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Evaluating the Effect of Local Slenderness on the Response of Silo Supporting Steel Structure

Aiswarya Lekshmi GS[1], Chaithra S[2]
[1]PG Scholar, Civil Engineering Department, SNIT Adoor, India
[2]Assistant Professor, Civil Engineering Department, SNIT Adoor, India

Abstract: Silos are commonly used for bulk storage of grain, coal, cement, carbon black, food products etc. Here in this project evaluates the effect of local slenderness on silo supporting steel structure. The strength of compression members made of steel sections depends on their slenderness ratio. Higher strengths can be obtained by reducing the slenderness ratio. Local buckling has the effect of reducing the load carrying capacity of columns and beams. Therefore, it is desirable to avoid local buckling before yielding of the member. For finding out the local slenderness, a silo supporting steel structure is modelled, analysed and designed using ETABS. Wind loads and earthquake loads as per Indian Standard codes are applied on the structure in order to find out the effect of lateral loads on slenderness limit. Modal analysis is done to get the required number of mode shapes. Response spectrum analysis is done to determine the dynamic characteristics of the structure.
Keywords: Silos, Slenderness ratio, Local buckling, ETABS, Steel Structure

I. INTRODUCTION

Silo is a structure for storing bulk materials. Silos are used in agriculture to store grain or fermented feed known as silage. Silos are commonly used for bulk storage of grain, coal, cement, carbon black, woodchips, food products and sawdust. Three types of silos are in widespread use today: tower silos, bunker silos and bag silos. Concrete silos, steel silos, bag silos are the types of grain storage silos. Steel structure is a structure which is made from the organized combination of custom-designed structural steel members to meet architecture and engineering requirements of users. Slenderness is the ratio of the member‘s unsupported length to its least radius of gyration. Slenderness is a measure of tendency of a member to buckle. In structural engineering, slenderness is used to calculate the propensity of a column to buckle. The effective length is calculated from the actual length of the member considering the rotational and relative translational boundary conditions at the ends. It assesses the ability of the reinforced concrete column to resist buckling pressure. If the slenderness ratio of a column is high, it will collapse under a smaller compression load in contrast to a short column with the same cross sectional dimensions. So, the slenderness effect should be taken into consideration during the design process. Structural members under significant compressive forces may fail due to overall buckling or local buckling depending upon the positioning of the load, the asymmetry of the built-up section, imperfections and the un-braced length of the member. The strength of compression members made of steel sections depends on their slenderness ratio. Local buckling has the effect of reducing the load carrying capacity of columns and beams due to the reduction in stiffness and strength of the locally buckled elements. Consequently, local buckling becomes a limit state for the strength of steel shapes subjected to compressive stress. Therefore, it is desirable to avoid local buckling before yielding of the member. Local buckling can be prevented by controlling the width-thickness ratio.

II. MODELLING

A. Modelling of Supporting Steel Structure

Modelling of the supporting steel structure is done in ETABS. Steel sections made of mild steel (Fe250). For main members I section is selected. For secondary members channel sections are used. For main members I section is selected, this shape makes excellent for unidirectional bending parallel to the web. The horizontal flanges resist the bending movement, while the web resists shear stress. It comes in a variety of weights, section depths, flange widths, web thickness, and other specifications for different purposes. I beams have a variety of important uses in the structural steel construction industry. They are often used as critical support trusses or the main framework in buildings. The immense power of I beams reduces the need to include numerous support structure, saving time and money as well as making the structure more stable. For secondary members channel section is selected, a channel section is defined as the cross-section taken perpendicular to the main flow direction. Channels or C-beams are often used where the flat, back side of the web can be mounted to another flat surface for maximum contact area. For braces angle sections are selected, steel angle are the most basic type of roll-formed steel. They are formed by bending a single angle in a piece of steel.

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Angle steel is L‘ shaped; the most common type of steel angles are at a 90 degree angle. The legs of the L‘ can be equal or unequal in length. Angle sections are widely used for roof truss constructions and for filler joist floors. For slabs chequer plates are used. Chequer plate involves heating a slab of steel above its recrystallization temperature and then bringing it through a series of smooth rollers to desired thickness.

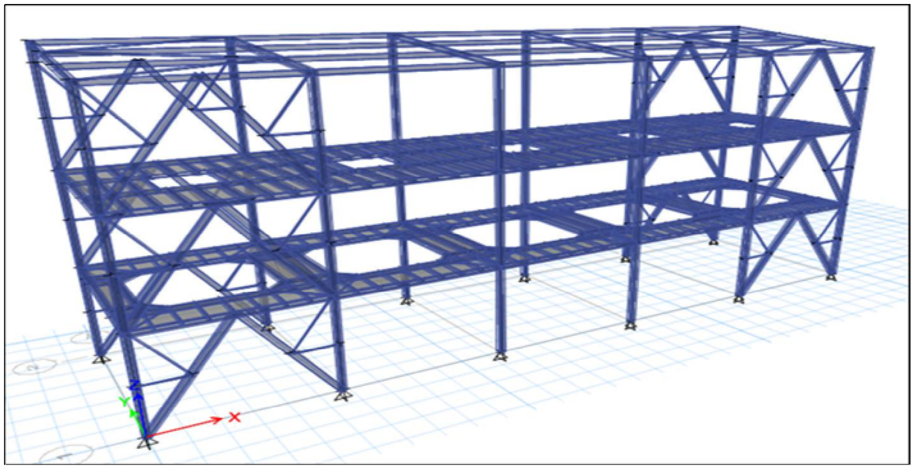
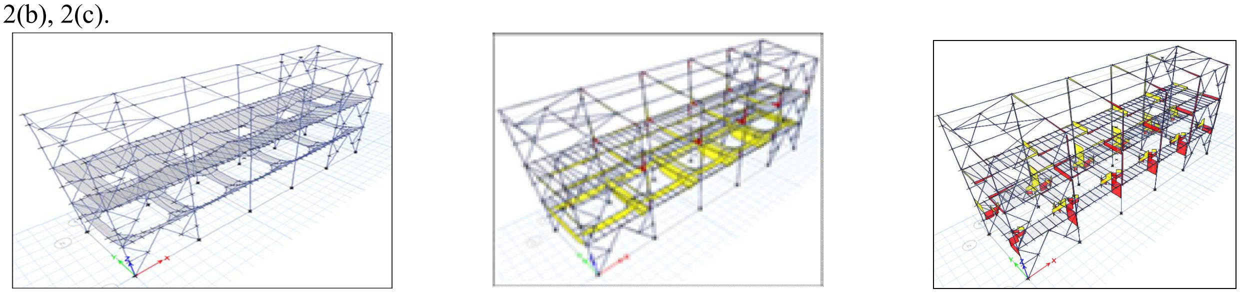


Fig. 1 3-d model of the supporting steel structure

As per IS 875 part 1 for Purlins and Roofing’s dead load is 0.2 $KN/m^{2.}$ And for silos is 50 KN/m. Beam live loads (is 875 part 2) for roofing’s and silos is 0.75 KN/m^2 and 75 KN/m. Slab live loads (IS 875 part 2) is 5 KN/m^2.
Static equivalent analysis is used in regular structure with limited height. Deflection diagram as per static equivalent analysis result is shown in figure 2(a). Shear and bending moment diagrams are analytical tools used in conjunction with structural analysis to help perform structural design by determining the values of shear force and bending moment at a given point of a structural element such as a beam. These diagrams can be used to easily determine the type, size and material of a member in a structure and is as shown in figure 2(b), 2(c).



(a) (b) (c)

Fig. 2 (a) Defection diagram, (b) Bending moment diagram, (c) Shear force diagram

B. Column Fixity

Fixity in structures affects the failure modes and behaviour of structure under various loading condition. Fixity simply means that rotation is restrained / prevented. This is in contrast to a ―hinged‖ connection where rotation is possible. Fixity means how much rotation is restrained at support. When full rotation is restrained, it is called fixed connection. There are several cases where fixity varies. From RCC design point of view, fixity helps for economic design. The degree of fixity of a column base is the ratio of the stiffness of the base to the sum of the base and column stiffness. Early days (when calculation is done manually), percentage of steel of any beam and column are calculated by taking simply supported structure. And for that reason high percentage of steel comes in span, because as you now the bending moment value is more in span and zero in support. The fixity degree of a column end, in a specific direction, depends on the relative stiffness between the column and its framing beams. Here Translation is restrained in all direction. Rotation is restrained in X direction since the columns are oriented in Y direction. Web of the column is very thin so no moment capacity in X direction. Changing the fixity judicially we can calculate the support moment(which is more than span moment in fixed beam) and value of span moment decreases. So less percentage of steel is required in span and also support can take more moment. It‘s same for column.

C. Semi Rigid Diaphragms

In structural engineering, a diaphragm is a structural element that transmits lateral loads to the vertical resisting elements of a structure (such as shear walls or frames). Diaphragms are typically horizontal, but can be sloped such as in a gable roof on a wood structure or concrete ramp in a parking garage. Unless RCC slabs, Chequered plates are flexible. Here semi-rigid diaphragms are assigned instead of flexible diaphragms. For flexible diaphragms, the mid point displacement is higher and it doesn't impart rigidity. Semi-rigid diaphragm falls somewhere between the other two. A semi-rigid diaphragm has some diaphragm stiffness, and the diaphragm is able to translate, rotate, and deform. This deformation influences how the loads get distributed to the frames depending on their relative stiffness and the stiffness of the diaphragm. This is the most complex of all the analyses due to the many degrees of freedom and complexity of the interaction of the elements. Allen cautioned against confusing the use of the terms flexible and semi-rigid.

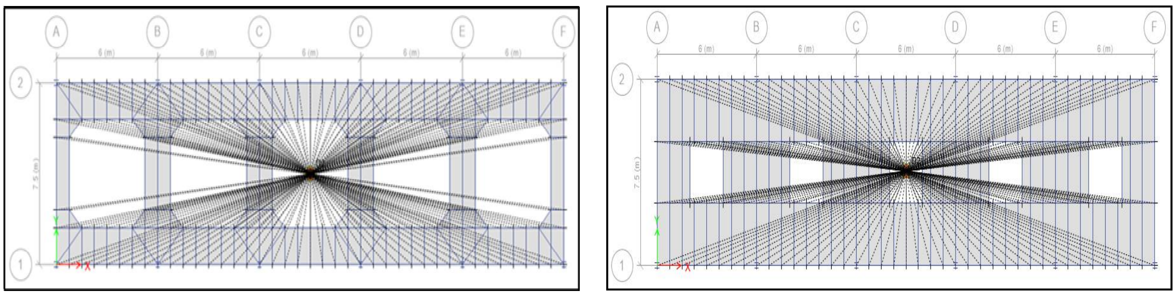


Fig 3. Diaphragms at first and second floors

D. Modal Analysis and Response Spectrum Analysis

Modal analysis is a powerful tool to identify the dynamic characteristics of structures. Every structure vibrates with high amplitude of vibration at its resonant frequency. It is imperative to know the modal parameters — resonant frequency, mode shape and damping characteristics of the structure at its varying operating conditions for improving its strength and reliability at the design stage. Modal analysis is based upon the fact that the vibration response of a linear time-invariant dynamic system can be expressed as the linear combination of a set of simple harmonic motions called the natural modes of vibration. Modal analysis embraces both theoretical and experimental techniques. 12 number of modes are taken for analysis (At mode 12, mass participation ratio is approximately 100%). Mass participation ratio specifies the percentage of how much the structural mass of the model is participating for a given direction and mode. The results of modal analysis are the frequencies at which the amplitude increases to infinity.

Response spectrum analysis is a method to estimate the structural response to short, nondeterministic, transient dynamic events. Examples of such events are earthquakes and shocks. Since the exact time history of the load is not known, it is difficult to perform a time- dependent analysis. The response spectrum method is based on a special type of mode superposition. When applying zone factor and soil type ETABS generate a curve which is called response spectrum curve with acceleration on the Y axis and time period on the X axis. At different time how much acceleration is generated. This curve gives the expected earthquake in zone 3.

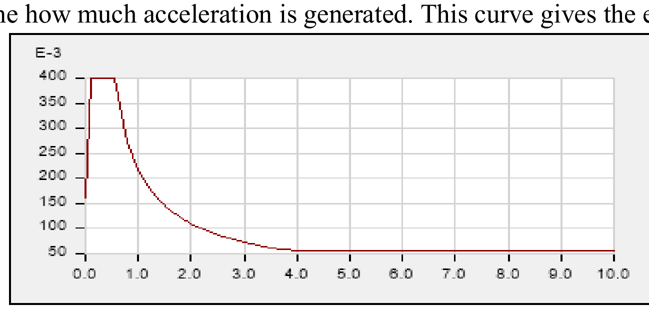


Fig 4. Response Spectrum Curve

Response spectrum can be interpreted as the locus of maximum response of a SDOF system for given damping ratio. Response spectra thus helps in obtaining the peak structural responses under linear range, which can be used for obtaining lateral forces developed in structure due to earthquake thus facilitates in earthquake-resistant design of structures. Usually response of a SDOF system is determined by time domain or frequency domain analysis, and for a given time period of system, maximum response is picked. This process is continued for all range of possible time periods of SDOF system.

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III.PUSH OVER ANALYSIS

A. Pushover Curve for Flange Slenderness

Pushover analysis is a static procedure that uses a simplified nonlinear technique to estimate seismic structural deformations. Structures redesign themselves during earthquakes. As individual components of a structure yield or fail, the dynamic forces on the building are shifted to other components. A pushover analysis simulates this phenomenon by applying loads until the weak link in the structure is found and then revising the model to incorporate the changes in the structure caused by the weak link. A second iteration indicates how the loads are redistributed. The structure is ―pushed‖ again until the second weak link is discovered. This process continues until a yield pattern for the whole structure under seismic loading is identified. Pushover analysis is commonly used to evaluate the seismic capacity of existing structures and appears in several recent guidelines for retrofit seismic design. It can also be useful for performance-based design of new buildings that rely on ductility or redundancies to resist earthquake forces. It is a non-linear analysis to assess the structural capacity under static horizontal loads growing until the collapse of the structure. The results of the pushover analyses are some capacity curves identified by the variation of the base shear in function of the displacement of a control point on the structure.

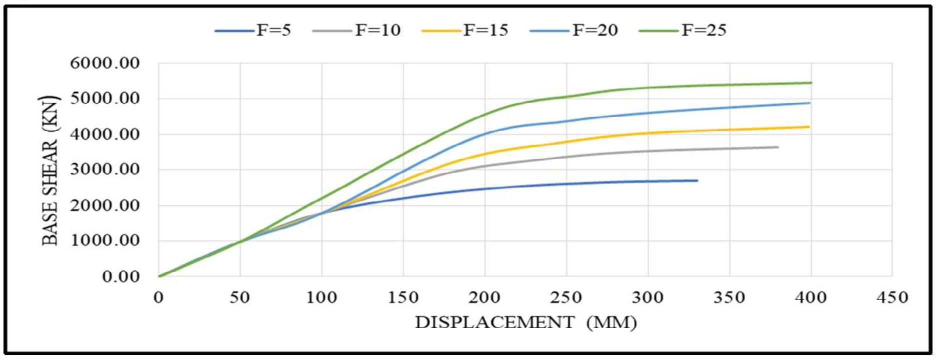

Fig 5. Push over curve for flange slenderness with base shear vs. displacement

TABLE I
ESTIMATION OF OVER STRENGTH FACTOR FOR FLANGE SLENDERNESS

	Design Base shear (kN)	**Maximum Base Shear (kN)**	**Over strength Factor (Rμ)**
F-5	2028.52	5446.58	2.69
F-10	2089.24	4888.84	2.34
F-15	2176.92	4214.52	1.94
F-20	2423.75	3633.21	1.50
F-25	1882.89	2700.07	1.43

TABLE II
ESTIMATION OF DUCTILITY FACTOR FOR FLANGE SLENDERNESS

	Yield Displacement (mm)	**Maximum Displacement (mm)**	**Ductility Factor (Rμ)**
F-5	212.9	400.0	1.9
F-10	188.4	399.0	2.1
F-15	161.3	398.6	2.5
F-20	125.8	379.6	3.0
F-25	106.7	330.0	3.1

Displacement ductility ratio was used to determine ductility factor. Ductility reduction factor, sometimes called the strength reduction factor. Over strength helps structures to remain safe during powerful tremors and reduces elastic strength demand. This feature was determined through the force reduction factor.

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Over strength factor is obtained by dividing maximum base shear and design base shear. Also ductility factor is estimated by dividing maximum displacement and yield displacement. Pushover is a static-nonlinear analysis method where a structure is subjected to gravity loading and a monotonic displacement-controlled lateral load pattern which continuously increases through elastic and inelastic behaviour until an ultimate condition is reached.

B. Pushover Curve for web Slenderness

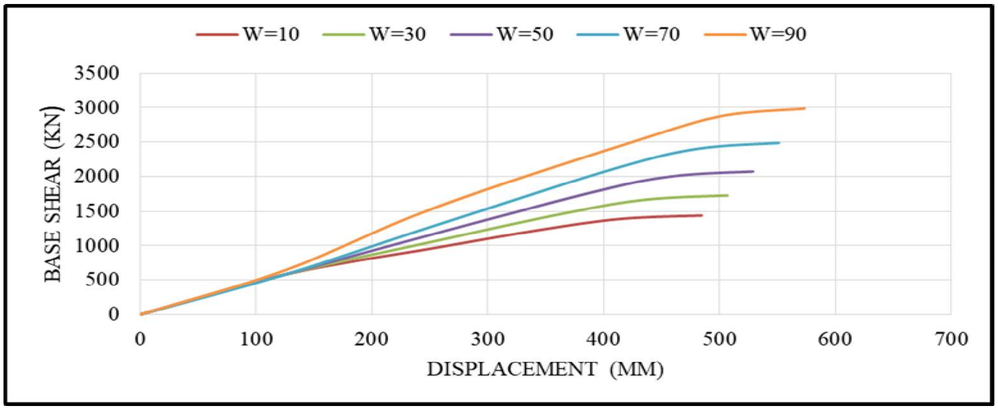

Fig 6. Push over curve for flange slenderness with base shear vs. displacement

TABLE III
ESTIMATION OF OVER STRENGTH FACTOR FOR WEB SLENDERNESS

	Design Base Shear (kN)	Maximum Base Shear (kN)	Over strength factor (Rμ)
W-10	1002.17	2986.48	2.98
W-30	972.16	2488.73	2.56
W-50	978.27	2073.94	2.12
W-70	939.29	1728.29	1.84
W-90	911.54	1440.24	1.58

TABLE IV
ESTIMATION OF DUCTILITY FACTOR FOR FLANGE SLENDERNESS

	Yield Displacement (mm	Maximum Displacement (mm)	Ductility Factor (Rμ)
W-10	322.0	573.1	1.8
W-30	279.6	550.9	2.0
W-50	226.1	528.7	2.3
W-70	194.9	506.6	2.6
W-90	176.0	484.4	2.8

C. Estimation of Response Modification Factor

Response modification factor (R) has a main function in the seismic design of new construction materials and is a seismic design parameter in equivalent static analysis. It determines the nonlinear performance of building structures during strong earthquakes. R is based on experimental test and engineering judgment and no uniform technique exists to determine such a value for different conditions. The development in the reliability of modern earthquake-resistant buildings requires systematic assessment of building response characteristics that mainly affect the rates allocated to R, which is formulated based on three aspects, namely, strength, ductility, and redundancy factors. Response modification is affected by the height of structures. Response modification factor (R) is a key parameter in seismic construction design. Equivalent statistical analysis, which is frequently used to estimate the seismic response of structures, can be implemented by determining R. In particular, R indicates the ability of a structure to dissipate energy through inelastic behaviour, as demonstrated in recent building codes.

R is the main factor to be considered in the seismic design process but is still subject to debate. R factor is the ratio of strength required to maintain structural elasticity in force-based seismic design procedures. This factor is important in estimating the seismic force of a structural building. R is expressed as the products of three factors: $R = R_s\ R\mu R_R$ Where R_S is the period-dependent strength factor, $R\mu$ is the period-dependent ductility factor, and R_R is the redundancy factor. According to applied technology council (ATC) 19, structural redundancy factor is taken as 1.15. R is an important parameter in seismic construction design. Equivalent statistical analysis is frequently applied in estimating structural seismic response.

TABLE V
RESPONSE MODIFICATION FACTOR

Slenderness Ratio	Response Modification Factor (R)
F-5	5.8
F-10	5.7
F-15	5.5
F-20	5.2
F-25	5.1
W-10	6.1
W-30	5.8
W-50	5.7
W-70	5.5
W-90	5.0

IV. CONCLUSIONS

For silo supporting steel structure, the effect of slenderness ratio is an important factor. I-sections are provided as main structural member because the shape of I beams makes them excellent for unidirectional bending parallel to the web. The horizontal flanges of the I beam resist the bending movement, while the web resists the shear stress. Angle sections are provided as bracings due to its feasibility to accommodate angular connections. This section is highly used for point load applications to resist shear, tension and compression. This section is a perfect fit to be used as a connection member. Most common usages of this section are connection between I-shapes, bracing in truss members etc. Channel sections are used as secondary members because it is best to be used in uniformly distributed load applications with small moment or bending. This section is highly efficient to be used as a secondary structural member where the loading is transferred onto other primary structural members. Most common usages of C Shape or Channels as secondary structural member are transverse joists supporting floor. The maximum capacity is for F-5, i.e. when slenderness ratio increases the capacity of the structure reduces. When slenderness increases from F-5 to F-25, the capacity of the structure reduced to 47%. When slenderness ratio increases from F-5 to F-25, the percentage of ductility also reduces. Also maximum capacity is for W-10 and ductility increases with increase in web slenderness. The R factor for heavy load bearing steel structure as per Indian codal provision is obtained as 5 to 6.1

V. ACKNOWLEDGMENT

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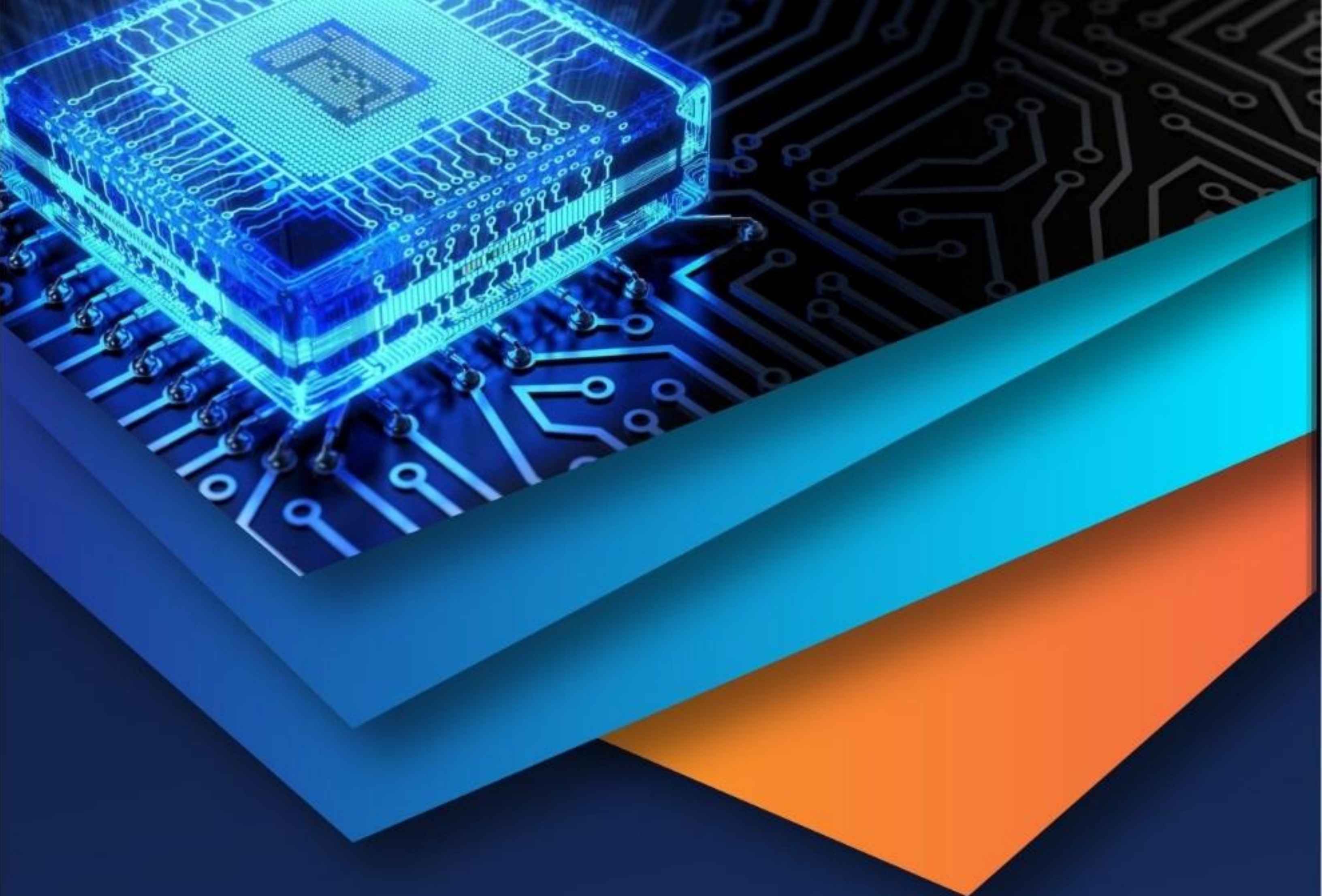

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