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To Evaluate the Seismic Response of a Building Having Stiffness Irregularity and Plan Irregularity with Quintuple Friction Pendulum System

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Abstract: Quintuple friction pendulum (QFPS) bearing is a new generation sliding isolation system having multiple spherical sliding surfaces. The friction isolation system with single sliding surface is designed for a specific level of ground shaking, which may prove ineffective in case of other hazard levels. The QFPS bearing on the other hand, exhibits adaptive behavior and imparts greater amount of flexibility to the designer for various levels of earthquake shaking. Here, the effectiveness of Quintuple Friction pendulum system is carried out to study the seismic demands of base-isolated building frames with stiffness irregularities and plan irregularities subjected to various earthquake ground motions i.e. Far field ground motion, near field ground motion with fling step and near field ground motion with forward directivity by comparing their estimates with the benchmark responses obtained by the Non-Linear Time History Analysis (NLTHA). SAP 2000 Software has been used for the same. The two soft storey buildings and two buildings with plan irregularity will be modelled and analyzed. The seismic demands namely, Inter story drift, peak storey acceleration, maximum base shear are considered for the study.The reduction in absolute acceleration is found more in case of PI as compared to SS for all the considered time histories. The reduction in Maximum Base-Shear is found more in case of Plan irregularity as compared to Stiffness Irregularity (Soft Story) in all the considered Time History. In isolated structure, the Inter-storey drift is found to be maximum in case of structure having soft storey as compared to plan irregularity 1 and 2.

Keywords: Multi storied RC structures, Plan irregularities, Soft storey, Quintuple Friction Pendulum, Non linear Time History Method(NLTHM)

I. INTRODUCTION

Base isolation is one of the most widely accepted seismic protection systems in earthquake prone areas. It mitigates the effect of an earthquake by essentially isolating the structure from potentially dangerous ground motions. Hence it can be simply defined as decoupling or separating the structure from its foundation. It can be understood by comparing it to suspension system used in automobiles. The term isolation refers to reduced interaction between structure and the ground. When the seismic isolation system is located under the structure, it is referred as “base isolation”. An isolation system provides an additional means of energy dissipation, thereby reducing the transmitted acceleration into the superstructure.

The Non-Linear Time History Analysis (NLTHA) is the dynamic analytical method found to be most accurate for seismic evaluation and design verification of building structures. It predicts inelastic demands with high accuracy in the members of superstructure subjected to different types of earthquakes.

Earthquake field investigations repeatedly confirm that irregular structures suffer more damage than their regular counterparts. Mass irregularity is one of the most important factors, which causes severe damage (even collapse) for the structures. A large number of studies exist which investigate various aspects of mass irregularity.

The concept of soft first story has been recognized by Fintel and Khan (Fintel and Khan 1969). Researchers had pointed out some aspects of a flexible first story in the 1930s (Martel 1929, Green 1935, Jacobsen 1938). But the practical significance was evident from observations of damage to multi-storey buildings during earthquakes in the 1960s. The damage and collapse due to soft storey are most often observed in buildings which leads to carry out detailed study on soft storey.

Fenz and Constantinau (2008b, 2008c) developed principles of operation and force-displacement relationships of the TFP system based on the first principles. The force-displacement relationship developed theoretically was also validated through experimental work. Fenz and Constantinau (2008a) further described how to model the TFP bearing using an assembly of gap elements and single concave FP elements connected in series.

The results obtained by direct numerical integration of the equations of motion based on series connection of three single concave FP elements and gap elements were compared with the experimental data. Very recently developed Quintuple Friction Pendulum (QFPS) bearing [Lee and Constantinou, 2015] is an extension of the TFP isolator consisting of six spherical sliding surfaces. It offers a more complex multi-stage behavior than the TFP isolator, which may be implemented to control the response of the isolated structure when advanced performance objectives are considered or when the isolator displacement demand needs to be within acceptable limits during very strong seismic event. In this thesis comparative study for various seismic demand parameters is done for TFP and QFP system for special moment resisting frame structure

II. LITERATURE REVIEW

Donghun Lee and Michael C. Constantinou[1] This paper describes the behavior of the Quintuple Friction Pendulum isolator. An analytical model is presented that is capable of tracing the behavior of the isolator in two general configurations of geometric and frictional properties. Force displacement relations are presented for all 9 regimes for both the possible configurations. A computational model that can be implemented in program SAP2000 is also presented and verified by comparison to the analytical model. A model Quintuple Friction Pendulum isolator has been tested and the results have been used to validate the analytical and computational models. While the computational model is inherently tri-axial in nature, it has not been validated for these conditions, which would have required tri-axial shake table testing or multi-directional motion testing of individual isolators.

Hamed Keikha & Gholamreza Ghodrati Amiri.[2] The focus of this study is on the effect of velocity, heat generation, and temperature rise, which occurs at the sliding surfaces under large friction forces and high velocities, on the frictional behavior of this new type of isolators. This research shows that 3D FEM and analyzing could be an appropriate solution to predict the exact thermal–mechanical behavior of these types of sliding isolators under seismic events. The mathematical expressions to predict the dependency of friction coefficient of sliding surfaces to local surface variables like velocity and temperature have good agreement with delivered numerical results. The variation of the isolator’s mechanical behavior predicted by the numerical procedure during cyclic loading acknowledged that the reduction in stiffness and energy dissipation capacity of sliding isolators during seismic events is a possible issue related to frictional heating of the sliding surfaces

Hamed Keikha & Gholamreza Ghodrati Amiri[3] This paper aims to develop, assess, and numerically implement analytical models for the newly introduced Quintuple Friction Pendulum Isolator (QFPI) which can identically capture its real experimental performance and also have the ability to capture the bi-directional, tri directional, and vertical-horizontal coupling behavior of it, raising the predictive capability of nonlinear response history analyses and also lowering computational and experimental complexity and cost. The developed 3D QFPI element has the option to be subjected to tri-directional excitations and capture 3D responses. Based on the captured 3D responses compared to horizontal-only responses, significant amplification of the horizontal responses due to vertical-horizontal coupling behavior of this system has been observed. The delivered QFPI 3D element numerical results and also analytical evaluation of a single degree-of-freedom (single rigid mass) structure isolated with QFPI system subjected simultaneously to vertical and horizontal excitations showed that the vertical excitation causes an increase in the horizontal acceleration of the mass.

A. H. Sodha, D. P. Soni, M. K. Desai[4] To study the effect of directivity focusing and fling step, 15 records consist of far-field, near-fault with forward directivity and fling step effect are also considered. Three types of effective period and effective damping in combination with two different displacement capacities of QTFP bearing resulting in six isolator designs are considered in this work. The seismic demand parameters like base shear, top floor absolute acceleration and isolator displacement have been studied. It is found that the QTFP bearing stiffens at low input, softens with increasing input, and then stiffens again at higher levels of input. With the increase in time period and damping of the QTFP, isolator displacement increases and top floor absolute acceleration and base shear reduces. Due to forward and backward momentum conveyed by the directivity pulse, near-fault directivity effect imposes higher demand compared to fling step having forward momentum only.

Michael C. Constantinou, M. EERI[5] The behavior of the triple Friction Pendulum bearing is not exactly that of a series arrangement of single concave Friction Pendulum bearings—though it is similar. This paper describes how to modify the input parameters of the series model in order to precisely retrace the true force-displacement behavior exhibited by this device. Recommendations are made for modeling in SAP2000 and are illustrated through analysis of a simple seismically isolated structure. This paper shows how to capture the force-displacement relationship of the triple FP bearing using a series assembly of gap elements and single concave FP elements. With proper modification, the overall force-displacement relationship can be reproduced, though the exact internal sliding behavior cannot. The lack of a coupled gap element means that the proposed modeling scheme will not be exact for bidirectional analysis, though results can be obtained within reasonable engineering tolerances simply by arranging multiple gap elements radially.

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III. OBJECTIVE AND SCOPE OF WORK

A. Objectives

1) To carry out Non-Linear time history Analysis of structure with stiffness irregularity and plan irregularity using SAP 2000 considering fixed base.
2) To evaluate seismic response of above-mentioned structures using Quintuple friction pendulum system.
3) Fixed base and isolated building should be compared for below mentioned seismic demands to evaluate effectiveness of the Quintuple system:

a) Peak storey acceleration
b) Maximum Base shear
c) Inter-Storey drift

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B. Scope Of Work

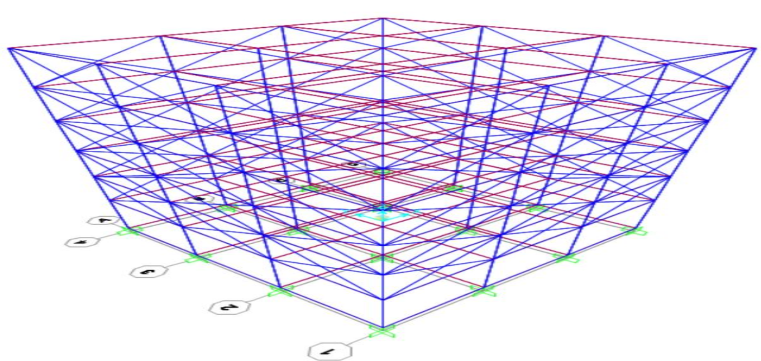
1) To study the SAP 2000 software and perform validation procedure.
2) To make a model of the building considering fixed base in SAP2000.
3) Non- Linear *Time History analysis shall be done for G + 5 storey buildings having bay width 5m x 5m each is taken for the study.*

Model Description

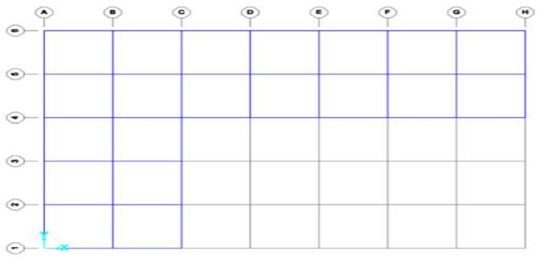
SR NO	Description	Dimension (mm)
1	Beam	300 x 500
2	Column	450 x 450
3	Bay width	5000 x 5000
4	Story height	3000

Time History Data

Hazard level	Earthquake	Magnitude	Duration (sec)	PGA (cm/ s^2)
FF	Imperial Valley, 1940	6.95	40	307.05
	Northridge, 1994	6.7	29.9	518.95
NFD	Northridge California, 1994	7.3	60	720
	Northridge California, 1994	6.7	60	730
NFS	Kocaeli, 1999	7.4	135.82	230
	Chi Chi, 1999	7.6	72.01	590



3D model of Soft storey



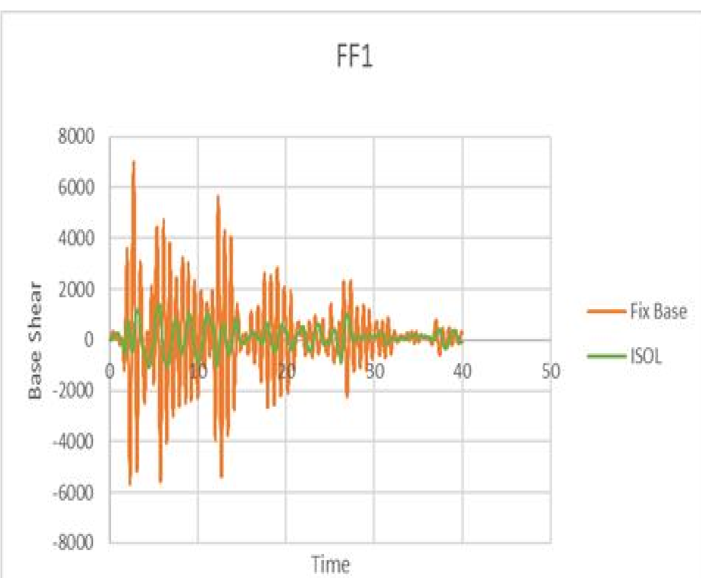
Plan View of L shape

Plan View of C shape

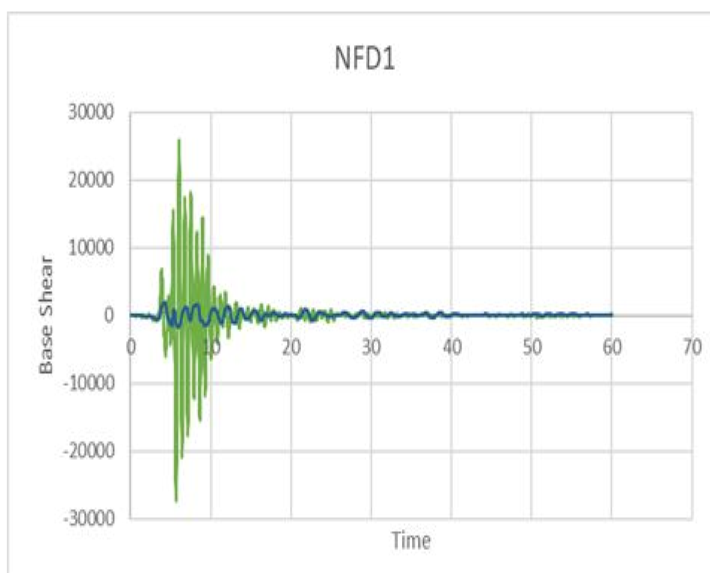
Properties of Quintuple Friction Isolator

Radius of sliding surface (m)	Height of the element (m)	Co- efficient of friction of surfaces	Displacement capacity (m)
R_1 = 1.7	h_1 = 0.2032	μ_1 = 0.1	d_1 = 0.32
R_2 = 0.680	h_2 = 0.1524	μ_2 = 0.06	d_2 = 0.15
R_3 = 0.409	h_3 = 0.1016	μ_3 = 0.01	d_3 = 0.075
R_4 = 0.409	h_4 = 0.1016	μ_4 = 0.01	d_4 = 0.075
R_5 = 0.73	h_5 = 0.1524	μ_5 = 0.03	d_5 = 0.13
R_6 = 1.6	h_6 = 0.2032	μ_6 = 0.07	d_6 = 0.29

IV. RESULT AND DISCUSSION



base shear vs time for SS1



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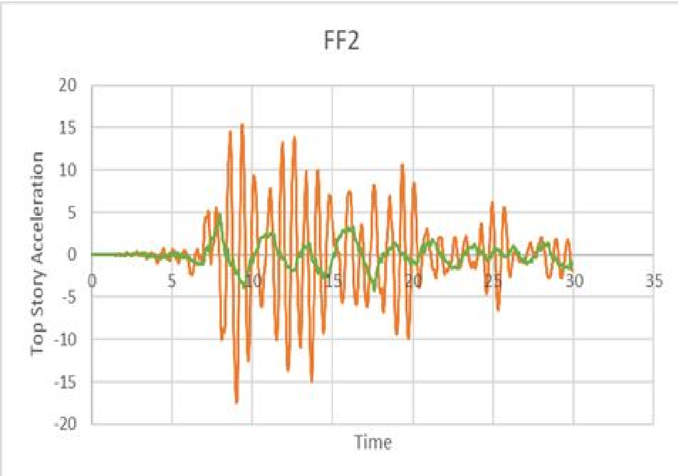
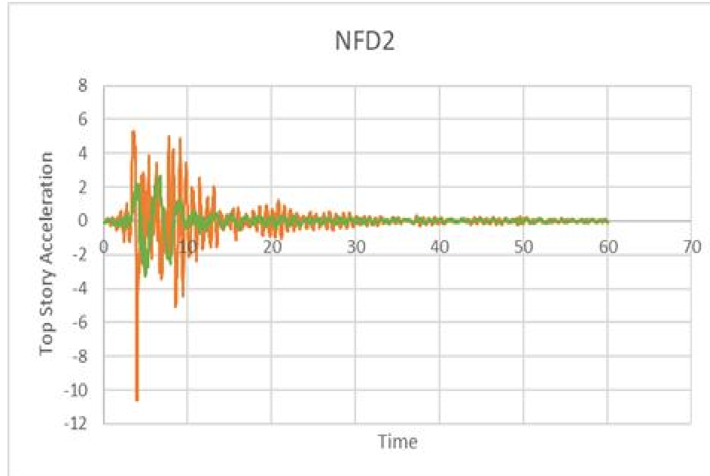
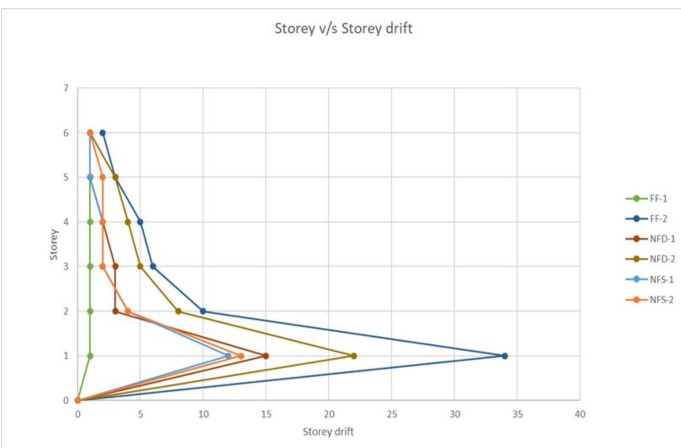


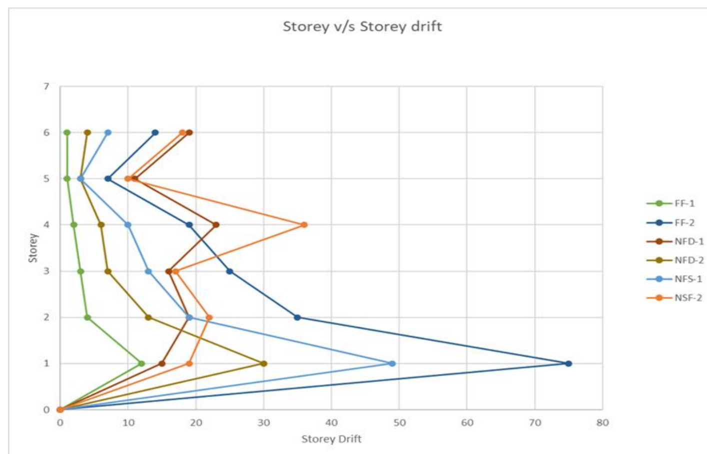
acceleration vs time for SS1



acceleration vs time for SS1



story vs story drift for QFPS having SS1



story vs story drift for Fixed having SS1

- The maximum reduction in absolute acceleration as compare to fixed base structure is 91.27 % for the structure having soft storey(1), 89.42 % for the structure having soft story(2), 98.9 for plan irregularity 1 and 98.17 % for plan irregularity 2 isolated by QFPS
- The reduction in Maximum Base Shear is 93.1% for the structure with soft storey(1), 91.60 for soft story(2), 98.56% for L-Shape and 98.17 for C-Shape isolated by QFP
- In case of the C-Shape having fixed base average inter-story drift for 6 ground motion is 45.33mm while for building isolated by QFPS this value reduces to 6.83mm

V. CONCLUSION

A. Absolute Acceleration

1) The reduction in absolute acceleration is found more in case of PI as compared to SS for all the considered time histories.

2) The maximum reduction in absolute acceleration as compare to fixed base structure is 91.27 % for the structure having soft storey(1), 89.42 % for the structure having soft story(2), 98.9 for plan irregularity 1 and 98.17 % for plan irregularity 2 isolated by QFPS.

B. Maximum Base Shear

1) The reduction in Maximum Base-Shear is found more in case of Plan irregularity as compared to Stiffness Irregularity (Soft Story) in all the considered Time History.

2) The reduction in Maximum Base Shear is 93.1% for the structure with soft storey(1), 91.60 for soft story(2), 98.56% for L-Shape and 98.17 for C-Shape isolated by QFPS.

C. Interstorey Drift

1) In isolated structure, the Inter-storey drift is found to be maximum in case of structure having soft storey as compared to plan irregularity 1 and 2

2) In case of the Soft-Story having fixed base average inter-story drift for 6 ground motion is 37.5mm while for building isolated by QFPS this value reduces to 16.5mm

3) In case of the L-Shape having fixed base average inter-story drift for 6 ground motion is 48.67mm while for building isolated by QFPS this value reduces to 10.33mm

4) In case of the C-Shape having fixed base average inter-story drift for 6 ground motion is 45.33mm while for building isolated by QFPS this value reduces to 6.83mm

VI. FUTURE SCOPE OF WORK

A. Similar work can be done by designing the isolation system for different displacement capacities and comparing the seismic demand parameters for various displacement capacities.

B. Along with this analysis can be done considering the soil structure interaction effect.

C. Another work can be taken as, different buildings with mass irregularities isolated with combination of various isolators.

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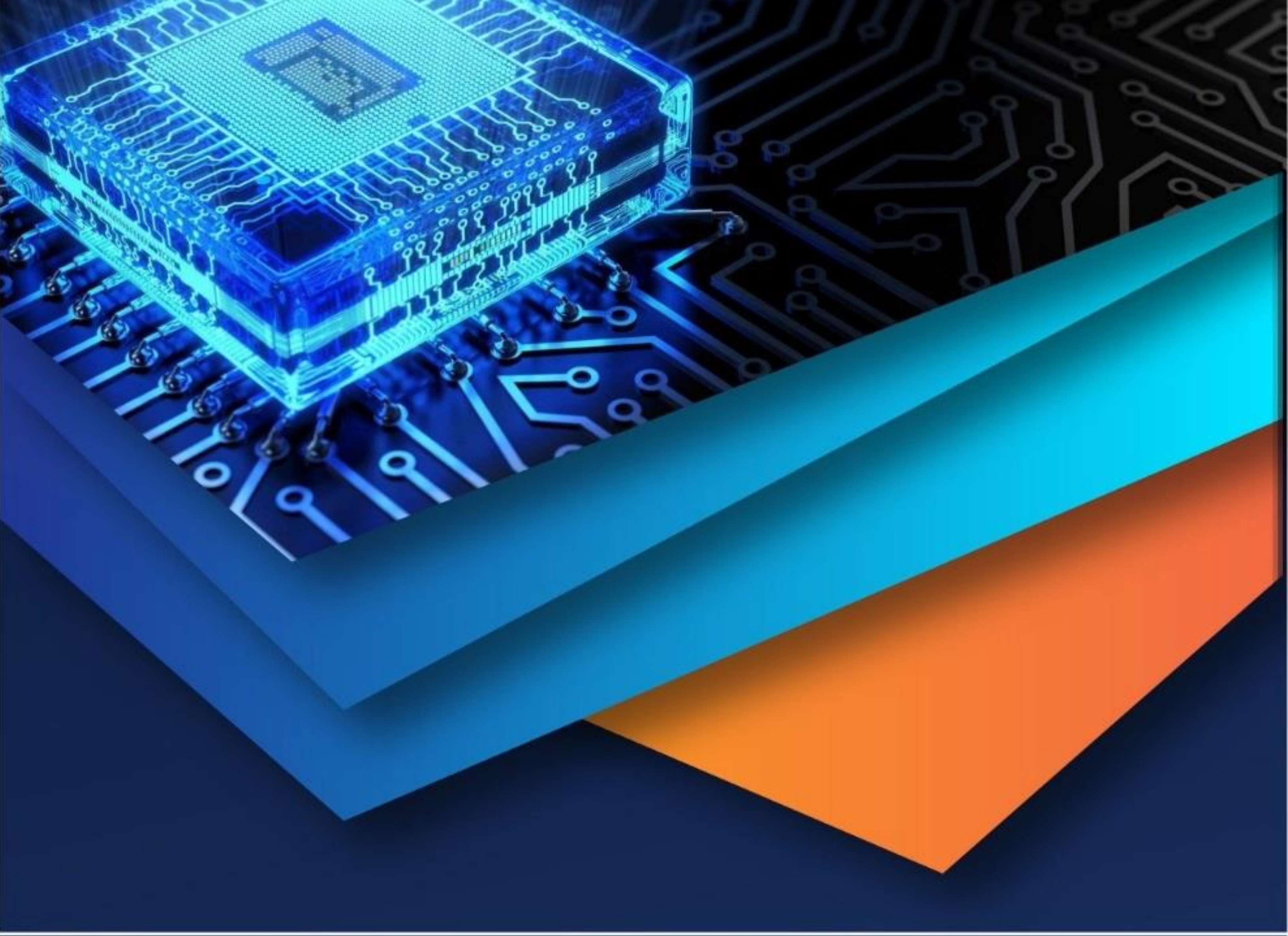

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