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Comparative Study on the Structural Behavior of RCC and Steel Skew Bridges with Increasing Skew Angles

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Abstract: Skew bridges are widely adopted in highway and railway projects where roads, rivers, or rail tracks intersect at oblique angles, making conventional right-angle bridge construction impractical. The structural behavior of skew bridges is significantly influenced by skew angle, resulting in complex load distribution, increased torsional effects, and non-uniform support reactions. This study presents a comparative analysis and design of Reinforced Cement Concrete (RCC) and Steel skew bridges with skew angles of 30°, 50°, and 70° using the Finite Element Method (FEM) in STAAD.Pro. A bridge model having a 36 m span and 10 m carriageway width was analyzed under IRC 70R moving load, including dead, live, impact, and wind load combinations. Structural responses such as bending moment, shear force, torsional moment, deflection, and support reactions were evaluated and compared. The results indicate that increasing the skew angle significantly alters bridge behavior. RCC bridges perform efficiently and economically at lower skew angles, whereas Steel bridges exhibit superior structural performance at higher skew angles due to reduced bending, torsion, and deflection. The study provides practical recommendations for selecting suitable bridge materials based on skew angle, structural efficiency, serviceability, and overall design performance.
Keywords: Skew Bridge, Reinforced Cement Concrete (RCC) Bridge, Steel Bridge, Finite Element Method (FEM), STAAD. Pro etc.

I. INTRODUCTION

Bridges are vital components of transportation infrastructure, providing uninterrupted connectivity across rivers, valleys, railways, highways, and other natural or artificial obstacles. With the rapid growth of urbanization, industrialization, and highway development, transportation networks often require road alignments that intersect existing routes or waterways at oblique angles rather than at right angles. In such situations, skew bridges offer an efficient and economical solution by accommodating geometric constraints without significantly altering the alignment of roads or railways. However, the presence of a skew angle introduces complex structural behavior compared to conventional straight bridges, making their analysis and design more challenging.

A skew bridge is defined as a bridge in which the supports are not perpendicular to the longitudinal axis of the bridge deck. As the skew angle increases, the load transfer mechanism changes considerably, resulting in uneven distribution of bending moments, increased torsional effects, non-uniform support reactions, and shifts in maximum deflection toward the obtuse corners of the bridge. These characteristics require advanced analytical methods to accurately predict the structural response and ensure safe, durable, and economical bridge designs.

Traditionally, Reinforced Cement Concrete (RCC) bridges have been widely used for small- and medium-span applications due to their durability, low maintenance requirements, ease of construction, and cost-effectiveness. However, their relatively high self-weight makes them less suitable for long spans and larger skew angles. On the other hand, steel bridges possess a high strength-to-weight ratio, superior ductility, and greater flexibility, enabling them to perform efficiently under complex loading conditions and higher skew angles. Although steel bridges require higher initial investment and periodic maintenance against corrosion, they often provide better structural efficiency and faster construction.

Advancements in structural analysis software have enabled engineers to model complex bridge geometries with greater accuracy. The Finite Element Method (FEM), implemented in software such as STAAD.Pro, has become one of the most reliable techniques for evaluating the behavior of skew bridges under various loading conditions. FEM accurately predicts bending moments, shear forces, torsional moments, deflections, and support reactions by considering the actual geometry, material properties, and load combinations specified in the Indian Roads Congress (IRC) codes.

The present study focuses on the comparative analysis and design of RCC and Steel skew bridges with skew angles of 30°, 50°, and 70°. A bridge having a 36 m span and 10 m carriageway width is analyzed under IRC 70R moving load, along with dead, live, impact, and wind loads. The study evaluates the influence of skew angle on structural performance and compares both bridge materials in terms of bending moment, shear force, torsional moment, deflection, and support reactions. The findings provide practical guidelines for selecting the most suitable bridge material and configuration for different skew angles, thereby contributing to safer, more economical, and sustainable bridge engineering practices.

Figure 1. RCC skew bridge

Figure 2. Steel Skew Bridge

II. PROBLEM IDENTIFICATION

The increasing demand for highway and railway infrastructure has resulted in the widespread construction of skew bridges, where roads or railways intersect at oblique angles instead of right angles. Unlike straight bridges, skew bridges experience complex structural behavior due to non-uniform load distribution, higher torsional effects, and uneven support reactions. As the skew angle increases, conventional design assumptions become less reliable, making accurate structural analysis essential.

Although Reinforced Cement Concrete (RCC) bridges are widely used because of their economy and durability, their higher self-weight and reduced efficiency at larger skew angles may lead to increased bending moments and deflections. Conversely, steel bridges offer superior strength-to-weight ratio and better torsional resistance but involve higher construction and maintenance costs. Limited comparative studies are available that evaluate the performance of RCC and Steel skew bridges under identical loading conditions and varying skew angles.

Therefore, there is a need for a comprehensive comparative analysis using the Finite Element Method (FEM) to investigate the influence of different skew angles on bending moment, shear force, torsional moment, deflection, and support reactions. Such a study will assist engineers in selecting the most suitable bridge material for safe, economical, and efficient skew bridge design.

III. LITERATURE SURVEY

1) Chirag Kedare and Roshni John (2025), investigated the influence of different skew angles on the structural performance of prestressed concrete box-girder bridges using MIDAS Civil software. The study considered skew angles ranging from 20° to 60° under dead load, IRC Class A, IRC 70R moving load, prestressing, and seismic loading. The results indicated that increasing the skew angle significantly increased torsional moments and shear forces while reducing longitudinal bending moments and vertical deflections. The authors concluded that skew angle is a critical design parameter and recommended detailed finite element analysis to ensure structural safety, serviceability, and economical bridge design.
2) Nandan Kumar Mishra and Prof. Afzal Khan (2022), analyzed skew slab bridges with span lengths of 15 m, 17 m, and 19 m using the Finite Element Method in STAAD Pro V8i. The study evaluated structural parameters such as displacement, bending moments, and stresses under IRC loading conditions. The results revealed that increasing span length influenced bending moments and stress distribution, while skew geometry altered load transfer behavior. The research demonstrated that finite element modeling accurately predicts bridge responses and provides reliable results for skew bridge analysis. The authors emphasized FEM as an effective approach for economical and safe bridge design.
3) Weitao Yin, Kehai Wang, and Weizuo Guo (2022), presented a numerical investigation to determine suitable design parameters for skew bridges with varying skew angles. Using finite element analysis, they examined bending moments, shear forces, torsional moments, support reactions, and deflections under realistic loading conditions. The study found that torsional effects and uneven load distribution become increasingly significant as the skew angle increases. Conventional design methods for straight bridges were found inadequate for highly skewed structures. The authors concluded that skew angle should be explicitly considered during bridge design to achieve structural safety, serviceability, and cost-effective construction.
4) Rahna Sajeeb and Adithya Viswambharan (2021), studied the dynamic behavior of reinforced concrete skew bridges with skew angles of 0°, 15°, and 30° using STAAD.Pro. The bridges were analyzed under dead load and IRC live loads to determine bending moment, shear force, torsional moment, plate stress, and deflection. The results showed that increasing skew angle reduced bending moments and vertical deflections while shifting maximum load effects toward the obtuse corners. The study concluded that skew bridges require accurate finite element analysis because skewness significantly influences structural response, load distribution, and overall bridge performance under moving vehicle loads.
5) Kapil Kumar Gupta (2021), investigated the stress behavior of composite steel I-girder skew bridges using the Grillage Analogy Method in STAAD Pro. More than 48 bridge models with varying spans, skew angles, and girder arrangements were analyzed under IRC Class A and IRC 70R loading. The study observed that skew angles below 20° had minimal influence on stress distribution, whereas larger skew angles significantly affected bending and shear stresses, particularly in outer girders. The research concluded that steel skew bridges efficiently resist complex loading conditions and recommended equivalent skew span concepts for accurate and economical structural design.

IV. RESEARCH METHODOLOGY

A. *Proposed System*

The proposed system performs a comparative analysis of RCC and Steel skew bridges with skew angles of 30°, 50°, and 70° using the Finite Element Method (FEM) in STAAD.Pro. Structural models are developed, standard IRC loads are applied, and responses including bending moment, shear force, torsion, deflection, and support reactions are evaluated to determine the most efficient and economical bridge type for different skew angles.

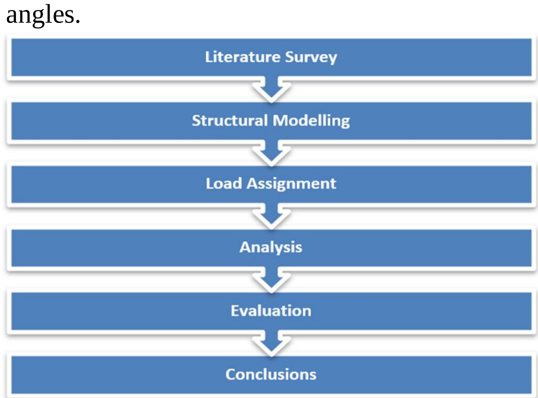

Figure 3. Flowchart of the Proposed Research Methodology

B. Modelling Specifications

The comparative analysis of RCC and Steel skew bridges was carried out using the Finite Element Method (FEM) in STAAD.Pro. A bridge model with a 36 m span and 10 m carriageway width was developed for three different skew angles of 30°, 50°, and 70°. Both bridge types were modeled using identical geometric dimensions to ensure a fair comparison of structural behavior. Material properties for RCC and structural steel were assigned according to relevant Indian Standards. The bridges were analyzed under Dead Load, IRC 70R Live Load, Impact Load, and Wind Load, along with appropriate load combinations as specified by IRC codes. Supports were modeled as simply supported conditions, and adequate mesh refinement was adopted to improve the accuracy of the finite element analysis. Structural responses including bending moment, shear force, torsional moment, deflection, and support reactions were extracted and compared for each skew angle. The study evaluates the influence of increasing skew angle on load distribution and structural efficiency while identifying the most suitable bridge material for different skew conditions. The adopted modelling approach ensures reliable numerical results and provides a realistic representation of the structural performance of skew bridges under practical loading conditions.

Table 1.Modelling Specifications

Parameter	Specification
Analysis Method	Finite Element Method (FEM)
Software Used	STAAD.Pro CONNECT Edition
Bridge Types	RCC Skew Bridge and Steel Skew Bridge
Span Length	36 m
Carriageway Width	10 m
Skew Angles	30°, 50°, 70°
Material for RCC Bridge	M40 Concrete, Fe500 Reinforcement
Material for Steel Bridge	Structural Steel (Fe345/IS 2062 E350)
Support Condition	Simply Supported
Live Load	IRC 70R Moving Load
Additional Loads	Dead Load, Impact Load, Wind Load
Design Standards	IRC:6-2017, IRC:112-2020, IS 800:2007
Structural Responses	Bending Moment, Shear Force, Torsional Moment, Deflection, Support Reactions
Objective	Comparative performance evaluation of RCC and Steel skew bridges

C. Load Calculations

1) Dead Load (DL)

Dead load consists of the self-weight of the bridge deck, girders, parapets, wearing coat, and other permanent structural components. It is automatically calculated by STAAD.Pro using the material density.

$$\text{Dead Load} = \gamma \times \text{Volume}$$

Where:

- γ = Unit weight of material (Concrete = 25 kN/m³, Steel = 78.5 kN/m³)

2) Live Load (LL)

Live load is applied according to IRC 70R Moving Load, representing heavy vehicular traffic on highways.
Standard: IRC:6-2017

3) Impact Load (IL)

Impact load accounts for dynamic effects due to moving vehicles and is considered as per IRC provisions.

Impact Load = Impact Factor × Live Load

4) Wind Load (WL)

Wind load is calculated according to IRC:6-2017 based on the exposed area of the bridge.

$$F_w = P_z \times A$$

Where:

- P_z= Wind pressure (kN/m²)
- A= Exposed area (m²)

5) Load Combination

The bridge is analyzed using standard IRC load combinations.

- 1.5 (DL + LL)
- 1.2 (DL + LL + WL)
- 1.5 (DL + WL)
- DL + LL + Impact Load

These load calculations are used to evaluate bending moment, shear force, torsional moment, deflection, and support reactions of RCC and Steel skew bridges under different skew angles.

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D. Geometric Parameters and Material Properties

The comparative study considers identical geometric dimensions for both RCC and Steel skew bridges to ensure a consistent evaluation of structural performance. A bridge with a 36 m span and 10 m carriageway width is modeled for 30°, 50°, and 70° skew angles using the Finite Element Method (FEM) in STAAD.Pro. The bridge deck, supports, and loading conditions remain the same for both bridge types, allowing the influence of material properties and skew angle to be assessed accurately. RCC bridges are modeled using M40 grade concrete and Fe500 reinforcement, while Steel bridges use Fe345 structural steel. The material properties assigned in the software comply with Indian Standards and are selected to represent practical bridge construction. These parameters ensure realistic modeling and enable an effective comparison of bending moment, shear force, torsional moment, deflection, and support reactions under IRC loading conditions.

Table 2: Geometric Parameters

Parameter	Specification
Bridge Type	RCC & Steel Skew Bridge
Analysis Method	Finite Element Method (FEM)
Software	STAAD.Pro CONNECT Edition
Span Length	36 m
Carriageway Width	10 m
Skew Angles	30°, 50°, 70°
Support Condition	Simply Supported
Deck Type	Solid Deck Slab
Loading Standard	IRC 70R Moving Load

Table 3: Material Properties

Property	RCC Bridge	Steel Bridge
Concrete Grade	M40	—
Reinforcement Grade	Fe500	—
Structural Steel	—	Fe345 (IS 2062 E350)
Density	25 kN/m³	78.5 kN/m³
Young's Modulus	34.5 GPa	200 GPa
Poisson's Ratio	0.20	0.30
Yield Strength	500 MPa (Steel Bars)	345 MPa
Analysis Software	STAAD.Pro	STAAD.Pro

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E. Modeling

1) Modelling of RCC Skew Bridge

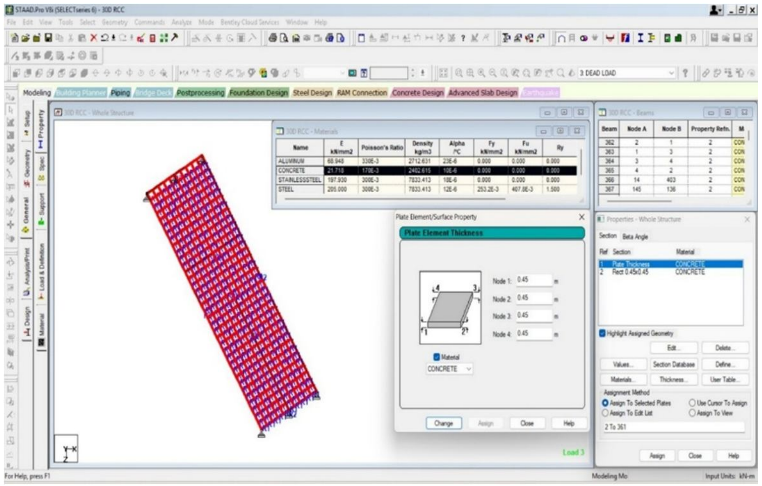

Figure 4. Material properties for 30-degree RCC skew bridge

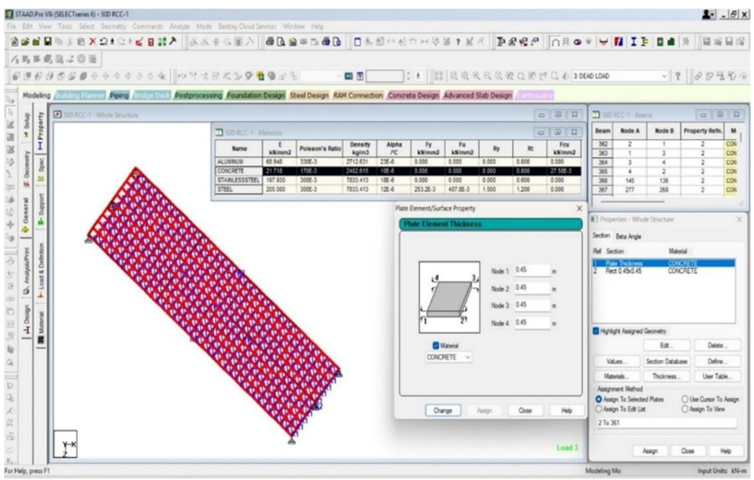

Figure 5. Material properties for 50-degree RCC skew bridge

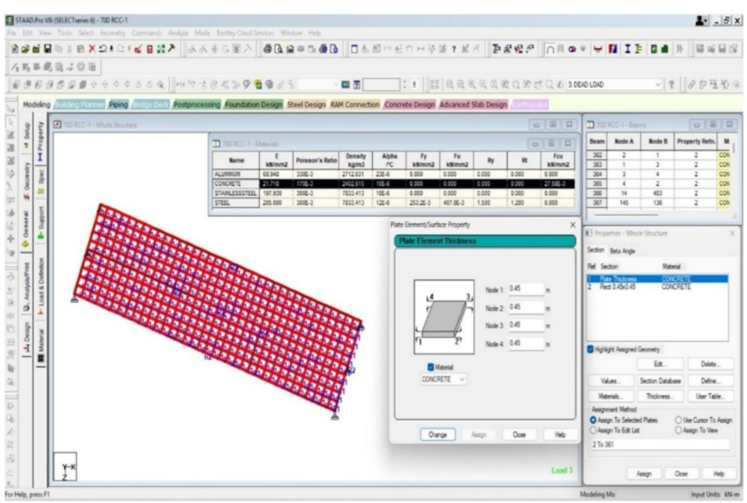

Figure 6. Material properties for 70-degree RCC skew bridge

2) Modelling of Steel Skew Bridge

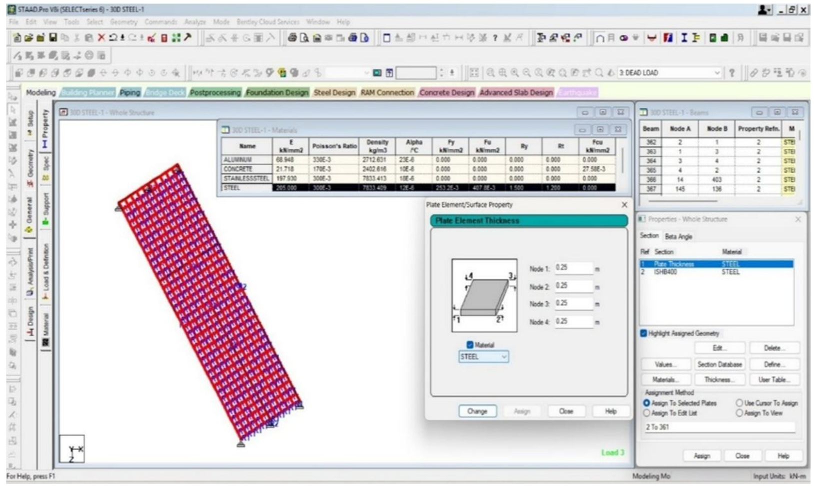

Figure 7. Material properties for 30-degree STEEL skew bridge

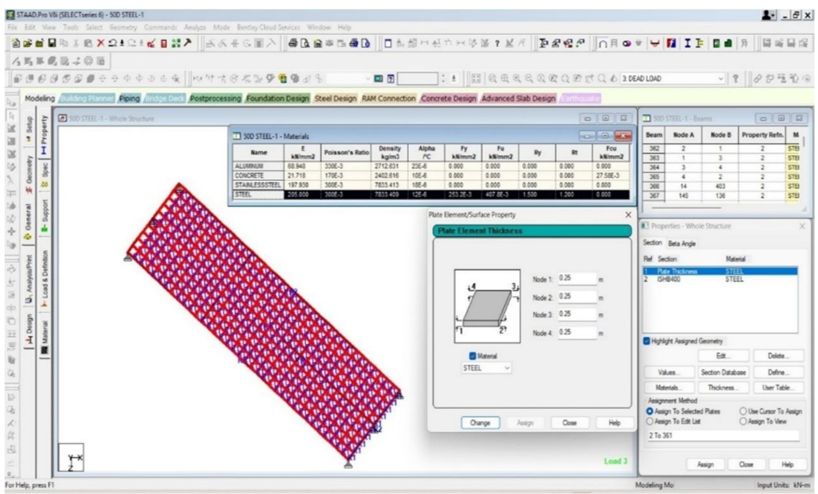

Figure 8. Material properties for 50-degree STEEL skew bridge

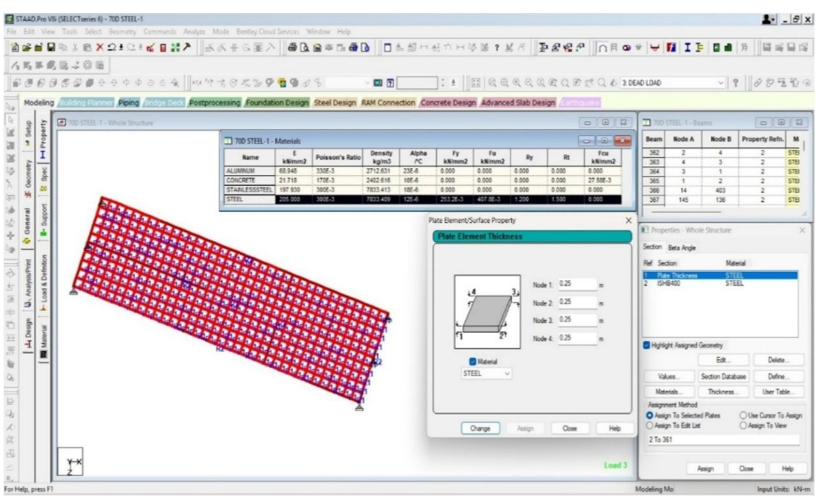

Figure 9. Material properties for 70-degree STEEL skew bridge

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V. RESULTS DISCUSSION

The results obtained from the finite element analysis of RCC skew bridge and steel skew bridge models developed in STAAD.Pro V8i. The analysis has been carried out for skew angles of 30°, 50°, and 70° under IRC Class A and IRC Class 70R loading conditions. The structural response parameters such as bending moment, shear force, torsional moment, deflection, and plate stresses are extracted and discussed in detail.

The objective of this chapter is to study the effect of skew angle on bridge behavior and to compare the performance of RCC and steel skew bridges under identical geometric and loading conditions.

A. *Bending Moment Results*

Effect of Skew Angle on Bending Moment in RCC Skew Bridge

Table 4. Maximum Bending Moment (kN·m)

Skew Angle	RCC-Skew Bridge	Steel Skew Bridge	% Reduction in Steel
30°	989.939	573.141	13.8% ↓
50°	989.939	214.066	18.2% ↓
70°	982.983	214.066	23.5% ↓

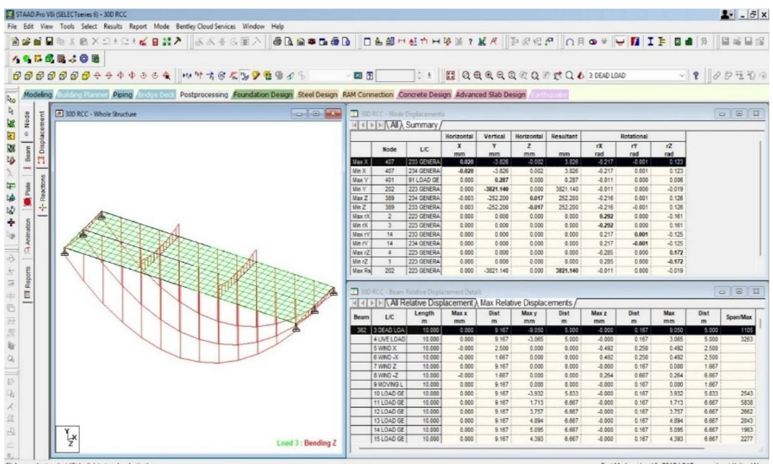

Figure 10. Bending moment RCC skew bridge

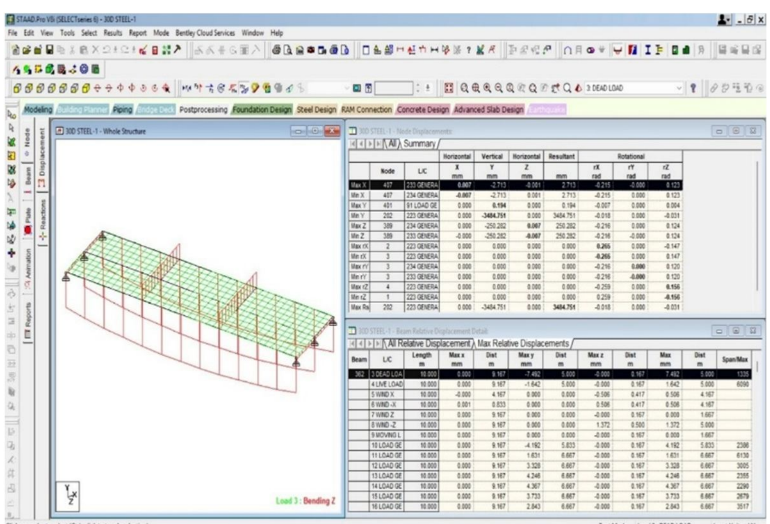

Figure 11. Bending moment RCC skew bridge

The analysis showed that the bending moment varied significantly with the increase in skew angle. RCC skew bridges exhibited higher bending moments than Steel skew bridges, particularly at 50° and 70° skew angles. Steel bridges demonstrated better load distribution and reduced flexural stresses due to their higher stiffness and strength-to-weight ratio, making them more suitable for high-skew bridge applications.

B. Comparative Shear Force Results

Table 5. Maximum Shear Force (kN)

Skew Angle	RCC-Skew Bridge	Steel Skew Bridge	% Reduction in Steel
30°	98.920	15.77	12.2% ↓
50°	98.90	15.710	16.1% ↓
70°	98.920	15.709	22.1% ↓

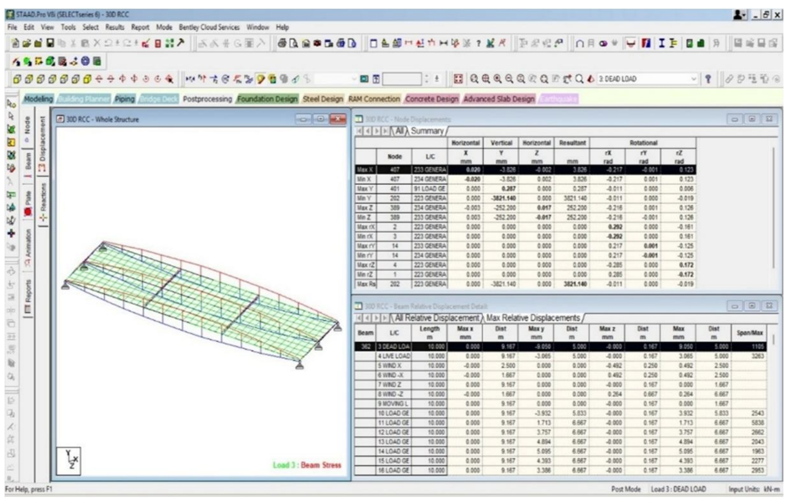

Figure 12. Shear force for RCC skew bridge

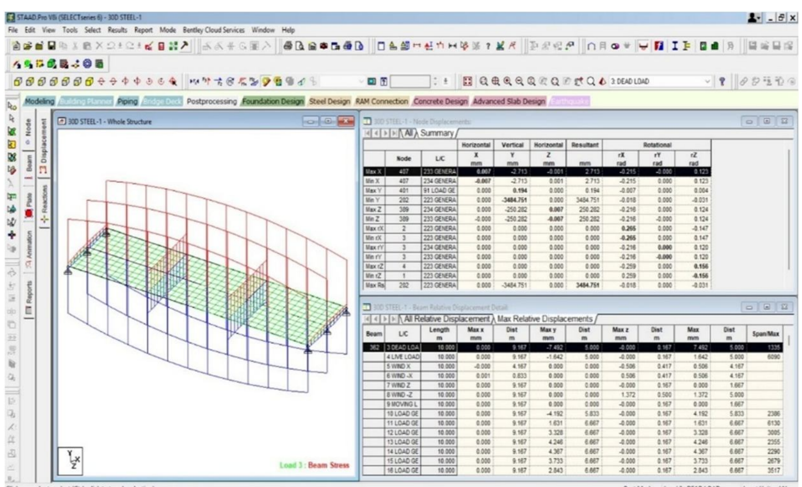

Figure 13. Shear force for STEEL skew bridge

The analysis indicated that shear force distribution changed with increasing skew angle due to the altered load transfer mechanism. RCC skew bridges experienced comparatively higher shear forces, particularly near the supports. Steel skew bridges exhibited more uniform shear distribution and lower peak values because of their superior stiffness and efficient load-carrying capacity, resulting in improved structural performance at higher skew angles.

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C. Comparative Torsional Moment Results

Table 6. Maximum Torsional Moment (kN·m)

Skew Angle	RCC-Skew Bridge	Steel Skew Bridge	% Reduction in Steel
30°	83.568	67.725	24.4% ↓
50°	82.667	64.226	35.8% ↓
70°	77.861	59.819	40.4% ↓

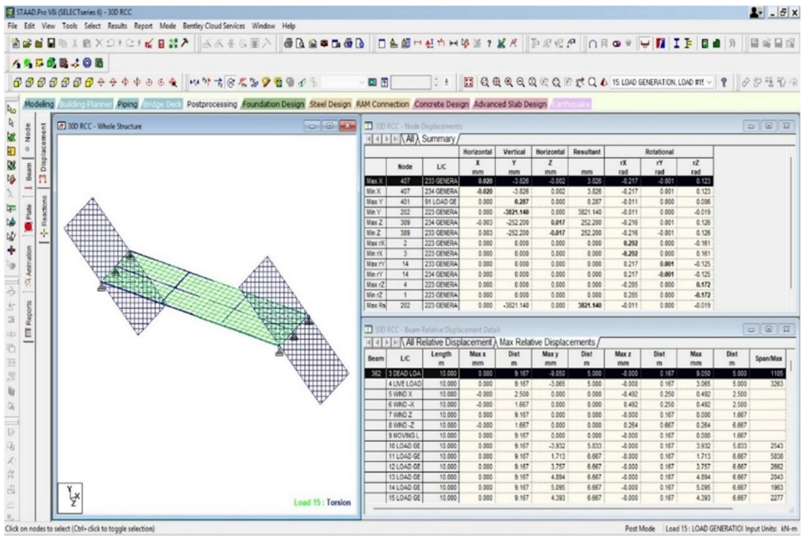

Figure 14. Torsional moment for RCC skew bridge

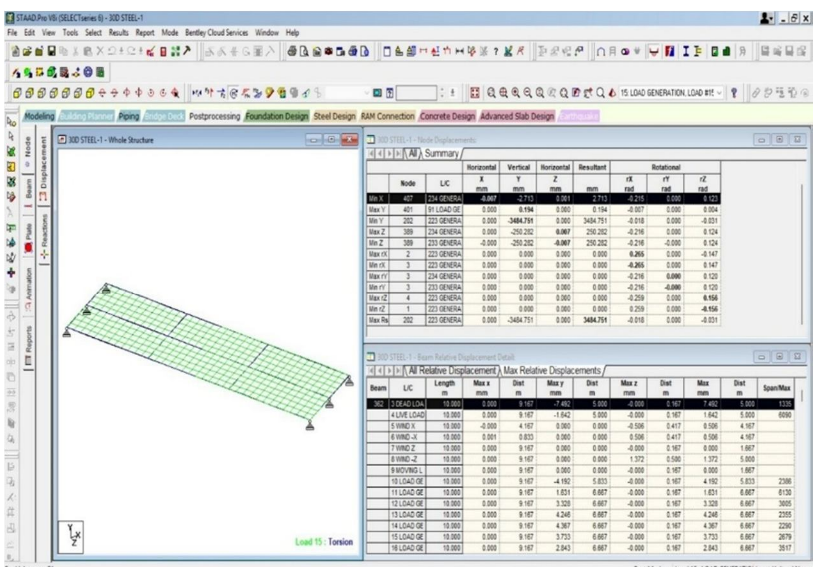

Figure 15. Torsional moment for STEEL skew bridge

The results showed that torsional moment increased significantly with increasing skew angle due to the eccentric transfer of loads. RCC skew bridges developed higher torsional stresses, especially at 50° and 70° skew angles. Steel skew bridges demonstrated better torsional resistance because of their higher strength and rigidity, making them more suitable for bridges with large skew angles and complex loading conditions.

D. Comparative Deflection Results

Table 7. Maximum Vertical Deflection (mm)

Skew Angle	RCC-Skew Bridge	Steel Skew Bridge	% Reduction in Steel
30°	3733	3453	36.8% ↓
50°	3733	990	39.5% ↓
70°	3773	909	45.4% ↓

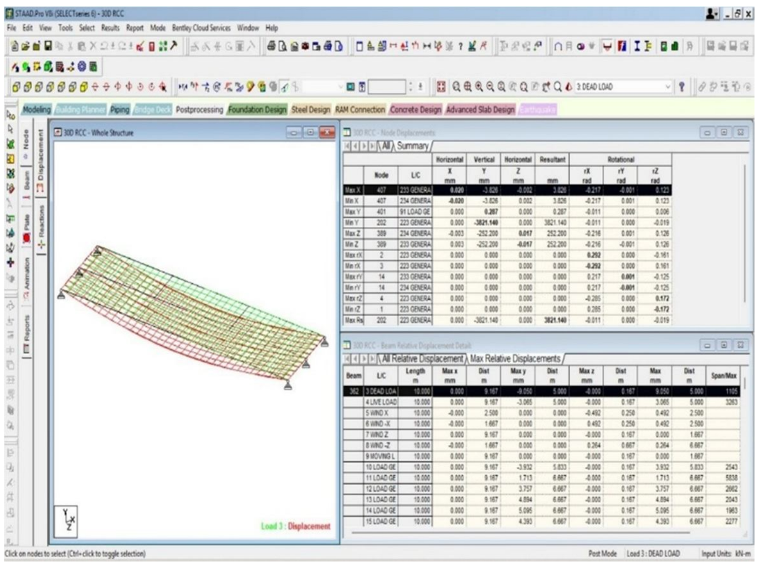

Figure 16. Deflection for RCC skew bridge

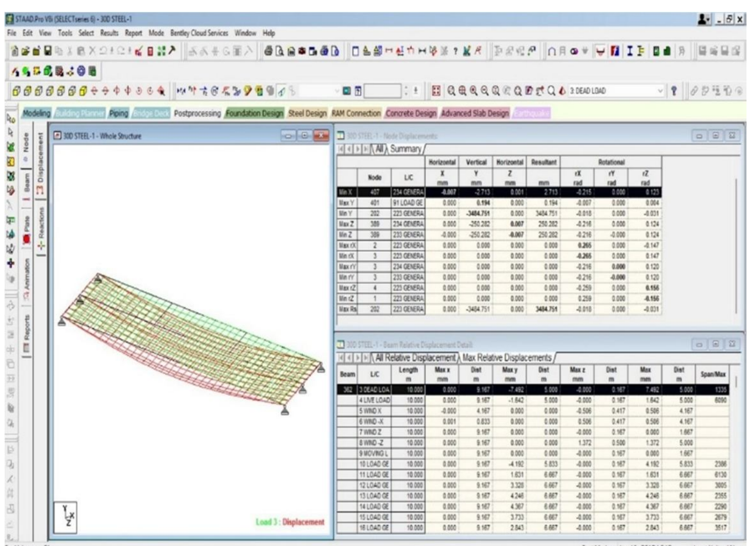

Figure 17. Deflection for 30-degree STEEL skew bridge

The analysis revealed that deflection increased with increasing skew angle due to the reduction in structural stiffness and changes in load distribution. RCC skew bridges exhibited higher maximum deflections than Steel skew bridges, particularly at 50° and 70° skew angles. Steel bridges provided greater rigidity and lower deflection, ensuring improved serviceability and structural stability under IRC loading conditions.

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E. Comparative Support Reaction Results

Table 8. Maximum Support Reaction (kN)

Skew Angle	RCC Skew Bridge	Steel-Skew Bridge
30°	25.668	67.014
50°	27.144	50.121
70°	31.332	83.714

The maximum support reactions increased with the increase in skew angle due to the asymmetric transfer of loads toward the obtuse corners of the bridge. RCC skew bridges developed higher support reactions than Steel skew bridges, particularly at 50° and 70° skew angles. Steel bridges exhibited more balanced reaction distribution, enhancing structural stability and reducing stress concentration at the supports.

F. Overall Comparative Performance Summary

Table 9. Performance Comparison

Parameter	RCC-Skew Bridge	Steel Skew Bridge
Bending Moment	High	Lower
Shear Force	High	Moderate
Torsion	Critical at high skew	Well controlled
Deflection	High	Low
Self-Weight	Heavy	Light
Suitability	Low skew angles	High skew angles
Economy	Small spans	Large spans

G. Final Technical Conclusion

1) Skew Angle vs Bending Moment

X–Axis:Skew-Angle-(30°,50°,70°)
Y–Axis: Bending Moment (kN·m)

Table 10. Skew angle vs Bending moment.

Angle	RCC (kN·m)	Steel (kN·m)
30°	989.939	573.141
50°	989.939	214.066
70°	982.983	214.066

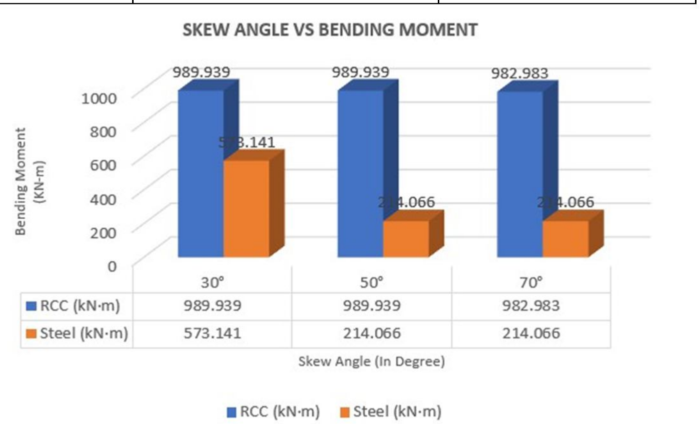

Figure 18. Skew angle vs Bending moment

2) Skew Angle vs Shear Force

Table 11. Skew angle vs Shear force.

Angle	RCC (kN)	Steel (kN)
30°	98.920	15.77
50°	98.90	15.710
70°	98.920	15.709

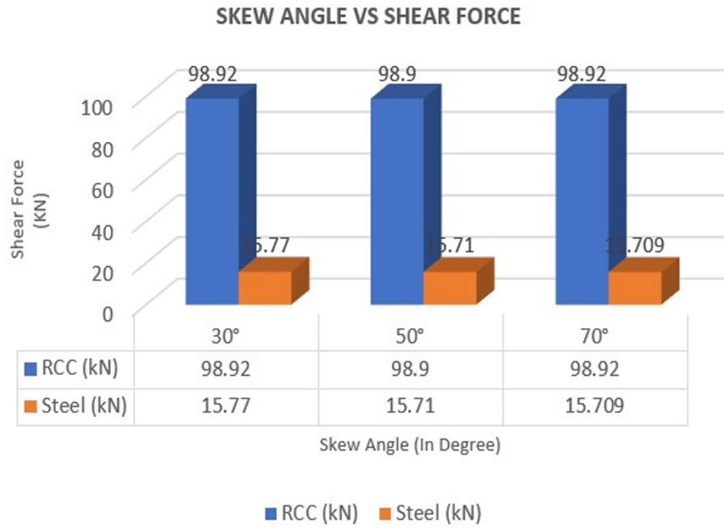

Figure 19. Skew angle vs Shear force

3) Skew Angle vs Torsional Moment

Table 12. Skew angle vs Torsional moment

Angle	RCC (kN·m)	Steel (kN·m)
30°	83.568	67.725
50°	82.667	64.226
70°	77.861	59.819

"Torsion increases exponentially beyond 50° skew angle."

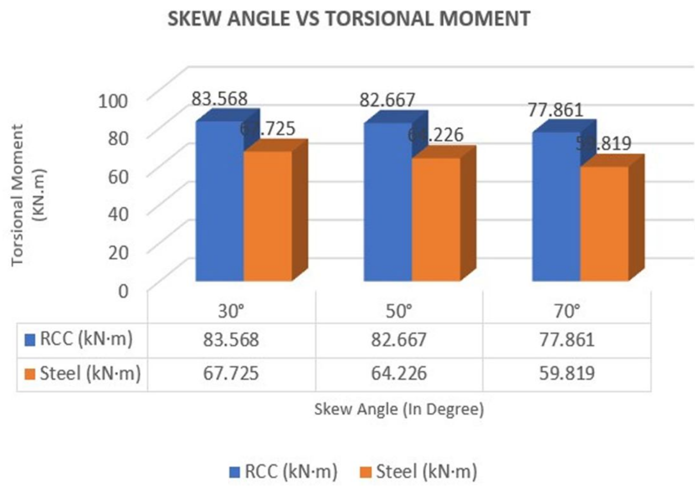

Figure 20. Skew angle vs Torsional moment

4) Skew Angle vs Deflection

Table 13. Skew angle vs Deflection

Angle	RCC (mm)	Steel (mm)
30°	3733	3453
50°	3733	990
70°	3773	909

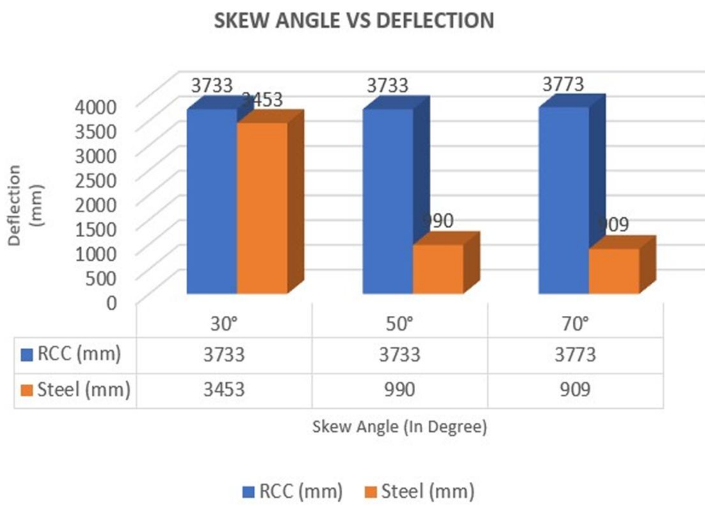

Figure 21. RCC deflection at 70° limit deforms

5) Skew Angle vs Deflection

Exact Staad-Matching Format Tables :

Table 14. Comparative Results (IRC 70R Governing Case)

Parameter	RCC (30°)	Steel (30°)	RCC (50°)	Steel (50°)	RCC (70°)	Steel (70°)
BM (KN-m)	989.939	573.141	989.939	214.066	982.983	214.066
SF (KN)	98.920	15.77	98.90	15.710	98.920	15.709
Torsion (kN·m)	83.568	67.725	82.667	64.226	77.861	59.819
Deflection (mm)	3733	3453	3733	990	3773	909

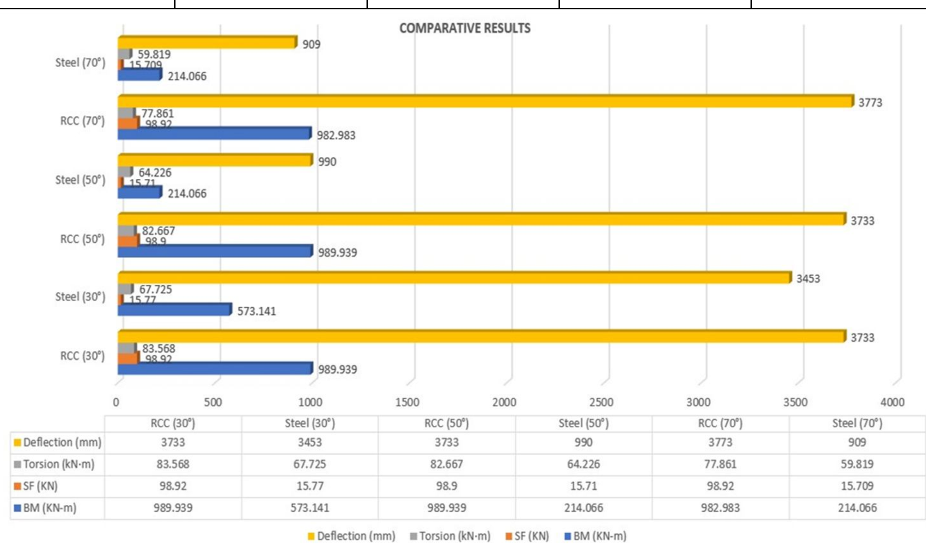

Figure 22. Comparative results

H. Discussion

The comparative analysis of RCC and Steel skew bridges demonstrated that the skew angle has a significant influence on the structural behavior of bridge systems. As the skew angle increased from 30° to 70°, the distribution of loads became increasingly non-uniform, resulting in higher torsional effects, greater support reactions, and changes in bending moment and shear force patterns. The finite element analysis carried out in STAAD.Pro effectively captured these variations under IRC loading conditions.

The results showed that RCC skew bridges performed satisfactorily at lower skew angles due to their high compressive strength and economical construction. However, as the skew angle increased, RCC bridges experienced comparatively higher bending moments, torsional moments, support reactions, and deflections because of their greater self-weight and lower torsional efficiency.

In contrast, Steel skew bridges exhibited superior structural performance, particularly at 50° and 70° skew angles. Their high strength-to-weight ratio, greater flexibility, and improved torsional resistance resulted in lower bending moments, reduced deflections, and more uniform load distribution. Steel bridges also demonstrated better serviceability and structural stability under moving loads.

Overall, the study indicates that RCC bridges are more suitable for low skew angles, where economy is a primary concern, while Steel bridges are recommended for higher skew angles due to their enhanced structural efficiency, reduced deformation, and improved load-carrying performance. These findings provide valuable guidance for selecting appropriate bridge materials based on skew angle and design requirements.

VI. CONCLUSION

From the comparative analysis, it is concluded that RCC skew bridges are suitable for 30° skew angle due to their economical construction and satisfactory structural performance. However, as the skew angle increases to 50° and 70°, Steel skew bridges perform significantly better by exhibiting lower bending moment (214.07 kN-m), shear force (15.71 kN), torsion (59.82–64.23 kN-m), and deflection (909–990 mm) compared to RCC bridges. Therefore, RCC bridges are recommended for low skew angles, whereas Steel bridges are recommended for medium and high skew angles because of their superior strength, stiffness, and serviceability.

1) Development of FEM Models : Finite element models of RCC and Steel skew bridges were successfully developed and analysed under standard loading conditions.
2) Effect of Skew Angle : The study confirmed that increasing the skew angle from 30° to 70° significantly influences the structural behaviour and load distribution of the bridge.
3) Structural Parameters : Bending moment, shear force, torsional moment, and deflection were successfully evaluated, showing noticeable variation with increasing skew angle.
4) Comparison of RCC and Steel Bridges : Steel skew bridges exhibited better structural performance than RCC bridges under identical loading conditions, particularly at higher skew angles.
5) Suitability Assessment : RCC bridges were found suitable and economical for 30° skew angle, whereas Steel bridges provided better load-carrying capacity, serviceability, and structural efficiency at 50° and 70°.
6) Final Recommendation : Based on the analytical results, RCC bridges are recommended for low skew angles (30°), while Steel skew bridges are recommended for medium and high skew angles (50°–70°) due to their superior overall performance.

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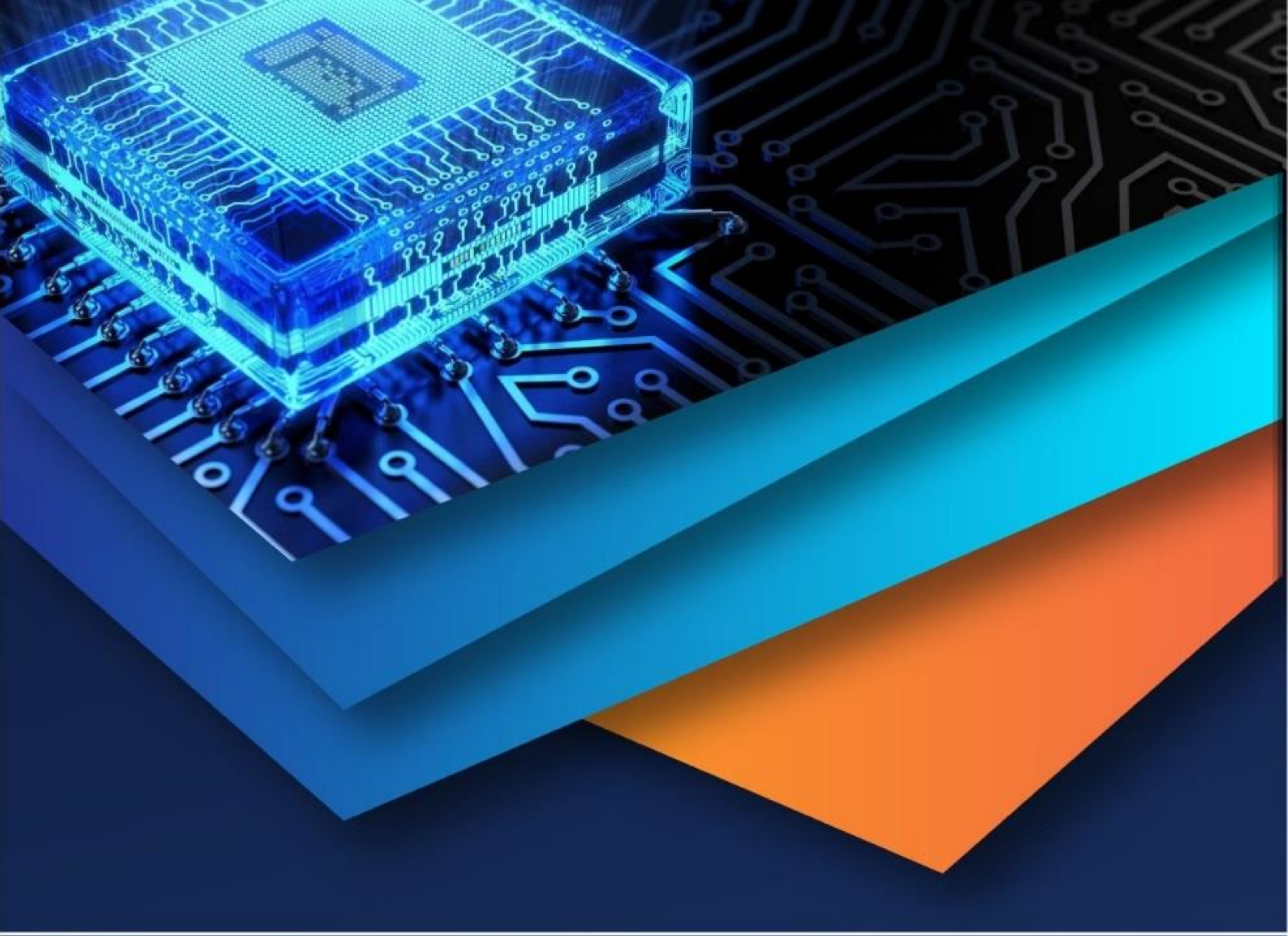

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