iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 **Issue:** IV **Month of publication:** April 2017

DOI: http://doi.org/10.22214/ijraset.2017.4109

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Analysis of Beam-Column Joint in a Pre-stressed Concrete Structure using Finite Element Method

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Abstract: Pre-stressed concrete is the type of concrete in which internal stresses of a suitable magnitude and distribution are induced so that the stresses resulting from external loads are counteracted to a desired degree. Pre-stressed concrete structures exhibit high strength and durability. These types of structures are very popular in use in bridge deck systems and culverts. However, various elements of pre-stressed concrete member undergo different types of stresses. The weakest element of these being beam column joint. The beam column joint in pre-stressed concrete member undergoes direct compression as well as bending compression and tension. This peculiarity of the beam column joint makes it vulnerable to failure.
It was found that many authors studied the analysis of pre-stressed concrete structures using Finite Element Analysis. However, they have not included the beam column joint in their analysis. Hence, this study emphasized on this aspect of analysis of pre-stressed concrete structures. This paper presents the review of literature on 'Analysis of Beam Column Joint of a Pre-stressed Concrete Structure Using Finite Element Analysis'. It is been also observed from the existing literatures that Finite Element Method (FEM) is widely used for analysis of Pre-stressed Concrete Structures. The FEM is capable of incorporating complex boundary conditions and material non-linearity. The results of FEM are also comparable with that of hand calculations. Also the structure can be finely idealized using FEM which enhances accuracy of analysis. This will economize the structural sizes of Pre-stressed Concrete Element.
The literature also indicates that the various researchers have used ANSYS, MIDAS and Stadd-Pro for the analysis of Pre-stressed Concrete Structures using FEM. This was an important observation and hence the present study aims to use ANSYS for the analysis of Beam Column joint using FEM.
The present study aims at reviewing various research efforts undertaken by authors in the past. The study also aims at finding a gap in literature on analysis of beam column joint in a pre-stressed concrete member using Finite Element Analysis.
Keywords: FEM, Beam Column Joint, Pre-stressed Concrete Structure

I. INTRODUCTION

Reinforced cement concrete (RCC) is a widely used building material in the world, because it is reliable, cheap, easy to use and there are sufficient skilled workers to work with .RCC has some inherent problems like cracking, due incompatibility in strain in steel and concrete, high coefficient of thermal conduction etc. These problems associated with RCC can be minimised by the application of pre-stressimg. The application of permanent compressive stress to a material like concrete, which was strong in compression but weak in tension, increases the apparent tensile strength of that material, because the subsequent application of tensile stress must nullify the compressive prestress. In 1904, Freyssinet attempted to introduce permanently acting forces in concrete to resist the elastic forces developed under loads and this idea was later known as "Pre-stressimg" .Pre-stressed concrete is basically concrete in which internal stresses of a suitable magnitude and distribution are induced so that the stresses resulting from external loads are counteracted to a desired degree .Various studies are reviewed on the analysis of pre-stressed concrete structural members and after going through the existing literature on analysis of pre-stressed concrete element using FEM it is found that not many studies are available on analysis of beam to column connection.

II. LITERATURE REVIEW

Many researchers have worked and published their work on use of finite element method (FEM) for the analysis of pre-stressed concrete structures. Some important papers relating to this are referred in this work. The methodology, observations, conclusions and further scope of work of these publications are used to finalize the objectives of present work. Summary of such reports is presented in further sections.
The available literature is classified in two parts

A. Literature on Design of Pre-stressed Concrete Structure using Finite Element Method

Keshav et al., 2014 Presented the analysis of pre-stressed pre-tensioned beam to evaluate deflection and stress distribution under a static concentrated load at midpoint of the beam by Finite element method using ANSYS V 11.0. Necessary hand calculations were also performed for the comparison and verification of the result. While analysing, the beam was assumed to be homogeneous and isotropic. For the loading condition, it was assumed as a simply supported beam having a central concentrated load. Stress strain behaviour of the beam was assumed to be linearly elastic. Result obtained from the analytical solution and that form the finite element analysis was nearly equal and it also can be concluded that results obtained by Finite element analysis are lower bound. Variation in the deflection calculated by analytically and by ANSYS was found to be 2.2 % and that for stresses was 1.4%.

Mayank Chourasia et al., 2015 presented design and analysis of pre-stressed concrete box girder (4 cells & 1 cell) for national highway bridge, by finite element method. Analysis is done by using MIDAS 3.1S software and all the specification are on the basis of codal provisions of IRC 6:2000, IRC 18:2000, IS 1342-1980, IRC 21:2000. This paper discusses the parametric study of two different cross section of box girder for same loading conditions to find the most economical cross-section. Box girder Super structures were assumed to be subjected to IRC class AA loading. Optimised cross section is found comparing the different design parameters such as steel consumption, concrete consumption, stresses and deflection at centre of span. They reported that after analysis it was observed that Bending moment, deflection, concrete consumption, steel consumption are more in four cell bridge than one cell bridge. Hence, one cell pre-stressed concrete box girder section bridge was more economical than four cell bridge due to minimum value of bending moment, which in turn requires less steel to counter the bending stresses. Less reinforcement leads to the most economical cross section for box girder. Results obtained from software and manual calculation are then compared to check the adequacy of the software tool.

Varghese et al., 2012 presented a study of pre-stressed beams using finite element analysis to understand the response of pre-stressed concrete beams due to transverse loading. Structural static properties such as deflection and stress distribution of rectangular pre-stressed concrete beam were analysed analytically and by finite element method. ANSYS 12.1 package was used as a tool for finite element analysis. The pre-stressed beam was assumed as isotropic and simply supported. Calculation of stresses, bending moment and deflection in the beam was calculated manually and also by using ANSYS. On comparing, it is found that both the results are approximately equal. In this analysis rectangular cross section of beam was considered. Apart from it composite beams of varying cross section can also be analysed using FEM. They concluded as Flexural failure of the pre-stressed concrete beam was modelled well using a finite element package, and the load applied at failure was very close to hand calculated results.

Fahmi et al., 2008 presented a study of the strength and behaviour of pre-stressed concrete members under short-term and sustained load conditions by finite element method.The degenerated eight-node shell finite element was used with each node having five degrees of freedom. Nonlinearity of material was also included in the analysis. Concrete was considered as an elasto-plastic material in compression with strain hardening. Pre-stressimg tendons were modelled by a multi linear five branches stress-strain relationship. The layered approach was used to represent the concrete and tendons are modelled as axial members embedded within the concrete elements. A computer program then developed and used for the analysis of pre-stressed concrete members. The capability of the computer program resulting from the present developments was verified by analysing experimentally tested pre-stressed concrete slabs. The comparison verified the accuracy and adequacy of the method and models utilizing the developed computer program. For further studies analysis can be done for the dynamic loading condition also.

Lenik et al., 2015 presented a study on process of testing and mathematical computation of model was described by the equations of function of the position and time for the nodes. The development of individual models and their groups and definitions of boundary conditions were carried out using computer program for finite element method. Basic equation of finite element method, Newton Raphson method and Jacobi methods were used for this analysis. From the result it was found that the result of the simulation models of plastic deformation processes carried out by the finite element method describes the behaviour of the system in space approximately and the results were always subjected to errors. Quality of the results depends on the boundary conditions, geometry of the study area, method of discretization, number and shape of finite elements and physical properties of the object. Errors can occur due to not taking appropriate boundary condition. To minimise these errors special care to be given to the boundary condition, numbers and shape of finite elements and physical properties of the structure.

Christopher et al., 2002 presented a study for investigating the effect of barriers, sidewalks and diaphragms (secondary elements) on bridges structure, ultimate capacity and load distribution. Simple span, two lane highway girder bridges with composite steel and pre-stressed concrete girder was considered. The finite element method was used for analysis. For the elastic range, typical secondary elements can reduce girder distribution factors between 10-40%, depending on stiffness and bridge geometry. For the inelastic response, steel was modelled using von mises yield criterion and isotropic hardening. Concrete was modelled with a softening curve in compression with the ability to crack in tension .At ultimate capacity, typical secondary elements can reduce girder distribution factor an additional 5-20%,and bridge system ultimate capacity can be increased from 10-20% of that the base bridge without secondary elements, depending on bridge geometry and secondary elements dimensions. They concluded that, if ignoring the effects of secondary elements on load distribution and ultimate capacity typically leads to conservative results, their effect varies greatly, depending on bridge geometry and element stiffness. Bridges designed according to the current LRFD code thus have varying levels of safety or reliability, a topic to be investigated in the future.

John et al., 2001 presented a study on evaluation of flexural live-load distribution factors for a series of three-span pre-stressed concrete girder bridges. The response of one bridge, measured during a static live load test was used to evaluate the reliability of a finite element model. The finite element models were also used to investigate the effects that lifts, intermediate diaphragms, end diaphragms, continuity, skew angle and load type have on distribution factors. Live load distribution factors were calculated by modelling five possible cases of bridges and from there live load distribution factors are calculated and compared with recommendation of codes for live load distribution factors. Moments on girders were calculated by taking differences in reading of strain gauge embedded in the girders. The girder element was modelled as shell element. From the analysis it can be observed that distribution factor calculated by finite element method was 6% higher than that of calculated by LRFD specifications. Distribution factors decreased with increasing skew. If the distribution factors calculated with the finite element analysis had been used in the design of the bridge, the number of stands and the release strength could have been reduced and the span could have been increased.

Rabee et al., 2015 presented a study on establishing a numerical analysis model which is based on finite element code to investigate structural behaviour of keyed joint under direct shear. The concrete damage plasticity model along with the pseudo damping scheme were incorporated to analyze the system for micro cracks and to stabilize the solution. The established numerical model was then used for parametric study on factors affecting shear behaviour of keyed dry joints, in the case of confining pressure. For the analysis ABAQUS software was used for modelling and analysing and experimental analysis was also done for comparison purpose. Initial stiffness, vertical displacement at the peak load and ultimate shear strength of a dried keyed joint increased as the confining pressured increased. Crack propagation obtained from numerical simulation accords very well with that from experimental study for the entire specimen. The maximum deviation in the prediction of ultimate shear strength was found to be 9%. Ultimate failure of the dry keyed joints was fracture of concrete along the root of the key with shearing off. The initial stiffness, vertical displacement at the peak load and ultimate shear strength of a keyed dry joint increased as the confining pressure increased.

Abdelatif et al., 2015 presented a parametric study to illustrate the impact of diameter of pre-stressimg steel, concrete cover, concrete strength, initial prestress, section size, surface roughness of pre-stressimg steel, time of prestress release and the member length on the transfer of stress in pretension concrete element. ANSYS was used as a tool for finite element analysis. Linear Closed form expression has been proposed to predict the transmission length and the stress profile along the transmission zone. Use of thick wall cylinder theory was found to be reliable in modelling the prestress transfer. Size of the element was found to have no significant effect on the prestress transfer.

Patil, 2013 presented a study to describe method of determining the optimum dimensions of cylinders made of specified material and to withstand a specified internal pressure so that the volume (and weight) is minimum. ANSYS was used as a tool for finite element analysis. Theoretical and FEA results were matching within 5% accuracy. As accuracy of finite element software has improved many folds, thus avoiding the need for physical prototype testing. This optimization technique can be used for optimising dimensions of pre-stressed bridge section.

B. Literature's on Design & Analysis of Beam Column Joint using Finite Element Method

Kaya et al., 2009 presented a study presented an analysis of, post tensioned precast beam to column connections were tested experimentally at different stress levels, and are modelled analytically using 3D nonlinear finite element modelling method. Finite element software ANSYS was used for this analysis. Nonlinear static analysis was used to determine the connection strength, behaviour and stiffness when subjected to cyclic inelastic loads simulating ground excitation during an earthquake. The results obtained from the analytical studies were compared with the test results. In terms of stiffness, it was seen that initial stiffness of the analytical modes was lower than that of the tested specimen. It can be concluded that, due to the fact that difference between the loading programs applied to analytical model and experiment may cause storey drift differences. Loading was applied as load controlled steps to the analytical models. As a result, modelling of these types of connection using 3D FEM can give crucial beforehand information, and overcome the disadvantages of time consuming workmanship and cost of experimental studies.

Wei Yue et al., 2004 presented a study on examination of failure modes as well as shear strength capacity and seismic performance of pre-stressed beam-column joints which is based on experimental results. In order to estimate shear strength capacity and overall seismic behaviour of pre-stressed beam-column joint assemblages, seven test units were constructed and tested under earthquake-simulating cyclic loads. A reinforced concrete beam-column joint assemblage whose beam section has as large as moment capacity as the pre-stressed concrete test units were included in the test program. The test units failed in shear and tendon anchorage deteriorated in the joint core. Load carrying capacity, ultimate displacement, hysteretic energy, joint shear distortion were obtained and discussed. Anchorage location is outside of beam for two samples and for remaining four samples anchorage location is placed inside the beam. The main experimental parameters were location of tendon anchorage, concrete compressive strength and pre-stressimg steel content in the beam section. It should be noted that location of tendon anchorage had a great influence on shear capacity of the joint and load-displacement relation of the assemblage. From this analysis following results were obtained-

1) The closer the tendon anchorage was located to the joint centre, the smaller the shear reinforcement strains were, which indicates that the effective pre-stressimg force in the beam was not fully transferred into the joint.
2) Effect of tendon anchorage location and pre-stressimg force were not clearly observed before the maximum load of the beam end was reached, beam ordinary longitudinal reinforcements yielded.
3) With the increase in beam rotation angle increasing the ratio of the joint shear deformation increased.

From the analysis it can be concluded that when the tendon anchorage is placed outside the joint, the shear deformation decreased. The joint shear cracking load was small in the test units with inside anchorage, because the full effective pre-stressimg force in the beam was not transferred into the joint. The maximum load capacities for the units with the inside anchorage 9% to 13% smaller than those having their anchorage outside the joint core. The joint shear deformation was small in the test units with the outside anchorage. The ultimate input joint shear force in the units with the outside anchorage was larger than the units with the inside anchorage and damage to the beam-column joint assemblages and the decay of the maximum capacities of the test units were not due only to joint shear failure, but to the anchorage deterioration of pre-stressimg steel bar also.

Noguchi et al., 2000 presented a study on testing four one-third scaled PC interior beam-column joints. The main parameters of this test were the pre-stressimg force and the bond condition between grouted mortar and pre-stressimg tendons through a joint. These beam-column joints were analyzed using nonlinear finite element method (FEM). This analysis was carried out by considering the bond between grouted mortar and pre-stressimg tendons similar to the tests. Experimental analysis is done. All specimens failed in the joint shear failure in both test and FEM analysis. The FEM analytic results gave a good agreement with the test results on the maximum story shear forces and the failure mode. From the comparisons between the experimental and FEM analytical results, the effects of the pre-stressimg force and the bond condition between grouted mortar and pre-stressimg tendons on the joint shear capacity were discussed. The calculated shear cracking strength overestimated the tests results over 1.5 times large. The joint shear cracking strength obtained from the tests was almost constant. However, because the angles of shear cracking in the joint changed with the pre-stressimg forces, it was considered that the shear cracks were affected by the joint pre-stressimg stresses. From the analysis conclusion drawn are as follow

4) The joint shear cracking strength obtained from the tests was almost constant. However, the angles of shear cracking in the joint changed with the pre-stressimg forces.
5) The shear capacity of the joint was not especially affected by the pre-stressimg forces.
6) Because the bond between grouted mortar and rounded tendons was vanished on the earlier loading stage, the effect of the bond conditions on the joint shear capacity was not obtained obviously.

Deng et al., 2005 presented an analysis of the ductility, energy dissipation, hysteresis property and the mechanical behaviour of four joints of pre-stressed concrete beam and composite concrete column with core of concrete filled steel tube and one joint of ordinary pre-stressed frame structure. Specimens were tested in the laboratories. Experimental results indicate that this kind of joints can raise the shear strength of core area of joints and its seismic performance is also good, this design method can resolve the problem of the traditional concrete filled steel tubular structure effectively, and can also meet the requirement of the high-rise and large span structure. It can be useful reference to engineering design. Appropriate numbers of stirrups around longitude bars are necessary, it can provide effective restriction on concrete between steel tube and longitude bars. Strength of Joints can be largely improved because of the restriction effect of steel tube. Steel tube could function as longitude bars to transfer longitude force, and also could function as stirrups to resist shearing force. it can be concluded that the composite concrete column with core of concrete filled steel tube is a good reinforcement style that has prominent beneficial action on seismic behaviour, and it can also improve the shearing capacity of joints as concrete could be effectively restricted by steel tube in core area. Development speed of the inclined cracks is more slowly than normal concrete structure joints after the inclined cracks occurred in joint area. This kind of joints has good performance of ductility and energy dissipation capacity and the equivalent hysteretic damping factor is also larger than that of ordinary concrete frame structure joints. Also Experiment results show that steel tube reinforced concrete column is a good reinforcement form with excellent seismic performance, high bearing capacity and high shear strength.

Faur et al., 2012 presented a study to describe a modelling technique that can be used in various finite element based software products to facilitate the modelling and design of hybrid frame connections. The complex behaviour of an interior beam-column sub-assembly is counteracted using frame elements with fibre hinges, nonlinear springs and cable objects. An analytical model is compared with a full scale, hybrid frame connection specimen that has been tested to a displacement controlled cyclic loading sequence. A full scale specimen consisting in an interior beam-column joint was tested to a displacement .The results show that the numerical model is unable to represent very accurate the unloading branches of the envelope hysteresis curves and, as a consequence, the self-centering ability is significantly overestimated (i.e., the residual displacements are equal to zero). The loading branches for the negative loading differ considerably, especially at higher drifts, where the differences regarding the horizontal forces reach up to 16.7%. The model considers an almost perfectly symmetrical behaviour between the positive and negative loading, while the test results proved the opposite. On the other hand, the estimation of the initial stiffness is sufficiently accurate for both positive and negative loading. The interior areas of the curves shown differ by 19.1%, the areas of the curves obtained through the numerical analysis being lower. This result is relevant only if the interior areas of the envelope curves can be associated with the energy dissipation capacity of the frame sub-assemblage. If so, the analytical model underestimated this aspect. The obtained force-displacement curves are analyzed and compared with both positive and negative envelopes of a similar specimen that was tested at a cyclic loading sequence. The similarity between the monotonic force-displacement curve obtained from the numerical analysis and the loading branch of the positive envelope curve resulted from the testing program, proves that the proposed model is suitable to predict the initial stiffness and the displacement capacity of the test specimen, without the need for any cyclic analysis. However, it seems that the cyclic behaviour of the connection is characterized by an asymmetrical response that the analytical model is unable to capture. Moreover, the unloading branches are not properly evaluated through the one-cycle analysis, and more research is needed to capture the self-centering ability and the energy dissipation capacity of the connection.

Hawileh et.al, studied the behaviour of precast hybrid frame connections under cyclic loading. A 3-D nonlinear finite element model was developed to study the response and to predict and validate experimental results for a 1/3 scale-model of a precast hybrid concrete building subjected to cyclic loads. Full stress and strain fields in the mild steel bars at the beam-column hybrid connection were generated. Experiments were performed in the laboratory and a finite element analysis using ANSYS V 8.0 was used to build a detailed model to predict the behaviour and to validate the experimental results for hybrid connection. The results compare the lateral load versus time curve, lateral load versus displacement (hysteresis) curve, lateral load versus story drift (hysteresis) curve, and the peak load for each displacement cycle. FE results correlate well (within 15 %) with the experimental results. From the study it can be concluded that a high level of detailing was used in the model to represent all the experimental components. Special attention was given to material properties description; mesh refinement, contact surfaces, pre-tensioning, and boundary conditions to simulate the experimental setup. The boundary conditions at the top face of the column required fine calibration, as the results proved to be sensitive to the boundary conditions at the top. This was especially important since the deflection measurements were taken close to the top boundary conditions. The FE model proved to be very adequate in producing results that were in good agreement with the experimental results in the elastic and plastic ranges. The development of the FE model allows for additional investigation of such a connection under other loading conditions and different design parameters.

Rami et al. presented a study on developing 3-D nonlinear FE model to study the response and predict and validate experimental results for a 1/3 scale model of a prototype precast concrete building subjected to cyclic loads. The Hybrid frames contain precast elements (beams and columns), connected by unbounded post-tensioning steel and bonded reinforcement bars, both of which contribute to the overall moment resistance. A very interesting feature of the connection between beam and column is the hybrid combination of mild steel and post-tensioning steel where the mild steel is used to dissipate energy by yielding in tension and compression and the post-tensioning steel is used to clamp the beam against the column. Experiments were performed in the laboratory and a finite element analysis using ANSYS V 8.0 was used to build a detailed model to predict the behaviour and to validate the experimental results for hybrid connection. Results generated from the FE model compared to the experimental results. Close correlation exist in the initial to the middle stages of the loading. Deviations up to 25% are observed in the last two stages of loading cycle. Upon refinements of the boundary conditions at the top and repeating the analysis, substantial improvement of the FE results is observed with maximum deviations from the experimental results is always within 10% everywhere. From the study it can be concluded that the, the fracture of the mild steel resulted from high levels of plastic strain developed in the bars. Having a reliable FE (Finite Element) model is crucial since FEA gives a full field of stress and strain values throughout the structure. This is an advantage over the experimental measurements, which are limited to strain gauges, LVDT, and load cells locations. The FE model can provide a variety of results at any location within the model. The conditions of boundary conditions at the top required fine calibration, as the results proved to be sensitive to the boundary conditions at the top. This is especially true, since the experimental measurements and the FE readings are taken close to the top boundary conditions.

Kulkarni et al.,2008 presented a nonlinear finite element (FE) analysis of hybrid steel concrete connections is presented. However, due to the inherent complexity of beam–column joints and the unique features of the tested specimens, the experimental study was not comprehensive enough. Therefore, in this paper, analytical investigation based on the FE models and using the

DIANA software is presented. The critical parameters influencing the joint's behaviour, such as the axial load on column, the connection plate thickness, and the continuation of beam bottom reinforcement, are varied, and their effects, especially implications on code specifications were studied. This paper is aimed at developing and calibrating a nonlinear FE model, and further uses it to investigate the behaviour of hybrid-steel concrete joints by varying the main control parameters. Comparison of the analytical and experimental results of all the specimens showed that results obtained by Finite element analysis are quite similar to experimental results. The FE analyses also showed that results of the deformations and cracking patterns matched well with the experimental observations.

7) The FE results showed that axial load was beneficial to the joint's performance.
8) Connecting plate thickness at joint influenced the energy dissipation and deflection during the cyclic loading. The increase in plate thickness gradually increased the energy dissipation and strength of the joint. Continuation of beam bottom reinforcement increased the ultimate strength of the specimens and reached an optimum value of approximately 8% when the reinforcement was 0.75%of Ag. The specimens also showed good energy distribution and smooth stress distribution. The use of FE modelling techniques can be further extended to study the joint performance by varying different parameters.

III. CONCLUSION

After going through the existing literature on analysis of pre-stressed concrete element using FEM, not many studies is available on analysis of beam-to-column connection. As pre-stressimg of beam column connection warrants knowledge of specific state of stress in the absence of this pre-stressimg shall be erroneously executed. Hence, this study aims at critically analysing the beam-column connection using FEM by application of suitable software tool like ANSYS, Stadd-Pro or MIDAS.

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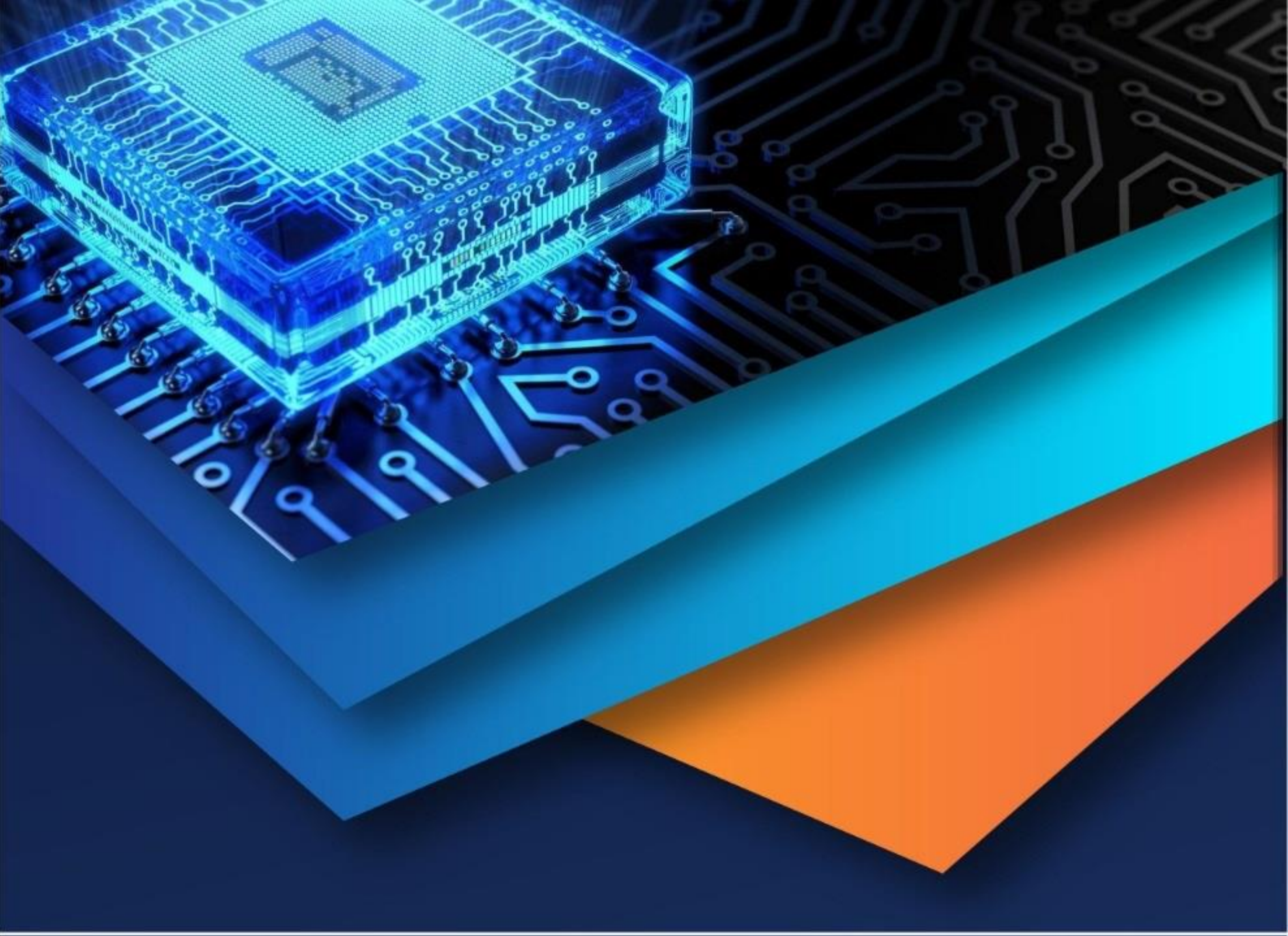

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