sponheuer–Karnik scale (MSK), and was felt at Uri. MSK VII was felt in Kupwara and Baramulla. In Srinagar, the earthquake was felt with an MSK intensity of V. At areas where the seismic intensity was lower, collapses were documented.

Most of the devastation hit north Pakistan and Pakistan administered Kashmir. In Kashmir, the three main districts were badly affected and Muzaffarabad, the state capital of Pakistan-administered Kashmir, was hardest hit in terms of casualties and destruction. Hospitals, schools, and rescue services including police and armed forces were paralysed. There was virtually no infrastructure and communication was badly affected. More than 70% of all casualties were estimated to have occurred in Muzaffarabad. Bagh, the second-most-affected district, accounted for 15% of the total casualties.

The Pakistani government's official death toll as of November 2005 stood at 87,350 although it is estimated that the death toll could reach over 100,000. Approximately 138,000 were injured and over 3.5 million rendered homeless. According to government figures, 19,000 children died in the earthquake, most of them in widespread collapses of school buildings. The earthquake affected more than 500,000 families. In addition, approximately 250,000 farm animals died due to the collapse of stone barns, and more than 500,000 large animals required immediate shelter from the harsh winter.

At least 1,350 people were killed and 6,266 injured in Jammu and Kashmir state in India. The tremors were felt as far away as Delhi and Punjab in northern India. Four fatalities and 14 injured survivors were reported in Afghanistan.

In Kashmir, traditional timber-brick masonry construction consists of burnt clay bricks filling in a framework of timber to create a patchwork of masonry, which is confined in small panels by the surrounding timber elements. The resulting masonry is quite different from typical brick masonry, and its performance in this earthquake has once again been shown to be superior, with no or very little damage. No collapse was observed for such masonry even in the areas of higher shaking.

Unreinforced masonry is the most preferred type of construction in the north-east parts of Kashmir Range where single story, small houses prevail. Most of the damaged buildings comprised of unreinforced stone and brick masonry units, which were constructed to withstand gravity loads and low-intensity lateral loads. The lack of appropriate lateral load resistance mechanisms caused the collapse of walls, which in turn resulted in the collapse of entire buildings. The FRP is a high strength, corrosion resistant but brittle material and it is available in fabric, laminates and rods. In previous studies, it has been observed that FRP enhances the lateral strength of URM buildings. However, FRP is highly costly and requires skilled workmanship. The shot Crete overlays have the same drawbacks of requiring skilled workmanship and being very costly for small units. The center core technique requires special equipment for installation. The grout and epoxy injection requires skilled workmanship for high degree of accuracy. The use of steel elements is very costly, and susceptible to corrosion and bond failures. On the other hand, reinforced plaster, commonly known as ferro-cement overlay, has proved to be structurally efficient and cost effective technique [ElGawady and Badoux, 2004], which makes it suitable for Pakistan. However, very limited research has been performed on the seismic performance of full-scale URCBM buildings retrofitted with ferro-cement overlays [Ashraf, 2010]. In this context, a full-scale URCBM building was built and subjected to a quasi-static lateral load test. The damaged building was retrofitted with ferro-cement overlays and retested to measure the effectiveness of the repair approach. The retrofitting approach was well suited for the locally available materials and labor and further modified to work with the existing URCBM buildings. It is expected that the experimental data reported in this paper will serve as a basis for developing guidelines for retrofitting URM structures using ferro-cement overlays.

II. EXPERIMENTAL PROGRAM

A. Retrofitting Using Ferro-Cement Overlay

The URCBM structure previously tested under quasi-static reverse cyclic loading was first repaired with surface grouting having 1:4 cement-sand mortars. The walls were repaired with a rich cement mortar and cured afterwards for seven days. Galvanized steel welded wire mesh capable of resisting corrosion was attached to the outside and inside walls of the structure by means of 38 mm (1.5 in) long screws, plastic plugs, and steel washers. Special care was taken to ensure that the holes drilled for the screws in blocks (and not in mortar), since the latter could further damage the already cracked masonry to be repaired. Two screws per square foot were placed over the retrofitted region.

The walls were then cured for a period of three days so that the repair mortar develops the necessary bond. Locally designed and fabricated assembly was used for injecting the grout at a known pressure. Before grout injection, cracks in the masonry walls were sprinkled with tap water to ensure proper adhesion of the masonry and mortar. As the water was passed through the walls, the cracks became visible from the exterior. After a few minutes of this operation, grout was then injected through the nozzles at a pressure of three bars for 2–3 min so that the injected grout gets absorbed. The wall was cured afterwards for three days in order for the injected grout gain sufficient strength and develop bond. The walls were plastered with 1:4 cement-sand mortar and then allowed to undergo regular wet curing for a period of 14 days. Finally, the walls were white washed with lime to better visualize the cracks during testing.

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B. Test Setup and Testing Procedure

The original full-scale building was subjected to lateral loading using a hydraulic jack that was attached to the roof slab on the east side. A higher lateral resistance was expected for the retrofitted building, therefore, two hydraulic jacks that were connected to the building through two loading shoes. The capacity of the loading jacks was 200 KN. Whenever the actuator was pushed towards the structure, bearing through the loading shoes were the means of transmitting the force to the building. For the pull direction, rods were placed passing through the walls above and below the slab starting from the out-of plane east wall and extending up to the out-of-plane west wall. To ensure that the rods do not leave their position; bolts were fastened at both ends. To measure displacements, 12 linear variable displacement transducers (LVDT), were used. Gauge 01 was used to record the in-plane displacement at the middle center of the slab and served as the control gauge. Twisting of the structure was recorded with the help of Gauges 02–05. Gauges 06–10 were used to record the displacement at the top of the piers. Gauges 11 and Gauge 12 were installed to measure the possible vertical displacement due to global rocking of the structure. After repair, the test structure was instrumented with the same gauge arrangement as was done before retrofitting. A data acquisition system at a sampling rate of 20 samples per second was used for the load cell and transducer readings. The stresses due to dead load on the north walls (i.e., Pier 01 and 02), and the central pier (i.e., Pier 04) and the end piers (Pier 03 and 05) of the south wall were calculated as 0.14, and 0.16 and 0.12 MPa, respectively. The dead load values over the in-plane walls are purposefully given in stress units so that they could be compared to material properties.

III. OBSERVED DAMAGE

A. Intact Building

Cracks started to appear at the beginning of the test suggesting that the URCBM behaves nonlinearly even at very low drift ratios. Horizontal cracks started from the bottom of the window and extended over the entire width of the pier. At the lintel level and above, diagonal shear cracks started to propagate upward extending to the slab passing through the mortar joints only. At Pier 03, diagonal cracks started at the sill level of the window and propagated downwards to the floor. A combination of horizontal and diagonal cracks was observed at the lintel level of the pier as shown in Fig. 7i. At Pier 04, only horizontal cracks that passed through the two windows at the sill level were observed; while, at the lintel level stepped shear cracks were observed. Pier 05 exhibited the maximum number of cracks. Stepped shear cracks that started from the sill level and propagated downwards to the floor of the structure were seen. Stair stepped cracks and cracks passing through the solid block are seen.

B. Observed Damage for Repaired Building

The cracking pattern of the structure after retrofitting is shown observed damage at the in-plane north wall and out-of-plane east wall are provided. A spiral cracking pattern rather than stair stepped pattern was observed for the retrofitted building. The increase in the thickness of the walls due to the application of the ferro-cement overlay caused a reduction in the aspect ratio, which resulted in a stable rocking mode of failure rather than a mixed compression-shear failure.

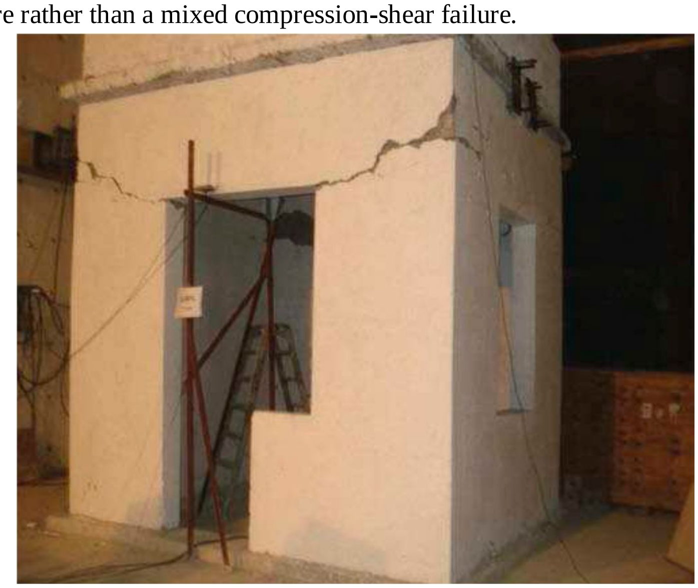

Fig. Final damage pattern for the retrofitted building

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Fig. Falling of plaster observed on retrofitted building.

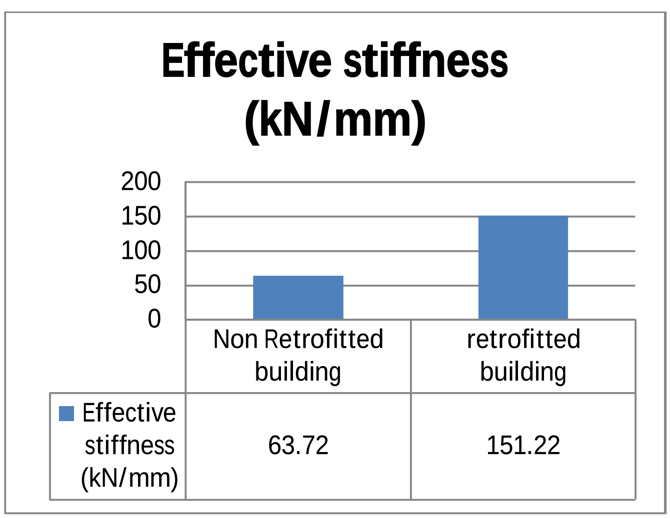
IV. TORSIONAL EFFECTS

In design of the model building, an attempt was made to keep the lateral stiffness of both in-plane walls the same in order to avoid any torsion in the building. To record any possible torsion, two out-of-plane gauges were installed. The diaphragm rotation was calculated as sum of the displacement recorded by these gauges divided by the distance in-between. The diaphragm rotations as a function of story drift for the tested structure before and after retrofitting. The maximum rotation was 0.0044 and 0.167 radians for the original and retrofitted structure, respectively. The rotation was smaller in positive direction in comparison with that in negative direction. It is seen that the stiffness symmetric design was successful; however, the increasing level of damage caused increasing levels of stiffness asymmetry (due to uneven loss of stiffness in walls) resulting in torsional effects. A non-negligible level of torsion was observed in the retrofitted building.

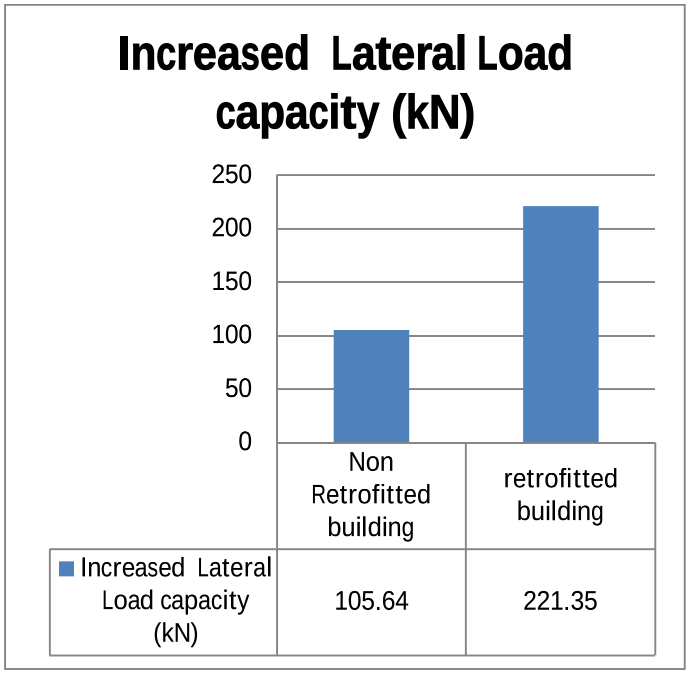
V. CONCLUSION

The following conclusions are made based on the experiments and ensuing calculations.

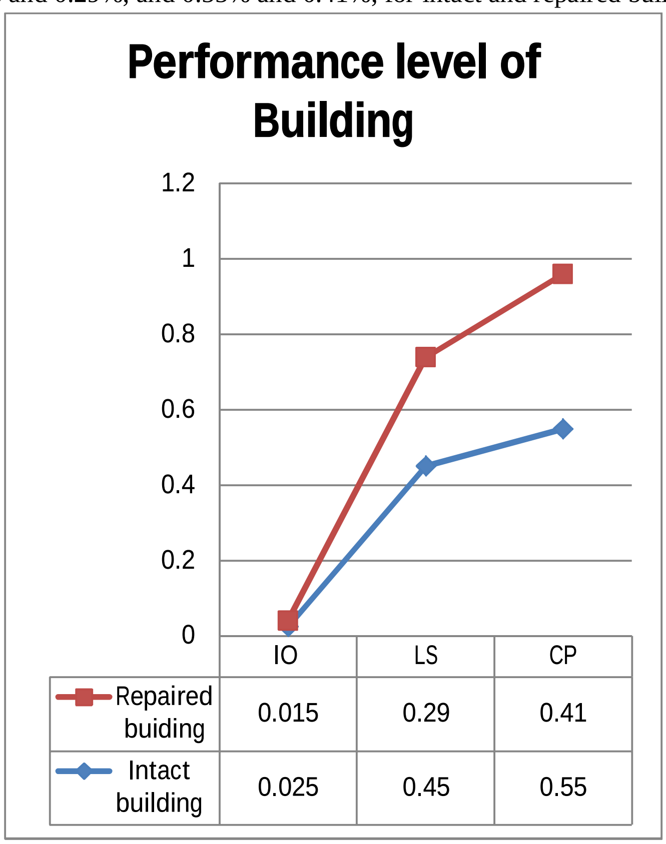
1) Reinforced plaster is an effective means of enhancing the seismic performance of single-story unreinforced concrete block masonry buildings (URCBM). The effectiveness should be investigated for multi-story buildings.
2) Applying wire mesh on both faces of the walls increases the confinement of the piers. Additionally, the wire mesh acts as an additional reinforcement, which makes the walls strong enough to resist diagonal tension cracks up to drift levels of 0.65%.
3) Reinforced plaster also helps change the failure mode from shear to rocking.
4) The effective stiffness, Keff, for the retrofitted building increased from 63.72 kN/mm to 151.22 kN/mm, which is 137.3% higher.



5) The lateral load capacity of the structure after retrofitting increased from 105.64 kN to 221.35 kN , which is 109.5% higher.



6) Performance levels of the building were obtained according to ASCE/SEI-41-06 [2007] for the building before and after retrofitting. Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) limit-states were achieved at story drifts of 0.025% and 0.015%, 0.45% and 0.29%, and 0.55% and 0.41%, for intact and repaired buildings, respectively.



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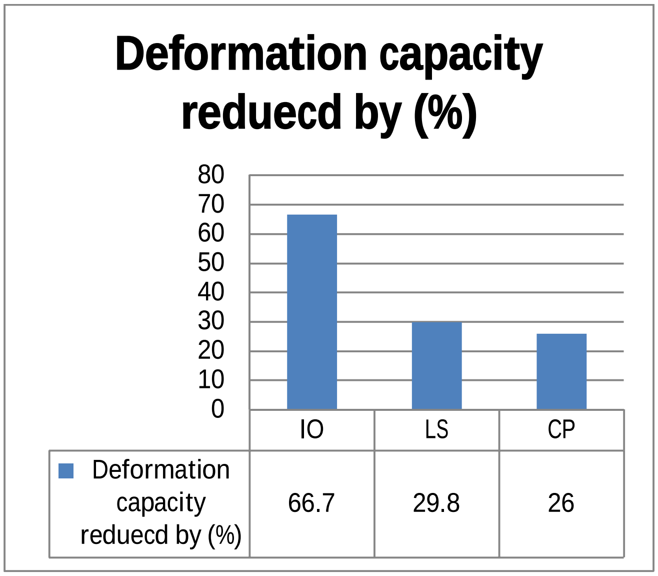
7) The deformation capacity of the retrofitted structure reduced by 66.7%, 29.8%, and 26% for the IO, LS, and CP limit states, respectively.



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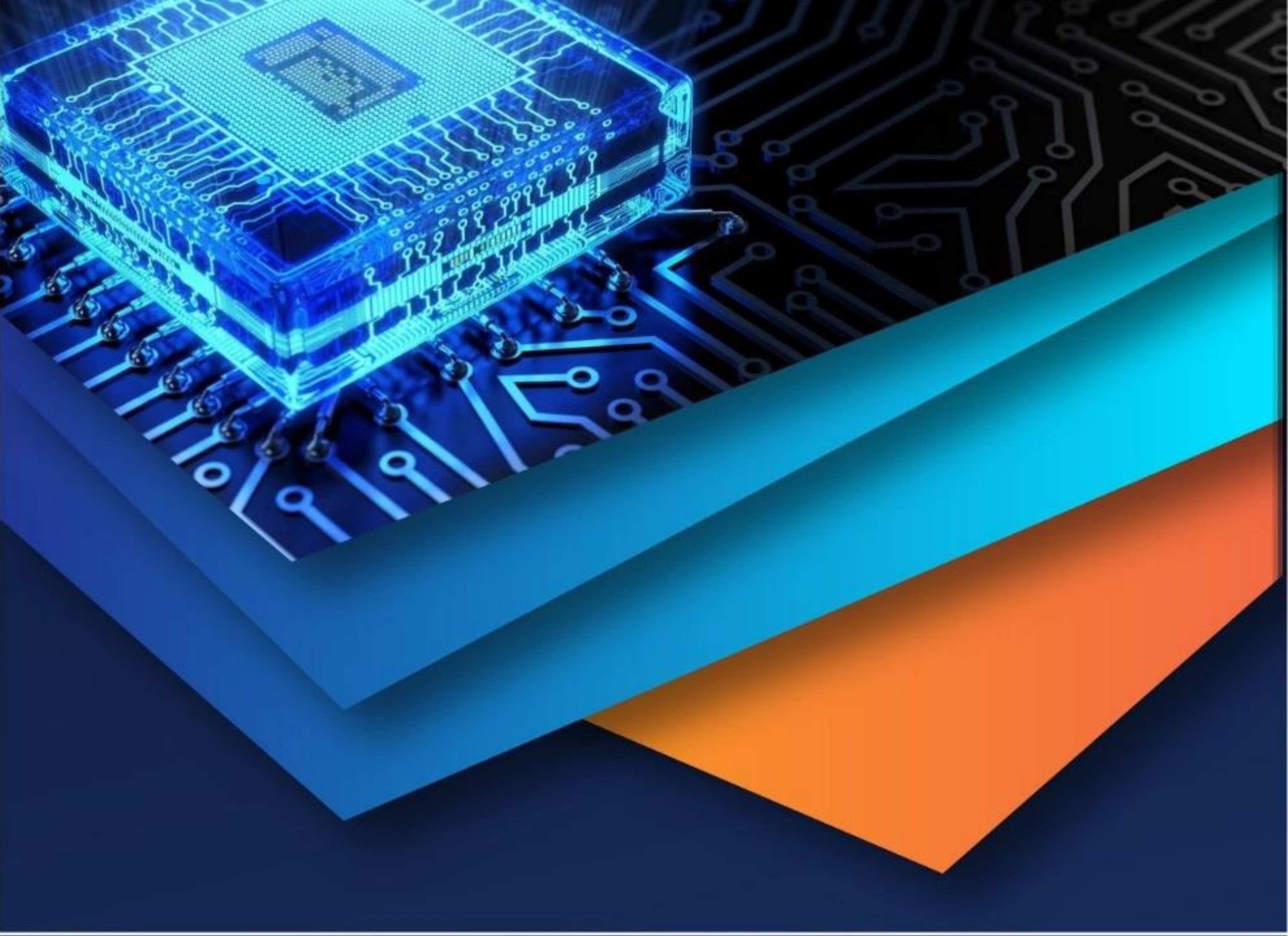

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