International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 8 **Issue:** XI **Month of publication:** November 2020

DOI: https://doi.org/10.22214/ijraset.2020.32095

Analytical Study on Shear Behavior of Dry Joint in Precast Concrete Segmental Bridge with Different Shaped Keys

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Abstract*: The precast concrete segmental bridges (PCSBs) are the most preferred bridge in modern bridge construction. The structural behavior of precast concrete segmental bridge is based on the behavior of joints. The joints are formed by interlocking of shear keys in precast concrete segments. The dry joint is a highly recommended joint in PCSBs for more safety and accelerated construction. The aim of this study is to understand the effect of shape of shear key on shear behavior of dry joints of PCSBs. Single keyed dry joint with six key shapes are considered for the study. The joint performance in shear is evaluated by considering the ultimate load of joint and also by the shear stress at the time of ultimate load. Analytical study is performed using ANSYS Workbench. The performance of single keyed dry joint specimens is studied under displacement controlled vertical loading and constant horizontal confining pressure.
Keywords*: Dry Joints of PCSBs, Precast Concrete Segments, Precast Concrete Segmental Bridges, Shear keys, Ultimate load of joint.

I. INTRODUCTION

Bridge is an important civil engineering structure that makes a safe passage over the obstacles. The bridge has a great influence on the development of a country. In present bridge construction the precast concrete segmental bridges (PCSBs) are most preferred due its durability and it makes the longer bridge construction easier and economic. In this type segmental bridge the girder is made by the assembly of precast concrete box girder segments. So the super structure of PCSBs contains joints. The joints are formed by the interlocking of small projections called shear keys in one precast concrete segment with depressions in adjacent segment. This joint can be provided with or without infill material. The joint filled with epoxy is called epoxied joint and the joint without any infill material is called a dry joint. The dry joint is preferred in PCSBs to make bridge construction more accelerated and for safety. The joints have high relevance in controlling the structural behavior of PCSBs. Through this joint the compression and the shear forces are transmitted. The joint in PCSBs is subjected to horizontal prestressing force and shear force in vertical plane. The present using shape of shear key is bevelled rectangle shape. This study is an investigation to understand the effect of shape of shear key in shear behaviour of single keyed dry joint in precast concrete segmental bridge. This study also provides an attempt to derive a dry joint with better joint performance in shear. And to compare the performance of dry joint with standard key shape with other dry joints with new key shapes.

II. ANALYTICAL INVESTIGATION

The analytical study is conducted on single keyed dry joint with different key shapes. The shapes of key considered for the study are bevelled rectangle shape (standard key shape), bevelled square shape, bevelled triangle shape, round shape, slot shape and rectangle shape.

A. Details of Geometry

The dry joint specimen consists of two parts. The part with shear key is called as female part and other part is male part. The length, width and height of each joint part are the same. The details of dimensions of dry joint are shown in Fig. 1. For each joint the shape of shear key and height of area of contact is changed. The height of contact area is consists of 50 mm length additional to vertical height of each key at top and bottom. From the formulas related to the shear strength of PCSBs joint the base area of key has a significant role in shear strength. The base area of key is approximated to 25000 mm^2. The parts are modeled and assembled in Fusion 360 Modeling software. The files of geometry in .iges format are imported to ANSYS Workbench for the analysis. The dimensions of keys are shown in Fig. 2 to Fig. 3.

Table 1. Dimensions of Part of the Joint

Length of part	Width of part	Height of part	Depth of key
350 mm	250 mm	420 mm	50 mm

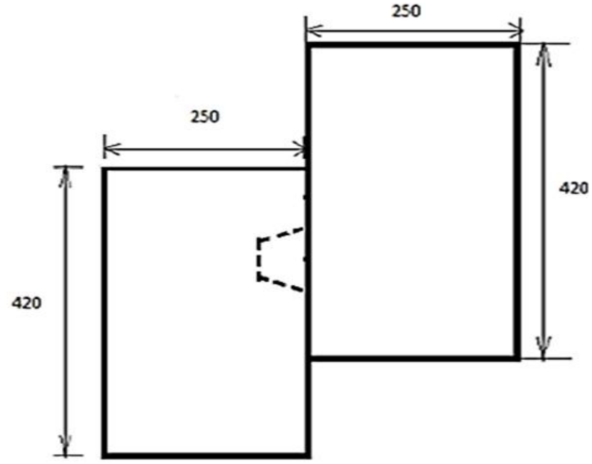

Fig. 1 Typical Dimensions of Joint in mm

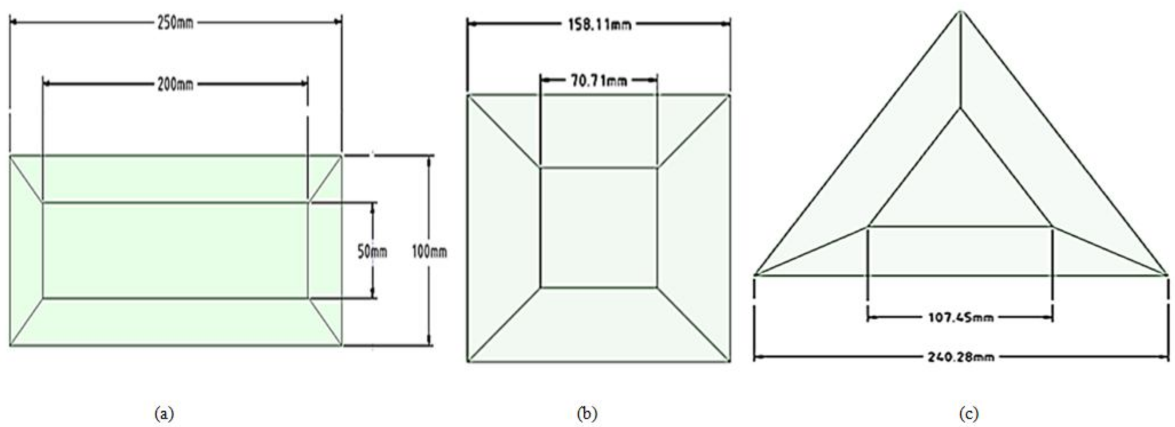

Fig. 2 Dimensions of (a) Bevelled Rectangle Key (b) Bevelled Square Key (c) Bevelled Triangle Key in mm

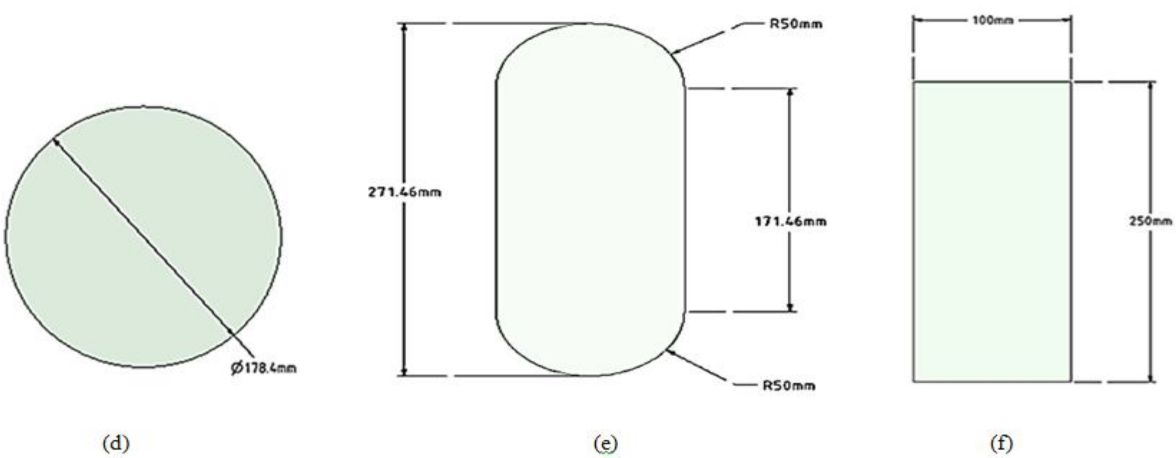

Fig. 3 Dimensions of (d) Round Key (e) Slot Key (f) Rectangle Key in mm

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue XI Nov 2020- Available at www.ijraset.com

B. Material Properties

The parts of joint are made of concrete. Concrete with compressive strength of cube 30 N/mm^2 is used in this work. The properties of concrete used are given in Table 2. The solid 65 element is used for modeling the concrete. Solid 65 element in Ansys is a three dimensional element used to model solids, especially concrete. It represents the concrete with or without reinforcement. The stress strain curve of concrete is shown in Fig. 4.

Table 2. Material Properties of Concrete

Material property	Value
Young's modulus	29250 N/mm^2
Poisson's ratio	0.2
Compressive strength	30 N/mm^2
Tensile strength	3 N/mm^2
Density	2400 kg/m^3
Open shear transfer coefficient	0.3
Closed shear transfer coefficient	0.8

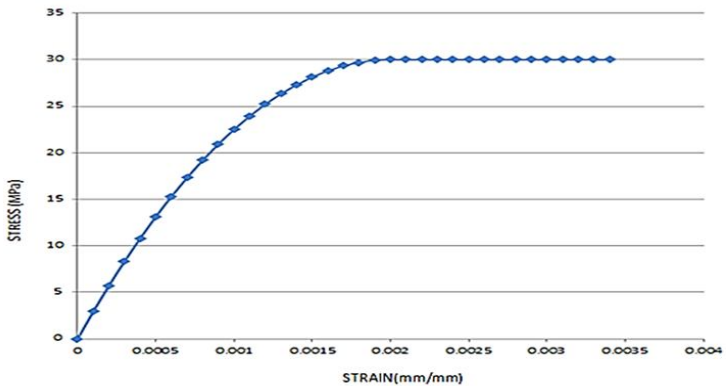

Fig. 4 Stress Strain Curve of Concrete

C. Meshing , Loads and Boundary Condition

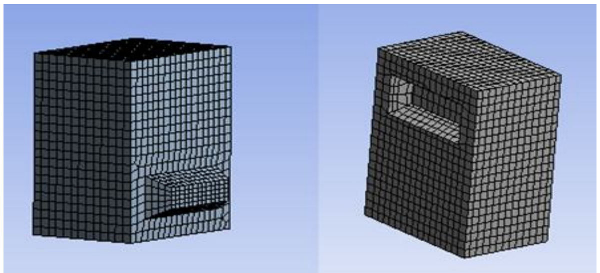

Fig. 5 Typical Meshing of Female and Male Parts of Joint

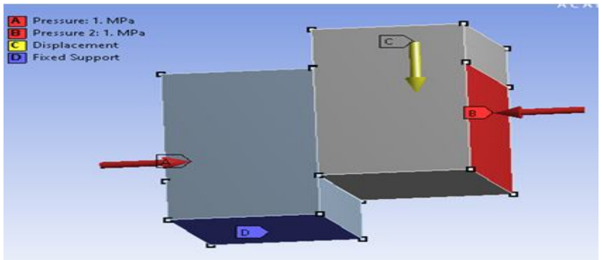

Fig. 6 Loading and Boundary Condition at Joint

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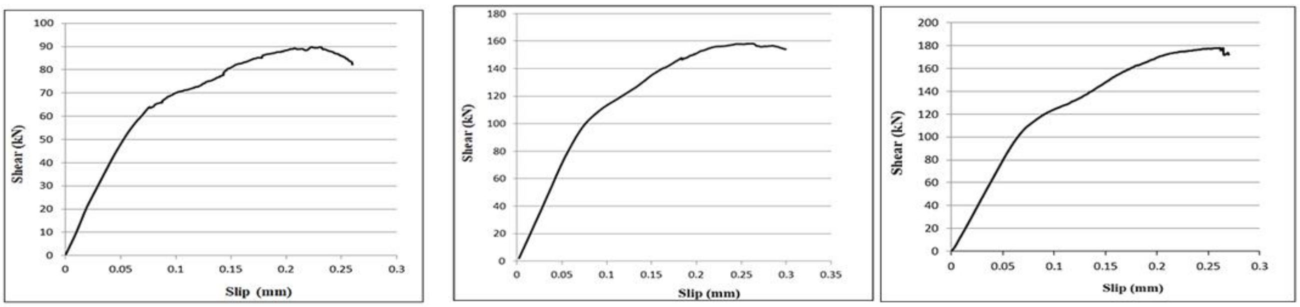
To study analytically the behavior of dry joint the static structural analysis is conducted in ANSYS Workbench. For the analysis bottom of male part is fixed and the load is applied through the female part in which the shear key is present. The displacement controlled vertical loading with a rate of 0.005 mm/s is applied on the top surface of the female part. The constant horizontal confining pressure of 1 MPa is provided in both sides of joint specimen.
The contact is defined before the loading. The frictional contact is present in contact region of dry joint. The frictional coefficient is taken as 1.1. The maximum value of coefficient of friction is taken for this analysis.

III. RESULTS AND DISCUSSION

The study of ultimate load and also the shear stress are essential to understand the response of the joints in PCSBs towards the shear.

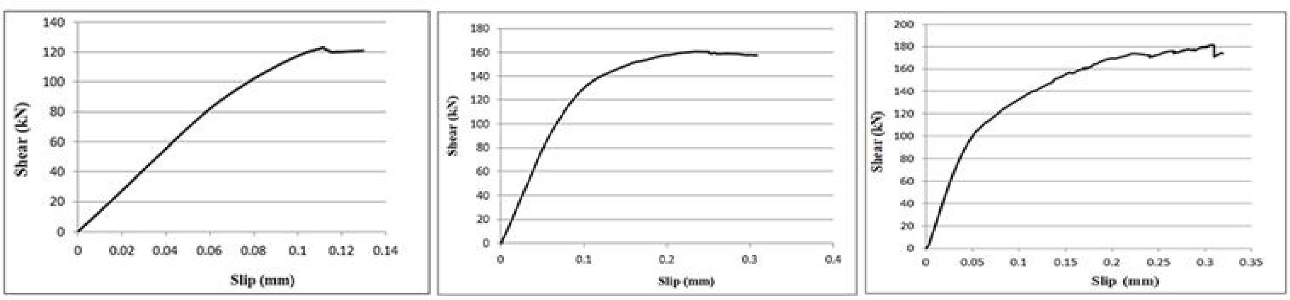
A. Ultimate Load

The ultimate load of the each joint is obtained by the shear vs. slip curve. For this graph the shear in the face situated at the base of shear key is taken. The slip is the vertical displacement of the loading surface.



(a) (b) (c)

Fig. 7 Shear vs. Slip Graph of (a) Bevelled Rectangle Key Dry Joint (b) Bevelled Square Key Dry Joint (c) Bevelled Triangle Key Dry Joint



(d) (e) (f)

Fig. 8 Shear vs. Slip Graph of (d) Round Key Dry Joint (e) Slot Key Dry Joint (f) Rectangle Key Dry Joint

Table 3. Details of Ultimate Load of Different Types of Dry Joints

SI No.	Joint name	Ultimate load (kN)	Time of loading at ultimate load (s)
1	Bevelled rectangle key dry joint	90	44.636
2	Bevelled square key dry joint	158.13	51.389
3	Bevelled triangle key dry joint	178	52.85
4	Round key dry joint	123	22.49
5	Slot key dry joint	160.8	47.193
6	Rectangle key dry joint	181.36	61.402

The rectangle key joint showed excellent performance in the case of ultimate load. This joint achieved higher value of 181.36 kN as ultimate load at higher value of slip before failure.

B. Shear Stress

The study of shear stress is also reveals the actual condition of leads to failure of joint and helpful in the assessment of the key performance.

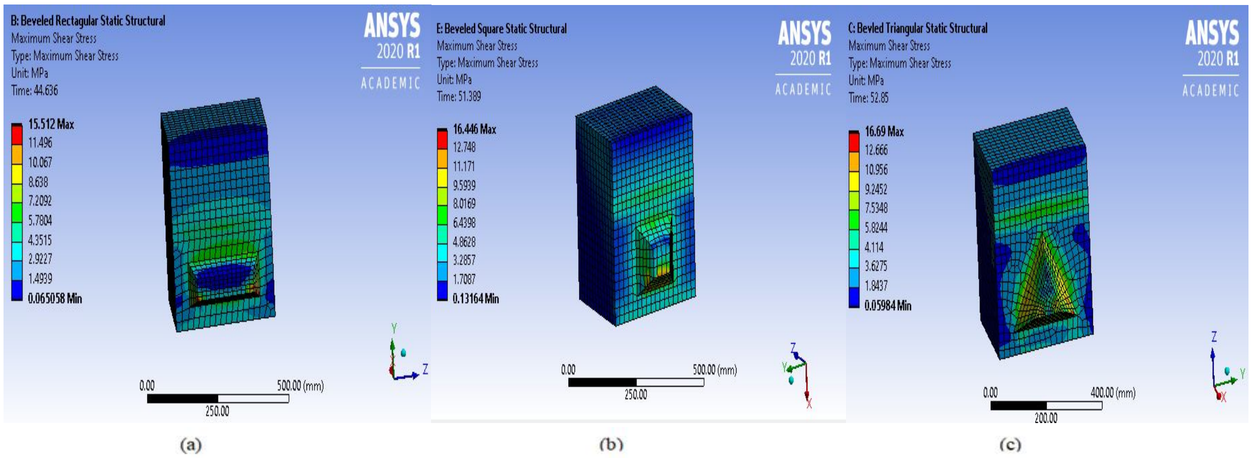


Fig. 9 Shear Stress distribution in key region of (a) Bevelled Rectangle Key Dry Joint (b) Bevelled Square Key Joint (c) Bevelled Triangle Key Dry Joint

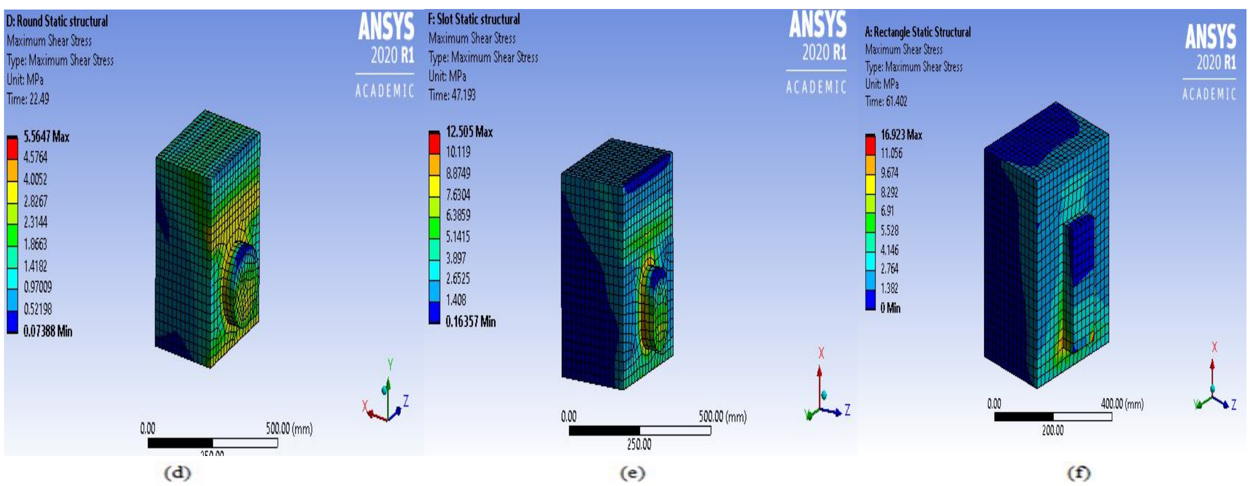


Fig. 10 Shear Stress distribution in key region of (d) Round Key Dry Joint (e) Slot Key Dry Joint (f) Rectangle Key Dry Joint

The shear stress intensity is higher in the bottom portion of the key and the bottom edge of the depression in the male part. The values of maximum shear developed in male part and the female part is in shear plane region. Thus the region of interlocking in joints subjected to greater shear stress before failure. This is the region of PCSBs the shear failure likely to occur. Rectangle key failed before attaining a higher shear stress of 16.9 N/mm^2 with higher shear strength. The Table 4 shows the maximum value of shear stress by considering the performance of joint at the time of ultimate load.

Table 4. Details of Maximum Value of Shear Stress in Dry Joints at Ultimate load

SI No.	Joint name	Max. Shear Stress (N/mm^2)
1	Bevelled rectangle key dry joint	15.512
2	Bevelled square key dry joint	16.446
3	Bevelled triangle key dry joint	16.69
4	Round key dry joint	5.564
5	Slot key dry joint	12.505
6	Rectangle key dry joint	16.923

IV. CONCLUSIONS

From this study it was found that the shape of shear key affects the behavior of dry joints. All dry joints with new key shape have higher ultimate load than the dry joint with standard key. Rectangle key joint performance was excellent in both ultimate load and shear stress. It attained higher values of ultimate load and shear stress before failure. The rectangle key, bevelled square key and bevelled triangle key dry joints provided better performance in both ultimate load and shear stress. Hence these key shapes can be used as a substitute for the present shear key shape to improve the performance of dry joint of PCSBs in shear.

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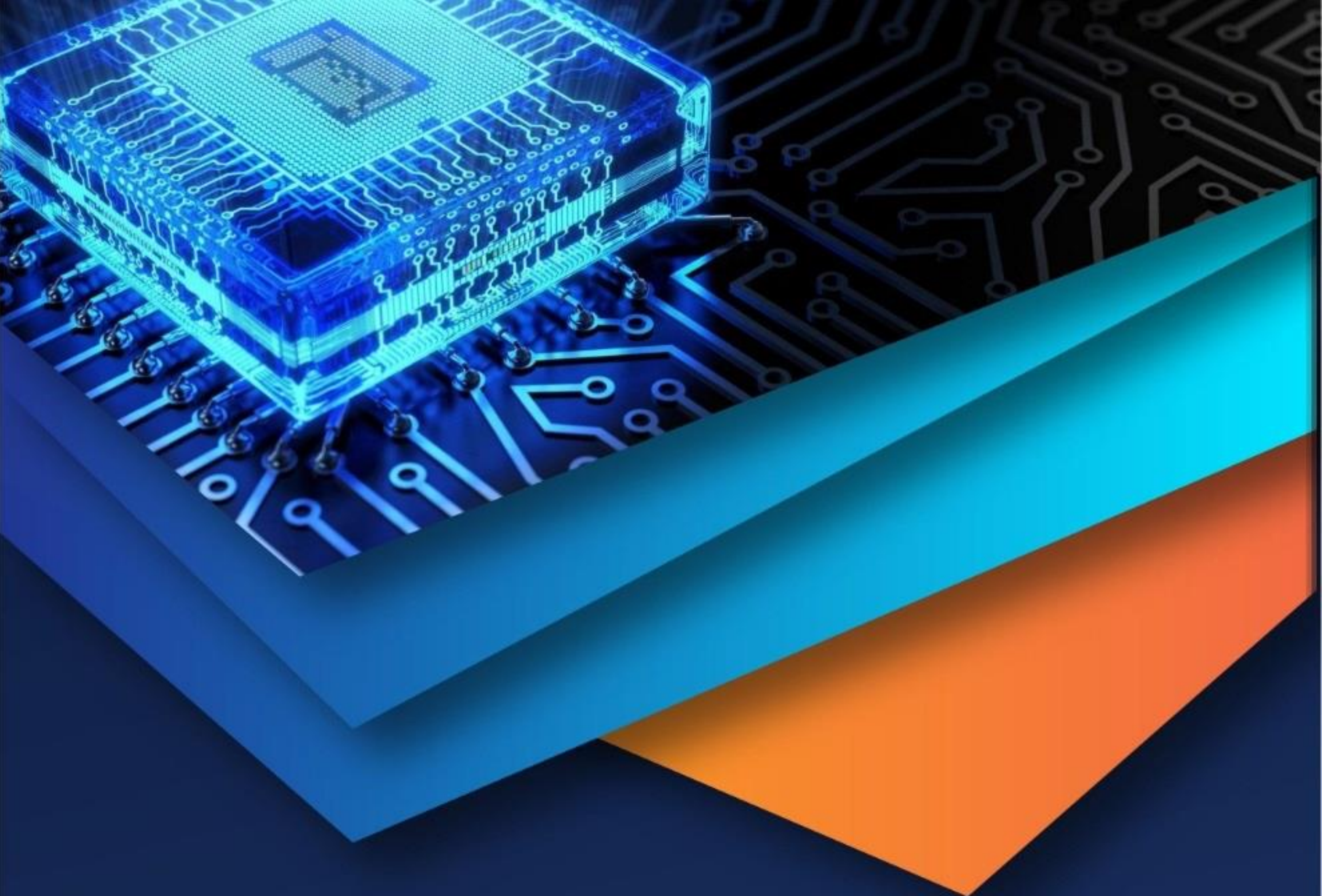

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