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Effect of Irregularity on the Response Reduction Factor for RC Building

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Abstract: ***Most current seismic design includes the nonlinear response of a structure through a response reduction factor (R). This allows the designer to use a linear elastic force-based approach while accounting for nonlinear behavior. In fact, the response reduction factor is used in modern seismic codes to scale down the elastic response of a structure. This study focuses on estimating the actual 'R' value for reinforced concrete (RC) buildings. The ductility and over strength of representative RC buildings are investigated. Nonlinear pushover analysis is performed on structural models in order to evaluate the seismic performance of buildings. Different irregular building with variety of characteristics are selected and studied. Furthermore, the effects of over strength on the ductility factor is examined. Finally, the results obtained in form of Time period, base shear, displacement, drift etc. are further analyzed and compared with different structural parameters of the buildings.***
Keywords: Static Nonlinear Pushover Analysis, Regular and Irregular Structure, Elevation Irregularity.

I. INTRODUCTION

In reality, many existing buildings contain irregularity, and some of them have been designed initially to be irregular to fulfil different functions e.g. basements for commercial purposes created by eliminating central columns. Also, reduction of the size of beams and columns in the upper storeys to fulfil functional requirements and for other commercial purposes like storing heavy mechanical appliances, etc. This difference in usage of a specific floor with respect to the adjacent floors results in irregular distributions of mass, stiffness, and strength along with the building height. In addition, many other buildings are accidentally rendered irregular due to a variety of reasons like non-uniformity in construction practices and material used. The building can have irregular distributions of mass, strength, and stiffness along with the plan also. In such a case it can be said that the building has a horizontal irregularity

Encounters during past seismic occasions have exhibited that common customary techniques for building structure and development need creating protection from parallel powers when all is said in done and quake powers specifically. That is the reason the idea of quake safe plan approached to improve the conduct of structure during horizontal burdens. The essential methodology of tremor safe plan ought to be to expand the sidelong quality, deformability and pliability limit of structure with restricted harm however no breakdown (Agarwal et al., 2010). This can be accomplished by planning and enumerating structure to get satisfactory durability and flexibility. This will prompt withstand the seismic tremor of any estimate and type, which is probably going to understanding during its lifetime.

Moreover, the response of symmetrical structures during earthquake events is far better than asymmetric structures (I.S. 13920-1993, 1993). It has well recognized that asymmetric buildings are especially vulnerable to earthquakes due to coupled lateral and torsional motions. The effect of such coupling and how well these effects are represented in seismic codes has been the subject of numerous investigations (Sunagar, 2012). The effects of coupling between lateral and torsional motions in the code designed systems were generally evaluated by comparing element ductility demands in asymmetric plan and the corresponding symmetric plan buildings. These investigations generally concluded that elements on the stiff side of the code designed asymmetric plan buildings are likely to suffer more damage, whereas elements on the flexible side are expected to suffer less damage (Wood, 1991).

In the present examination, endeavors have been made in assessing the seismic conduct of strengthened solid medium-ascent uncommon minute opposing edge (SRMF) having inconsistency (asymmetry) in rise by utilizing non-direct static weakling investigation and contrast it and codal values (Andrew et al., 1999; Balendra, 2003). The casing has been planned according to the rules of IS 456:2000. The horizontal burdens following up on the casings were gotten from the rules of IS 1893(part1). The non-direct weakling investigation is performed to discover execution point and broke down the conduct of the sporadic structure.

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II. MATERIALS AND METHODS

A. Computational Model

In the present study, finite element method-based software SAP2000 has been used to model reinforced concrete ductile frames. The frame is designed as per provision of I.S 456:2000, I.S 875:1987, I.S:1893(Part 1) and I.S 13920:1993. The building frame is with 5 bays each direction and 6 storey and 9 storey with storey height 3 m and bay width 4 m located in seismic zone V in India on medium soil type. The analysis is done in two different story of 6 story and 9 story building. Mainly ten models are created for particular each building. Among them, one is a symmetrical model with no irregularity in elevation and the other nine models are created having different irregularities in elevation. A total of twenty models are taken for the study. Models are named as T0 for the model without any irregularity and irregular models are named T1, T2, T3, T4, T5, T6, T7, T8, and T9.

Two types of irregularity are considered in this study.

One is sudden irregularity: T1- 20%, T2- 40%, T5- 26.6%, T7- 50%, T8- 53.3%

Second is gradual irregularity: T3- 23%, T4- 43%, T6- 46.6%, T9- 56.6% and preliminary design consideration is tabulated in Table 1.

Table 1. Description of the modelled building used for the study

Sr. No.	Contents	Description
1	Type of structure	Multi Storied RC Rigid jointed Plane Frame (Special moment resisting frame) regular in shape
2	Number of storey	G + 5
3	Floor Height	3 m
4	Materials	Concrete (M25); Steel Reinforcement (Fe415)
5	Size of Beams	230 X 450 mm
6	Size of Column	600 X 600 mm
7	Depth of slab	150 mm
8	Specific weight of infill	20 KN/m3 (150 mm width)
9	Specific weight of RCC	25 KN/m^3
10	Type of soil	Medium Soil
11	Impose load	3 KN/m^2
12	Importance factor	1.2
13	Seismic zone	V
14	Zone Factor	0.36

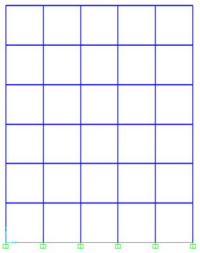
The examination thinks about two sorts of casing models; Irregular structures and ordinary structure. To approve the product created consequences of customary structure outline, those are contrasted and that of ordinary structure as given in IS 1893(Part 1). According to IS 1893 (Part 1). A structure is characterized to be sporadic if the proportion of one of the amounts (such as mass, stiffness or strength) between adjacent stories exceeds a minimum prescribed value. However, in the recent version of IS 1893 (Part 1) irregular configuration of buildings has been defined explicitly. Five kinds of vertical abnormality have been recorded. They are: vertical geometric abnormality, re-participant corner inconsistency, firmness anomaly (delicate story), in-plane intermittence in parallel power opposing vertical components, and brokenness in limit. In this investigation we center around vertical anomalies.

A normal building is the one which have four traits like: straightforward and ordinary setup, sufficient parallel quality, firmness and flexibility. Structures having basic ordinary geometry and consistently dispersed mass and firmness in design just as in height, endure substantially less harm than structures with sporadic setups (FEMA, 1995; FEMA, 2004). The model casings on which the investigations made may include: normal strengthened bond solid structure, vertically unpredictable structure.

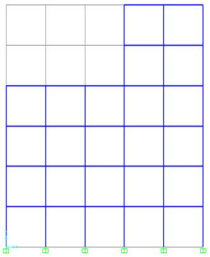
Displaying a structure includes the demonstrating and gathering of its different burden conveying components. The model in a perfect world speaks to the mass appropriation, quality, firmness and deformability. The bar segment joints are demonstrated by giving end-counterbalances to the casing components, to get the twisting minutes and powers at the pillar and segment faces. The bar section joints are thought to be inflexible

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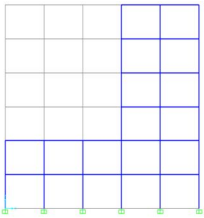
B. 6 Storey models



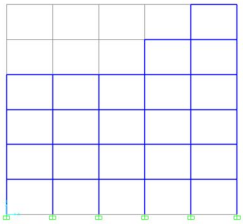
6T0



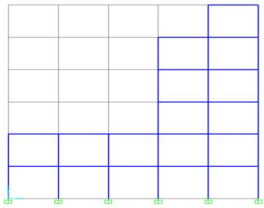
6T1



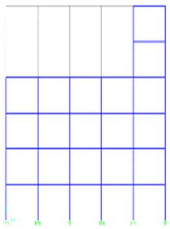
6T2



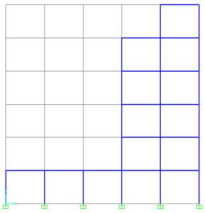
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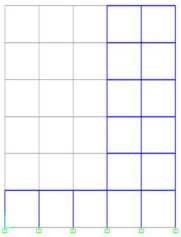
6T4



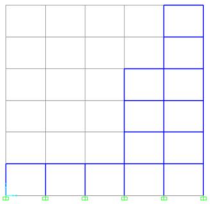
6T5



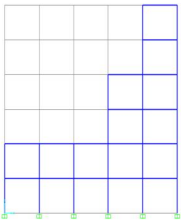
6T6



6T7

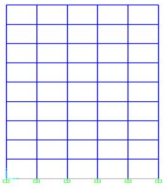


6T8

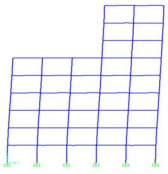


6T9

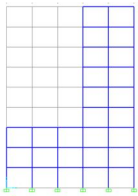
C. 9 Storey Models



9T0

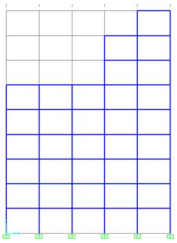


9T1

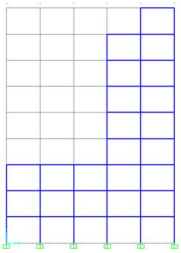


9T2

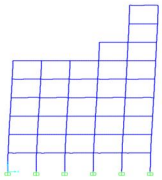
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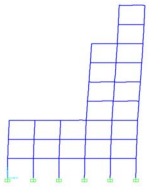
9T3



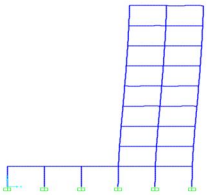
9T4



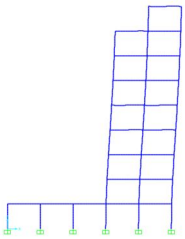
9T5



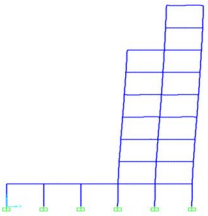
9T6



9T7



9T8



9T9

D. Pushover Analysis

The idea of a sucker examination can be used for evaluating the dynamic needs forced on a structure by seismic tremor ground movements and the likely areas of the disappointment zones in a structure can be discovered by watching the sort of pivot arrangements. The quality limit of the feeble zones in the post-flexible range would then be able to be expanded by retrofitting.

Nonlinear static weakling examinations of the three study outlines are performed. For this investigation nonlinear plastic pivots have been relegated to the entirety of the essential components. First-minute pivots (M3-pivots) have been appointed to pillar components and afterward hub minute 2-moment3 pivots (PMM-pivots) have been doled out to segment components.

In the examination, the range from the base to Center of gravity of holder is 18m and henceforth the objective dislodging is set to 72 mm. The relocation is applied bit by bit to the structure in a gradual way. The base shear and rooftop uprooting are recorded at each progression. Because of the arrangement evenness of the structure, the weakling investigation is completed in X bearing as it were. Henceforth, quake heaps of tank full conditions are provided in X-guidance as it were.

E. Performance-based Analysis

The cutting-edge approach of execution-based building offers a balanced plan structure for settling on plan choices by surveying the suitable dangers and meeting different execution targets of the built offices that are exposed to normal perils. Execution based seismic plan and appraisal rules for new structures and different structures have been proposed by a few FEMA programs (FEMA-350; FEMA-P695; FEMA-P752). With the scale and multifaceted nature of current tall structures, the seismic presentation-based plan requires broad computational assets and exertion. Execution based structure advancement is a mix of cutting edge.

The presentation-based investigation is an improved, static-nonlinear examination under a predefined example of changeless vertical burdens and continuously expanding horizontal burdens. Normally, the principal weakling load case is utilized to apply gravity burden and afterward resulting parallel sucker load cases are determined to begin from the last states of the gravity sucker. Normally, a gravity load weakling is power controlled and sidelong suckers are relocation controlled. The heap is applied steadily to structures until a breakdown component is come to. In this manner, it empowers the assurance of breakdown burden and ductility.

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F. Analytical Calculation of Design base Shear

The concept of a push over-analysis can be utilized for estimating the dynamic needs imposed on a structure by earthquake ground motions and the probable locations of the failure zones in a building can be ascertained by observing the type of hinge formations. The strength capacity of the weak zones in the post-elastic range can then be increased by retrofitting. Being the basic step of pushover analysis, the base shear is calculated as per the codal provisions and compared it with software values for regular RCC building. Further base shear for rest irregular buildings is obtained. The total design lateral force or design base shear along any principal direction shall be determined by the following equation 1, Clause 7.5 of IS 1893(Par1):2002

$V_b = A_h W$ [1]

W = Seismic weight of building

Z = Zone factor

I = Importance factor

R= Response Reduction Factor

G. Response Reduction Factor

Response reduction is used to scale down the elastic response of the structure. This factor is unique and different for a different type of structures and materials used.

The structure is allowed to be damaged in case of severe shaking. Hence, the structure is designed for seismic force much less than what is expected under strong shaking if the structure were to remain linearly elastic.

As stated earlier, the Response reduction factor is the most important factor for the seismic design of the structure. The response reduction factor takes into account the nonlinearity of structure and reduces the elastic response of the structure. As per global standard codes such as ATC-40, FEMA 273 this factor has been defined as a function of ductility factor, Strength factor, redundancy factor, and damping factor.

R = Rs * Rμ * RR ……. (1.1)

Where, Rs is strength factor,

Rμ is ductility factor and

RR is Redundancy Factor.

Rs Strength factor:

The maximum lateral strength of building (Vu) will generally exceed the design lateral strength (Vd) of the building because the members or elements are designed with capacities substantially greater than design actions and material strength also exceed specified nominal strengths. Thus, the strength factor or over-strength factor is defined as the ratio of ultimate base shear to design base shear.

Rs = vu/vd

H. Ductility Factor(Rμ)

The ductility factor is a measure of global Nonlinear (whole structure) response of the framing system and not the component of that system. It is measured as the ratio of ultimate or maximum base shear to base shear corresponding to yield (Ve). The ductility factor shows the response of the structure in terms of its plastic deformation capacity. It depends upon the ductility level (μ) and the time period of the system.

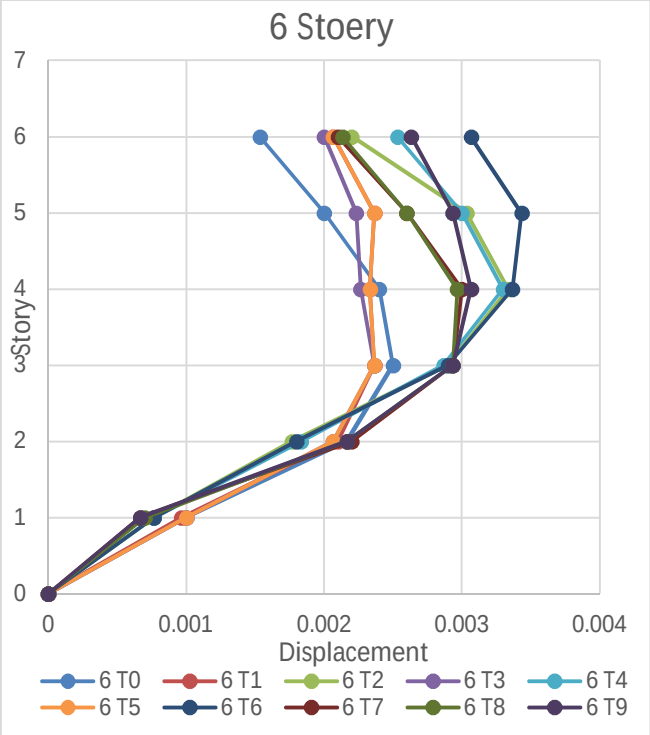
I. Redundancy Factor (RR)

The redundancy factor RR is a measure of redundancy in a lateral load resisting system. In RC structures, the moment-resisting frames, shear walls or their combinations are the most preferred lateral load resisting systems. Sometimes, the central frames are only designed for gravity loads and the perimeter frames are designed as the lateral load resisting systems.

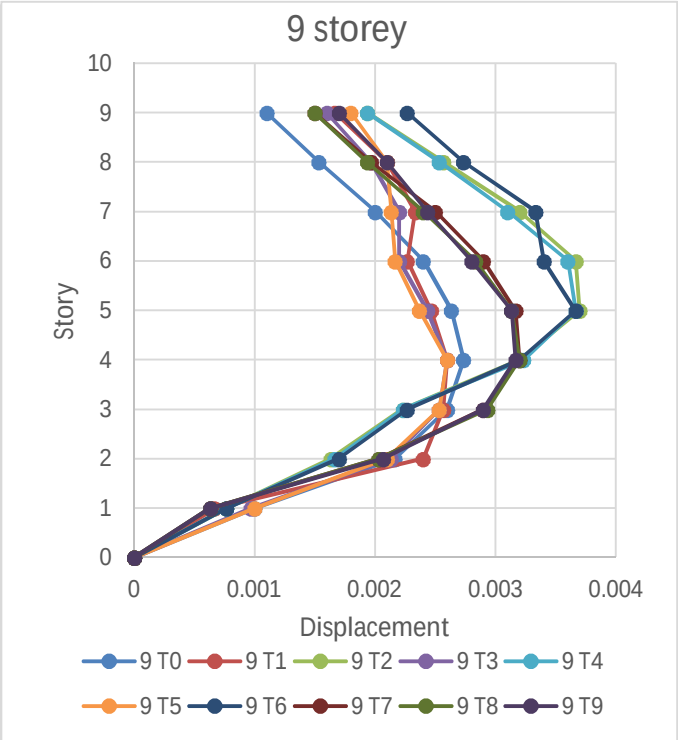
Thus, the redundancy in lateral load resisting systems depends on the structural system adopted. It is obvious that a less redundant structural system is to be designed for a higher seismic force demand. ASCE 7 recommends a redundancy factor RR= 1.0 for systems with parallel frames and the same is adopted for this work as the case study structures fall in this category.

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J. Analysis of Result



Storey drift of ten models of 6 storey



Storey drift of ten models of 9 storey

K. Final R Calculation

Model	V_0	V_d	delta Y
6 T0	8839.46	2485.89	51.25
6 T1	8460.46	2115.11	44.26
6 T2	6633.49	1559.10	63.91
6 T3	8431.34	2341.90	55.05
6 T4	6749.24	2045.15	59.48
6 T5	8460.46	2473.6	55.20
6 T6	6640.94	2200.2	54.98
6 T7	5437.34	1327.55	91.20
6 T8	5485.32	1250.36	84.45
6 T9	5404.29	1173.18	78.39

Time period	R_s	R_u	R
1.4	3.56	1.40	4.9
1.3	4.00	1.20	4.8
1.3	4.25	1.10	4.6
1.2	3.60	1.30	4.7
1.2	3.30	1.20	3.9
1.3	3.42	1.30	4.7
1.2	3.02	1.40	4.2
1.3	4.10	0.72	2.9
1.2	4.39	0.79	3
1.2	4.61	0.87	3.6

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Model	V_0	V_d
9 T0	10038.61	3137.06
9 T1	8824.11	2999.39
9 T2	6801.90	2304.75
9 T3	9853.26	2936.20
9 T4	7754.01	2241.55
9 T5	9867.85	2859.02
9 T6	6864.18	2164.37
9 T7	4940.15	1841.65
9 T8	5431.16	1778.46
9 T9	4934.08	1701.27

delta Y	Time period	R_s	R_u	R
94.6	2.3	3.20	1.30	4.3
85.92	2.1	2.94	1.30	3.5
119.51	2.1	2.95	0.90	2.6
94.59	1.9	3.36	1.10	3.6
111.54	2.0	3.46	0.97	3.0
92.9	1.9	3.45	1.17	3.7
102.54	1.9	3.17	1.05	3.2
141.79	2.2	2.68	0.74	2.1
117.95	2.1	3.05		
131.87	2.0	2.90		

III. CONCLUSION

The 9 storey models (height – 27mt) show significant relation between irregularity and response reduction factor and are inversely proportional. The results indicate that, the R factor is also dependent on the abruptness of the irregularity, but no clear proportionality can be concluded. This is shown by comparison of models (9T1, 9T3 and 9T5) and (9T2, 9T4 and 9T6) However, the same is not true for the 6 storey models, where no clear proportion can be observed.
It can be concluded that the strength of the structure (height 27mt and above) goes on decrease as increase in height of the structure when more than 40% irregularity is induced in the structure which is abrupt nature and is not gradual.

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Research Paper

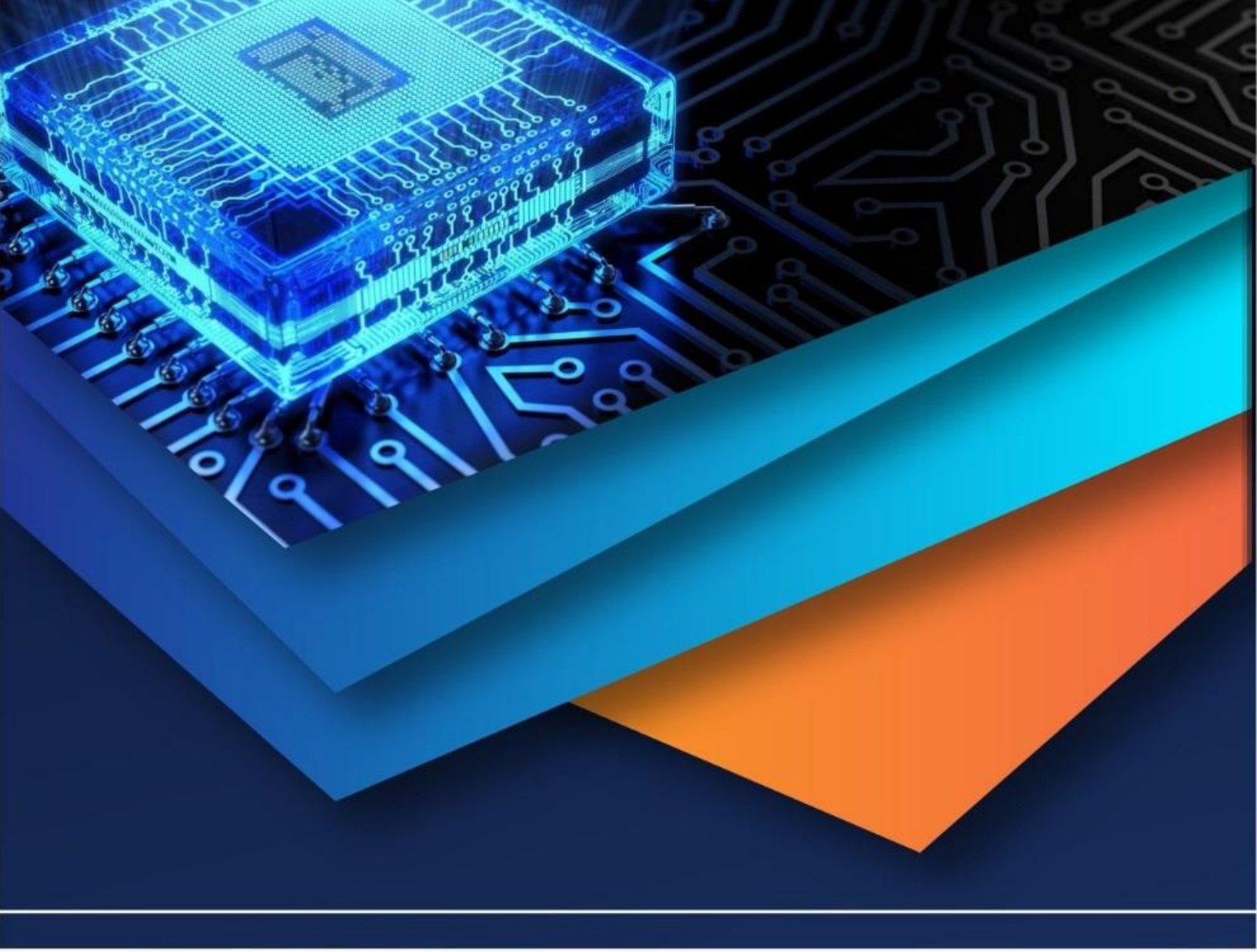
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DECLARATIONS

Author’s contribution

Mr. Shreyas barad has done a complete analysis and drawn conclusions according to the results. He wrote the manuscript submitted to this journal.

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