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Assessment of Actual and Predicted Hydraulic Conductivity of various Gradations of Natural Sand

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Abstract: Hydraulic conductivities of natural sand with different gradation estimated experimentally. The natural sand is further artificially graded into three models accounting for sixteen gradations (4.75–2, 2–1.18, 1.18–0.6, 0.6–0.425, 0.425–0.3, 0.3–0.075, 4.75–0.075, 2–0.075, 1.18–0.075, 0.6–0.075, 0.425–0.075, 4.75–0.6, 2–0.6, 4.75-0.425, 2–0.425, 1.18–0.425 mm). The natural sand's hydraulic conductivities were found to range from 0.013 to 0.002 cm/sec. The results clearly showed that the grading characteristics (d_{10}, d_{20}, d_{30}, d_{50}, d_{60}, Cu, Cc, n, I_o) would influence the hydraulic conductivity considerably. Besides, comparisons were made with other formulas available in the literature between the results obtained in the present study and the hydraulic conductivity estimations. The comparisons suggested that the best hydraulic conductivity estimate depending on the gradation and shape properties of the measured sands.

Keywords: Natural sand, Artificial grading, Hydraulic conductivity, Correlation.

I. INTRODUCTION

Hydraulic conductivity, which defines a porous media's ability to convey water through its voids, is one of the most important geomaterial parameters for many natural phenomena, including water resource management, drinking water supply, waste repository protection, hydrogeological circulation in the basin, stability analyzes, and many other problems related to subsurface hydrology and geotechnical engineering. (Moore et al. 1982; Wintsch et al. 1995; Terzaghi and Peck 1964; Person et al. 1996; Boadu 2000; Chapuis 2012). Attempts were made to estimate hydraulic conductivity based on a distribution of grain size (Mualem 1976; Freeze and Cherry 1979; Uma et al. 1989; Salarashayeri and Siosemarde 2012). In the literature empirical and statistical methods for estimating hydraulic conductivity were developed using quantitative relationships. Kozeny 1927 Hazen (1911), proposed and provided a widely accepted equation $k = cd^2_{10}$ for predicting the hydraulic conductivity of saturated sands. Where k is hydraulic conductivity, c is constant, and d_{10} is an effective diameter at which 10 % of the grains are finer. Krumbein and Monk (1942) expressed the hydraulic conductivity of unconsolidated sands through an empirical form equation $k = (760d_w^2)\exp(-1.3\sigma_\psi)$ where d_w is mean diameter by weight in mm, σ_ψ is the variance of the ψ distribution function.

It is suggested by Masch and Denny (1966) about the use of d_{50} median grain size to compare hydraulic conductivity with grain size as the representative size. Also, Kozeny (1927) and Carman (1937) had generally accepted hydraulic conductivity derivation, developed a semi-empirical method for the prediction of porous media permeability. It was reported by Koltermann and Gorelick (1995) that the use of geometric mean predicts hydraulic conductivity by several orders of magnitude for soils with substantial fines content, while the harmonic mean grain size predicted by k for soils with lower fines content by several orders of magnitude. A series of statistical power regression analyses on published data is carried out by Shepherd (1989) to determine the effect of grain size on hydraulic conductivity.

A grain-size distribution curve equation based on an analysis of 32 samples integrating the initial slope and the intercept was proposed by Alyamani and Sen (1993). A model was developed by Sperry and Peirce (1995), to delineate the significance of particle size/shape, and porosity to describe the hydraulic conductivity variability of a porous granular medium. Several analytical formulae were used by Ishaku et al. (2011) to determine the hydraulic conductivity of in-field aquifer materials. According to Vukovic and Soro 1992, several different techniques have been proposed to determine the hydraulic conductivity value, including field methods, application of these empirical formulae to the same porous medium will yield different values of hydraulic conductivity due to the difficulty of considering all possible variables in porous media.

While engineers, geologists, hydrogeologists, and soil scientists have carried out many field and laboratory determinations of hydraulic conductivity, the fundamental relationships between the gradation and the flow through them remain poorly understood and inadequately quantified. Also, these methods can not produce clear results concerning the specific values of hydraulic conductivity.

Therefore the present study aims to assess a new conceptual model for quantifying the inherent coupling between changes in gradation of sand grains and hydraulic conductivity by using constant head permeability tests on 16 different grain size fractions i.e. (Model 1: 4.75–2, 2–1.18, 1.18–0.6, 0.6–0.425, 0.425–0.3, 0.3–0.075, Model-2: 4.75–0.075, 2–0.075, 1.18–0.075, 0.6–0.075, 0.425–0.075, Model – 3: 4.75–0.6, 2–0.6, 4.75–0.425, 2–0.425, 1.18–0.425 mm) of NTS samples.

II. MATERIAL USED AND EXPERIMENTAL SETUP

The sand used in the study were taken from nearby sandpits, which is being used for construction purpose and its abbreviated as Natural Sand (NTS) from here onwards. The NTS is further artificially graded into 16 different grades. The specific gravity of the NTS was found to be 2.65. The grain size distribution of the sand and artificially graded sand samples used in the present study was developed from sieve analysis in Fig. 1. The samples were initially kept for complete consolidation for 24hours before it is tested for hydraulic conductivity under constant head in the laboratory set up. Later the values of hydraulic conductivity were estimated from the Darcy's equation ($k = ql/Ah$). The physical characteristics of the graded samples is listed in Table I. The influence of grain size on hydraulic conductivity is seen from the table.

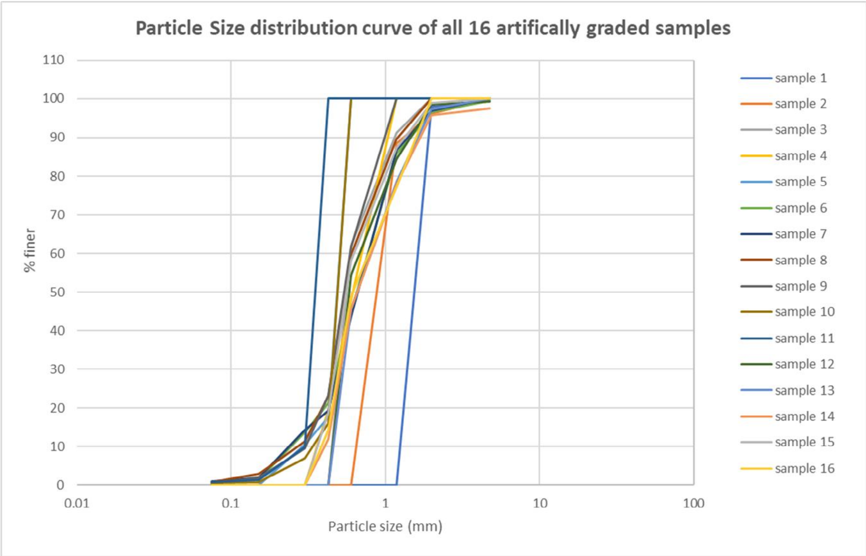

Fig. 1 Grain size distribution curves

TABLE I
physical characteristics of the artificially graded samples

MODEL	SAMPLE No.	GRADATION	D_{10}	D_{20}	D_{30}	D_{50}	D_{60}	Cu	Cc	n	e	ṗ	k(cm/sec)
M1	1	4.75-2	1.25	1.30	1.40	1.50	1.60	1.28	0.98	0.42	0.73	1.51	0.013
	2	2-1.18	0.65	0.72	0.78	0.90	0.98	1.51	0.96	0.37	0.59	1.57	0.011
	3	1.18-0.6	0.45	0.47	0.49	0.56	0.60	1.33	0.89	0.37	0.59	1.57	0.009
	4	0.6-0.425	0.37	0.43	0.49	0.62	0.72	1.95	0.90	0.38	0.61	1.55	0.008
	5	0.425-0.3	0.30	0.45	0.46	0.49	0.50	1.67	1.41	0.32	0.47	1.56	0.004
M2	6	4.75-0.075	0.24	0.40	0.48	0.66	0.78	3.25	1.23	0.30	0.42	1.64	0.004
	7	2-0.075	0.22	0.44	0.49	0.70	0.80	3.64	1.36	0.32	0.47	1.63	0.005
	8	1.18-0.075	0.28	0.38	0.44	0.54	0.60	2.14	1.15	0.37	0.59	1.64	0.002
	9	0.6-0.075	0.31	0.39	0.45	0.54	0.60	1.94	1.09	0.36	0.57	1.59	0.003
	10	0.425-0.075	0.34	0.44	0.46	0.49	0.50	1.47	1.24	0.31	0.45	1.58	0.003
	11	0.3-0.075	0.30	0.32	0.33	0.36	0.37	1.23	0.98	0.38	0.60	1.56	0.003
M3	12	4.75-0.6	0.45	0.47	0.50	0.60	0.70	1.56	0.79	0.34	0.52	1.59	0.005
	13	2-0.6	0.46	0.49	0.54	0.66	0.82	1.78	0.77	0.38	0.62	1.61	0.003
	14	4.75-0.425	0.41	0.46	0.50	0.66	0.84	2.05	0.73	0.38	0.62	1.58	0.004
	15	2-0.425	0.35	0.42	0.46	0.56	0.64	1.83	0.94	0.43	0.77	1.57	0.004
	16	1.18-0.425	0.39	0.45	0.49	0.56	0.80	2.05	0.77	0.37	0.59	1.60	0.005

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III.RESULTS AND DISCUSSION

The summary of the test reports of the samples tested in the laboratory is presented in Table II. Sixteen different sizes of artificially graded NTS were tested under constant head.

TABLE III
Summary of the test reports of the samples tested in the laboratory

GRADATION	ACTUAL VALUE OF "K"	HAZEN	K-C	TERZAGHI	SLITCHER	BREYER	USBR
4.75-2	0.013	0.244	0.287	0.159	0.091	0.244	0.442
2-1.18	0.011	0.063	0.053	0.018	0.019	0.075	0.133
1.18-0.6	0.009	0.035	0.030	0.066	0.011	0.043	0.058
0.6-0.425	0.008	0.028	0.025	0.052	0.009	0.031	0.054
0.425-0.3	0.004	0.025	0.015	0.047	0.006	0.038	0.108
4.75-0.075	0.004	0.014	0.008	0.052	0.003	0.023	0.088
2-0.075	0.005	0.012	0.007	0.005	0.003	0.015	0.090
1.18-0.075	0.002	0.066	0.056	0.035	0.020	0.074	0.172
0.6-0.075	0.003	0.048	0.038	0.024	0.014	0.057	0.112
0.425-0.075	0.003	0.050	0.029	0.020	0.012	0.084	0.174
0.3-0.075	0.003	0.050	0.043	0.026	0.015	0.059	0.074
4.75-0.6	0.005	0.061	0.043	0.028	0.017	0.085	0.117
2-0.6	0.003	0.115	0.104	0.064	0.037	0.127	0.191
4.75-0.425	0.004	0.078	0.071	0.043	0.025	0.084	0.141
2-0.425	0.004	0.065	0.084	0.045	0.025	0.058	0.105
1.18-0.425	0.005	0.052	0.044	0.028	0.016	0.059	0.104

Sixteen different sizes of artificially graded NTS, which have resulted in the same gradation characteristics (d_{10}, d_{20}, d_{30}, d_{50}, d_{60}, C_u, C_c, I_o) within the specified ranges, have been classified as according to Indian Standard Soil Classification System (ISSCS) as ‘poorly graded’. The equations used for assessment of the hydraulic conductivity of artificially graded sand samples are listed in Table III. The equations developed by Hazen (1892), Kozeny-Carman (1956), Terzaghi (Odong 2007), Slichter (1898), Breyer (Kresic 1998) and USBR (Vukovic and Soro 1992), were used in this study. To estimate Hazen (1892) the hydraulic conductivity of uniformly graded loose sand with effective grain size (d10) between 0.10 and 3.0 mm and Cu less than 5. It evident from Table II shows that hydraulic conductivity values ranged from 0.244 to 0.012 cm/s for the NTS samples falling in specified gradations. While the presence of porosity (n) in the formula appears to be an advantage of the formula, due to the limits of Cu indicated in Table 3, this method does not provide accurate estimates for the sands. In the present study, the effect of the parameter Cu was ignored, and therefore the results of the grain size distribution might yield the same Cu for different sands.

Kozeny – Carman (K – C) method is one of the widely used methods developed for hydraulic conductivity calculations, and does not apply to clayey soils or soils with an effective size greater than 3 mm (Carrier 2003). Besides, the Kozeny (1927) and Carman (1937) equations were updated by some researchers (Collins 1961; Bear 1972; de Marsily 1986), who included the effect on hydraulic conductivity of both the particle diameter and porosity. Koltermann and Gorelick (1995) compared different methods and found that the actual Kozeny – Carman equation (Carman 1937; Bear 1972) is approximately at the core of potential relationships. Thus the original Kozeny – Carman equation is used in the present analysis, and Table 3 showed that hydraulic conductivity values varied between 0.007 to 0.287 cm/s for the NTS samples falling in specified gradations. Estimated values of hydraulic conductivity (k) by varying use of the Terzaghi approach is varied between 0.005 to 0.159 cm/s. Cheng and Chen (2007) found out that the formula of Terzaghi applied most to large-grain oil. Comparing the experimental results and the k values obtained via Terzaghi's method, it is revealed that the equation of Terzaghi, which has no recorded limitations, provides more accurate results than the other equations employed for NTS. Interestingly, the tests for bigger grains are far less reliable. It is therefore interpreted that grain size should not be the only parameter for making an accurate estimation of the hydraulic conductivity.

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This research shows that the Slitcher formula is the best suited to the hydraulic conductivity of NTS samples between 4.75-2, 4.75-0.075, 2-0.075, 1.18-0.075, 0.425-0.075, 0.3-0.075, 4.75-0.6, 2-0.6, 4.75-0.425, 2-0.425, 1.18-0.425. Estimated k values using the USBR equation were found to be deviating much for NTS samples. The deviation between measured and assessed values of hydraulic conductivity using different equations is due to either inaccuracy in measured soil parameters or to a deficiency in predictive equations. Table 4 presents a comparative analysis for the NTS samples using all the formulae considered in this study.

TABLE IIIII
List of equation employed in the study

Researcher	Equation	Limitations
Hazen	k = 6* 10-4 * $\left(\frac{g}{v}\right) * [1 + 10(n - 0.26)] * \left(d_{10}^2\right)$	Cu < 5
Kozeny-carman	k = 8.3*10-3*$\left(\frac{g}{v}\right) * \left[\frac{n^3}{(1-n)^2}\right] * (d_{10})^2$	0.1 < d10 < 3.0
Terzaghi	k = 0.0084 * $\left(\frac{g}{v}\right) * \left[\frac{n-0.13}{\sqrt[3]{1-n}}\right]^2 * (d_{10})^2$	-
Slitcher	k = 1*10-2*$\left(\frac{g}{v}\right)$* n3.287 * $(d_{10})^2$	0.01 < d10 < 5.0
USBR	k = 4.8*10-3*$\left(\frac{g}{v}\right) * (d_{20})^{0.3} * (d_{20})^2$	Cu < 5
Breyer	k =6*10-4 *$\left(\frac{g}{v}\right)$* log$\left(\frac{500}{Cu}\right) * (d_{10})^2$	1 < Cu < 20

The Table 4 displays the results of calculations performed to assess hydraulic conductivity on the basis of six different methods, expressed as a relative ratio of the difference between expected and measured values to the expected hydraulic value of the NTS samples at 16 different gradations.

TABLE IV
Results Of Predicted Hydraulic Conductivity Of Samples

Gradation	Actual Value of "K"(cm/s)	Predicted "k" (cm/sec) and Best fitted equation
4.75-2	0.013	0.0907 (SLITCHER)
2-1.18	0.011	0.0532 (KOZENY CARMAN)
1.18-0.6	0.009	0.0301 (KOZENY CARMAN)
0.6-0.425	0.008	0.00879 (KOZENY CARMAN)
0.425-0.3	0.004	0.0247 (HAZEN)
4.75-0.075	0.004	0.00321 (SLITCHER)
2-0.075	0.005	0.00286 (SLITCHER)
1.18-0.075	0.002	0.0199 (SLITCHER)
0.6-0.075	0.003	0.0478 (KOZENY CARMAN)
0.425-0.075	0.003	0.012 (SLITCHER)
0.3-0.075	0.003	0.0152 (SLITCHER)
4.75-0.6	0.005	0.0165 (SLITCHER)
2-0.6	0.003	0.0365 (SLITCHER)
4.75-0.425	0.004	0.0249 (SLITCHER)
2-0.425	0.004	0.0254 (SLITCHER)
1.18-0.425	0.005	0.016 (SLITCHER)

The results of correlation of predicted and actual values hydraulic conductivity by all equation is graphically represents in Fig.2

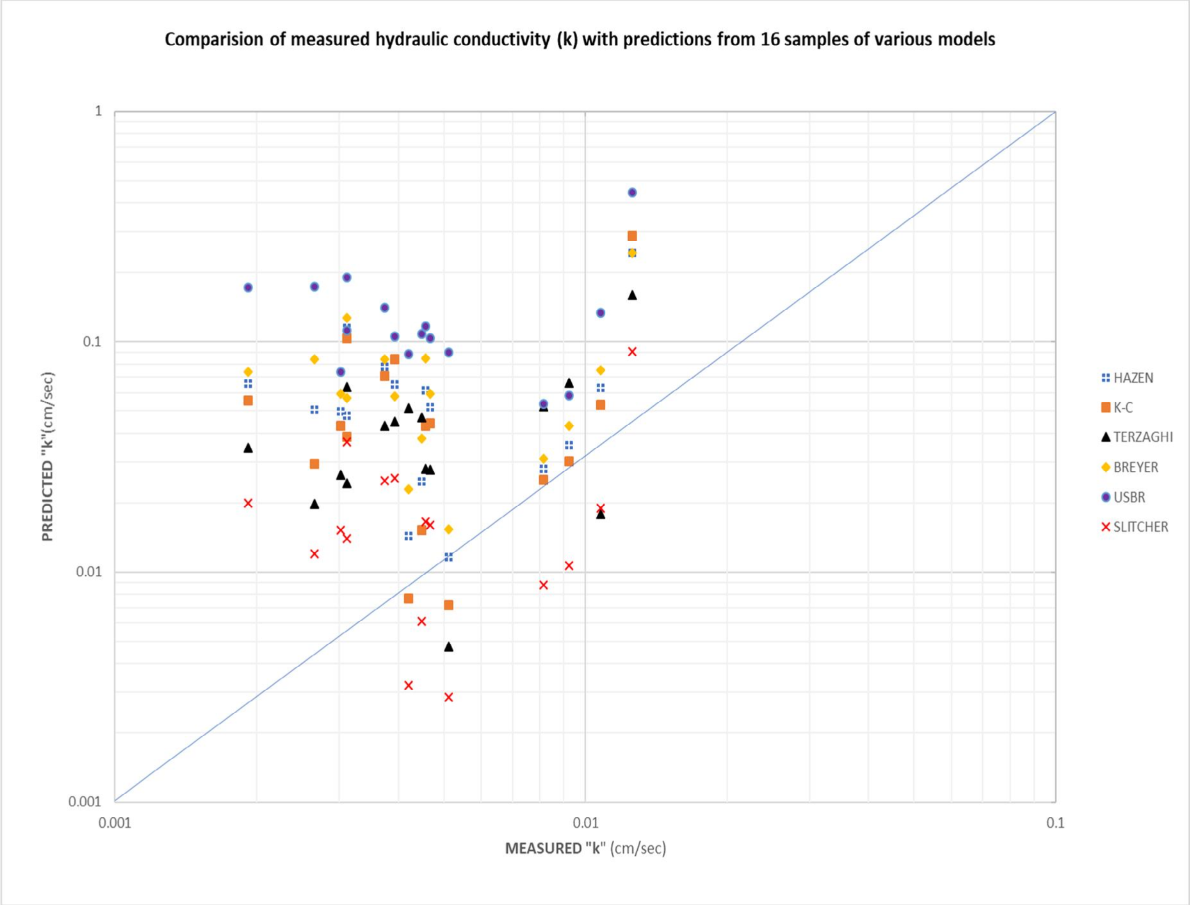

Fig. 2 Grain size distribution curves

IV. CONCLUSIONS

The objective of the present study is to study the gradation influences on soil hydraulic conductivity, which is of significance concerning some geotechnical problems, including stability analyzes, settlement, and conductivity computations. The sand used in the present study is "Well graded" Natural Sand. Later it is artificially graded into sixteen sets of grading Sixteen ranges of grain sizes (4.75–2, 2–1.18, 1.18–0.6, 0.6–0.425, 0.425–0.3, 0.3–0.075, 4.75–0.075, 2–0.075, 1.18–0.075, 0.6– 0.075, 0.425–0.075, 4.75–0.6, 2–0.6, 4.75–0.425, 2–0.425, and 1.18–0.425 mm) to test the hydraulic conductivity (k) under constant head condition. Six various methods were employed to estimate the hydraulic conductivity, i.e. Hazen, Kozeny–Carman, Terzaghi, Slitcher, USBR, and Breyer). The estimated values were then compared with the actual experimental values. The Slitcher and Terzaghi's equations gave the best fit values on the correlation between actual and estimated k values. whilst USBR and Breyer approaches give a low correlation with measured k values.

The results of the present studies and the correlation analysis of predicted and actual k-values published here suggest the following behavioral aspects:

A. The hydraulic conductivity is signifcantly influenced by grading properties which includes d_{10}, d_{20}, d_{30}, d_{50}, d_{60}, C_u, C_c, n, and I_o.
B. Grain size distribution of the soil have a signifcant effect on hydraulic conductivity of NTS samples.
C. The comparative research with other methods available in the literature on the interpretations of actual and estimated outcomes suggested that the best predictor of hydraulic conductivity shifts depending on the gradation of the tested sands.".

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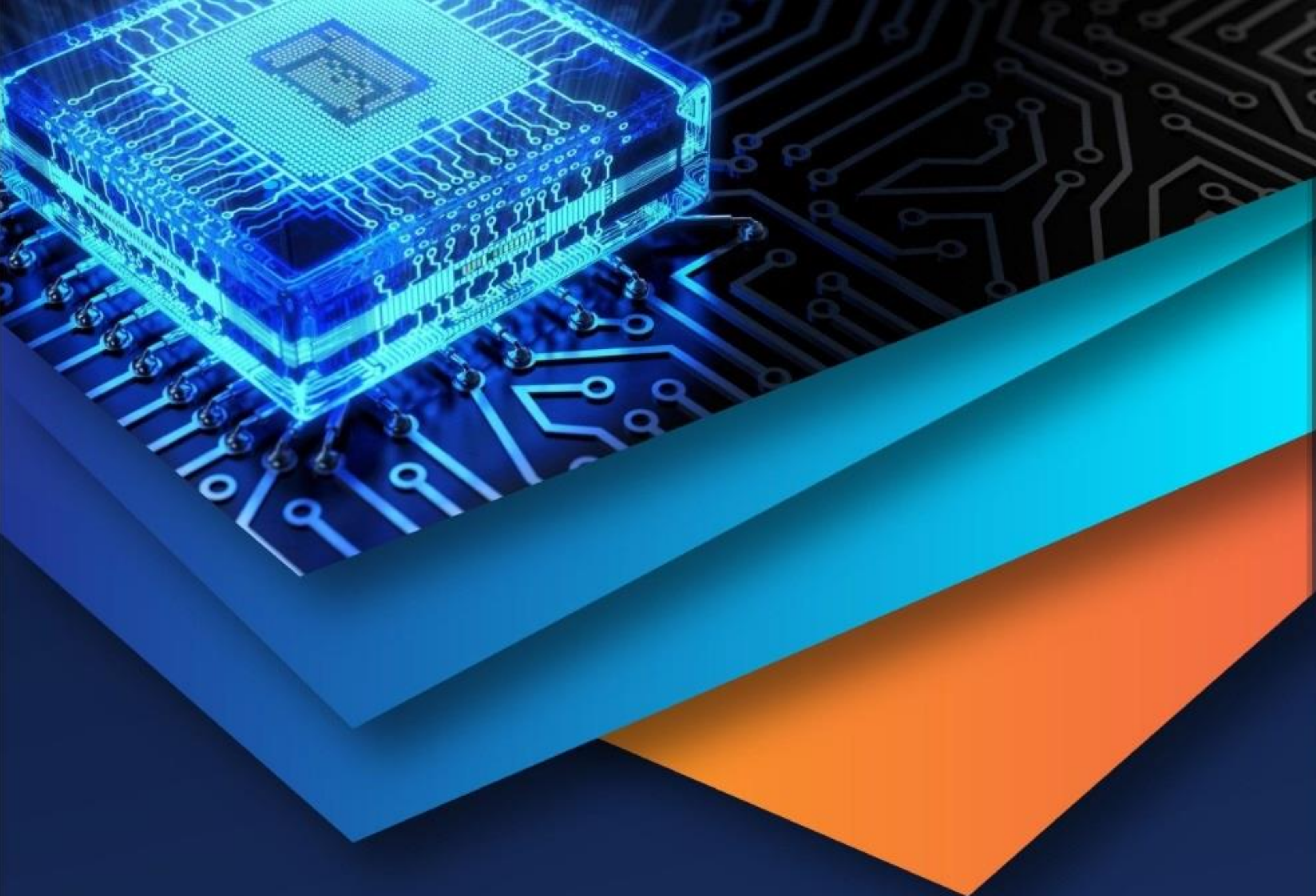

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