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A Comparative Study of Various Clauses of New IS 1893 (Part 1):2016 and Old IS 1893 (Part 1):2002.

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***Abstract:** The sixth revision of IS 1893 (Part 1): 2016, "Criteria for Earthquake Resistant Design Of Structures" have been published by Bureau of Indian Standards recently in December 2016. In this new code many changes have been included considering standards and practices prevailing in different countries and in India.*
This work aims at studying revisions in various clauses of new IS 1893 (Part 1): 2016 with respect to old IS 1893 (Part 1): 2002 and their effect especially, Separate response spectra for Equivalent static method and Response spectrum method. Old IS-1893-2002 has given one response spectra for Equivalent Static Method and Response Spectrum method for 4.0 s periods. Expressions are given for calculating design acceleration coefficient (Sa/g), for Rocky/hard soils, medium soils and soft soils. New IS 1893-2016 has given response spectra for Equivalent Static Method and Response Spectrum method separately for 6.0 s periods. Expressions are given for calculating design acceleration coefficient (Sa/g), for Equivalent Static Method and Response Spectrum method separately for Rocky/hard soils, medium soils and soft soils. It will change the Sa/g values.
Definition of soft storey and weak storey, change in definition of mass, torsion and vertical irregularities has been modified. Importance factor of 1.2 has been specified in new code for residential buildings, in old code residential buildings were assigned importance factor of 1.0. Naturally, it will increase the design horizontal seismic coefficient A_h. New expression for T_a for building with RC structural walls, requirements for rigid and flexible diaphragm has been modified, modelling of unreinforced masonry infill walls as equivalent diagonal struts, etc. and critical comments on that are covered.
***Keywords:** Response spectrum, centre of stiffness, Geometric irregularity, Damping ratio, Diaphragm.*

I. INTRODUCTION

India is prone to strong earthquake shaking, and hence earthquake resistant design is essential. The Engineers do not attempt to make earthquake proof buildings that will not get damaged even during the rare but strong earthquake. Such buildings will be too robust and also too expensive.
Design of buildings wherein there is no damage during the strong but rare earthquake is called earthquake proof design. The engineers do not attempt to make earthquake proof buildings that will not get damaged even during the rare but strong earthquake. Such buildings will be too robust and also too expensive. The aim of the earthquake resistant design is to have structures that will behave elastically and survive without collapse under major earthquakes that might occur during the life of the structure. To avoid collapse during a major earthquake, structural members must be ductile enough to absorb and dissipate energy by post elastic deformation.

II. LITERATURE REVIEW-COMPARISON OF CODES

A comprehensive study of various clauses of New IS 1893 (Part 1):2016 and Old IS 1893 (Part 1):2002 has been made. Many clauses of old IS 1893-2002 has been revised in new IS 1893-2016. The revisions in major clauses has been presented in the table below with critical comments on that.

Sr. No.	IS 1893 (PART 1): 2002	IS 1893 (PART 1): 2016	Comments
1	Importance Factor(I): cl. 6.4.2	Importance Factor(I): cl. 7.2.3	Design horizontal seismic coefficient A_h=(Z/2).(I/R).(Sa/g)

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	Importance factor 1.5 was for important structures, and 1.0 for all other buildings, Table-6.	For Residential or commercial buildings, with occupancy more than 200 persons importance factor 1.2 has been assigned, in new code , Table-8.	As I increases, A_h will increase and therefore Base shear V_B will increase. This may lead to increase in amount of lateral loads on the structure and eventually increases the sizes of the lateral load resisting members and reinforcement. Ultimately structure cost may increase, but at the same time the structural strength is also increased towards earthquake forces.
2	Design Acceleration Spectrum : cl. 6.4 Old IS-1893-2002 has given one response spectra for Equivalent Static Method and Response Spectrum method in Fig.2. The response spectra is given for 4.0 s periods. Expressions are given for calculating design acceleration coefficient (Sa/g), for Rocky/hard soils, medium soils and soft soils.	Design Acceleration Spectrum : cl. 6.4.2.1 New IS-1893-2016 has given response spectra for Equivalent Static Method and Response Spectrum method separately in Fig.2A and 2B. The response spectra are given for 6.0 s periods. Expressions are given for calculating design acceleration coefficient (Sa/g), for Equivalent Static Method and Response Spectrum method separately for Rocky/hard soils, medium soils and soft soils. For Equivalent Static method, for T<0.4 sec, Sa/g=2.5 constant, but in Response spectrum method, Sa/g values varies as 1+15T up to 0.10sec.	As response spectra for Equivalent Static Method and Response Spectrum method are given separately, in both cases Sa/g values will change. It will change the values of A_h and V_B. Alternatively, as the Expressions for calculating design acceleration coefficient (Sa/g), for Rocky/hard soils, medium soils and soft soils are given separately for static and Dynamic analysis, it will change the values of A_h and V_B. .
3	URM Infill walls Modeling Code is silent about modeling of masonry infill walls. Only equation for T_a= 0.09h/√d for Buildings with masonry infill walls is given. Cl.7.6.1 Hence, in analysis T_a is taken considering masonry infill, but stiffness of infill is not considered in analysis.	RC Framed Building with Unreinforced Masonry Infill walls: cl. 7.9 This clause has been newly added and discusses the calculation of EQ loads when infill are considered. A detail procedure for URM infill by Equivalent diagonal strut method has been given in cl.7.9.2.2	As per old code the modelling of brick infill was not incorporated in the code and because of this the designers used the empirical formula which is conservatively written for all the RCC structures. Hence the modelling of brick infill by equivalent Strut represent the actual stiffness distribution of structure as a whole thus the time period calculation will be more close to realistic condition of Building Structure. As per IS 1893-2016 New code, Modelling with URM infill consider the stiffness of the infill in analysis thus, sizes of columns/shear walls may Increase or decrease as per the stiffness distribution of brick infill in the Structure.

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4	Soft story: cl. 4.20 A soft storey is defined as the storey in which the lateral stiffness is - less than 70 % of that in the storey above, or - less than 80 % of the average lateral stiffness of the three storey above.	Soft story: cl. 4.20.1 A soft storey is defined as the storey in which the lateral stiffness is less than that in the storey above.	In new code IS 1893-2016, the criteria for soft story are made more strict. The stiffness of lower story should not be less than that of the upper story. Soft story is a source of weakness in the structure and should be avoided.
5	Weak story: cl. 4.25 As per old IS 1893-2002, a weak storey is defined as the storey in which the lateral strength is - less than 80 % of that in the storey above.	Weak story: cl. 4.20.2 As per new IS 1893-2016, a weak storey is defined as the storey in which the lateral strength [cumulative design shear strength of all structural members other than that of unreinforced masonry-URM in fills] less than that in the storey above.	In new code IS 1893-2016, the criteria for weak story are also made more strict. The design shear strength of lower story should not be less than that of the upper story. Weak story is a source of weakness in the structure and should be avoided.
6	Dynamic Analysis Requirement : cl.7.8.1 For Regular Buildings: Zone-IV, V--------height >40m Zone-II, III--------height >90m For Irregular Buildings: Zone-IV, V-------- height >12m Zone-II, III------- height >40m	Dynamic Analysis Requirement : cl.7.7.1 Equivalent static analysis shall be applicable for regular buildings with height < 15m in seismic Zone II. [cl. 7.6. and cl.7.7.1] Equivalent Static method should be used for regular building structure with approximate natural periods is less than 0.4 sec. [cl.6.4.3]	Dynamic analysis consider different mode shapes, modal mass participation in each mode and modal combinations. Hence, in seismic zones III, IV and V and height of building more than 15 m, it is more safer to perform dynamic analysis. i.e. Dynamic analysis is compulsory for almost all buildings in all zones.
7	Moment of Inertia (I): Clause regarding Moment of Inertia is not mentioned in old code. Thus analysis is made considering full Moment of Inertia, i.e. Uncracked section is considered.	Moment of Inertia (I): cl.6.4.3.1 The moment of inertia for structural analysis shall be taken as given below. For RC and Masonry Structures : I_{eq}= 0.70 I_{gross} for columns I_{eq}= 0.35 I_{gross} for beams For Steel structures : I_{eq}= I_{gross} for beams and columns This clause of code takes into account, the cracked section properties.	This clause is added for safety and post earthquake effect. In old IS 1893-2002 full section, i.e. full M.I. of columns and beams is considered. In new code IS 1893-2016, cracked section with 70% MI of columns and 35 % MI of beams is considered. As concrete is seems to be cracked section all time, one cannot consider the full MI of RC section for analysis. Full MI of RC members make structure stiff hence the deflection at top storey, drift of storey, lateral displacement of storey etc. are estimated wrongly as smaller values. On the other hand by considering the cracked moment of inertia lateral deflection, drifts etc. will increase and to

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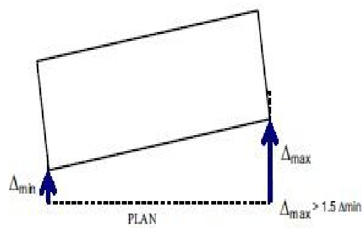
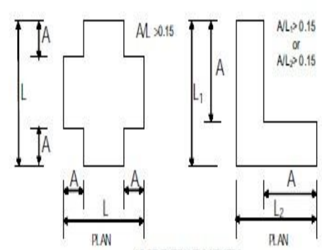
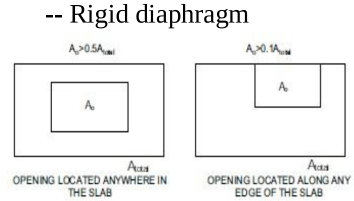
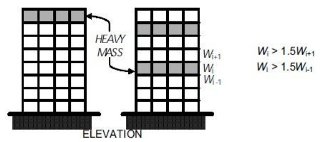
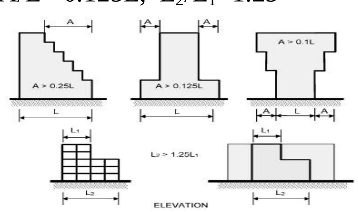
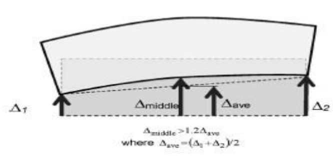
			control one should have to increase the sizes of lateral load resisting members which ultimately cause safety of structure. Hence for safety it is more reasonable to consider cracked section properties in analysis.
8	Torsion irregularity: cl.7.1 Table-4 Torsional irregularity As per old code is $\Delta_2 > 1.2 (\Delta_1 + \Delta_2)/2$	Torsion irregularity: cl.7.1 Table-5 Torsional irregularity As per new code is $\Delta_{max} > 1.5\Delta_{min.}$ When $\Delta_{max} > (1.5- 2.0)\Delta_{min}$ Configuration shall be revised.  3A TORSIONAL IRREGULARITY	As per old code IS 1893-2002, torsional irregularity is based on 1.2 times average drift of structure, While as per new code it is based on 1.5 times minimum displacement.
9	Re-entrant Corners: cl.7.1,Table - 4 As per Old code, For re-entrant corner, A/L > 0.15-0.20	Re-entrant Corners: cl.7.1 Table - 5 As per New code, For re-entrant corner A/L > 0.15  3B RE-ENTRANT CORNERS In buildings with re-entrant corners three dimensional dynamic analysis shall be performed.	As per new code for re-entrant corners, A/L values has been restricted to 0.15 which was permitted by old code as 0.15-0.20. For buildings with re-entrant corners three dimensional dynamic analysis shall be performed.
10	Diaphragm Discontinuity: (excessive cut-outs) cl.7.1 Table – 4 In old code Flexible or rigid diaphragm words are not mentioned. If $A_o > 0.5A_{total}$---it is mentioned discontinuous diaphragm. Where, A_o= cutout or open area.	Diaphragm Discontinuity: (excessive cut-outs) As per new code, cl.7.1 Table - 5 If $A_o > 0.5A_{total}$ -- Flexible diaphragm If $A_o < 0.5A_{total}$ -- Rigid diaphragm  3C FLOOR SLABS HAVING EXCESSIVE CUT-OUT AND OPENINGS	As per new code when cut out or opening is located near the edge of the slab and If $A_o > 0.1A_{total}$ it is considered flexible diaphragm. For continuity of in plane stiffness, the diaphragm shall be rigid.

11	Mass Irregularity: cl.7.1 , Table - 5 As per old code, mass irregularity is considered to exist when the seismic weight of any floor is more than 200 % of that of the floor below or above.	Mass Irregularity: cl.7.1 , Table -6 As per new code, mass irregularity is considered to exist when the seismic weight of any floor is more than 150 % of that of the floor below. Wi > 1.5 Wi-1. Wi > 1.5 Wi+1.  4B MASS IRREGULARITY In buildings with mass irregularity and located in seismic zones III, IV and V dynamic analysis shall be performed.	The criteria for a building to become mass irregular has been made more strict in new code. In old code mass variation of any floor with respect to near floor was allowed 200%, which has been reduced to 150 %.
12	Vertical Geometric Irregularity: cl. 7.1 , Table - 5 As per old code, the vertical geometric irregularity Shall be considered to exist, when the horizontal dimension of the lateral force resisting system in any story is more than 150 % of the storey below or above. A/L >0.15L, L_2/L_1>1.5.	Vertical Geometric Irregularity: cl. 7.1 , Table - 6 As per new code, the vertical geometric irregularity Shall be considered to exist, when the horizontal dimension of the lateral force resisting system in any story is more than 125 % of the storey below. A/L >0.125L, L_2/L_1>1.25  4C VERTICAL GEOMETRIC IRREGULARITY	The criteria for vertical geometric irregularity has been made more strict in new code. In old code variation of horizontal dimension of lateral load resisting system was allowed up to 150 %, which has been restricted in new code up to 125 %.
13	Diaphragm: Clause regarding flexible or rigid diaphragm does not appear in old code.	Diaphragm: cl. 7.6.4 The requirements for the floor diaphragm to be rigid or flexible are revised. When Δ_{middle}> 1.2Δ_{ave} --it is considered flexible diaphragm, otherwise it is rigid diaphragm.  FIG. 6 DEFINITION OF FLEXIBLE FLOOR DIAPHRAGM Usually floor slab with plan aspect ratio (L/B) less than 3 is considered rigid diaphragm.	Usually RCC slab with Monolithic slab-beam floors are considered to be rigid diaphragm. In case of flexible diaphragm design storey shear shall be distributed to the various vertical elements of lateral load resisting system considering the in-plane flexibility of the diaphragms (cl. 7.6.4)

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14	Damping ratio: cl. 7.8.2.1 Damping of 2% was allowed for steel structures in old code, which is now 5 %. Table-3 of old code, multiplying factors for obtaining values for other damping.	Damping ratio: cl. 7.2.4 The value of damping shall be 5 % of critical damping for calculating A_h, irrespective of the material of construction (steel, reinforced concrete, masonry, etc.) of its lateral load resisting system. The value of damping is same (5%) irrespective of the method of analysis used, namely, Equivalent Static Method, or Dynamic analysis Method. Table-3 of old code, multiplying factors for obtaining values for other damping has been removed.	For steel structures in new code damping allowed is 5 % which was 2 % in old code. As per Table 3 of old code multiplying factor for 5 % damping is 1.0 while for 2 % damping it is 1.40. As damping increases Sa/g value decreases.
15	Centre of Mass(CM): cl. 4.4 The old code define centre of mass as the point through which the resultant of the masses of a system acts. It is the centre of gravity of the mass system. Centre of Stiffness : cl. 4.5 As per old code it is the point through which the resultant of restoring forces of a system acts.	Centre of Mass(CM): cl. 4.4 As per new code the CM is defined as a point in a floor of a building through which the resultant of the inertia force of the floor acts during ground shaking. Centre of Resistance (CR) : cl.4.5 As per new code, for single storey building, it is the point on the roof of a building through which when the resultant inertial resistance acts, the building undergoes pure translation in horizontal direction, but no twist about vertical axis through the CR. Similarly, CR is also defined for multi storey buildings, by the new code.	Definition has been modified. Definition of centre of stiffness has been modified and made more elaborate.
16	Increase in permissible stresses in materials. cl.6.3.5.1 When earthquake forces are considered along with other design forces, the permissible stresses in materials may be increased by 33%. For steel having a definite yield stress, the stress be limited to yield stress. For steel without definite yield point, the stress will be limited to 80 % of the ultimate strength or 0.2 % proof stress whichever is smaller.	The clause of old code regarding increasing the stresses by 33.0% when EQ loads are acting, is removed. Thus designer is indirectly forced to use the limit state method.	Designers took advantage of the old code as follows: The whole building is designed by using L. S. Method, but the foundations are designed by using working stress method and benefit of stress increase is considered. When 1.5DL + 1.5 EL is critical, while using working stress method, this will be equivalent to 0.75 (DL + EL). If M_{DL} = 100 kNm and M_{EL} = 160 kNm, M = 260kNm and M_u = 1.5(100+160) = 390 kNm. If we use working stress

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			method, the moment is 100+160=260 kNm and with 33.0% increase in stress it will be equivalent to 0.75 x 260=195 kNm. In fact, the code should specify somewhere that for a given building, mixing of WSM and LSM will not be permitted. Anyway, by removing this clause, we are forced to use L. S. method. From IS:800 also, such a writing was removed in 2007 edition, and in design of purlin, and roof trusses in the load combination DL+WL, the increase in permissible stress is not allowed, thus forcing us to use L. S. method.
17	Increase in allowable soil pressure cl.6.3.5.2 When earthquake forces are considered, increase in allowable pressure in soils for different types of soils (Type-I, II, III) and different types of foundations, namely, piles, raft, well foundations, etc, was given in Table-1 from 25 % to 50 %.	Increase in net pressure on soils in design of foundations cl.6.3.5.2 New code IS 1893-2016, gives percentage increase in net bearing pressure and skin pressures for soil types A, B, and C as 50%, 25%, and 0% respectively in Table-1. For soft soil no increase in bearing pressure shall be applied because, settlements cannot be restricted by increasing bearing pressure.	For determining percentage increase in net bearing pressure, soils have been classified in to four types, Type-A, B, C, and D in Table-2, which is not available in old code. Soil Type-D is included and designated as unstable collapsible, liquefiable soils. When N values are less than desirable N values in Table 1, it is stipulated that using suitable ground improvement technique, the N values should be increased. In old code compacting was suggested for increase of N. The new code is silent for the method. It is necessary to know, for how much depth, the compaction is required. Dynamic compaction is a costlier method and can be used in VIP structures. For conventional structures, what shall be the guideline?

III. CONCLUSIONS

The following conclusion are made from the literature review as mentioned above:

Importance factor for multi storey residential buildings has been changed from 1.0 to 1.2. As I increases, A_h will increase and therefore Base shear V_B will increase. This may lead to increase in size of lateral load resisting members and reinforcement. Ultimately structure cost may increase.

Response spectra for Equivalent Static Method and Response Spectrum method are given separately, in both cases Sa/g values will change. It will change the values of A_h and V_B.

As per Old code IS 1893-2002 if Stiffness of masonry infill is not considered in analysis, it will increase the sizes of lateral load resisting elements like-columns/shear walls.

As per IS 1893-2016 New code, Modelling with URM infill consider the stiffness of the infill in analysis thus, sizes of columns/shear wall may decrease or increase as per the stiffness distribution..

In old IS 1893-2002 full section, i.e. full M.I. of columns and beams is considered.

In new code IS 1893-2016, cracked section with 70% MI of columns and 35 % MI of beams is considered.

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As cracks may develop in structure after some period, MI of sections may reduce and hence for safety it is more reasonable to consider cracked section properties in analysis.

As per new IS 1893-2016 Equivalent static analysis shall be applicable for regular buildings with height < 15m in seismic Zone II. i.e. Dynamic analysis is compulsory for almost all buildings in all zones.

The clause of old code regarding increasing the stresses by 33.0% when EQ loads are acting, is removed. Thus designer is indirectly forced to use the limit state method.

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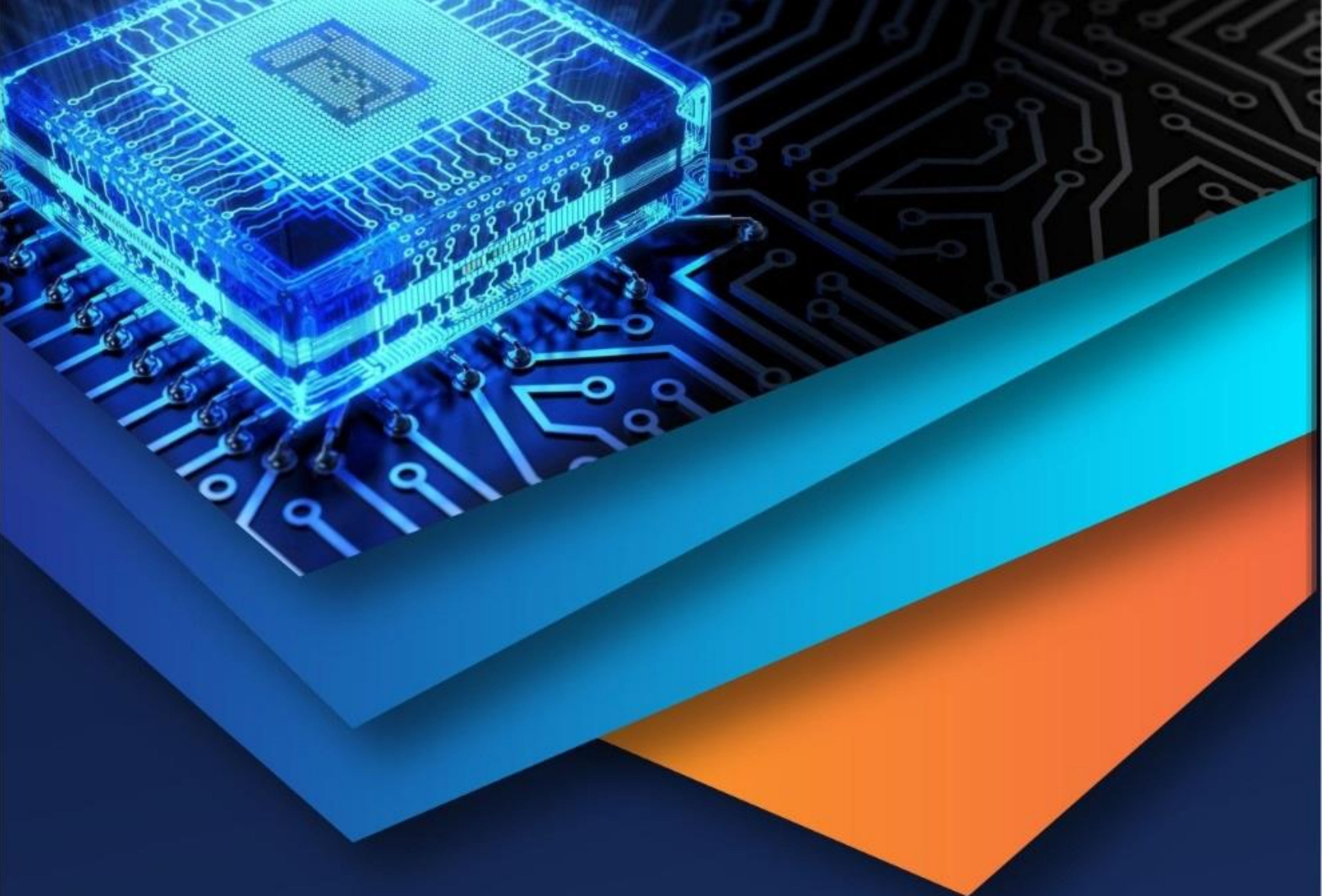

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