iJRASET
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.2020.32321

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

Seismic Study on Tall Structures with RC Shear Walls: Static and Dynamic Analysis

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Abstract: Structural design is the primary aspect of civil engineering. In India, multi-storied buildings are usually constructed due to high cost and scarcity of land. In order to utilize maximum land area, builders and architects generally propose symmetrical as well as asymmetrical plan configurations. The asymmetrical plan buildings, which are constructed in seismic prone areas, are likely to be damaged during earthquake. Earthquake is a natural phenomenon which can generate the most destructive forces on structures. Buildings should be made safe for lives by proper design and detailing of structural members in order to have a ductile form of failure.

The concept of earthquake resistant design is that the building should be designed to resist the forces, which arises due to Design Basis Earthquake, with only minor damages and the forces, which arises due to Maximum Considered Earthquake, with some accepted structural damages but no collapse. This present analytical study comprises of seismic analysis various storeyed R.C. structures (from low-rise to mid-rise to high-rise) with regular or symmetrical plan. The following building models such as G+1, G+4, G+9 and G+24 storeyed have been taken into account. The building is modelled as a 3D space frame with six degrees of freedom at each node using the software STAAD PRO v8i v 14.2.4. All the building models are analysed using Equivalent Static analysis. The building models are located in zone IV with S.M.R.F. Furthermore, Response Spectrum Analysis is also conducted on the entire regular plan building models as well as irregular plan building models. Detailed seismic response and behaviour are discussed well in this present study.

Keywords: Response spectrum, Modal analysis, Shear wall, Tall structure, Storey drift.

I. INTRODUCTION

Earthquake and wind forces is known to be one of the most destructive phenomena experienced on earth. It is caused due to a sudden release of energy in the earth's crust which results in seismic waves. When the seismic waves reach the foundation level of the structure, it experiences horizontal and vertical motion at ground surface level [1]. Due to this, earthquake is responsible for the damage to various man-made structures like buildings, bridges, roads, dams, etc. it also causes landslides, liquefaction, slope-instability and overall loss of life and property. When earthquakes occur, a building undergoes dynamic motion. This is because the building is subjected to inertia forces that act in opposite direction to the acceleration of earthquake excitations. These inertia forces, called seismic loads, are usually dealt with by assuming forces external to the building. So apart from gravity loads, the structure will experience dominant lateral forces of considerable magnitude during earthquake shaking. It is essential to estimate and specify these lateral forces on the structure in order to design the structure to resist an earthquake. The ductility of a structure is the most important factors affecting its seismic performance and it has been clearly observed that the well designed and detailed reinforced structures behave well during earthquakes and the gap between the actual and design lateral force is narrowed down by providing ductility in the structure. A braced frame is a structural system commonly used in structures subject to lateral loads such as wind and seismic pressure. The members in a braced frame are generally made of structural steel, which can work effectively both in tension and compression. The beams and columns that form the frame carry vertical loads, and the bracing system carries the lateral loads [2]. This system tube in tube is also known as 'hull and core' and consists of a core tube inside the structure which holds services such as utilities and lifts, as well as the usual tube system on the exterior which takes the majority of the gravity and loads. The inner and outer tubes interact horizontally as the shear and flexural components of a wall-frame structure. They have the advantage of increased stiffness. The core tube system concept is based on the idea that a building can be designed to resist lateral loads by designing it as a hollow cantilever perpendicular to the ground. In the simplest incarnation of the tube, the perimeter of the exterior consists of closely spaced columns that are tied together with deep spandrel beams through moment connections.

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1) *Shear Wall Design*: The requirements of this section apply to the shear walls, which are part of the lateral force resisting system of the structure. The thickness of any part of the wall shall preferably, not be less than 150 mm. The effective flange width, to be used in the design of flanged wall sections, shall be assumed to extend beyond the face of the web for a distance which shall be the smaller of (a) half the distance to an adjacent shear wall web, and (b) l/10 th of the total wall height. Shear walls shall be provided with reinforcement in the longitudinal and transverse -directions in the plane of the wall. The minimum reinforcement ratio shall be 0.0025 of the gross area in each direction. This reinforcement shall be distributed uniformly across the cross section of the wall. If the factored shear stress in the wall exceeds 0.25 dfz or if the wall thickness exceeds 200 mm, reinforcement shall be provided in two curtains, each having bars running in the longitudinal and transverse directions in the plane of the wall.

II. LITERATURE REVIEW

Past RC panel tests performed at the University of Houston [2] show that reinforced concrete membrane elements under reversed cyclic loading have much greater ductility when steel bars are provided in the direction of principal tensile stress. In order to improve the ductility of low-rise shear walls under earthquake loading, high seismic performance shear walls have been proposed to have steel bars in the same direction as the principal direction of applied stresses in the critical regions of shear walls. The study presents the test results of four large-scale shear walls, including two shear walls under shake table tests and two shear walls under reversed cyclic loading. The height, length, and width of the designed shear walls for the shake table tests are 0.7 m, 1.4 m and 0.085 m, respectively. The height, length, and width of the designed shear walls for the reversed cyclic tests are 1.4 m, 2.8 m and 0.12 m, respectively. Steel bars are provided in the directions of 45 degrees to the horizontal that are very close to the principal direction of applied tensile stresses according to the elastic analysis of the shear walls. The steel ratio in both perpendicular directions of the shear walls is 0.36% for the shake table tests, and 0.48% for the cyclic tests. For the two shear walls under dynamic loading induced by the shake table, the response time histories for the accelerations and displacements as well as the hysteretic loops are presented. For the two shear walls under reversed cyclic loading, the force-displacement hysteretic loops are presented. Based on the experimental results, the tested high performance shear walls have greater ductility than that of conventional shear walls.

Another critical work presented [3], investigates the effects of openings in shear wall on seismic response of structures. For parametric study 15 storied 4 m X 5m bays apartment buildings with typical floor plan of 25mx12m and floor height of 3m with different openings size and location in shear walls were modeled in ETABS-2015. An equivalent dynamic analysis for three dimensional models of the buildings was performed as per IS 1893 (part 1): 2002. Seismic responses of the analyzed structures were compared. The results reveal that for opening area < 15%, the stiffness of the system is more affected by the size of openings than its arrangement [4]. However, for opening area >15%, the stiffness of the system is significantly affected by openings configuration in shear walls [5].

III. MODEL SPECIFICATION

The various specifications for the RC structure model are mentioned as follows:

A. Building plan-24.5m X 22.5m.
B. No of storey-50.
C. Floor to floor height-3m;
D. LL-3kN/m^2.
E. Grade of concrete –M 30. Grade of steel-Fe 500.
F. Spacing between frames-4.9m X 4.5m.
G. Damping-5%. Seismic zone-4.
H. Type of soil-loose/soft clay.

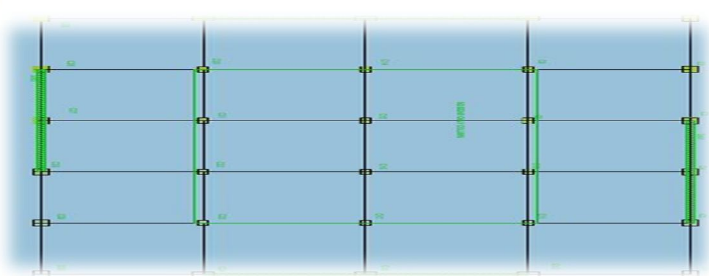

Fig. 1 Plan of the Building Model

IV. EQUIVALENT STATIC ANALYSIS (IN ACCORDANCE WITH IS 1893:2016)

For Equivalent static analysis [6], [7],[11], based on the natural time period of the structure will be calculated as per Eqn. (1)

$$T_a = \frac{0.09h}{\sqrt{d}} \tag{1}$$

Where, T_a= Natural time period of the structure and d= Base dimension of the building at the plinth level. Similarly, the design horizontal seismic coefficient (A_h) may be calculated as per Eqn. (2)

$$A_h = \frac{ZIS_a}{2Rg}. \tag{2}$$

Where, Z= seismic zone factor, I= importance factor, S_a/g= average response acceleration coefficient, R= response reduction factor. The total design lateral force or design seismic base shear (V_b) along any principal direction will be calculated by the Eqn. (3) and the distribution of lateral forces along all the floors can be calculated by eqn.

$$V_b = A_h W. \tag{3}$$

where, W= total seismic weight of the building.

$$Q_i = \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_j^2}. \tag{4}$$

where, Q_i = design lateral forces, W_i = Seismic weight at i^{th} floor, h_i= height of the ith floor measured from the base, n = number of storeys. It is known to all that according to IS 1893:2016 [11], Response Spectra method should be conducted for irregular buildings based on modal analysis.

A. *Structure without shear wall*

Table I. Variation of Lateral Forces at each Floor Heights vs base Shear (No shear wall)

Floor Height(m)	Lateral Force (kN)	Base Shear (kN)
0	0.18	8183.651
3	0.719	8183.651
6	1.618	8183.651
9	2.876	8183.651
15	6.471	8183.651
18	8.808	8183.651
24	14.56	8183.651
30	21.751	8183.651
36	30.379	8183.651
42	40.446	8183.651
48	51.95	8183.651
54	64.893	8183.651
60	79.273	8183.651
66	95.092	8183.651
72	121.517	8183.651
81	140.931	8183.651
87	161.783	8183.651
93	184.072	8183.651
99	207.8	8183.651
108	246.088	8183.651
117	287.612	8183.651
123	317.1	8183.651
126	332.372	8183.651
135	380.367	8183.651
141	414.161	8183.651
147	431.598	8183.651
150	467.55	8183.651

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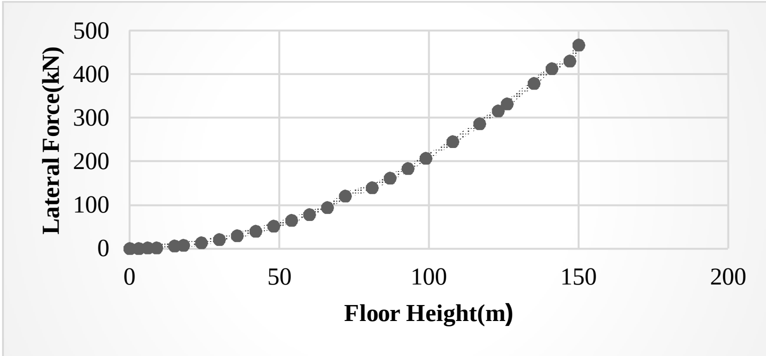

Fig. 1 Variation between the Lateral forces (kN) at every floor height (m) without shear wall

B. Structure with Shear Wall

Table III
Variation of Lateral Forces At Each Floor Heights vs Base Shear (No Shear Wall)

Floor Height(m)	Lateral Force(KN)	Base shear(KN)
0	0.013	613.714
3	0.054	613.774
6	0.121	613.774
9	0.216	613.774
15	0.486	613.774
18	0.661	613.774
24	1.093	613.774
30	1.633	613.774
36	2.281	613.774
42	3.037	613.774
48	3.901	613.774
54	4.872	613.774
60	5.952	613.774
66	7.14	613.774
72	8.436	613.774
81	10.582	613.774
87	12.147	613.774
93	13.821	613.774
99	15.602	613.774
108	18.477	613.774
117	21.595	613.774
126	24.956	613.774
132	26.32	613.774
135	28.559	613.774
141	31.097	613.774
147	50.613	613.774
150	17.553	613.774

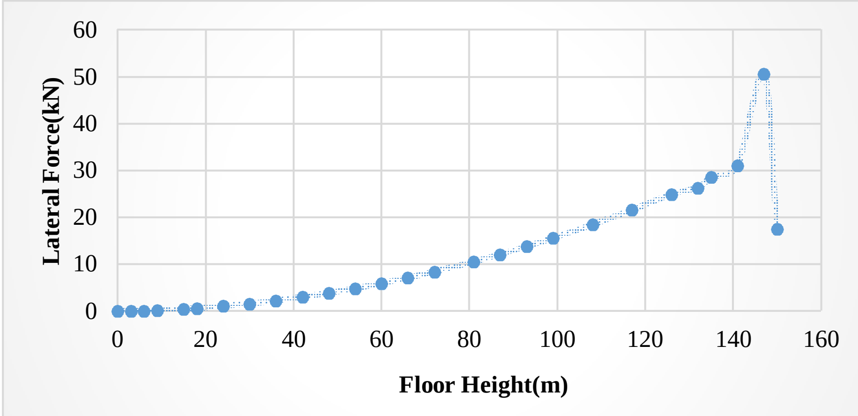

Fig. 2 Variation between the Lateral forces (kN) at every floor height (m) with shear wall

V. RESPONSE SPECTRUM METHOD ON THE STRUCTURE WITH SHEAR WALL (DYNAMIC ANALYSIS)

The equation of MDOF system [6], [7], [11] is represented by Eqn. (5)

$$[m]\{x\,(\ddot{t})\} + [c]\{\dot{x}(t)\} + [k]x(t) = -[m]\{r\}x_g\ddot{(t)} \quad (5)$$

Modal mass M_k of mode k can be calculated as per Eqn. (6).

$$M_k = \frac{\left[\sum_{i=1}^{n} W_i\phi_{ik}\right]^2}{g\sum_{i=1}^{n} W_i(\phi_{ik})^2} \quad (6)$$

where, ϕ_{ik}= mode shape coefficient at floor i of mode k.
Similarly, modal participation factor needs to be calculated as per above eqn.
Design lateral force as per Eqn. (7) and storey shear force as per Eqn. (8) are given below.

$$P_k = \frac{\sum_{i=1}^{n} W_i\phi_{ik}}{\sum_{i=1}^{n} W_i(\phi_{ik})^2} \quad (7)$$

$$Q_{ik} = A_k\phi_{ik}P_k \quad (8)$$

Where, A_k= design horizontal acceleration spectrum using natural time period of oscillation T_k of mode k obtained from dynamic analysis.

A. *Eigen Solution*

TABLE IIIII
LIST OF FREQUENCY VS PERIOD

Mode	Frequency(cycles/sec)	Period(sec)
1	0.245	4.082
2	0.297	3.361
3	0.543	1.843
4	0.882	1.133
5	1.051	0.952
6	1.558	0.642

B. Pick storey Shear without Torsion

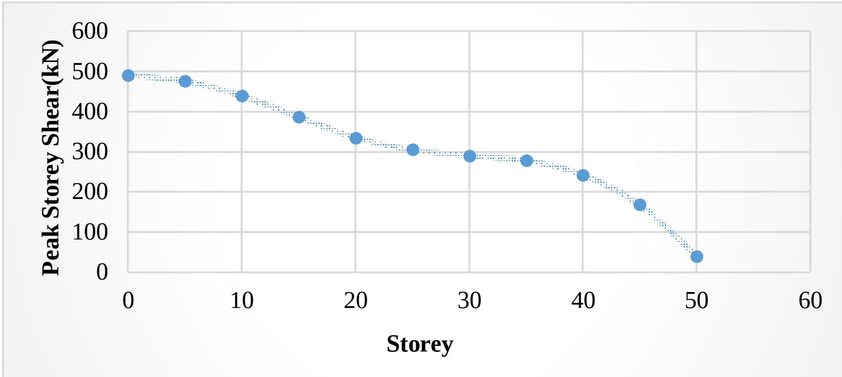

Fig. 3 Variation of Peak Storey Shear (kN) vs Various storey heights (m)

C. Variation of Mode vs Peak Acceleration

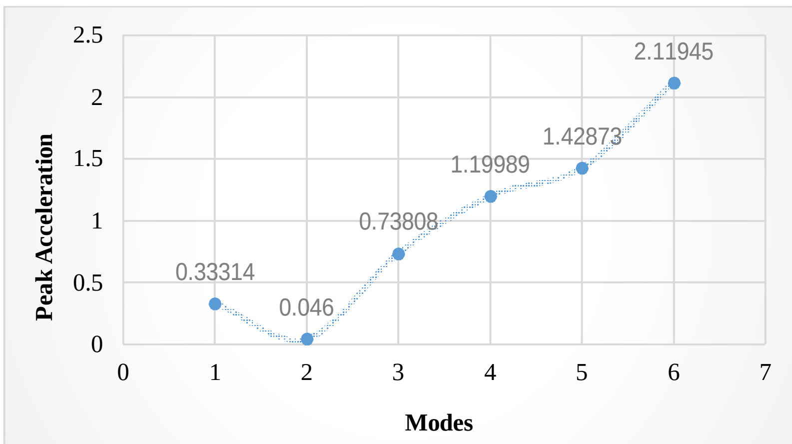

Fig. 4 Variation of Peak Acceleration vs Various modes

D. Modal Base Action

Table IVV
List Of Various Forces And Moments At Different Periods

Moments about the Origin

Mode	Period	F_X	F_Y	F_Z	M_X	M_Y	M_Z
1	4.083	0.09	0.03	5.14	528.64	-57.17	-8.93
2	3.361	377.12	2.37	-7.6	-704.7	3085.86	- 38686.66
3	1.843	0.49	-0.03	-0.22	-33.6	176.96	-60.6
4	1.133	0.35	-0.2	9.96	73.55	-111.27	-15.65
5	0.952	311.31	-7.1	-6.51	197.84	2636.66	-1485.19
6	0.642	0.52	0.13	8.02	48.83	-84.75	-0.48

E. Mass Participation factor vs Base Shear

Table V
Variation Of Various Mass Participation Factor (Mk) With Base Shear (Vb)

Mass Participation Factor in Percent

Modes	X	Y	Z	∑X	∑Y	∑Z	X	Y	Z
1	0.02	0	71.36	0.02	0.003	71.356	0.09	0	0
2	71.95	0	0.03	71.97	0.006	71.385	377.12	0	0
3	0.05	0	0.01	72.021	0.006	71.395	0.49	0	0
4	0.02	0.01	18.41	72.043	0.013	89.8	0.35	0	0
5	16.82	0.01	0.01	88.863	0.022	89.008	311.31	0	0
6	0.02	0	4.53	88.862	0.023	94.334	0.52	0	0

Base Shear in kN

Total SRSS Shear	489.02	0	0
Total 10PCT Shear	489.02	0	0
Total ABS Shear	689.88	0	0
Total CSM Shear	489.02	0	0

VI. RESULTS AND DISCUSSIONS

The present analytical study primarily focusses on the effect of presence of shear walls in RC tall structures. From analysis it is observed without shear wall the peak storey shear at 50th level (top storey) is 467.55 kN and base shear is 8183.75 kN. As shown in Table I, and for with shear wall the peak storey shear at 50th level (top storey) is 17.553 kN and base shear is 613.774 kN, as shown in Table II. Comparison between Table I and Table II shows that a sharp difference between these. In presence of shear wall, the gradual increment of lateral forces with respect to various storey heights (parabolic variation), the trend is changed. A sharp jump or downfall in the increment of lateral forces is observed which signifies the resistance of seismic lateral forces provided by the RC shear wall. Figure 3 represents the peak storey shear is in Response Spectrum Method is 489.02 kN at the 50th floor (top level). In variation of storey drift for RC structures, maximum storey displacement in case of equivalent static is 19.89 cm. at the top level. For response spectrum the maximum storey displacement is 10.01 cm. As per as storey drift is concerned, in case of equivalent static method without shear wall the analysis result of storey drift is failed due to maximum drift. In case of response spectrum method and equivalent static method with shear wall the result of storey drift is passed in each level in Staad analysis.

VII. CONCLUSION

In this present study, base shear values are obtained as cumulative of respective lateral loads experienced at each storey level with minimum base shear at the top storey and maximum base shear at the bottom storey are calculated with high level of accuracy. Magnitude of lateral forces increased at a steady rate as one moved higher from a lower storey to upper storey, reaching maximum at the topmost floor level. Irregular shaped buildings undergo more deformation and hence regular shape building must be preferred. It is recommended in very tall buildings (25 storeys) the floor displacement is very large in the top floor levels which makes for uneconomical section design and hence Dynamic analysis. Analysis of a 50 storied building has been done in Staad pro with and without shear wall by equivalent static and as well as response spectrum method. Different loading methods have been used in accordance with Indian Standard codes. In case of structure with shear wall, structures experiences less moment and less lateral force and also less base shear so deflection is less, leading to high moment resisting capacity of the respective structures. In the case of Rc structures without shear wall, structure experiences more lateral forces. Structural investigations are appropriate as per safety and serviceability demands as per Indian design codes. Major forces and effects are predominant in +X direction of the building plan with respective to +Z direction. Structural design is conducted as per Limit state design philosophies. Ductile reinforcement detailing as per IS 13920:2002 is provide, hence economical design.

VIII. ACKNOWLEDGEMENT

It is with immense pleasure that we express our sincere sense of gratitude and humble appreciation to Prof. Saurav Kar for his invaluable guidance, whole-hearted co-operation, constructive criticism and continuous encouragement in the preparation of this present work. Without his support and guidance, the present work would have remained a dream. We would also like to thank Prof. (Dr.) Tapas Sadhu, Head of Department of Civil Engineering Department, Heritage Institute of Technology for providing necessary facilities. We take this opportunity to thank all our scholar friends & family for their valuable support and encouragement throughout the preparation of this work. We also thank all those who have directly or indirectly helped in completion of this work.

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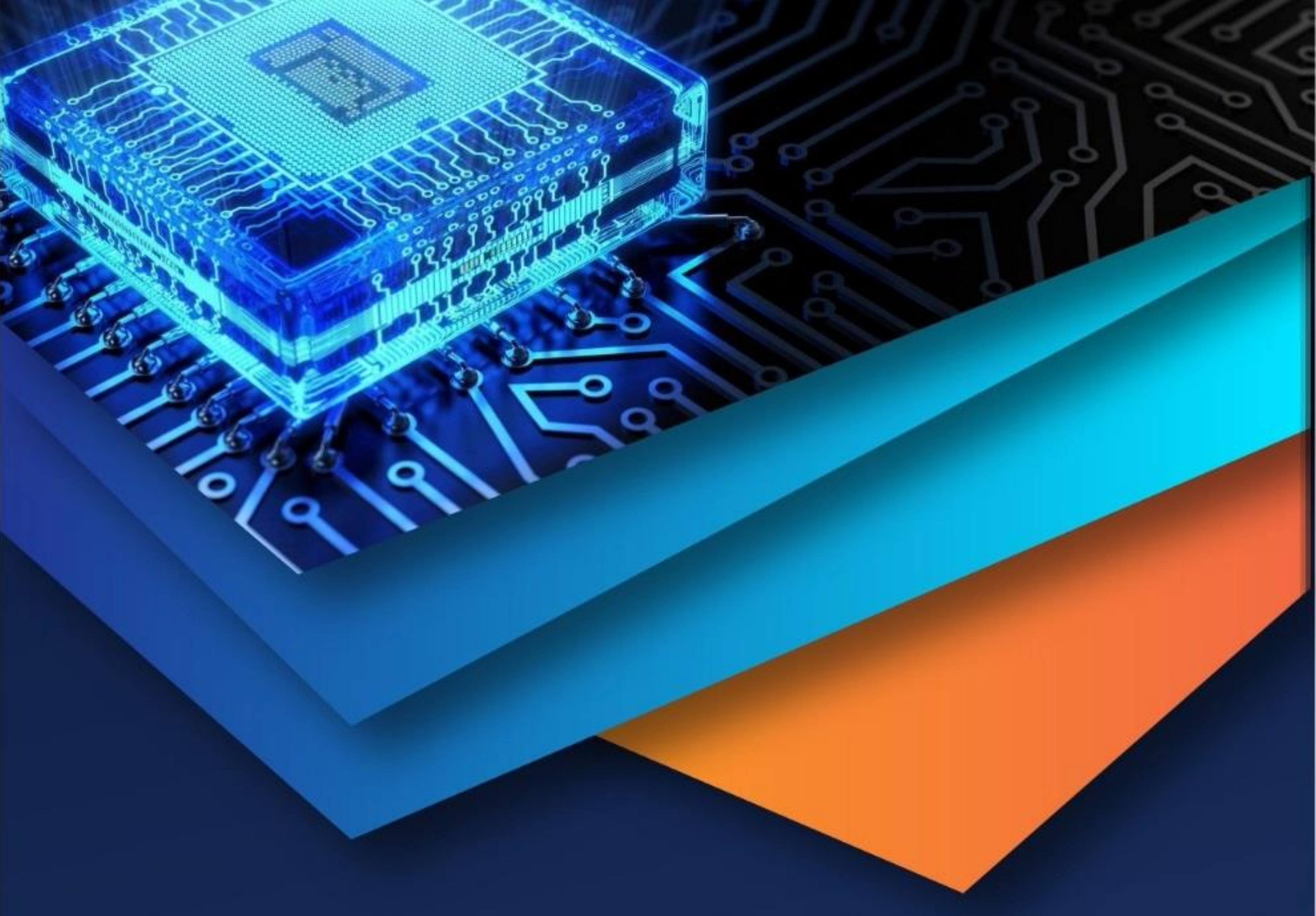

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