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Geometric Design of Roadway using DMRB for a Smart City

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Abstract: During the Design/Construction of any Roadway or Highway there are many elements, if overlooked can circumstance into complete hazardous wastage not only economically but also safety wise. For the proper Geometric Design of a Roadway all the physical is required to be designed as per the standard norms and following the constraints. Any design should be done in an optimistic manner to have the outcome not only economical but also eco-friendly. In this Design all the parameters concerning the roadway safety, aesthetic, economic & other human behavioural parameters directly being governed by the road Geometry are considered. The Geometric Design has three basic elements i.e. Horizontal Design, Vertical Design and Cross-Sectional Design. All these three parameters together integrated gives a 3-Dimentional layout of the roadway. The Project comprises of Detail Geometric Design using Design manual for roads and bridges (DMRB) of the Eastern Link Road Located at the East of Leighton buzzard in United Kingdom. Leighton Buzzard is in Bedfordshire, England. It's near Chiltern Hills with Luton(to East) and Milton Keynes(to North-West).
Author Keywords: Geometric Design, Design manual of Road and Bridges (DMRB), Superelevation, Design Speed

I. INTRODUCTION

Today the highway designers face much safety information originating from manuals, guidelines, handbooks, and research findings. This information continuously accumulating marks a new era in the field of highway geometric design. In order to have a safe system, elements pertaining to road-safety are dealt with by considering how different parameters of the road transport system interact, rather than by implementing individual countermeasures in relative isolation. The Geometric design elements are co-dependent and together work as a system maintaining individual significance.

Geometric design (GD) is a branch of computational geometry (Computational geometry is a branch of computer science devoted to the study of algorithms which can be stated in terms of geometry.).

GD is dynamic co-dependence between the construction and representation of curves, surfaces, or volumes and is managed by the Geometric modelling.

The surface modelling is required to be done with extreme care since all the designing is afterwards based on this surface model, the after that the Curves and its parameters are sorted out as per the design standards. GD studies especially the construction and manipulation of curves and surfaces given by a set of points using polynomial, rational, piece wise polynomial or piece wise rational methods.

The geometric design is concerned with the positioning of the physical elements of the roadway according to standards and constraints.

The basic objectives in geometric design to have an optimistic approach also by keeping the Environmental factors in mind. Geometric Design also affects the livelihood and all the basic requirements of day to day life which can be explained as designing roads to foster broader community goals, including providing access to employment, schools, businesses and residences, ranging from a number of travel modes such as bicycling, transit, walking, , and automobiles, and also minimizing fuel use, emissions and damage to the environment.

The Report is based on the geometric designing of highway comprising of the Horizontal as well as Vertical Design Using Civil 3D software as per the standards mentioned in the DMRB (Design Manual of Road and bridges) or any other amendments mentioned by the Bedfordshire council manuals.

To solve the problems, we had collected the preliminary survey data of Leighton Buzzard (United Kingdom).Complete Geometric Design of the section that is about 2.740 Km in length along a Greenfield is done. New Junction and a roundabout is proposed at the southern arm for proper and smooth traffic flow

II. LITERATURE REVIEW

Geometric design of highway comprises of the design of features of highway such as cross - sectional elements, visible sight distances, Horizontal alignment, curves, super elevation, and other allied features. Plan and design of the geometric elements of the road during the initial alignment stage itself by considering future traffic growth. Once the construction is complete any change in the Geometric features causes a handsome addition to the expenditure cost. This paper presents has covered the past work on geometric design of highway and elaborately presented the planning and designing of geometric features.

Although there are number of factors that influences design of highway, but suitable geometric design have objective of giving optimum efficiency in traffic operation with contentment safety measures at reasonable cost. The research paper includes the road safety parameter directly influenced by the Geometric parameters of the Road.

The insight given by the Paper "Highway Geometric Design from the Perspective of Recent Safety Developments" (George Kanellaidis-ASCE-2008).Research of human factors in highway engineering includes these two main areas: change in driver behaviour due to Geometric Design. A critical review of pertinent research and related provision. For the research purpose the review of the Geometric design of Germany and Great Britain is considered as presented in the paper "Human Factors In Highway Geometric Design" (By George Kanellaidis-ASCE-1996).

Review of the paper "Maximum curving speed" (Nazmul hasan -ASCE 2018) supporting the idea of the maximum curving speed modeled to ensure comfort and safety, considering two primary parameters: the curve parameters and the vehicle characteristics. "Exploring the Association between Traffic Safety and Geometric Design Consistency Based on Vehicle Speed Metrics" (Kun-Feng Wu, Eric T. Donnell, Scott C.

Himes, and Lekshmi Sasidharan-ASCE-2013) research has demonstrated the relationship between operating speeds and geometric design features on two-lane rural highways.Review of the paper "Aspects of Superelevation Design" (G. Kanellaidis -ASCE-1991), the paper shows the Superelevation design using the AASHTO design standards based on the relation-ship between the degree of curve and actual operating speeds, to harmonize highway Superelevation design with drivers' actual speed behavior, which could enhance highway safety.

The paper "Safety Evaluation and Adjustment of Superelevation Design Guides for Horizontal Curves Based on Reliability Analysis" (Hamid Farhad Mollashahi, Kasra Khajavi, and Asieh Khadem Ghaeini-ASCE-2017) gave a brief idea about the use of Superelevation and changes in a road's transverse slope and how they are typically based on the road's design speed to provide safety and comfort for a vehicle driving on a horizontal curve. However, due to the difference between operating and design speeds, there has always been uncertainty in determining the margin of safety using Superelevation.

The paper "Method of gtrading of Highway" (J. Tainganidis and G. Kanellaidis -ASCE-1992)The grading plan of a highway is mainly determined by the alignment, profile, cross sections, and drainage requirements of the highway. In the case of an intersection, the grading is determined through the consideration of the aforementioned elements of intersecting highways as a whole with adjacent roads, structures, and surrounding topography (AASHO: A policy 1965).The review of the paper "Method for Balancing Cut-Fill and Minimizing the Amount of Earthwork in the Geometric Design of Highways" (A. Burak Goktepe, A.M.ASCE, and A. Hilmi Lav - 2003) focuses on the economic considerations as important as other design controls and elements of design. Hence, the designer should maintain the cut-fill balance with focus on

Minimizing earthwork which may significantly decrease construction costs. In practice, one way to reduce the amount of earthwork is to set the grade line as closely as possible to the ground line while also considering cut and fill balance. However, this practice may be misleading since balancing is achieved along the center line of the road. In reality, the center line ground elevation rarely represents the whole cross section in terms of cut and fills balancing. Especially in mountainous terrain, transverse changes in ground elevation with respect to the center-line elevation of cross section are abrupt.

Consequently, conforming the grade line to the weighted ground line integration of the weighted ground elevations along the center-line would give balanced cut and fill and reduced amount of earthwork, giving a more economic result. The paper "Innovative Roadside Design Curve of Lateral Clearance: Roadway Spiraled Horizontal Curves" (Qing Chong You and Said M. Easa, M. ASCE-2017) presents an innovative design method for determining lateral clearance needs on a spiraled horizontal curve to satisfy sight distance requirements.

Review of the paper "Reliability Analysis of Vehicle Stability on Combined Horizontal and Vertical Alignments: Driving Safety Perspective" (Kesi You1 and Lu Sun, M. ASCE-2013) A driver/vehicle/road closed loop dynamic simulation model 3D alignment was made using Matlab/Simulink for reliability analysis of vehicle stability on the alignment and profile i.e. horizontal and vertical curves.

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A. *Scope of Work*

The Geometric design mainly consists of the following vital parameters.

1) Finalisation of Site (Fixating the ROW).
2) Determination of Design speed.
3) Site survey
4) Finalizing the cross-sectional elements of roadway
5) Horizontal Design
   a) Fixating the Centre Line of alignment and other road cross sectional features (in other words we can also say as "Fixation of the 2D Design".
   b) Design of Horizontal curves using DMRB standards.
   c) Identification of the intersections and its Design (In this case, one roundabout and one signalised Intersection)
   d) Design of cross-sectional elements.
   e) Super elevation Design.
6) Vertical Design.
   a) Design of crest and sag curves and check for their constant "K" Value (K= rate of change of gradient per unit Length).
   b) Cut and Fill Quantity balancing in Vertical Design
   c) Other site Considerations.

III. METHODOLOGY & DESIGN CONTRAINTS

Proper highway geometric design is an important issue in the design and evaluation of highways/Roadways to attain smooth and safe traffic operations. This paper presents a Detailed design of urban Roadway in Europe (East of Leighton Buzzard). Research work on design is categorized into four main areas: (1) Design speed determination; (2) Horizontal Design; (2) Vertical Design; and (3) Super elevation. Design Speed addresses the different effects of geometric parameters on the prediction of operating speed. The Design consistency of the Highway elements can directly be calculated by the Operating Speed of the Roadway. Safety considerations explain the different interdependencies between highway safety and highway/traffic elements & vehicle stability. A detailed design of the Leighton Buzzard Greenfield road located in the east of the city to solve its future requirements has been done.

The road alignment shall be designed to ensure that Standards of curvature, visibility, super elevation, etc. should be consistent with the anticipated vehicle speeds on the road & such provision shall be accompanied for the Design Speed. Normally driver tends to drive at a relatively higher speed at flat gradient terrain rather than at hilly terrain or among dense land use constraints.

A. *Finalisation of Site*

Leighton Buzzard is in Bedfordshire, England. It's near Chiltern Hills with Luton(to East) and Milton Keynes(to North-West). .It is Located at the global coordinates (Latitude - 51°55'11.88"N & Longitude- 0°39'35.67"W).In the west, Linslade is merged along with Southcott. There is economic expansion of Leighton Buzzard in east direction: 2,500–4,500 homes & 35% affordable housing privileges are planned for east Leighton Buzzard for the Luton/Dunstable/Houghton Regis growth area and 900 homes along with 35% affordable housing are considered west of Linslade. It now encompasses Stanbridge RAF & the former hamlet of Leedon. The population of Leighton-Linslade per 2001 census was 32,417.

Fig.1.1 Leighton Buzzard, England

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B. Determination of Design Speed

The Design at the existing road approach is looked into for the "Hockliffe Road" & the existing road is designed for the National speed (NS) that is - 30mph/48Kmph

Fig.1.2 Existing Sign Board, Hockliffe Road

SPEED LIMIT		DESIGN SPEED
MPH	KPH	KPH
30	48	60B
40	64	70A
50	80	85A
60	96	100A

Table.1.1 Design Speed table from (DMRB TD 9/93 table-2)

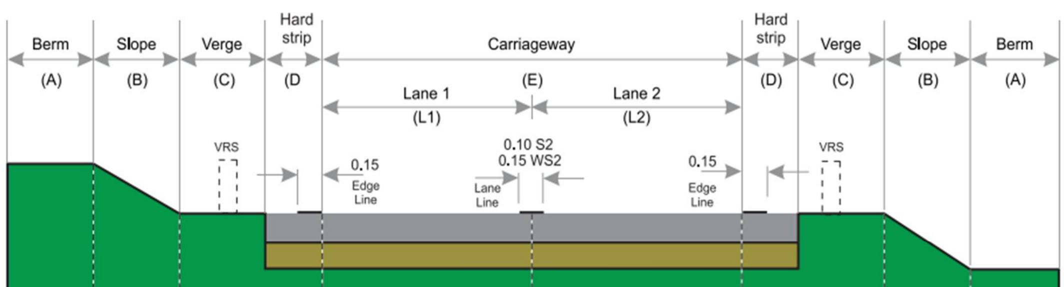
C. Site Survey

The survey of the Eastern Link road is done using a Lidar Machine and the survey output is received in the form of Grid patterns of widely spread three dimensional points over the site giving its coordinates in (PENZD format). {Note:- PENZD – is a widely .txt format mostly used for the Civil 3D Software denoting Point, Easting, Northing. Elevation & Description in coma delimited format). A second .Dwg file was also used with the 3D string models of the survey at certain places.

D. Finalizing The Cross-Sectional Elements Of Roadway

Two broad divisions are used in DMRB Standard for defining the cross-section in association with the environment through which the highway passes; namely Rural-roads and Urban-roads. These can be further classified as Motorways and All-Purpose roads with a further categorisation as Mainline and Connector road.

The roadway cross section is determined by using DMRB TD 27/05 Figure 4-1b. Hence, we will be using DG2B for Dual carriageway motorize track.



Road Type	A	B	C[2]	D[3, 11]	E[3]	E[3] L1	E[3] L2	D[3, 11]	C[2]	B	A
Single (S2)	Varies	Varies	2.50	1.00	7.30	3.65	3.65	1.00	2.50	Varies	Varies
Wide Single (WS2)	Varies	Varies	2.50	1.00	10.00	5.00	5.00	1.00	2.50	Varies	Varies

Single Carriageway

Fig .1.3 Dimensions of Cross-Section Components for Rural All-Purpose Roads Mainline (DMRB TD 2705- figure 4-3a)

E. Horizontal Design

Before the detail three dimensional designs commence the finalization of the 2D design is more important. The 2D design is the Top view projection of our project stretch. The "2D view design" comprises of the two-dimensional fixation of the boundary limits and its proper positioning of the different cross-sectional elements in X-Y plane. The most important parameter is to define the Boundary Site Limits (Right of way) i.e. the site constraints within which the limits of our project are defined. All the cross-sectional elements – (a) Carriageway centreline & Edges, (b) Verges, (c) Footpaths, (d)Ponds, (e) Junction approaches, (f)Leisure tracks, (g) Position of Utility services (e.g. Bus-Shelter, Lighting Poles, Pedestrian Crossings), (h)Position of Krebs its up stand and drop.The parameters required for the Horizontal Design of the roadway are mainly taken from the DMRB TD 9/93 Table no. 3, shown in figure from the above table, we have our minimum radius with a super elevation of 2.5% as 510 meters for speed of 60 mph.

Table 1.2 Geometry Design Elements (TD 9/93 Table no. 3)

DESIGN SPEED kph	120	100	85	70	60	50	V^2/R
STOPPING SIGHT DISTANCE m							
Desirable Minimum	295	215	160	120	90	70	
One Step below Desirable Minimum	215	160	120	90	70	50	
HORIZONTAL CURVATURE m.							
Minimum R* without elimination of Adverse Camber and Transitions	2880	2040	1440	1020	720	520	5
Minimum R* with Superelevation of 2.5%	2040	1440	1020	720	510	360	7.07
Minimum R* with Superelevation of 3.5%	1440	1020	720	510	360	255	10
Desirable Minimum R with Superelevation of 5%	1020	720	510	360	255	180	14.14
One Step below Desirable Minimum R with Superelevation of 7%	720	510	360	255	180	127	20
Two Steps below Desirable Minimum Radius with Superelevation of 7%	510	360	255	180	127	90	28.28
VERTICAL CURVATURE							
Desirable Minimum* Crest K Value	182	100	55	30	17	10	
One Step below Desirable Min Crest K Value	100	55	30	17	10	6.5	
Absolute Minimum Sag K Value	37	26	20	20	13	9	
OVERTAKING SIGHT DISTANCES							
Full Overtaking Sight Distance FOSD m.	*	580	490	410	345	290	
FOSD Overtaking Crest K Value	*	400	285	200	142	100	

F. Design of Intersections & Roundabouts

The intersections are properly accompanied with signalised junction development on the Hockliffe road and a roundabout design on the Leighton Road. The junctions play a vital role in affecting the traffic flow speed and are provided for the driver/user's safety on the road. All the Junction Design parameters are taken into consideration from the DMRB Volume 6 Section 1TD50/04 and the Roundabout is designed as per the DMRB Volume 6

Section1 TD16/07.

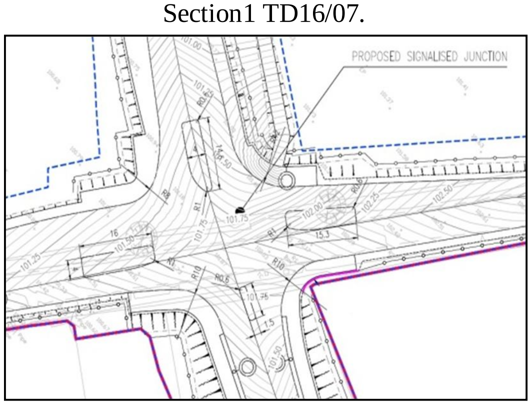


Fig .1.4 Junction design at Hockliffe Road using DMRB Volume 6 Section1 TD50/04

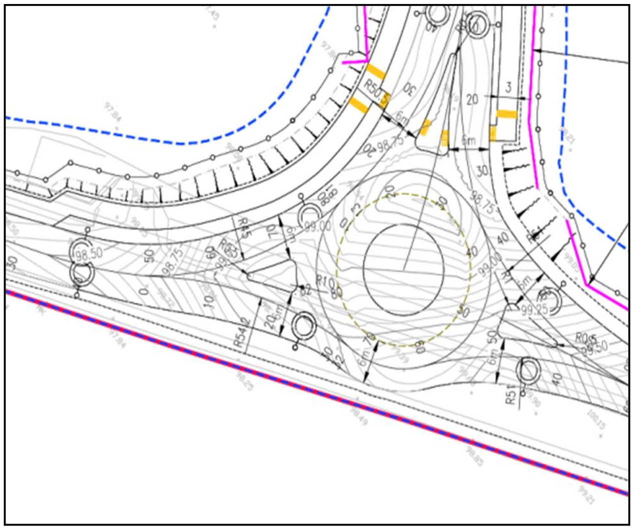


Fig .1.5 Roundabout design at Leighton Road using DMRB Volume 6 Section1 TD16/07

G. Super elevation Design

The calculation of the super elevation is one of the most important parameter for the safety point of view for the driver/user. The super elevation is provided on the curves for counterbalancing the centrifugal force acting on the vehicle on the radically outward direction. In this paper the super elevation is provided in accordance to the Volume 6 Section 1 TD 09/93. The table 1.2 above mentioned gives the required super elevation for the desired curves accordingly bifurcated as per the design speeds. The Formula for the Super elevation and Transition length provided for the super elevation is given below as per DMRB TD9/93 clause 3.2 & 3.16 respectively

$$S = \frac{V^2}{2.828 \times R} \qquad L = \frac{V^3}{46.7 \times q \times R}$$

Where V = Design Speed kph
R = Radius of Curve m.
S = Super elevation %.
L = Length of transition (m)
V = Design Speed (kph)
q = Rate of increase of centripetal acceleration m/sec^3)
In rural areas super elevation shall not exceed 7%
In urban areas with at-grade junctions and side
Accesses, super elevation shall be limited to 5%.

H. Vertical Design

It is physically impossible to design a roadway with a constant gradient and thus proper vertical curves (Parabolic) are introduced at the intersecting points of grade breaks. The parameters governing the vertical curves are its Length, Radius and the most important is the K value. The K is a constant parameter and is proportional to the radius and the change in gradient of the intersecting point. Other parameters like drainage governs the maximum and minimum required gradient (i.e. min. Gradient should be 0.5%), Forward visibility. There are many other parameters like no Compound curves are required. Also for the Vertical design a transition curves (spiral) are provided before and after the curve to have a proper transition .In this paper all the designs are done as per design standards mentioned in the DMRB and also all the tie-ins along all the junction points, Roundabout & any other leisure routes are done properly and checked by the output contour pattern generated by the software at interval of Minor Contours 0.05m. & Major Contours 0.25m.

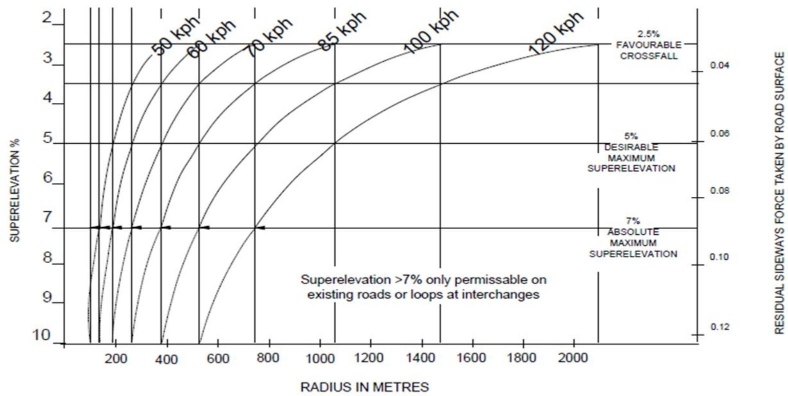


Fig .1.6 Super elevation (Volume 6 Section1 TD16/07 Fig5)

IV. CONCLUSION

The paper has represented a detailed Geometric Design based on the Design Manual of Roads and Bridges (DMRB) of a site in Leighton Buzzard , UK ,intended to give a brief idea of all the parameters pertaining to the Road Geometric design and all other safety parameters being considered. The project inclination is towards providing a conceptual approach and preliminary in-sights regarding all the safety parameters regarding the Design of a roadway for a smart city.

The Improved Road geometry gives us the eye-sparkling results of improved capacity and operational efficiency of the traffic, Improve in the safety reducing the accidents and traffic jam incidents, increase in the productivity for commercial vehicle by optimizing the design speed for more efficient travelling, increase in the traveller comfort and convenience of the road users, improve in the transportation operation on the intersections and congested areas of roads with appropriate alternatives, with a reduction in the environmental pollution and energy impact & a vital Improvement in the public transportation services and operations to increase the growth of public transport The present study re-ported a positive association between the increased user comfort and safety related parameters governed on the geometric design and its dynamic nature.

With regard to future research, it should be noted that all the design parameters, variables and formulae pertaining to the geometric design are taken directly from the DMRB and neither the derivations nor the factors being affected by the derivation are considered in this design. All values are directly taken from the DMRB.

Although the research has covered all the parameters pertaining to the Geometric Design of the Roadway, for the future research the Drainage design should also be considered to have a complete design ready as for the site requirement. This paper has provided a collective set of information that might be required or considered for the design of any roadway.

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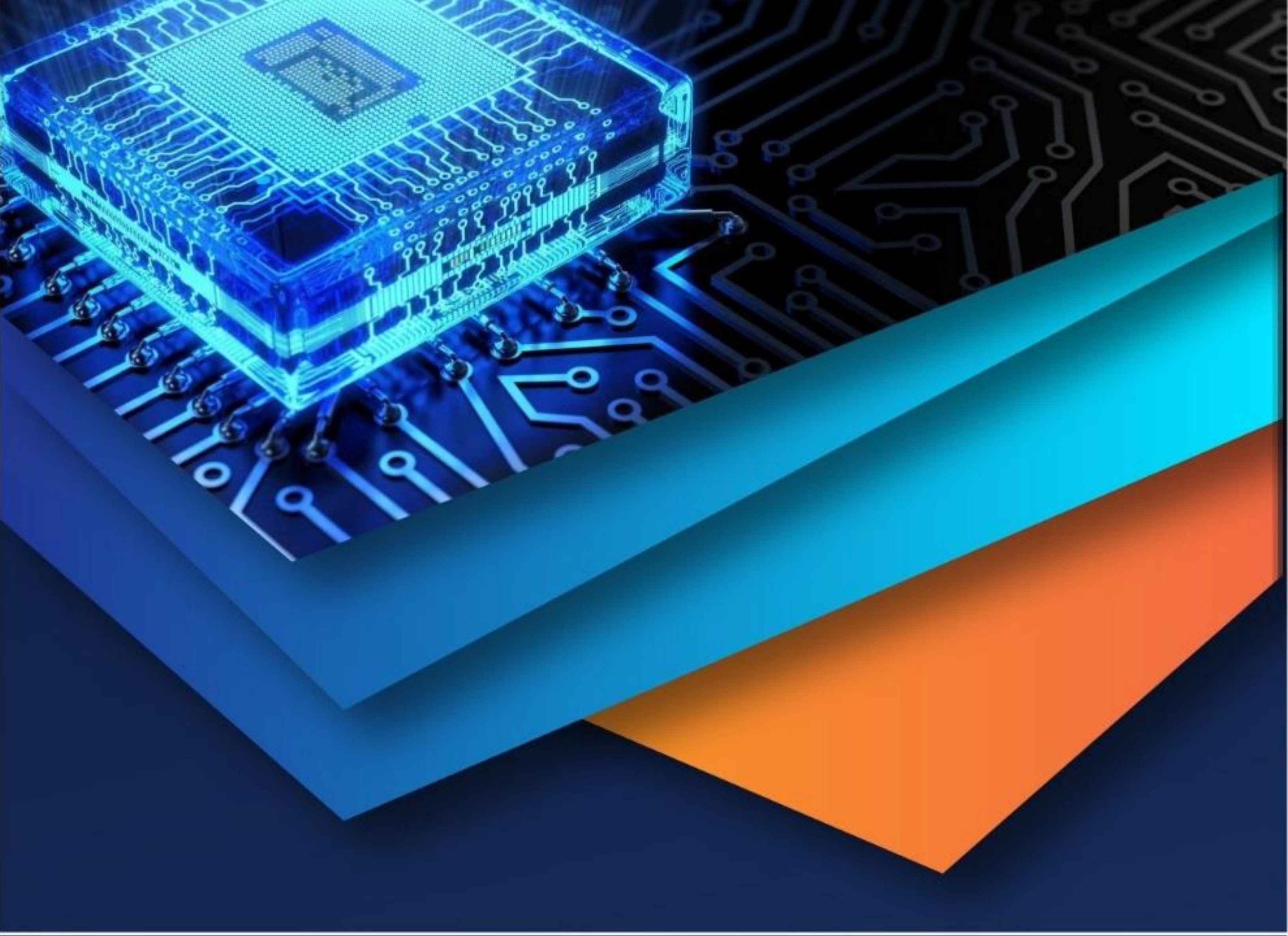

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