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Seismic Protection of Structures Using Vibration Controlling Devices: A Review

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Abstract: Past earthquake record depicts there is a significant increase in human loss, structural as well as economic losses. The current seismic design philosophy for building and infrastructures should be changed from lifesaving to business continuity for modern and resilient societies. Structure should be designed to be quickly restored to full operation with minimal disruption and low cost following a large earthquake. Analysis of this earthquakes show that a large number of existing structure need to be upgrade for their seismic action with new seismic design. This paper attempts the review of different aspects related to seismic design with various vibration controlling devices. Designing philosophy and case studies are discussed in this literature. Summarizing, it gives the total idea of the different literature review and recent research works summary.

I. INTRODUCTION

Earthquakes have remained a persistent threat to human lives and infrastructure, claiming countless lives and causing extensive damage to buildings and structures. Despite significant progress in seismic engineering, current seismic design approaches have shown limitations in effectively preventing building collapse under the impact of large earthquakes. Consequently, there is an urgent need to develop a new seismic design paradigm that not only mitigates casualties but also ensures rapid restoration to full operation with minimal disruption and cost following a seismic event. The devastation caused by earthquakes is a harsh reminder of the vulnerabilities in existing infrastructure, calling for immediate action to improve seismic design methodologies. Historically, seismic events have shown that even structurally robust buildings can fail under the extreme dynamic forces unleashed during earthquakes, leading to significant loss of life and property. Such catastrophic outcomes necessitate a comprehensive reevaluation of the seismic design process to develop innovative approaches that withstand the immense seismic stress. Current seismic design primarily focuses on limiting structural damage under smaller magnitude earthquakes, often leaving buildings ill-equipped to handle the intensified forces during a large seismic event. The challenge lies in enhancing the performance of structures to withstand strong ground motions while minimizing repair and recovery time, thereby ensuring quick resumption of services and reduced economic consequences. In this research paper, we aim that there is need for a new seismic design approach that prioritizes human safety and infrastructure resilience. By critically analyzing existing limitations in seismic design and exploring innovative solutions, we strive to present a transformative approach that integrates cutting-edge technologies and materials. The proposed design will be geared towards enabling structures to withstand large earthquake impacts, preventing collapse, and facilitating rapid restoration to full operational functionality. The research will involve a comprehensive review of literature, including case studies of past earthquakes and their aftermath, to identify the shortcomings in current seismic design strategies. Furthermore, numerical simulations will be conducted to assess the feasibility and efficacy of the proposed seismic design approach.

II. LITERATURE REVIEW

Seismic design plays a critical role in protecting lives and infrastructure during earthquakes. However, despite advancements in seismic engineering, limitations in current seismic design continue to result in significant loss of life. This literature review aims to examine existing research on the correlation between earthquake casualties and the identified limitations in current seismic design methodologies.

1) Putul Haldar et.al [2009] In the present study, the adequacy of this philosophy and relative importance of various code provisions were examined by estimating the expected performance of a set of code-designed buildings. The FEMA-440 and HAZUS methodologies were used for estimating the seismic performance and vulnerability. Author concluded that the Special Moment-Resisting Frame design under the current design provisions of Indian standards has a higher probability of damage, as compared with the Ordinary Moment-Resisting Frame design, because of the higher allowable ultimate drift limit.

2) Behroz Eldar et.al [2022] This study focuses on analyzing the seismic behaviour of G + 10 irregular buildings considering floating columns and without floating columns to compare with a regular building. The building models were analysed in ETABS V19 software, then analytical findings are explained in terms of (maximum storey drift, maximum storey displacement, and torsional irregularity). From the study it is found that providing floating columns in irregular buildings increase storey drift and storey displacement significantly and the torsion increases in buildings when the floating columns are not provided symmetrically.
3) M.A. Wasey et.al [2022] In present study vertically irregular structures are analysed using non-linear time history analysis (NLTHA). Five, ten and fifteen storey buildings with each type of vertical irregularities and a regular building are modelled and analysed. All the building models are tested with seismic control systems such as base isolators, fluid viscous dampers and shearwalls to find out the optimum seismic control system for any type of vertical irregularities.Author concluded that buildings with base isolators and dampers were more efficient in reducing the effect of an earthquake and displacements of the buildings were efficiently reduced with the help of a shear wall in the structure.
4) Iftekhar Ahmed [2023] This paper demonstrates the seismic vulnerability of Turkey and Syria and the importance of earthquake-resistant building design in reducing casualties and property damage. While cost remains a significant constraint in adopting earthquake-resistant measures, it is crucial to prioritize safety without disregarding economic realities. By implementing innovative and cost-effective solutions and supporting government policies, it is possible to strike a balance between cost and safety, ultimately creating a more resilient built environment that protects lives and mitigates the impact of earthquakes in Turkey and Syria
5) Vijay Namdev Khose et.al [2012] The author identifies various limitations in the Indian seismic design and detailing codes, particularly IS 1893 and IS 13920, when compared to the current state-of-the-art practices. A comparative analysis with ASCE 7 has been conducted, highlighting discrepancies in site classification, design response spectrum, modeling guidelines, drift control criteria, and ductile detailing.The site classification in the Indian codes relies on a single parameter, the SPT value, whereas a more direct characterization using shear wave velocity could yield more accurate results. The broad classification of Type I soil in IS 1893 compared to ASCE 7's Classes A to D may lead to inadequate design considerations.Further added that the Indian codes specify a design spectrum up to a 4-second period only.
6) Jiro Takagi et.al [2019]studied that the existing seismic design approach has been developed to allow for ductility of building structures to resist large earthquakes economically (goes under plastic deformation) and to remain elastic in small or moderate earthquakes. This design approach has been effective in terms of protecting people and not for structures. They noted that there is a large gap between structural safety levels that specialists consider acceptable and the expectations of lay people for buildings against large earthquakes. Author concluded that the goals of a modern seismic design philosophy should be changed from solely life-safety to also ensuring post-earthquake use and operation of structure.
7) Dhiraj Narayan Sahoo et.al. [2019] consider G+10 and G+15 structures with isolator and without isolator for zone II. In present study base isolation study along with seismic analysis is done in equivalent static method using E-TABS software. Author concluded that a)time period of structure increases approximately 2 times after providing the base isolator to fixed base structure,b) lateral earthquake Load, storey shear, column forces and moment are reduce c) maximum storey displacement in base isolated structure increases, maximum storey stiffness of structure decreases in base isolated structure and storey drift in base isolated structure increases
8) Farzad Shafiei Dizaji et.al. [2020] proposes and evaluates a superelastic memory alloy re-centering damper system for improving the reaction of steel frame buildings that have been exposed to several levels of seismic threat. Experimental experiments are conducted to describe the mechanical reaction of the SMARD device's subcomponents, namely the friction spring compound and high-performance SMA bars. Numerical analyses are used to determine the performance and efficacy of the suggested damper in minimizing the reaction of steel frame buildings to DBE and MCE level seismic loads. The results indicate that by installing SMARDs, the interstory residual drifts of buildings exposed to both DBE and MCE level earthquakes substantially decreases.
9) P.B.Lamb et.al [2012] considered a building with the help of different mathematical models and considered various methods for improving the seismic performance of the building with soft first storey. They have also considered analytical models represent all existing components that influence the mass, strength, stiffness and deformability of structure. The equivalent static and multimodal dynamic analysis has been carried out on the entire mathematical 3D model using the software SAP2000 and the comparisons of these models are presented. Finally, the performance of all the building models has observed in high seismic zone V.

10) Diana Samoila [2013]. The paper presented three one- bay, one- story frames, for which the diagonal strut width and the strength to different failure types are determined. It shows that effects of the masonry infill panels and seismic behavior of the frames structures was rendered by the capacity curves obtained from the pushover analysis carried out on a series of concrete frames with different number of stories.

11) Niruba et. al. [2014] investigated that infills modify the behavior of framed structures under lateral loads. This paper also shows that structural effect of brick infill is generally not considered in the design of columns as well as other structural components of RC frame structure also the brick walls shows significant in-plane stiffness contributing to the stiffness of the frame against lateral load. They concluded that the lateral deflection is reduced significantly in the infilled frame compared to the deflection of the frame without infill. A number of non-linear static (pushover) analyses were performed on proper structural models of the building, considering both bare framed structure and the infilled one, in order to appraise the influence of infill walls on the failure mechanisms.

12) Vojko Kilar and Peter Fajfar [1996] investigated that the structure consists of planar macro elements. In this paper for each planar macro element, a simple bilinear or multi linear base shear - top displacement relationship is assumed. By a step-by-step analysis of approximate relationship between the global base shear and top displacement is computed. During the analysis, the development of plastic hinges throughout the building has monitored. The method has been implemented into a prototype computer program. The method has been applied for the analysis of a symmetric and an asymmetric variant of a seven-story reinforced concrete frame-wall building.

13) Ravi Kumar et.al. [2014] had study on RC framed structures subjected to earthquake excitation and the pushover (non-linear static) analysis is compared to time history (nonlinear dynamic) analysis. He explained that the country lie in earthquake prone area and many of the destructive earthquakes occurred in the history so far resulting in high number of casualties due to collapse of buildings and dwellings. Hence, the paper proposed the methodology in a probabilistic manner to assess the seismic performance of Reinforced Concrete structure by considering uncertainties based on pushover analysis due to non-existence of code of practices in Indian context. They suggested that the methodology may use as guidelines for seismic risk evaluation of building structure.

14) Shailesh Ghildiyal [2016] investigated that in the world of concrete, rapidly constructed multi-storey building for commercial and residential purposes, but providing a proper parking space is major concern especially in metropolitan cities. They also explained that the trend has been utilize the basement of the building for parking purpose for this engineer provides the solution they make the basement of the building open, no infill masonry walls is provided in the basement, they did not consider the stiffness and strength of the masonry wall. He also stated that conservative design is not always right and when the earthquake occurs the column of the ground storey collapses down and the upper storey inclined towards the ground because the upper stories are more stiffer than the lower storey. He further concluded that in the structural design the value suggested by IS CODE 1893:2002 is not realistic. For the validation of the multiplication factor he prepared a separate model for infill wall and walls without any infill i.e. bare frame, and did the linear and non-linear analysis and compared their results. In Linear analysis he showed stiffness is constant in both open ground storey and bare frame while nonlinear shows the multiplication factor can be reduced.

15) J. Prakashvel and C. UmaRani[2002] investigated open ground storey buildings that have consistently shown poor performance during past earthquakes across the world. For example, during 1999 Turkey, 1999 Taiwan and 2003 Algeria earthquakes, a significant number of them have collapsed. They told that the presence of walls in upper storeys makes them much stiffer than the open ground storey, Still Multi storey reinforced concrete buildings are continuing to be built in India which has open ground storeys. These buildings are not designed as per the earthquake resistant design and imperative to know the behavior of soft storey building to the seismic load for designing various retrofit strategies. Based on the above an attempt is made in this paper to assess the seismic performance of the soft storey reinforced concrete building by shake table test.

16) Davis et. al. (2008) in his paper, open ground storey (OGS) framed buildings with soft-storey at ground storey were analysed by ignoring the infill wall stiffness (linear ‘bare frame’ analysis). They presented the study of typical variations in MF, by modelling infill walls using Smith and Carter (1961) for linear analysis and Crisafulli (1999) for nonlinear analysis, accounting for the variability of compressive strength and modulus of elasticity of infill walls. In this paper the Response Spectrum Analysis (RSA) and Nonlinear Dynamic Analysis (NDA) are carried out on a four storeyed and a seven storeyed building, for various infill wall arrangements. The results from RSA (linear analysis) indicated MF values in the range 1.04-1.13, for the four storeyed building and 1.11-2.39 for the seven storey building. However, the results of NDA (nonlinear analysis) including hysteresis effects in frame and infill, suggested that there is no need for applying MF to low-rise building frames.They observed that in the case of the seven-storeyed building frame, values of MF in the range 1.14 to 1.29 were observed, applicable to the base shear. However, this is not applicable to column bending moments, where MF values were found to be less than unity.

17) Aditya Deshmukh (2014) considered the RC framed building (G+10) with open ground storey located in Seismic Zone-II, III, IV and V. The main objective of his study is to strengthen the performance of Open ground storey (OGS) buildings according to various cases such as: (a) bare frame building (b)building with uniform infill in all storey (c) building with OGS (d) OGS with stiffer column (e) OGS with corner shear wall (f) OGS with corner cross bracing (g) OGS with composite columns. The separate models were generated using ETABS. Infill stiffness was modeled using an equivalent diagonal strut approach. Parametric studies on displacement, storey drift, shear force, bending moment and base shear have been carried out using equivalent static analysis to investigate the influence of this parameter on the behavior of building with OGS.
18) P.Sudheer Kumar et.al [2018] studied that presence of infill walls in the frames alters the behaviour of the building under lateral loads. Hence, the modeling of infill walls in the seismic analysis of framed buildings is imperative. They have also mentioned in the paper that Indian Standard 1893: 2002 allows analysis of open ground storey buildings without considering infill stiffness but with a multiplication factor 2.5 in compensation for the stiffness discontinuity. As per the code, the columns and beams of the open ground storey are to be designed for 2.5 times the storey shears and moments calculated under seismic loads of bare frames (i.e., without considering the infill stiffness). However, they experienced that the multiplication factor of 2.5 is not realistic for low rise buildings.
19) Amol Karemore and Shrinivas Rayadu [2015] investigated that in urban ground storey of frame building is generally kept open (i.e. soft storey) for parking or reception lobbies alnd upper storey have brick infill panels which provide certain stiffness to upper storey of structure, this increases forces, displacement, storey drift and ductility demand in ground storey.They have also mention that Indian Standard IS 1893:2002 allows analysis of OGS buildings without considering infill stiffness but in compensation of stiffness discontinuity, magnification factor 2.5 is to multiplied to shear force and bending moments of beams and column calculated under seismic loads of bare frame. (i.e. ignoring infill stiffness). However, they experienced that magnification factor 2.5 is not realistic for OGS building. The objective of paper is to check applicability of magnification factor 2.5 for OGS building.
20) Nesiya Yoosaf and Remya Raju [2015] investigated that the contribution of stiffness of infill walls present in upper storeys of open ground storey framed buildings are ignored in the structural modelling. In this study, they evaluated static and dynamic analysis of open ground storey RC frame with different infill materials using ETABS. In this project they used two types of blocks that is clay brick and fly ash brick. Masonry infill walls have been used in reinforced concrete frame structures as interior and exterior partition walls.They concluded that infill substantially alters the behaviour of the building subjected to lateral loads such as wind and earth quake forces and when subjected to a strong lateral load, infill panels tends to interact with bonding frame and may induce a load resistance mechanism that is not accounted for the design. From the studies they also concluded that the fly ash infilled structure having low value of displacement, drift and period of vibration and fly ash is better infill material than brick infill.
21) Sukanya V Raj and Vivek Philip [2017] considered the multi storied structures that extant in urban areas have open ground storey (OGS) as an inevitable feature, essentially to accommodate parking or reception lobbies in the ground storey. They have designed the members of the open ground story 2.5 times the member forces obtained without considering the effects of masonry infill in any story, as per Indian seismic code IS 1893 2002. In this paper the study of Magnification Factor for Regular and Plan irregular open ground storey buildings for different storey heights is carried out. They computed the Magnification Factor by comparison of Response spectrum Analysis of bare frame and infilled frame of different models using ETABS 2015.They concluded that there is no need for applying MF to soft storey beams, as increased demands due to stronger beams would further increase the seismic demands on the columns.
22) Piyush Tiwari and Prof. P. J. Salunke [2015] considered three different models of existing RC framed building with open ground storey located in Seismic Zone V is considered for the study using commercial Etabs Software. They have designed the members of the open ground story 2.5 times the member forces obtained without considering the effects of masonry infill in any story, as per Indian seismic code IS 1893 2002. Infill Stiffness with openings was modeled using a Diagonal Strut approach. Linear and Non-Linear analysis is carried out for these models and results were compared. In this study, virtuous results for frame design as per IS 1893 2002 is seen.
23) Akhilesh Yadav and Dr. A. K. Mishra [2017] In this thesis the objective is to assess the effect of infill wall, check the multiplication factor and effect of support condition of the building. In this analysis, the multiplication factor 2.5 is seen too high for the open ground storey low rise building and the problem of open ground storey low rise building cannot be properly

identified through the elastic analysis as the stiffness of open ground storey building and similar bare frame is same. They conclude that according to the nonlinear analysis of the OGS low rise building fails through the soft storey mechanism at a comparatively low base shear and displacement and the mode of failure is found to be brittle and this analysis shows that the support condition of the building influences the considerable and important parameter for the multiplication factor.

24) J. Yang et.al [2015] This paper proposes a simple approach to integration of the acceleration to acquire a realistic displacement–time series. In this approach, the acceleration data is firstly baseline corrected in the time domain using the least-square curve fitting technique, and then processed in the frequency domain using a windowed filter to further remove the components that cause long-period oscillations in the derived displacement. The feasibility of the proposed approach is assessed using several examples and comparisons are made between the results obtained using the proposed scheme and those using other complicated procedures.

25) H. Yoshioka.et.al (2002) this paper presents the results of an experimental study of a particular adaptable, or smart, base isolation system that employs magneto rheological ~MR! dampers. They constructed and tested the experimental structure, at the Structural Dynamics and Control/Earthquake Engineering Laboratory at the Univ. of Notre Dame. A sponge-type MR damper is installed between the base and the ground to provide controllable damping for the system. The effectiveness of the proposed smart base isolation system is demonstrated for both far-field and near-field earthquake excitations.

26) Saiful et. al. (2011) made effort to establish an innovative simplified design procedure for isolators incorporated in multi-storey building structures. Isolation systems namely lead rubber bearing (LRB) and high damping rubber bearing (HDRB) have been used for their work. Numerical formulation and limiting criteria for design of each element have been engendered. The suitability to incorporate isolation device for seismic control has been sight seen in details. The study reveals simplified design procedures for LRB and HDRB for multi-storey buildings in Bangladesh. The detail design progression has been proposed to be included in Bangladesh National Building Code (BNBC).

27) Pan Wen et al [2006] had presented the design of base isolation structure which involves two steps design method. In the first step, the estimation of isolation layer, and only a few basic data of structure were required. In the second step, detail design along with the step-by-step time history analysis was adopted for determination of superstructure, foundation and base isolation device. Computer software based on above method with user-friendly interface, pre-processor and post-processor was developed for practical engineering design of superstructure and foundation. The study reveals that in first stage design method, base isolation device lengthens the natural period of structure, in which the dynamic characteristic of the structure has been changed to achieve the aim of reducing the earthquake effect on superstructure. After the first step, base isolation device has tentatively selected based on the total horizontal stiffness of isolation layer. In the second step design method for seismic isolation structure is used to calculate earthquake resistant capacity of base isolation structure and optimize arrangement and parameters of base isolation device. It has been concluded that the computation result of two step design method is simple and practical, and its concept is clear and easy for further expansion and application also method is advantageous to enhance design quality and reduce design period.

28) Pradeep Kumar T. V. et al [1996] has shown force-deformation behavior of isolation bearings. In this paper the isolation bearing consists of an isolator which increases the natural period of the structure away from the high-energy periods of the earthquake and a damper to absorb energy in order to reduce the seismic forces. It has been observed that lead–rubber bearings have little strain-rate dependence for a wide frequency range which contains typical earthquake frequencies. The isolation bearings are modeled by a bilinear model based on the three parameters: initial stiffness, lower stiffness, and characteristic strength. It has given new relationship to find out the yield displacement and yield force for an equivalent bilinear isolation bearing system. The graphical representation of the new relationship shown in the paper is useful for bearing design.

29) Oinam et.al. , studied the seismic response of gravity load-designed reinforced concrete (RC) frames with a soft story by equipping metallic dampers as passive energy dissipation device. Experimental investigating tests such as Pseudo-dynamic testing for like of shake table test, and quasistatic cyclic test for to evaluated the collapse resistance of the strengthened specimen were carried out. In addition, a numerical model using computer software and the results of the numerical study matched reasonably well with the experimental findings. This method enhanced the lateral strength, stiffness, energy dissipation, and drift capacity of the non-ductile RC frame with a soft first story. The strengthened frame reached a story drift of 2.3% prior to its complete collapse.

30) Naghshineh et.al, studied the seismic performance of a 14 story moderately ductile concrete frame with and without friction dampers. The seismic performance of the building in both cases had evaluated using nonlinear dynamic analysis. The costs of the building frame with and without friction dampers was evaluated for comparison. Author concluded that, For ductile frame, the moments and shears were reduced by an average of 75%. In elastic model however, these values were reduced by an average of 56%. Formation of the plastic hinges was reduced by almost 45% in the model with friction dampers. An average cost saving of 11.5% the concrete frame due to integration of friction dampers.
31) Wang et.al, examined the feasibility and cost-effectiveness of various retrofit techniques to improve the seismic performance of an existing 35-story steel building. Study carried on, three types of supplemental energy dissipation devices. The results of nonlinear dynamic analyses indicated that the FVD scheme was the most efficient for this structure in achieving the targeted performance goal and provided the most costeffective means of improving the structural behavior.
32) Patil et.al., evaluated structural performance of RC frames with supplemental energy dissipation (SED) devices. A displacement based seismic design method was used for specifying the properties of SED devices. A considerable reduction in seismic response was noted with use of both SED devices
33) Kim et.al., developed a seismic retrofit procedure for estimating the proper amount of steel plate slit dampers required to keep the seismic response of low-rise asymmetric structures within a given target performance level. According to the nonlinear static and dynamic analysis results, the structure with hysteretic dampers installed in accordance with the proposed procedure showed satisfactory inter-story drifts in both the stiff and the flexible edges when they were subjected to the design level seismic load.
34) Williams et.al., gave methodology that could be used to make informed decisions on whether or not to retrofit structures for seismic events based on the expected economic benefit due to retrofitting. A parametric analysis was conducted to determine how certain parameters affect the feasibility of a seismic retrofit. Study concluded that, The retrofit of gravity-load designed buildings may not be financially viable.
35) Valente, carried out numerical investigations on R/C frames with energy dissipative bracing system. The proposed system was composed of ductile shear panel and concentric X-braces, and they used to provide both ductility and stiffness to existing structures. An energy based approach was used for design of brace and shear panel. Results of nonlinear dynamic analyses showed that the proposed bracing system could protect the primary structural elements of the frame preventing them from damage under severe seismic actions.
36) Madan et.al., studied plastic analysis procedure based on the energy balance concept for performance based seismic retrofit of multi-story multi-bay masonry infilled reinforced concrete (R/C) frames with a soft ground story using passive energy dissipation (PED) devices. performance based design (PBD) formulations were developed for PED devices that can use for seismic retrofit of existing frame structure. Non-linear dynamic analyses of the retrofitted masonry infilled R/C frames was performed to investigate the efficacy and accuracy of the proposed energy based plastic analysis procedure in achieving the target performance level under design level earthquakes. Concluded that, PBD a formulation was controlled well within the target drifts under near-field as well far-field earthquakes.
37) Islam et.al.,[2001] discussed the requirement of seismic retrofit of a building using passive energy-dissipation devices. The design criteria for seismic retrofit was adopted primarily from NEHRP and FEMA codes.
38) Chaudhari et.al.,[2015] gave a comprehensive based design methodology for performance based design of the frame buildings with metallic and friction dampers. Non-iterative step by step procedure had given for to achieve target performance level. Numerical investigation carried out on ten storey building for validation of proposed methodology and concluded that seismic response controlled effectively.
39) Lin et.al.,[2014] researched on the dynamic behavior of a 12-storey reinforced concrete framed structure with recently developed lead-shear dampers such as the Penguin Vibration Dampers under earthquake and wind loadings. Based on the simplified nonlinear static method and the optimal damping ratio of the dampers, a displacement based design procedure has been established to determine the damper yield strengths in the storeys for preliminary seismic design and gave satisfactory distribution of damper yield strengths in the storeys to reduce inter-storey drift.

III. LITERATURE REVIEW CONCLUSION

The literature review highlights significant limitations in current seismic design, leading to vulnerabilities in structures during earthquakes. The cost barrier hinders the widespread adoption of earthquake-resistant building measures, leaving communities at risk of severe damage and casualties.

The current seismic design philosophy should evolve from merely focusing on life-saving measures to encompassing business continuity for modern and resilient societies. Emphasizing the quick restoration of structures to full operation with minimal disruption and cost after a large earthquake will not only safeguard lives but also enhance community resilience and minimize the economic impact of seismic events. Innovative method is required to address these shortcomings and find effective solutions to ensure the safety and resilience of buildings in earthquake-prone regions. By adopting these principles, we can create a safer and more sustainable built environment that effectively addresses the challenges posed by earthquakes and ensures the well-being of future generations. .

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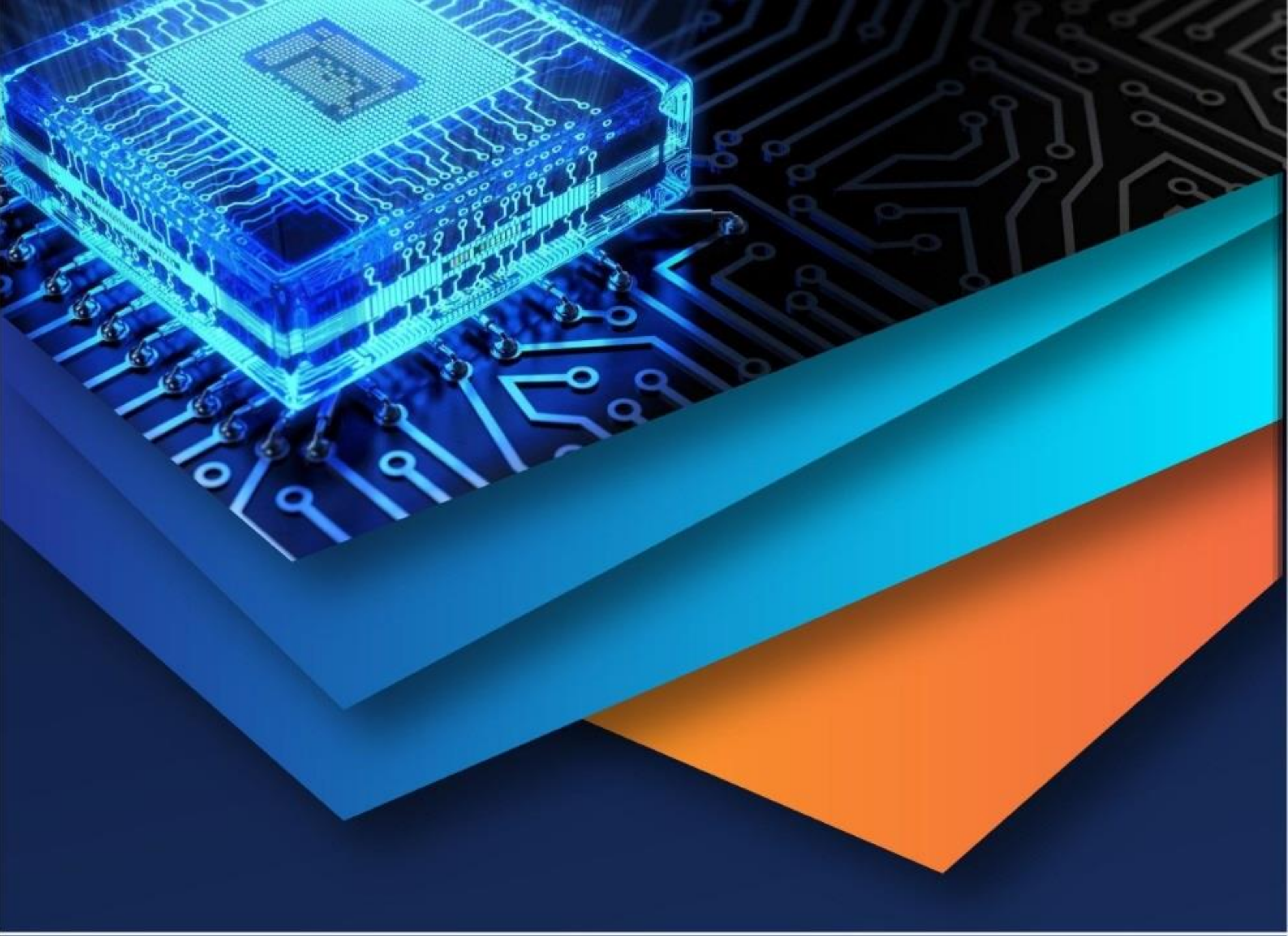

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