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Comparative Analysis of Steel Chimney with and without Soil Structure Interaction

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Abstract: Industrial Chimneys are tall and slender structures with circular cross-sections. The project based on the analysis of chimneys as per Indian codes provisions incorporation was also made through finite element analysis. Different models of steel chimney are made by keeping constant height, thickness and varying its geometry. All the models are prepared in the ANSYS Software. The main objective of this study is to perform comparative analysis of steel chimney with and without soil structure interaction and vibration analysis for combined static and dynamic wind loads effects. Three-dimensional soil-structure interaction analysis of 70m high self-supporting steel chimneys with flared base is considered in the present study. To understand the significance of SSI, Dry medium soil is considered for this study. The effects of soil-structure interaction on the Deformation, stresses are studied. The wind load was computed according to IS: 875 (Part 3)-2015 and IS: 6533 (Part 2)-1989. The integrated steel chimney chimney-foundation-soil system was analysed by commercial finite element software ANSYS.FE analyses were carried out for two cases of SSI (I) Self-supporting Steel chimney with Soil structure interaction and (II) Self-supporting steel chimney without Soil structure interaction. The vibration analysis of steel chimney is also been studied in the present study & the Effect of Manhole opening in steel chimney is also been studied. The responses in chimney such as tip deflection, Stresses, compared from the analysis. It is found that the responses in chimney depend on underlying soil and the Manhole openings should be considered while analysing the structure.

Keywords: ANSYS, Dynamic Wind, Soil structure interaction, Steel Chimney, Vibration Analysis.

I. INTRODUCTION

Chimneys are very important industrial structures for discharged waste harmful gases at higher elevation in atmosphere. These structures are tall, slender and tapering with circular cross sections. For construction different materials are used such as concrete, steel or masonry. Geometry of a steel stacks plays an important role in behaviour of structure under lateral loading. This is because geometry is primarily responsible for the stiffness parameters of the chimney. However, the basic geometrical parameters of the steel chimney (e.g., height of chimney, diameter at bottom, etc.) are associated with the corresponding actual site conditions.

The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as soil-structure interaction (SSI).so in this paper we studying that comparative analysis of self-supporting steel chimney with and without SSI and also to perform the vibration analysis of steel chimney.

Stack is a tall structure attached to a furnace, boiler, combustion chamber or ventilation system by which waste hot gases and solid particulates are discharged at an elevation such that it does not create nuisance to the surrounding environment. Steel chimneys are also known as steel stacks. Flue gases, with abrasive and corrosive characteristics, can damage the structural materials of chimney or liner. While a common impression is that industrial chimneys are simple vertical tubes of steel or concrete, to be forgotten once installed, in practice these are quite complex structures.

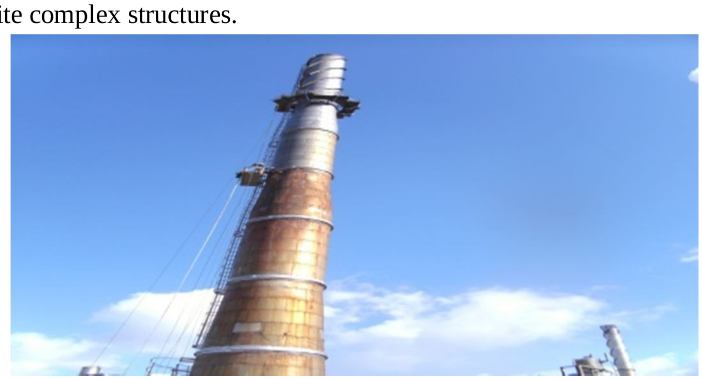

Figure -1: Industrial Steel Chimney (Ref: Anonymous)

II. LITERATURE REVIEW

1) *Kalpesh Dhopat et al (2018)*[1] *:* This paper summarizes the effect of height to base diameter ratio and top to base diameter ratio on behaviour of self-supported steel chimney. A total of 49 number of steel chimney configured with seven different heights and top diameter of chimney are selected and analysed for wind loadings and seismic loadings as per Indian standards (IS: 6533 part2) and IS 1893(part 4). The effect of geometric parameters on self-supported steel chimney is found out using STAAD pro.
2) *Kalagouda R Patil et al (2017)*[2] *:* This paper summarizes the analysis and design concepts of chimneys as per Indian codes provisions incorporation was also made through finite element analysis. Chimney models were designed on the basis of constant diameter with change in height taken into consideration. These models were analysed by finite element software STAAD Pro, ANSYS, emphasis also placed on effect of geometric limitations on the design aspects in designing chimney. The main objective of author was to study the design and constructional aspects of steel stack (with particular reference to steel plant) adhering to the guidelines given in internationally accepted standards/codes. Therefore, author had taken a practical case study and carried out design calculations by using the rules of codes viz., IS: 4533 part 1 and 2, IS: 875 part-3, IS: 1893 part1 and 4. Further to get full insight into the design of the steel stacks, a complete 3-D finite element analysis was carried out by using ANSYS software.
3) *M. Pavan Kumar et al (2017)*[3]*:* This paper presents a computer aided investigation on the seismic and wind effects on chimneys of different heights in the Indian scenario. Self-supporting steel stacks (provided as chimneys) of overall height 90m and 110m subjected to wind and seismic loads are considered in this study. The chimneys are analysed using STAAD.Pro software for seismic Zones II, III, IV and V and wind loads of basic wind speeds 39m/sec, 44msec, 49m/sec, and 50m/sec. Maximum shear force and bending moments developed in the steel stacks along with lateral displacements and mode shapes are determined and compared to study the structural response of steel stacks.
4) *Nimisha Ann Sunny et al (2017)*[4] *:* This paper includes the analysis of building structure in contact with soil involves an interactive process of stresses and strains developed within the structure and the soil field. The response of Piled-Raft Foundation system to the structure is very challenging because there is an important interplay between the component of building structure and the soil field. Herein, soil - structure interaction of buildings founded on Piled-Raft Foundation is evaluated through Finite Element Analyses using ANSYS v17.0. The building settlement and equivalent stress is computed. The study has been conducted by modeling building with soil and without soil. It is concluded that the interaction of building foundation-soil field and super-structure has remarkable effect on the structure.
5) *Rakshith B D et al (2015)*[5]*:* This paper summarizes the analysis and design concepts of chimneys as per Indian codal provisions incorporation was also made through finite element analysis. Effect of inspection manhole on the behaviour of Cantilever steel chimney, two chimney models one with the manhole and other without manhole were taken into consideration. These models are analysed by finite element software STAAD Pro, emphasis also placed on effect of geometric limitations on the design aspects in designing chimney.
6) *B. R. Jayalekshmi et al (2015)*[6]*:* This paper includes Three-dimensional (3D) soil-structure interaction (SSI) analysis of 300mhigh reinforced concrete chimneys having piled annular raft and annular raft foundations subjected to along-wind load is carried out in the present study. To understand the significance of SSI, four types of soils were considered based on their flexibility. The effect of stiffness of the raft was evaluated using three different ratios of external diameter to thickness of the annular raft. The along-wind load was computed according to IS:4998 (Part 1)-1992. The integrated chimney-foundation-soil system was analysed by commercial finite element (FE) software ANSYS, based on direct method of SSI assuming linear elastic behaviour. FE analyses were carried out for two cases of SSI (I) chimney with annular raft foundation and (II) chimney with piled raft foundation. The responses in chimney such as tip deflection, bending moments, and base moment and responses in raft such as bending moments and settlements were evaluated for both cases and compared to that obtained from the conventional method of analysis. It is found that the responses in chimney and raft depend on the flexibility of the underlying soil and thickness of the raft.
7) *K. Sachidanandam et al (2014)*[7] *:* The author found maximum deformation and maximum equivalent stress due to wind load in a self-supporting steel chimney with different combinations of foundation parameters. Three parameters considered in the paper. And also presented a step by step procedure for designing self-supporting Steel chimney using IS: 875(Part 3):1987, IS 1893 part 4:2005 and IS 1893 part 1:2002 standards. The relation between the different foundation parameter and corresponding deformation and stress compared by mini tab software were studied. This analysis had given maximum mean result and minimum SN ratio result for best one and evaluate from the modal analysis due to seismic loading a self-supporting

steel chimney. There was a need for revising the calculation model for vortex shedding of very slender chimney that is for chimneys with slenderness ratio (height through diameter) above approximately 30.

8) *Sahoo K et al (2013)[8] :* In this paper the Author carried out analysis of self-supported steel chimney with effect of manhole and geometric properties. Arbitrary models of steel stacks were selected and they were analyzed using ANSYS and Mathcad. Basis of selection of geometric parameters was top to bottom diameter ratio. Limitations of codal conditions were also highlighted. No mathematical equations or correlations were established by the authors for dynamic response variance and variance in geometry.

9) *B. Pallavi Ravishankar et al (2013)[9] :* This paper Tall asymmetric buildings experience more risk during the earthquakes (Ming, 2010). This happens mainly due to attenuation of earthquake waves and local site response which get transferred to the structure and vice versa. This can be well explained by the Dynamic Soil Structure Interaction (DSSI) analysis. In this research paper 150 m tall asymmetrical building with two different foundation systems like raft and pile is considered for analysis and assuming homogeneous sandy soil strata results are studied for input of Bhuj ground motion (2001, M= 7.7). The response of structure in terms of SSI parameters under dynamic loading for a given foundation systems has been studied and compared to understand the soil structure interaction for the tall structures. It has been clearly identified that the displacement at top is more than that at bottom of the building and stresses are more at immediate soil layer under foundation than the below layers.

10) *Gharad A.M. et al (2010)[10] :* In this paper A soil pile system and a soil pile system accompanied with stack like structure (chimney) is analysed. Linear analysis is carried out. For simulating radiation condition at infinity, Kelvin element was considered as boundary condition. Seismic excitations consisting of transient motion (El Centro earthquake time history) is used. Response (top nodes displacement) of a 2D soil pile model system is compared with the response of 3D soil pile model. The response (horizontal displacement) of top node of chimney without soil pile (fixed base) is compared with chimney with soil pile model.

III.METHODOLOGY

Following methodology is adopted for this research. It includes Study of codes for wind & Chimney codes, modelling in ANSYS, validation and results.

PHASE I

↓

FINALISE THE SUBJECT

↓

LITERATURE SURVEY

↓

DECIDE THE SEQUENCE FOR THE ANALYSIS OF THE MODELS

↓

PHASE II

↓

WIND LOADS CALCULATION (STATIC & DYNAMIC)

↓

MODELLING IN SOFTWARE

↓

WIND TUNNEL ANALYSIS (VALIDATION)

↓

INTERPRETATION OF THE RESULTS

↓

COMPARISION OF SELF SUPPORTING STEEL CHIMNEY

IV. MODELLING AND VALIDATION OF SOFTWARE

In this chapter, finite element modelling of self-supporting steel chimney is done and the validation of the model by using wind is done and the results are compared with the same model is prepared in ANSYS is mentioned bellow,

A. Finite Element Modelling

In this study, the FEA modelling and analyses were carried out by using the commercial finite element software. In the finite element modelling, the chimney, a three dimensional soil stratums and the foundation are modelled in ANSYS. The surface-surface contact elements were used to evaluate the interaction between foundation and soil. The foundation surface was established as "target" surface (TARGE170) and the soil surface contacting the foundation as "contact" surface (CONTAC174); these two surfaces constitute to comprise the contact pair. The coefficient of friction was defined between contact and target surfaces. Soil is modelled as rectangular solid around the foundation due to scope limit. Since soil is extended in infinity in actual case, we modelled it as finite sized solid and applied boundary conditions. For this study Bottom layer is considered as hard strata. So it restrains the movement in any direction, hence a fixed Support or boundary condition is provided at the bottom soil solid element.

B. Data Required For Analysis

It is located at a height 70m from ground. Considering K2 factor in this height range as per table 2, IS-875 (Part-3):2015, lateral wind force.

Details of the chimney as follows,

1) Height of the chimney – 70m
2) Outer diameter of chimney at bottom – (1.6 X Dtop i.e 1.6 x 2.25) - 3.6m
3) Outer diameter of chimney at top – 2.25m.
4) Thickness of shell at bottom (assumed) –0.02m
5) Thickness of shell at top (assumed) – 0.02m
6) Basic wind speed – 39m/s
7) Type of soil (assumed) – Dry medium sand
8) Density of soil – 1800 kg/m3
9) Modulus of elasticity of soil – 445,872 KN/m2
10) Poisson's ratio – 0.35
11) Shear Modulus - 165,138 KN/m2
12) Angle of friction – 35^0
13) Description of loading:

Density of various materials considered for design,
Concrete – 25kN/m3
Structural steel – 78.5kN/m3
Wind load:
The following wind parameters are followed in accessing the wind loads on the structure
Basic wind speed – 39m/s
Terrain category -2
Class of structure –B
Risk coefficient k1 – 1
Topography factor k3– 1
Importance factor K4–1.15

Table 4.1 Nomenclature of Modelled Steel Chimney

MODEL NO.1	Uniform + Tapered 70m with Soil structure interaction
MODEL NO.2	Uniform + Tapered 70m without Soil structure interaction
MODEL NO.3	Tapered 70m steel chimney
MODEL NO.4	Uniform 70m steel chimney
MODEL NO.5	Uniform 70m with inspection manhole

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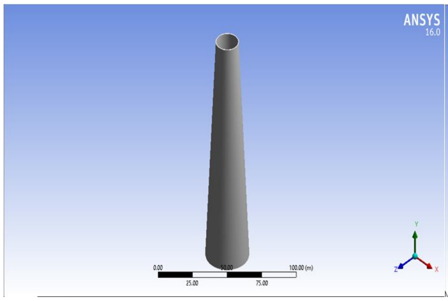
C. Ansys Modelling



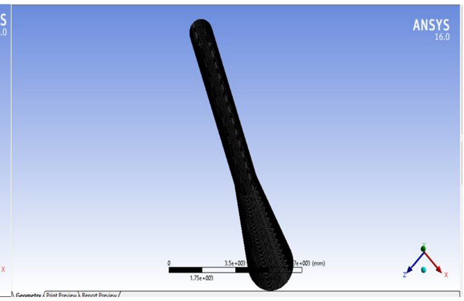


Figure -1: MODELLING   Figure -3: MESHING

Deflection due to DRAG force which is obtained from wind tunnel experiment:

$$\delta = F * L * L * L / 3EI$$

Deflection= (9.1*2203) / (3* 210,000 *739518.3)
=0.000211 mm

D. Deflection In ANSYS

The same prototype model is prepared in ANSYS and the force 9.1 N which is obtained in wind tunnel is applied and deflection observed is 0.000194 mm

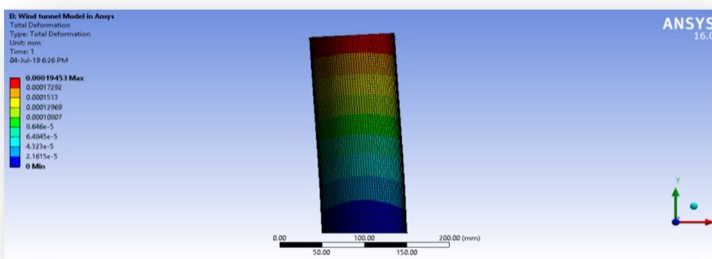
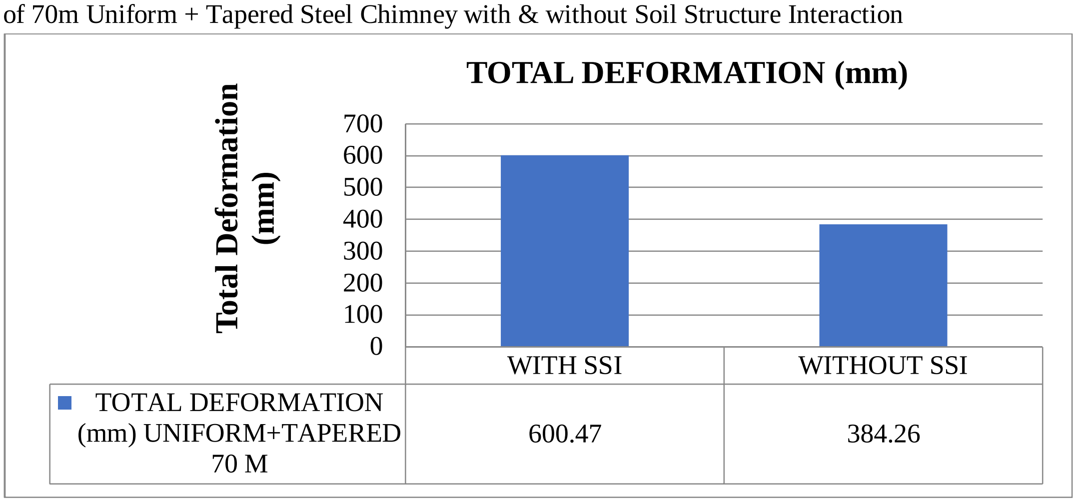


Figure -4: ANSYS Model of Prototype chimney Model

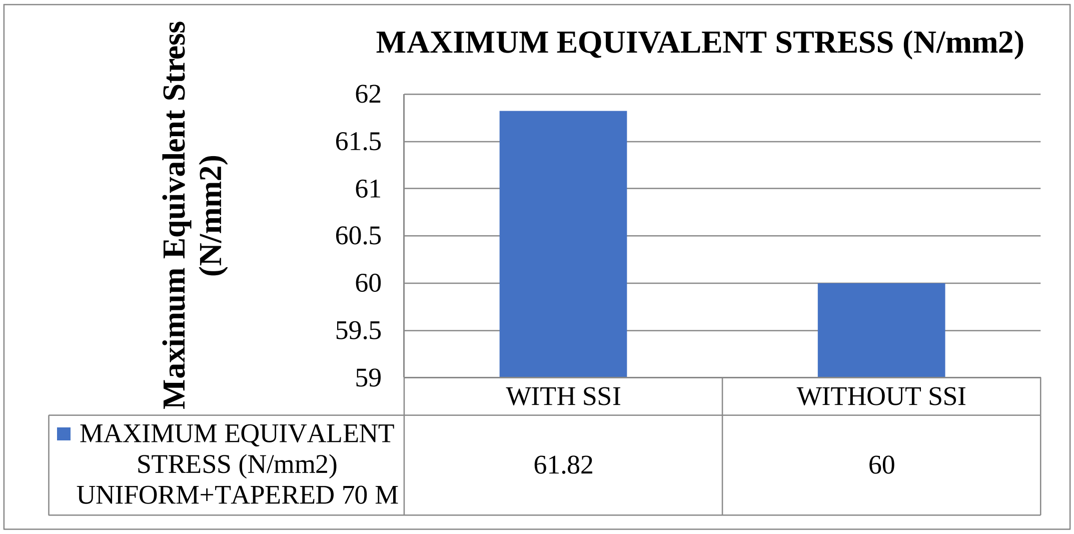
V. RESULT AND DISCUSSION

In this chapter, all the results that were obtained in terms of static wind responses and dynamic responses for all steel stacks models ranging from Model-1 to Model-5 are presented.

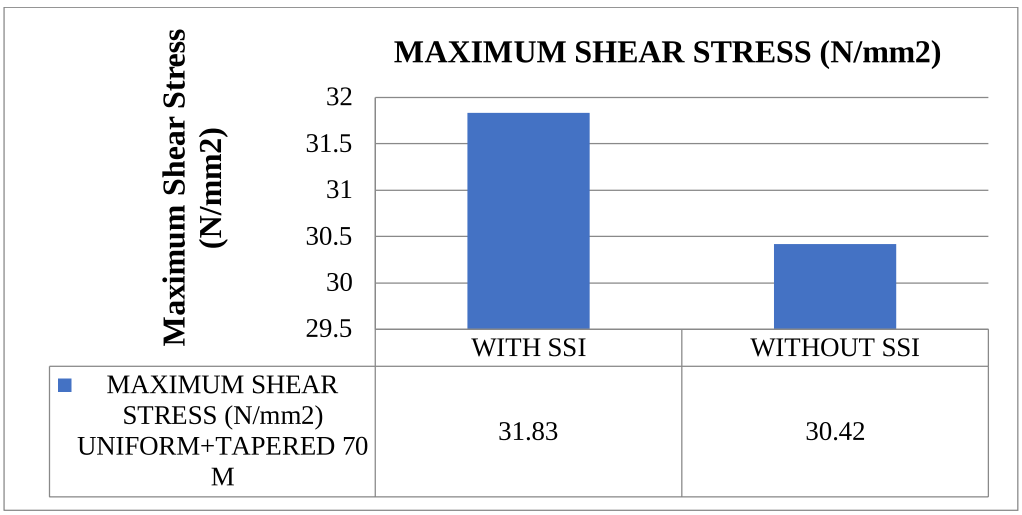
1) Comparison of 70m Uniform + Tapered Steel Chimney with & without Soil Structure Interaction



Graph -1: Total Deformation in (U+T) 70m high chimney

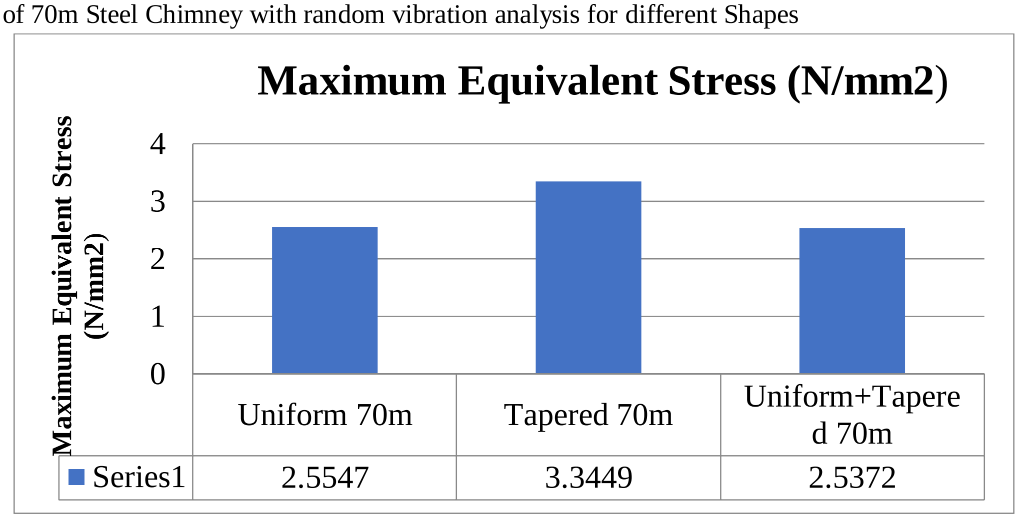


Graph -2: Maximum Equivalent stress in (U+T) 70m high chimney

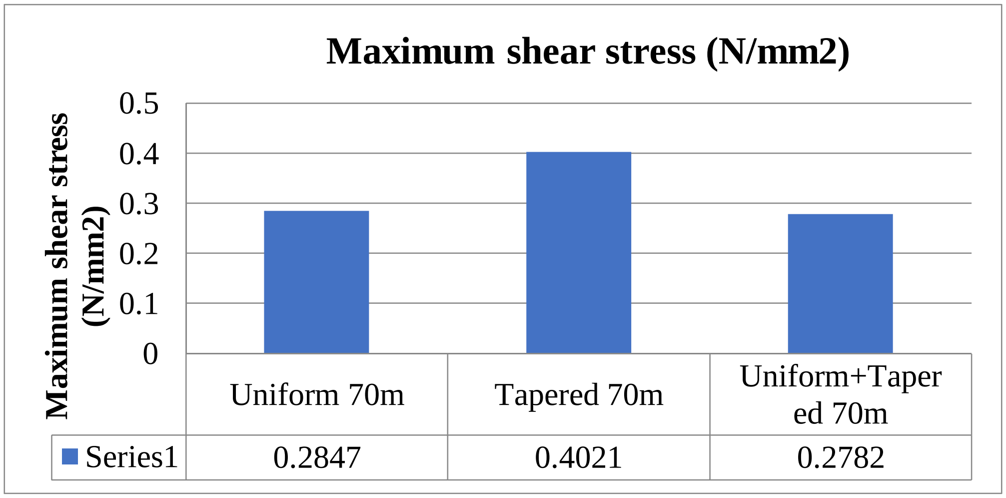


Graph -3: Maximum Shear stress in (U+T) 70m high chimney

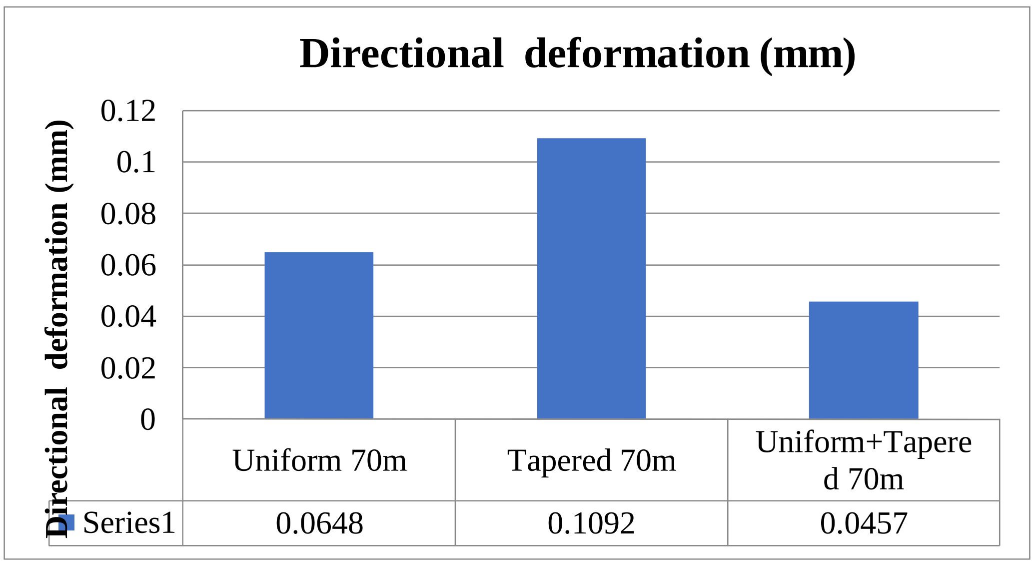
2) Comparison of 70m Steel Chimney with random vibration analysis for different Shapes



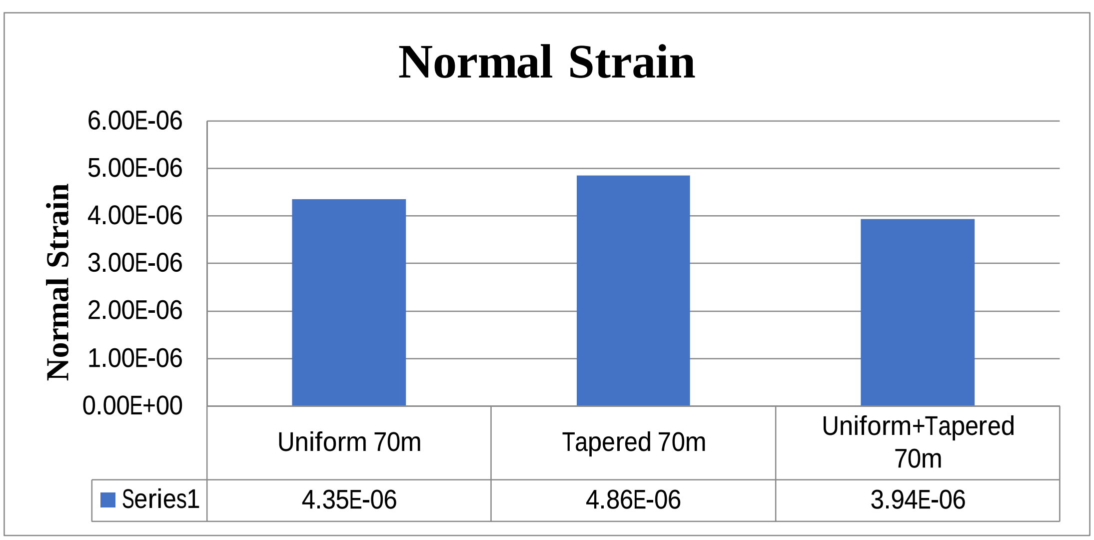
Graph -4: Maximum Equivalent Stress



Graph -5: Maximum Shear Stress



Graph -6: Directional Deformation



Graph -7: Normal Strain

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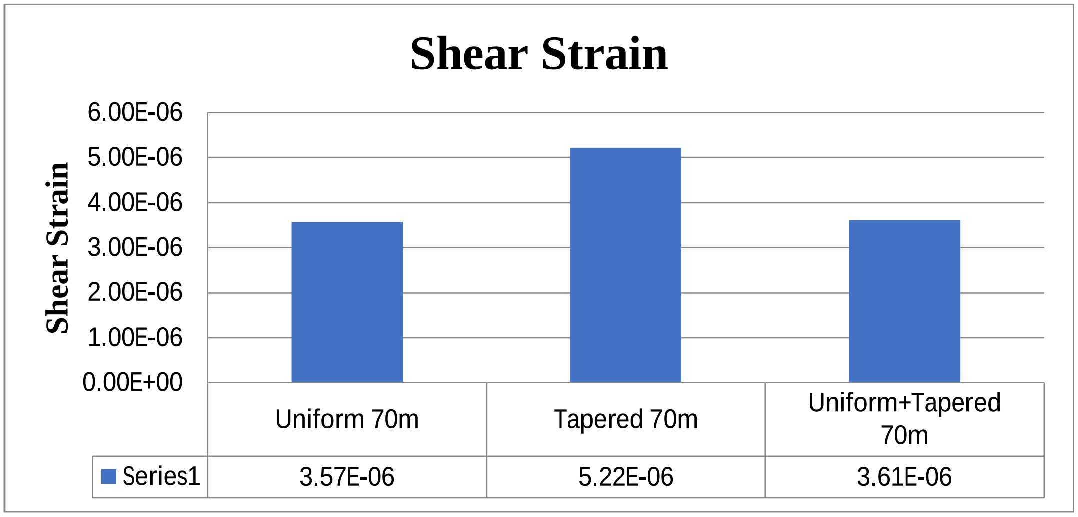
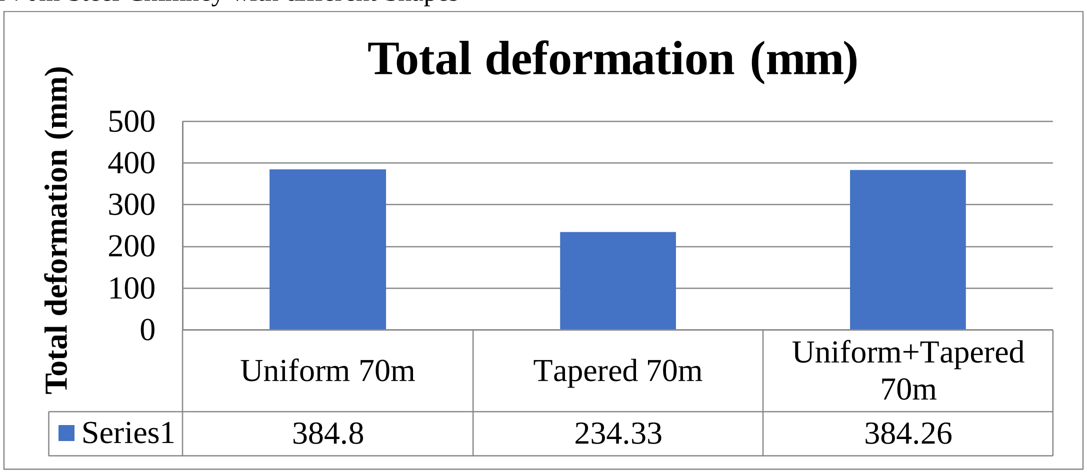
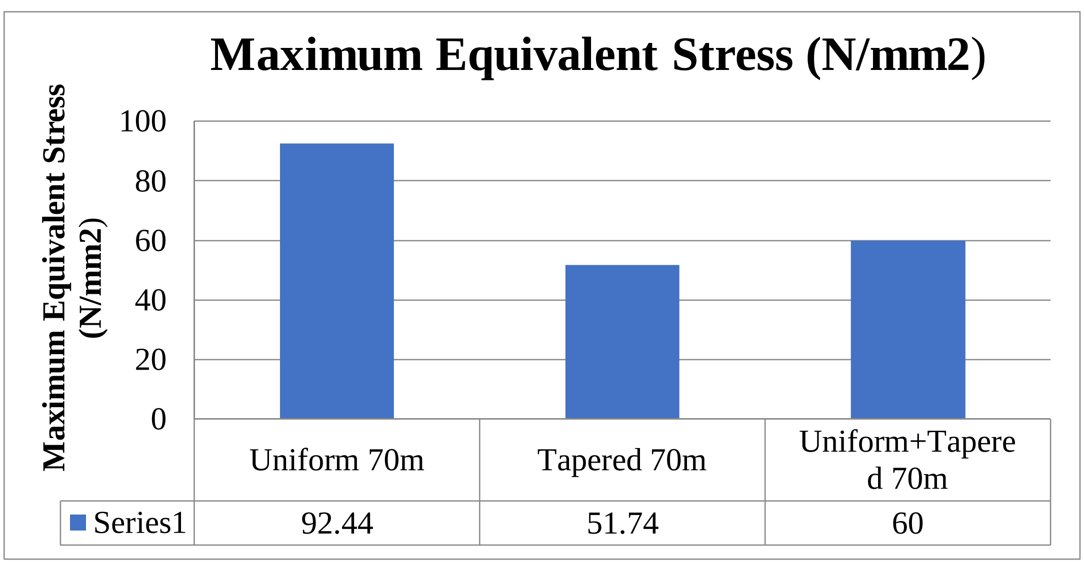


Graph -8: Shear Strain

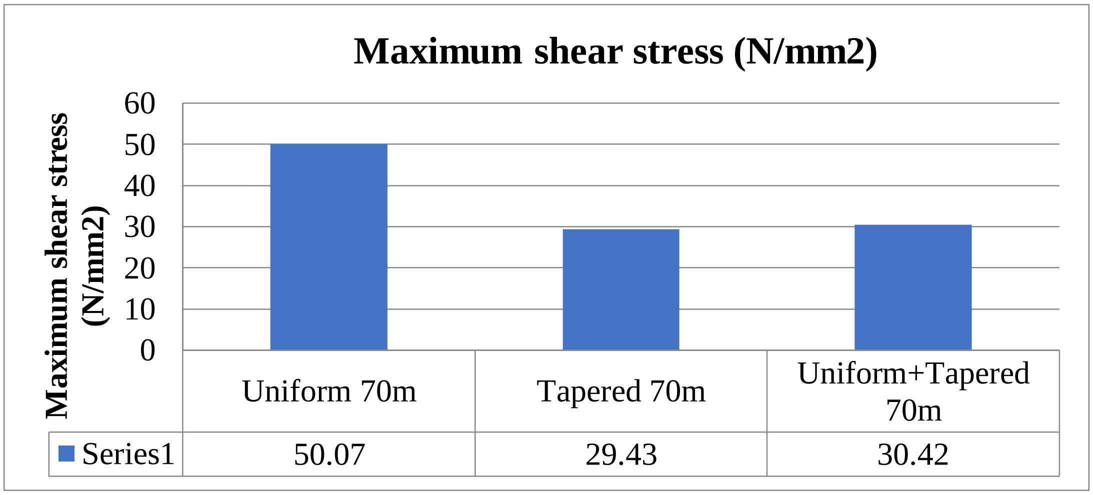
3) Comparison of 70m Steel Chimney with different Shapes



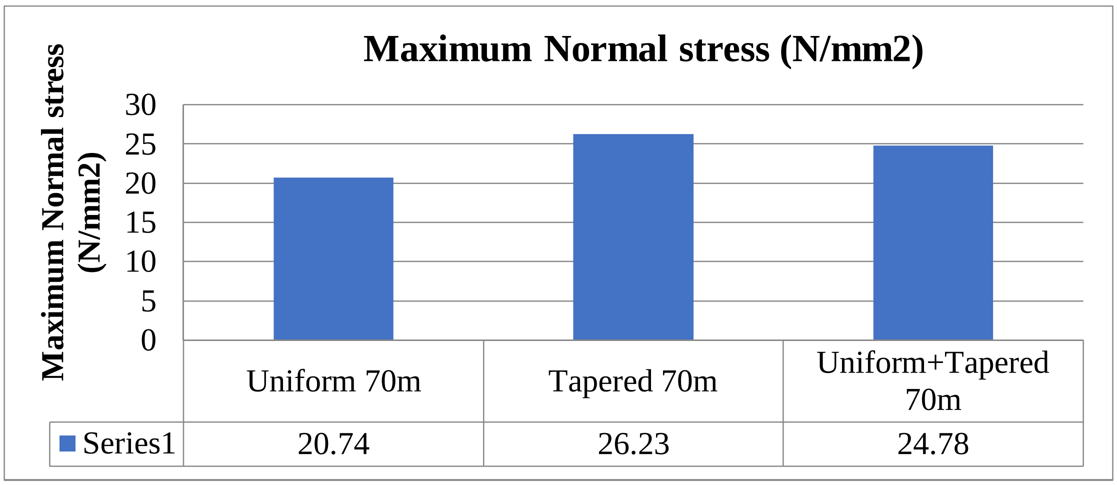
Graph -9: Total Deformation



Graph -10: Maximum Equivalent Stress

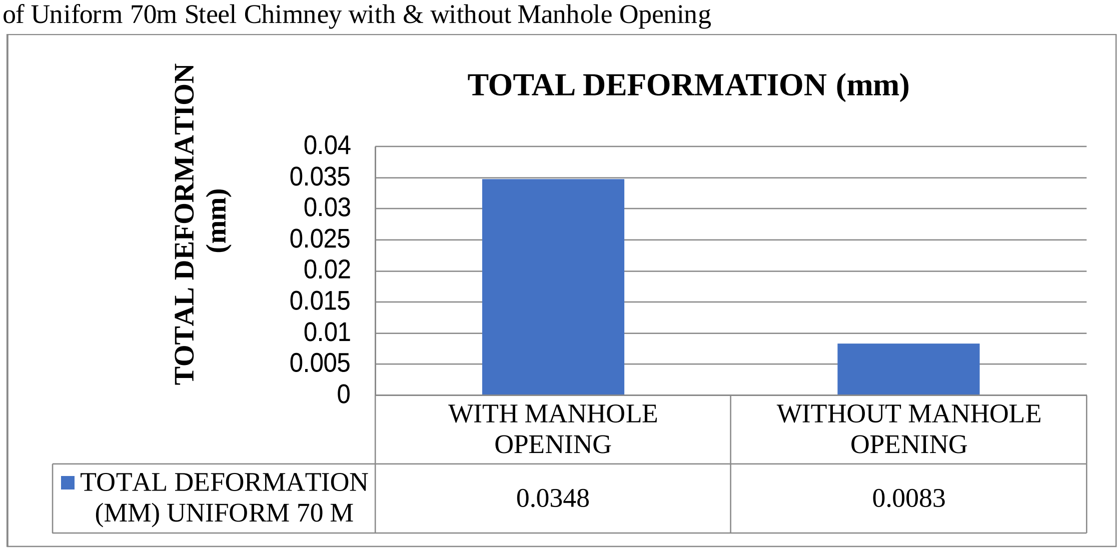


Graph -11: Maximum Shear Stress



Graph -12: Maximum Normal Stress

4) Comparison of Uniform 70m Steel Chimney with & without Manhole Opening



Graph -13: Total Deformation

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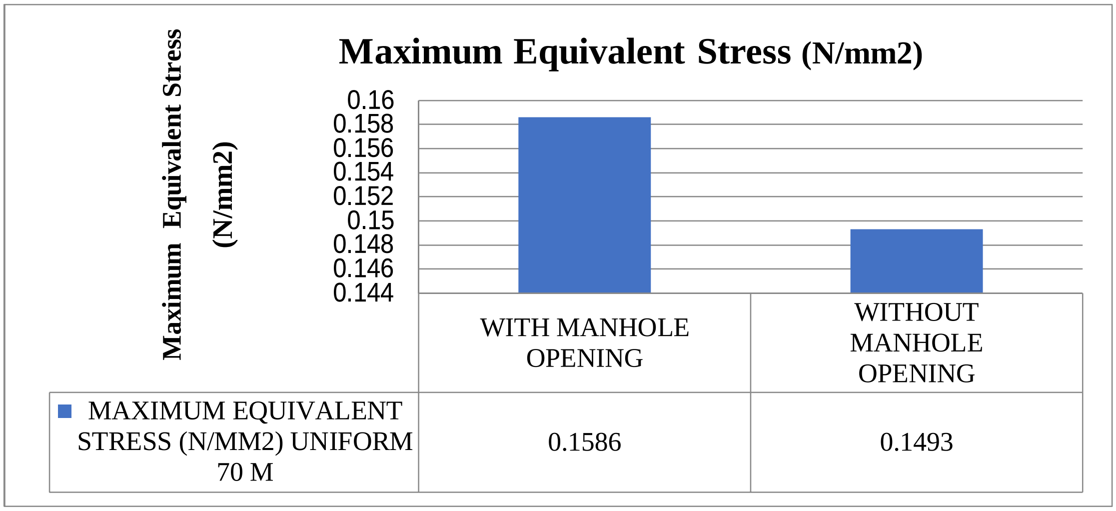
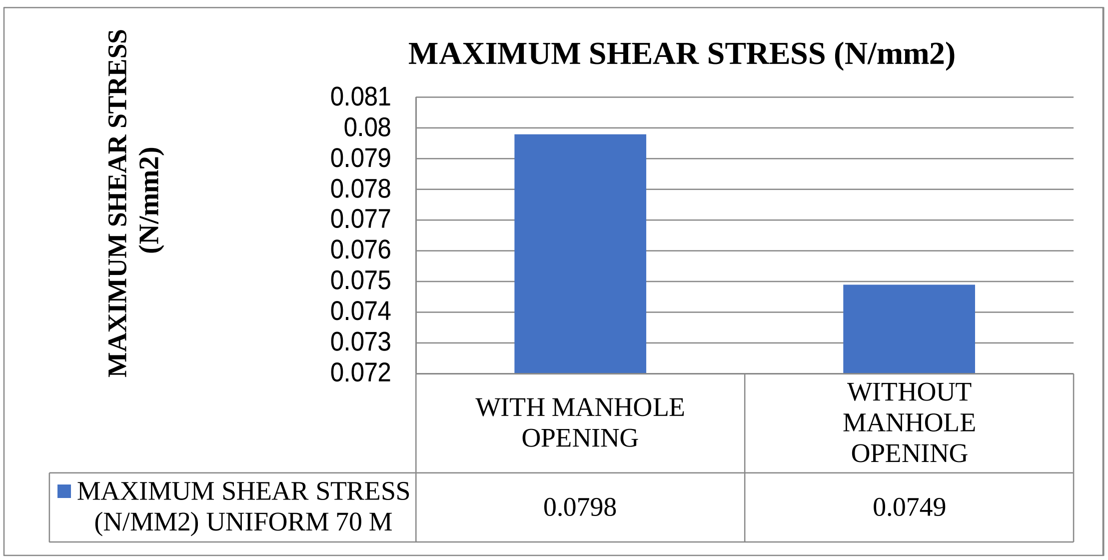
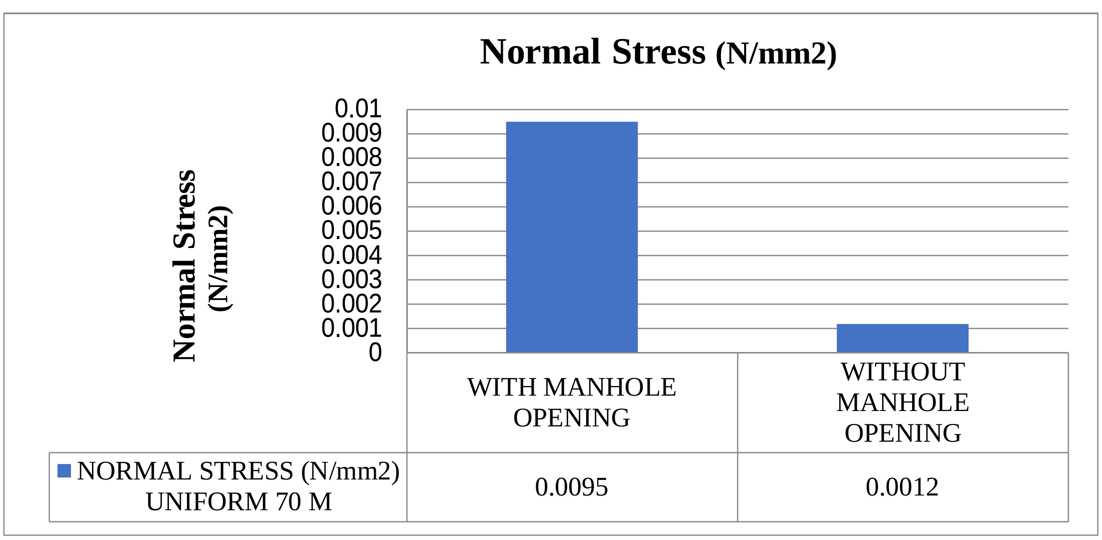


Graph -14: Maximum Equivalent Stress



Graph -15: Maximum Shear Stress



Graph -16: Maximum Normal Stress

VI. CONCLUSION

A. The deformation, stresses are observed more in the models with considering the soil structure interaction.

B. For random vibration analysis peak spectral displacement is calculated using natural frequency of 6 mode shapes and its corresponding deformation for height 70m for shapes uniform, uniform + tapered and tapered. The design parameter deformation, shear stress, normal stress, equivalent stress is observed 30-45 % more in tapered section than that of uniform + tapered section its due to the cross sectional area reduces continuously towards top which gives increase in stress.

C. The total deformation is observed to be 50-60% less in tapered section than others.

D. The stresses and top displacement in a Uniform steel chimney is found to be increased by considering the Manhole opening in the Uniform steel chimney this is Because of the Manhole opening cut down the stiffness of steel chimney.

E. For validation purpose an experimental method is adopted for Prototype Model and the deflection is compared by analytical and from ANSYS Software it was found that difference is observed up to 5-10% which is permissible. For experimental method a prototype of uniform section the drag force is calculated the overall.

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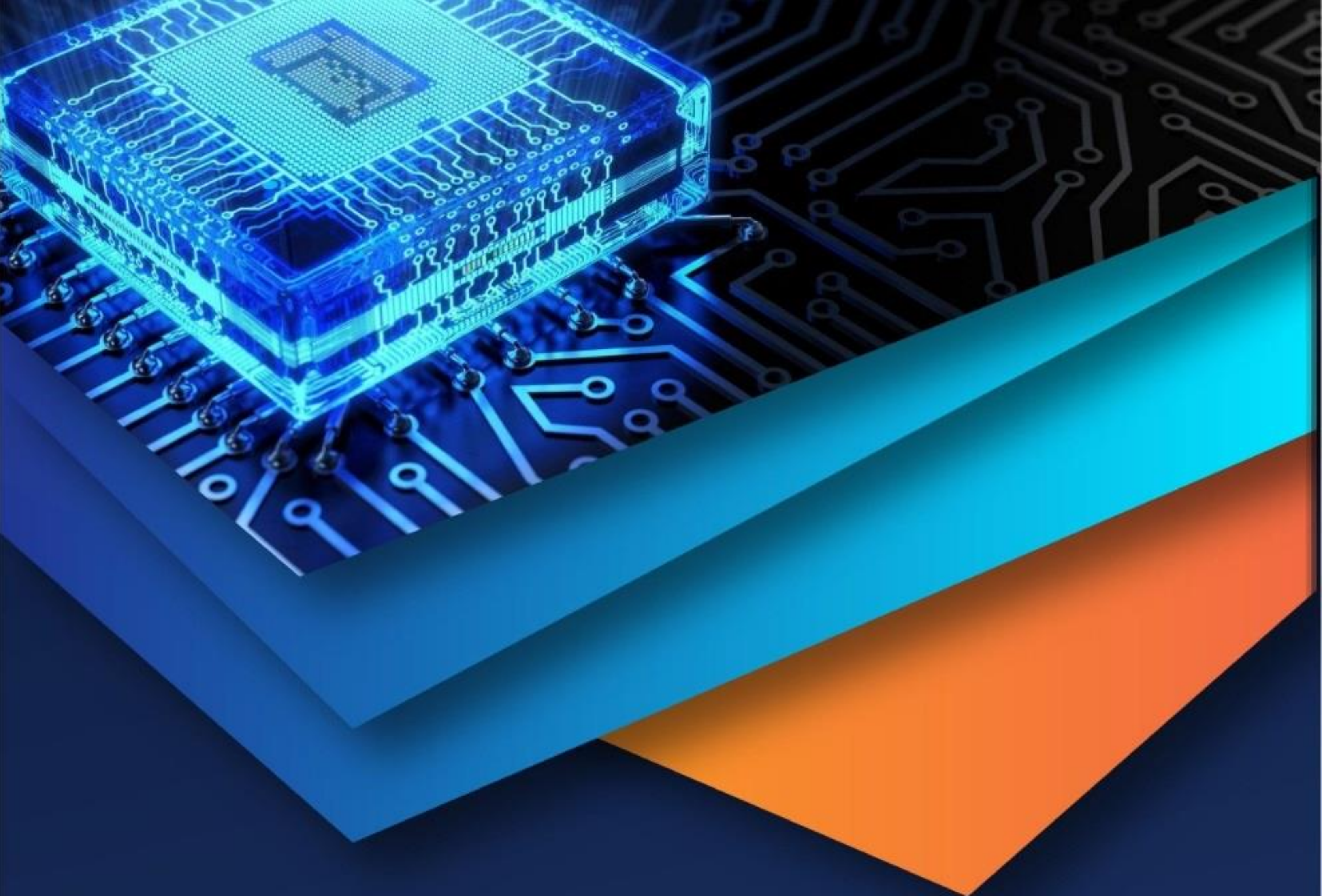

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