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Review of Design Procedure for Box Girder Bridges

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Abstract-Due to population growth and rapid urbanization, there has been an enormous growth in traffic volume on highways over the last few decades. In order to ensure smooth flow of traffic, numerous new highways and flyovers are being constructed. The use of box-girders has proven to be a very efficient structural solution for highway bridges and flyovers due to its high tensional rigidity, serviceability, economy, aesthetics and the ability to efficiently distribute the eccentric vehicular live load among the webs of the box-girder. For the multi-lane bridges, multi-spine/cell box-girders are most commonly adopted in order to limit the local deformations in the top slab of box. Many studies are available on suitability of box girder bridges for various spans and effect of stresses for skewed box girder bridge. The curvilinear nature of box girder bridges along with their complex deformation patterns and stress fields have led designersto adopt approximate and conservative methods for their analyses and design. Recent literature on straight and curved box girder bridgeshas dealt with analytical formulations to better understand the behavior of these complex structural systems.It was found that researchers have used finite element method for the analysis of box girder bridge. However, not much studies are available for the design of box girder bridge.Hence, this study emphasized on the design and analysis of box girder structure.The literature also indicates that the various researchers have used ANSYS, MIDAS and Stadd-Pro for the analysis of Pre-stressed Concrete Structures using FEM.
Keywords-Box girder, Torsional rigidity

I. INTRODUCTION

Bridge is life line of road network, both in urban and rural areas. With rapid technology growth the conventional bridge has been replaced by innovative cost effective structural system such as T-Beam Girder System and Box Girder Bridge System. In spite of difficult design procedure and complex form work requirement , box girders, have gained wide acceptance in freeway and bridge systems due to their structural efficiency, better stability, serviceability, economy of construction and aestheticappearance.In bridge design procedure span length and live load are important and affect the conceptualization stage of design. Various live loads that are defined by IRC 6:2016 and experienced by bridge deck system are Class A, Class B, Class AA and Class 70R. These are the combinations of wheel load and track loads. Wheel loads are one which are transferred by the wheels of trucks and track loads are one which are transferred by pair of wheels and axels connected by belts. The effect of these loadsvaries from span to span. For example, on shorterspans track load governs whereas on larger span wheel load govern. Designs considering combinations of these loads on bridge deck system provide scope for research. However, the bridge deck structural system adopted is influence by factor like economy and complexity in construction.

This paper undertakes the review of published records on all such efforts documenting the effect of various combinations of live loads stated above and design procedures adopted for such load combinations.

A. *Literature available on stated theme can be classified as*

1) Studies dealing with analysis and design of bridge deck system using various combinations of span to depth ratio.
2) Studies dealing with analysis and design skewed box girder bridges.
3) comparison among limit state method and working stress method.
4) Analysis of T-beam girder and box girder.

Following sections present the review divided in two such parts.

II. LITERATURE REVIEW

This section presents entire literature in four parts stated below;

A. Analysis and design of bridge deck system using various combinations of span to depth ratio.

1) Gupta et al: This paper presents a parametric study for deflections, longitudinal and transverse bending stresses and shear lag for the Rectangular, Trapezoidal and Circular cross-sections. Commercially available software SAP-2000 has been used to carry out linear analysis of these box girders. Three dimensional 4-noded shell elements have been employed for discretization of domain and to analyze the complex behavior of different box-girders. The linear analysis has been carried out for the Dead Load (Self Weight) and Live Load of IRC: 70R loading, for zero eccentricity as well as maximum eccentricity at mid-span. It was found that the rectangular section is superior to other two sections. In rectangular box girder with increase in depth of box girder the deflection decreases, but in lower proportion with the same increment of depth. Similarly with increasing the depth, the bending stress distribution along the span also decreases, but the reduction is not in same proportion with the increment in depth. Shear stress distribution across the section indicates that the value at the web flange junction was very high. As the depth increases, the shear stress reduces, but the reduction was not proportional to the increase in depth. In live load case for symmetric loading it was zero at the centre of the flange, but in eccentrically placed loading, its distribution at the centre of the flange changes in magnitude.Among rectangular, trapezoidal and circular cross section box girders for all depths, the deflection was highest in circular girder under the dead load and live load (centrally & eccentrically) cases and least in rectangular girder. Therefore it can be concluded that the rectangular section is the stiffest section among these three sections.

2) Satwik et al.: presented a comparative study of rectangular and trapezoidal concrete box girder using finite element method. In this study simply supported two lane, single cell concrete box girder bridge was analyzed for dead load and IRC: class 70R live load using Finite element Software SAP2000. The parameters investigated in this analytical study were shape (Rectangle and trapezoidal), span length and total depth of box girder.A total of 70 model of bridges subjected to Dead Load and IRC 70R loading were analyzed. In the first 35 models, rectangular Box girder Bridges are analyzed for different span length of 20m, 25m, 30m, 35m and 40m and also for different total depth of box girders 1.6m, 1.8m, 2.0m, 2.2m, 2.4m, 2.6m and 2.8m. In the second 35 models, Trapezoidal Box girder Bridges were analyzed for different span length of 20m, 25m, 30m, 35m and 40m and also for different total depth of box girders 1.6m, 1.8m, 2.0m, 2.2m, 2.4m, 2.6m and 2.8m.The maximum vertical deflection, bending moment, shear force and torsional moment are reported increase in span causes increase in maximum top flange deflection values for both rectangular and trapezoidal box girder sections, however increase in total depth of box girder causes decrease in maximum top flange deflection values for both sections. Also for span 40m and total girder depth of 1.8m, maximum top flange deflection value for rectangular section is 3.01% lower than that of trapezoidal section having similar conditions and for rectangular section of span 40m and girder depth of 1.8m, maximum deflection value was within span/800 as per Indian codal provisions. Increase in span causes increase in deflection and force values for both rectangular and trapezoidal sections, also increment of total depth of girder reduces deflection but increases force values for both sections. Bridge deflection for rectangular section, for total depth of girder equal to 1.8m and span of 40m was within the condition Span/800 as mentioned in IRC112:2011 section 12.4.1. Bridge forces in rectangular and trapezoidal section for girder depth of 1.8m and span 40m follows closely with 1.76% increment in bending moment value for rectangular section and 2% higher shear force value for rectangular section and net value of 7.41% lower for rectangular section in comparison with trapezoidal section. There was decrease in deflection value for rectangular section by 3.01% for span 40m and total depth of 1.8m than that of trapezoidal section.

B. Analysis and design of skewed box girder bridges.

1) *Ankush et a:* .presented a comparative Study on T-beam Girder and Box Girder Bridges for different skew angles and live load conditions. Study was carried out to understand the behavior of a two lane skew T-beam bridge and a skew box girder bridge for a fixed span of 20m and skew angles of 10°, 20°, 30°, 40°, 50° and 60°. The live loads considered on the bridge are IRC Class AA Tracked and IRC Class A Train. Modeling and analysis of all the bridge models was performed in SAP2000 (Version 14) software after validating it with the values obtained by manual calculations. From the analysis following conclusions are drawn-

a) The longitudinal bending moment on the obtuse angled girder of the T-beam decreases as the skew angle increases whereas for the inner girder it decreases till a skew angle of 30º and it further increases till the skew angle of 60º. Similarly for the obtuse angled web of the box girder the bending moment decreases and it increases for the acute angled web. This is because the centerline of the bridge or the traffic flow is not parallel to the plane of maximum stress.

b) The shear force for both T-beam and box girder bridges decreases as the skew angle increases

c) The deck slab moments generated also increases along with the increase in the skew angle due to wrapping of dec *d)* It is observed that the stresses generated by IRC Class AA Tracked vehicle are more compared to IRC Class A train vehicle. Indicating that the bridges designed using IRC Class AA Tracked can be adopted for multipurpose use

e) Comparing the results of longitudinal bending moment, shear force and torsional moment suggest that T-beam section is better than box girder section for medium span bridges

f) SAP2000 software is useful in developing bridge models and providing comparable results.

2) *Khaled et a: . This* paper presents highlights of references pertaining to straight and curved box girder bridges in the form of single-cell, multiple-spine, and multicell cross sections. The literature survey presented here deals with elastic analysis and experimental studies on the elastic response of box girder bridges. Among the refined methods, the finite-element method is probably the most involved and time consuming. However, it is still the most general and comprehensive technique for static and dynamic analysis, capturing all aspects affecting the structural response. The other methods proved to be adequate but limited in scope and applicability.

3) *Mulesh et a:*a study on performance of RCC box type superstructure inCurved bridges. In this paper, various behaviors like bending, shear, axial & torsion are presented for horizontally curved RCC box bridges considering 3-D FEM using SAP software. FEM models are prepared for four different span lengths keeping the same material properties with varying degree of curvature from 0° to 90° for different load conditions & combinations toget multiplication factor for various actions like BM, SF, AF & TM w.r.t to straight bridge tomultiply the desired parameters of straight bridge to get that for curved bridge. Result indicates that the increase in the torsion for any set of graph is comparatively steeper than that of bending moments, shear forces and axial carrying capacities which indicates that box section is having higher torsional stiffness and is nonlinearly vary with degree of curvature. The study also provides multiplication factors for all the parameters for varying degree of curvature (i.e. 10° to 90°) W.r.t. a straight bridge (0°) and for varying spans (between 15m to 30m). From the study it was observed that for different span, the multiplication factor for variable degree of curvature is varying linearly for axial force & bending moment, which is about 1.2 to 1.3 for 90° curvature. Multiplication factor for torsion moment is varying nonlinearly having 1.8 to 1.9 for 90° curvature, while there is no need to apply multiplication factor for shear force.

4) *Gokhan et a:* This paper examines the seismic performance of a three-span continuous concrete box girder bridge with skew angles from 0 to 60 degrees, analytically. The bridge was modeled using finite element (FE) and simplified beam-stick (BS) using SAP2000. Different types of analysis were considered on both models such as: nonlinear static pushover and linear and nonlinear time history analysis. A comparison was conducted between FE and BS, different skew angles, abutment support conditions, and time history and pushover analysis. From the analysis following conclusion can be drawn-

a) Predicted modal properties with the FE and BS models were comparable; the BS model was successful in capturing the modal coupling due to the skew and the significant modes needed for further analysis. Nonetheless, FE models should be considered when dealing with very large skew angles (> 30 degrees) in order to capture the higher mode effects.

b) The Uniform Load profile was the most consistent in predicting similar sequences of hinge formation between the FE and BS models. Ultimately, the BS model, when compared to the FE model, accurately captured the overall nonlinear behavior of the bridge when using the Uniform Load profile.

c) Bridges with larger skew angles (> 30 degrees) experienced larger deformations, which in turn, resulted in larger ductility demands; however, forces in the substructure elements remained relatively unaffected with exception to the torsional response of the columns (at are on the diagonal with respect to the acute corners of the bridges.

d) Time history analyses suggested that the shear keys had marginal effect in reducing the torsional response with increasing skew angles greater than 30 degrees.

e) The direction of the two horizontal components of the strong motions relative to the longitudinal and transverse directions did not have any significant effect on the overall response.

f) Maximum forces at the abutments of skewed bridges were unevenly distributed which would potentially lead to progressive failure of support elements.

g) For larger skew angles, the results from the nonlinear time history analyses agree with the observed yield mechanism in the columns from the pushover analyses.

*5) MdBasiret a:*The objective of this paper was to evaluate the dynamic responses of a curve-skew bridge deck supported by multi girders. The parameters influencing the deck behavior considered are transverse vehicle position,skew angle and curvatures. The numerical transient dynamic analysis is performed using a 3-D finite element model of bridge-vehicle-interaction (BVI). The analysis results show the deck displacement ratio of the curve-skewed bridge is significant along the transverse radial direction and especially maximum at the corner region of a skew deck. The torsion and deformation flexibility of the bridge caused by curvature and skew angle are key factors for higher displacement ratios which may induce cracking within the concrete. Hence special care needs to be taken for the curve-skewed deck especially at the bridge end location. The acute region skewed deck subjected to higher vertical and torsional deformation provides abrupt increase of displacement ratio along the transverse deck direction. Since high skewness in acute region arise difficulties in reinforcing of concrete, especially for orthogonal, hence special care needs to be taken for this region.

6) Shrutiet a: presented a static analysis of RC box girder bridge with skew angles, 0 and 15 degrees. The bridge was modeled using finite element (FE) method using SAP2000. The results of finite element (FE) and modal analysis were presented to study the influence of skew angle on the natural frequency for the entire skewed bridge. On the other hand the structural response for the superstructure covering elemental stresses, base reaction and joint displacements were also studied. Joint reaction and base reactions are calculated for different load cases . From the analysis following points can be concluded-

joint reactions are higher in case of vertical loads and least in case of parapet wall.

For the varying load cases, as the skew angle increases, base reactions also increases.

7) Yongda et al: This paper reports on the use of finite element analysis to evaluate the behavior of a curved, reinforced concrete box girder bridge.. This work shows that it is necessary to include concrete softening due to both shear and flexural cracking. A three-dimensional finite element model was first developed, based on the assumption that the behavior is linear. It was found that there were large differences between the analytical strains and those measured in the experimental investigation. The finite element model was then modified to calibrate the analytical results with the experimental results. The modification was based on the major cracks and the thermal behavior.The results of this study have shown qualitatively how finite element analyses can be modified to account for major cracks in reinforced concrete box girder bridges. The analysis requires correlation with test data. It is also demonstrated that thermal temperature differences must be included to fully explore the behavior.

The finite element analysis model was based on linear behavior. Test data were then used to make modifications to the model so that the strains in the model correlated to those from the field data. A further investigation based on inclusion of thermal stress distributions, both vertically and horizontally, was performed to study the cracking behavior. It has been shown that the morning temperatures produced strains that when added to those from the gravity load, produced shear cracks corresponding to those found in the field.

8) Tanmay et al: presents a review of the literature on the structural behavior of skew box-girder bridges subjected to static & dynamic loads including seismic effects. Moreover, this study also reviews the effect of skewness on load distribution among the multi-spine/cell box-girders bridges and presence of diaphragms in the bridge. It was found from the study that Width to span ratio play a major role in deciding the extent to which skew angle will affect the response of the bridge. Very long bridges tend to negate the skew effect but in short bridges high skew angle can generate a variety of extra forces which must be accounted in while designing. Although the presence of orthogonal diaphragms is proved to be most advantageous in skew box-girder bridges, as they reduce structural actions to great extent still, due to construction difficulties they might be omitted in some cases. Live load distribution factors in multi-cell skew box-girder bridges predicted by some of the codal provisions are found either way over-conservative or sometime risky also, especially in skew box-girder bridges. Studies on seismic analysis of box-girder bridges reveal that skew box-girder bridges are more vulnerable due to coupling of different vibration modes at very early stages. Natural frequency of highly skew bridges (45° or more) tends to decrease with respect to right bridges while for moderately skew bridges (30°-45°) it increases. For bridges with skew angle lower than 30° dynamic effects are not found severe. Although a good amount of research work has already been done to understand the behavior of skew box-girder bridges, however, still there are no exclusive guidelines available for selecting the optimum cross-section dimensions for different skew angle**.**

C. Comparison of limit state method and working stress method.

1) *ShivanandTenag:* presented a study on design of slab panel by Pigeaud's curves using IRC: 21-2000 and IRC: 112-2011.The study aims to determine how design by IRC-112 differs from IRC-21. Pigeaud's curves are used to calculate live load bending moments. Quantity of materials required in limit state method was compared with quantity of material required in working stress method. From the study it can be concluded that depth required is more in WSM than LSM. Volume of concrete required by limit state method is 30% less than working stress method. It was also observed that percentage steel required by limit state method is double than working stress method of design. With comparison of limit state method results generally an effective depth of 125 mm holds good for all class of loading and corresponding percentage of steel 1.078% can be provided.

D. Analysis of T-beam girder and box girder.

1) *AbrarAhmed et al*: presented a comparative analysis and design of T-beam girder and box girders. The purpose of this study was to identify the suitable section for bridges of different spans. For the analysis Working Stress Method is being used for the Manual design whereas the CSI bridge for Software analysis. Cost comparison for cases was done by estimating the Concrete and Steel quantity for two different girders. Structural components are designed by selecting the trail section. It was found that the IRC 70R vehicle producing maximum effect on the sections. Cost comparison has shown that the T-beam girder is suitable for spans up to 30metre, as we go for higher spans the depth of T-beam girder increases drastically which makes it uneconomical. For lower spans the T-beam girder can be adopted which is easy to install and maintain and for higher spans the box girder is suitable and number of cells in the box girder can be increased to decrease the overall depth of the girder for higher spans .From the obtained results we can conclude that the software results are acceptable and can be adopted for the design of substructures also. For lower spans the T-beam girder can be adopted which is easy to install and maintain.
2) *Thanushree et al:* presented analysis of RCC and PSC bridge deck slabs for various spans. The effect of various span were studied using finite element software SAP2000 on RC bridge decks and PSC bridge decks for dead load, live load and their combination. For the study, IRC class AA vehicle load was considered. The bridge deck models were analyzed to compute longitudinal moment, transverse moment, torsional moment and longitudinal stresses. From the analysis it was found that longitudinal moment increases with increase in span for both the decks. Transverse moment for both RCC and PSC decks are almost same moment is more for 30m span. This was due to the reason that torsional moment increases with increase in span for both deck slabs. The trend in longitudinal stresses was similar to combination of loads in longitudinal moment. It was observed that stresses increases with increase in span for both deck slabs.The longitudinal moment increases with increase in span of the bridge deck. From the study it can be concluded that the maximum longitudinal moments occurs at the centre of span for both RCC and PSC bridges. The variation of longitudinal moment varies from 1.5% to 2%.The transverse moment increases with increase in span of the bridge deck. The transverse moment varies from 3% to 4%.The torsional moment is found to be maximum at the corner regions. The torsional moment varies 9% to10%.The longitudinal stresses increases with increase in span. It varies from 3% to 5%.
3) *Amit et al:*presentedacomparative study of the analysis and design of T-beam girder and box girder superstructure .The purpose of the study was to design of bridge structure for 25 m of span. For this a two lane simply supported RCC T- Beam Girder and RCC Box Girder Bridge was analyzed for dead load and IRC moving load. The dead load calculation has been done manually and for live load linear analysis is done on Staad Pro. It has been concluded that the T-Beam girder are obvious choice for designer for 25 m span. For 25 m span, T-Beam Girder is more economical but if span is more than 25 m, so Box Girder is always suitable. This type of Bridge lies in the high torsional rigidity available because of closed box section. From the analysis following conclusions were drawn-

a) Service Dead load bending moments and Shear force for T-beam girder are lesser than two cell Box Girder Bridge, Which allow designer to have lesser heavier section for T-Beam Girder than Box Girder for 25 m span.
b) Moment of resistance of steel for both has been evaluated and it was found that T-Beam Girder has more capacity for 25 m span.
c) Shear force resistance of T-Beam Girder is more compared to two cell Box Girder for 25 m span.
d) Cost of concrete for T-Beam Girder is less than two cell Box Girder as quantity required by T-beam Girder.
e) . Quantity of steel for T-beam Girder is less so cost of steel in T-Beam is less as compared to two cells Box Girder Bridge.

4) *R. Shreedharet a:* presented a comparative study of grillage method and finite element method of RCC bridge deck. Analysis was done by both grillage analogy as well as by finite element method. The modeling and analysis is done by Staad-Pro software. The focus of this modeling is to find the reason of the results differences of the two models (Grillage, Finite Element), while the objective is to simulate the behavior of bridge structure in terms of bending moment value. Bridge deck analysis by grillage method is also compared for normal meshing, coarse meshing and fine meshing. Finite element method gives lesser values for bending moment in deck as compared to grillage analysis.Analysis by using finite element method gives more economical design when compared with the grillage analysis, But the benefit for grillage analysis is that it is easy to use and comprehend.
5) *Sevketet a.*presented a study toanalyze the concrete continuous box girder bridges by considering segmental construction stages through balanced cantilever method. Time dependent material properties of concrete and steel are also taken into account. Modeling was done using SAP2000 . Geometric nonlinearities are taken into consideration in the analysis using P-Delta and large displacement criterion. Time-dependent material properties are considered as compressive strength, aging, shrinkage and creep for concrete, and relaxation for steel. The structural behavior of the bridge at different construction stages is examined. It

was found from the analysis that there were large differences between some internal forces and displacements for the deck and the piers. It means the analysis in case of inconsideration of construction stages, cannot give the reliable solutions. Large differences observed between the results with and without considering construction stages. It can be stated that the analysis without construction stages cannot give the reliable solution.

6) *Hube et al:* This study aims to understand the load path, failure modes, andstrength of typical In-span Hinges (ISH) and determine the influence of utility and maintenance openings on the behavior and strength of ISHs. The computational study was based on nonlinear three-dimensional finite element analysis validated by the tested ISHs and used to conduct the parametric study for developing design guidelines. Results of the analysis shows that ISHs fail with a combination of three failure modes: beam shear, two-dimensional strut-and-tie model, and punching shear. The design ISH must consider these failure modes and their combinations, inaddition to the bending and sliding shear modes typically considered in the design approach of short cantilevers. The beam shear and punching shear design equations, on the basis of ACI 318 recommendations, were the ones that gave the best strength predictions for ISHs. The presence of utility openings in the ISHs reduced the strength by 9% for the as-built ISHs. By contrast, for the new design with low reinforcement ratio, the strength was not sensitive to the presence of utility openings.
7) *B. Kermani et al:*presented ananalysis of continuous box girder bridges including the effects of distortion.A method of elastic analysis was developed based on the stiffness approach which includes the effects of warping torsion and distortion in addition to the more familiar actions of bending moment and torsion. The method, which is applicable to straight single cell box girders with at least one axis of symmetry, is demonstrated here in the analysis of three different box girder models for which experimental or analytical results were already available.A method has been developed for the elastic analysis of single cell box girders with at least one axis of symmetry. The method, based upon the stiffness approach with six degrees of freedom ateach node, may be applied to all straight thin-walled box girder bridge configurations with a minimum number of elements. External loading may include concentrated loads applied at the nodal points and uniformly distributed load applied between the nodes.The performance and accuracy of the equivalent beam method has been shown to compare favorably with some reported studies of simply supported and continuous single cell box beams subjected to a variety of different loadings. The method may therefore be used to predict the behavior of deformable single cell box girders with confidence particularly during the conceptual design stage when a full 3-D finite element analysis is not justifiable.
8) *A. Ghaniet a:* presented a study of analysis of thin-walled multicell box-girder finite element.A thin-walled-box-girder finite element that can model extension, flexure, torsion, torsional warping, distortion, distortional warping, and shear lag effects was developed using an extended version of Vlasov's thin-walled beam theory. The element has two end nodes, but it has besides the six nodal degrees of freedom of a conventional beam element, additional degrees of freedom to account for torsional warping, distortion, distortional warping, and shear lag.The governing differential equation pertaining to each action was used to derive the exact shape functions and the stiffness matrix and nodal load vector of the element. An orthogonalization procedure was employed to uncouple the various distortional and shear lag modes. A numerical example was solved that compared the proposed method with the facet-shell finite element analysis, with good agreement between the two sets of results.The stress distribution in the webs is linear. The conventional beam theory results deviate from the shell finite element results by a maximum of 38%.A multicell box-beam finite element was developed using extended thin walled beam theory, which includes distortional and shear-lag effects. Based on some simplified assumptions, it was shown that the complex governing equations of extension, flexure, torsion, distortion, and shear lag can be uncoupled. It was also shown that the uncoupled equations can be solved in closed form and that the exact shape functions could be employed to develop a box-beam finite element with only two nodes. The utilization of exact shape functions and the systematic development of the stiffness matrix and nodal loads presented here make the computing time and the amount of effort needed for data input and for the interpretation of results substantially less than those required for shell finite element analyses of box girders. The present method also facilitates a physical understanding of the general structural response of box-girder structures.

III. CONCLUSION

After going through the existing literature on analysis of RCC box girder it was found that many researchers have studied the comparison between various section of box girder bridge and from the study it was found that rectangular box girder section is economical and hold good strength for torsional,warping stresses.As not many literatures are present on the design of Box girder bridge.Hence, this study aims at design and comparison of two different cross section of box girder bridge and analyzing it by finite element method by application of suitable software tool like ANSYS,SAP 2000,Stadd pro and MIDAS.

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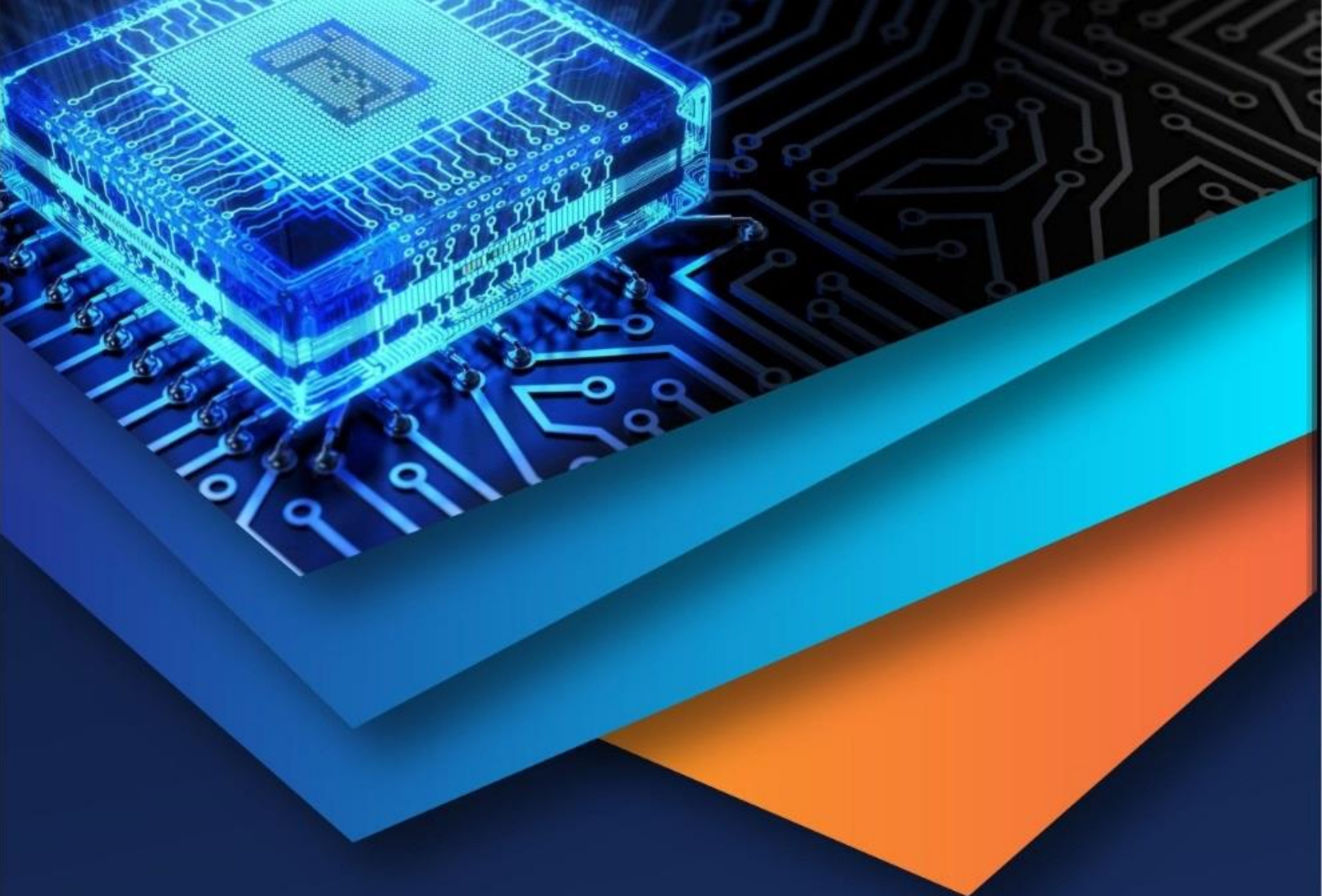

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TOGETHER WE REACH THE GOAL

IMPACT FACTOR: 7.429

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