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Performance-Based Seismic Analysis of Slab Variants in RCC Frames

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Abstract: *This research paper investigates the Flat slabs are commonly used in buildings requiring flexible layouts, such as offices, residential complexes, and parking structures, due to efficient load distribution. According to IS standards, the current study compares and analyses eight-story structures for regular, plan irregular, and vertical irregular structures for conventional slabs with gravity load and lateral stress circumstances. The structures are analyses by using Etabs Software. "Linear static analysis was carried out on regular, plan-irregular, and vertically irregular building designs integrating both standard slab systems and flat slabs with drop panels in compliance with IS 1893 (Part 1):2016. In order to evaluate the structural behavior of each slab system, the study compares seismic performance based on critical response parameters, such as storey drift, storey shear, storey stiffness, and lateral displacement.*

Keywords*:* Plan Irregularity, vertical irregularity, Linear Static Analysis, Etabs

I. INTRODUCTION

A slab is a crucial structural component that is usually made of reinforced concrete and used as a horizontal surface for decks, roofs, and floors in buildings. Because they greatly increase a structure's overall stability, strength, and durability, slabs are essential to modern building. Investigating the structural behavior of a standard slab system is the goal of the current study. It describes the methodical process used to model and analyze a construction plan that uses a traditional slab system.

1. Conventional Slab

"A conventional slab is a kind of slab that is mostly held up by columns and beams. The supporting beams in this arrangement are much deeper than the slab itself, which is very thin. From the slab, structural loads are first transmitted to the beams and then to the columns. Conventional slabs often require more extensive formwork than flat slab systems, which renders the construction process rather labor-intensive. A conventional slab system is one of the most widely used floor construction methods in reinforced concrete structures. It involves a horizontal structural element commonly referred to as a slab—that is supported by beams and columns. This system is categorized as a beam-slab arrangement, wherein the slab transfers loads to the supporting beams, which then distribute these forces to the vertical columns and ultimately to the foundation. Due to its simplicity, strength, and ease of execution, conventional slab construction is preferred in both residential and commercial projects, especially in low to mid-rise buildings.

Classification of Conventional Slabs:

1) One-Way Slab: Beams on two opposing sides support one-way slabs. Loads are mainly carried in one direction by these slabs. The Indian Standard (IS) rules state that a slab is considered one-way if the ratio of its larger span to shorter span is two or more.
2) Two-Way Slab: Two-way slabs can support loads in both directions and are held up by beams on all four sides. A slab is deemed two-way in accordance with IS regulations if its longer span to shorter span ratio is less than two.

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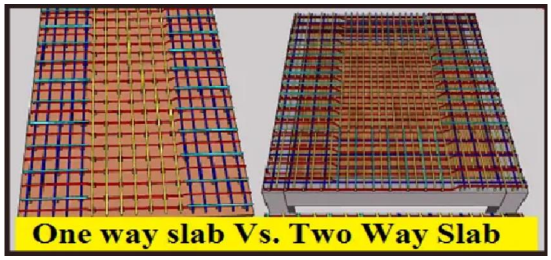

Fig. -1 Types of Conventional Slab

The traditional slab is still a mainstay of concrete construction techniques because of its versatility, structural stability, and simple design principles. Accurate design, appropriate reinforcement detailing, and high-quality execution are necessary for its performance. With ongoing advancements in construction technology, conventional slabs may evolve, but their core principles continue to form the foundation of reinforced concrete construction.

2. Flat Slab

A flat slab is a type of reinforced concrete slab that is directly supported by columns, eliminating the need for conventional beams. This structural system allows for a uniform slab thickness and removes the necessity for drop panels or deep beams, resulting in a more streamlined and efficient design. By transferring loads directly from the slab to the supporting columns, flat slabs help reduce the overall floor-to-floor height of a structure. This makes them particularly suitable for buildings that require greater architectural flexibility and efficient vertical space utilization.

Flat slabs are particularly suited for structures that require open floor spaces, such as office buildings, parking structures, hotels, and hospitals. In addition to making interior design simpler and more adaptable, the removal of beams in flat slab systems makes it easier to integrate plumbing, electrical, and mechanical services. Despite these benefits, punching shear is an important design concern since loads are transferred directly from the slab to the columns. Structural improvements like column capitals, drop panels, or carefully planned reinforcement features are necessary to handle the high localized shear stresses surrounding column heads in order to guarantee sufficient shear resistance and preserve structural integrity. Flat slabs have a number of benefits from a construction perspective, such as easier formwork, shorter building times, and greater flexibility for post-tensioning systems. However, span length and load conditions typically restrict their use, and thorough analysis is necessary to guarantee safety and serviceability, especially in seismic regions.

Flat slabs are generally classified into four distinct types, based on the configuration of drop panels and column heads:

- Columns without column heads and slabs without drop panels.
- Columns without column heads and slabs with drop panels.
- Columns with column heads and slabs without drop panels.
- Columns with column heads and slabs with drop panels.

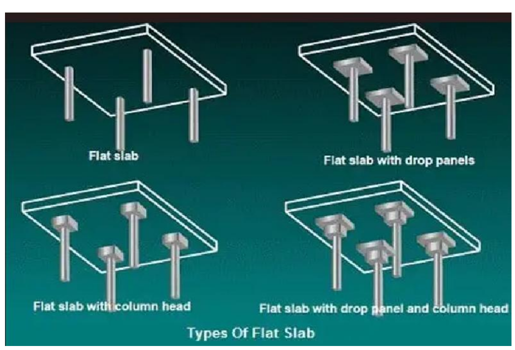

Fig.- 2 Types of Flat Slab

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3. Plan Irregularity

Plan irregularities, or discontinuities or non-uniformities in the horizontal configuration of the layout, can have a detrimental effect on the dynamic behaviour of a building, especially when lateral loading conditions, such as those caused by seismic events, are present. These anomalies disrupt the uniform distribution of mass, stiffness, or geometry in the horizontal plane, often leading to torsional effects, stress concentrations, and unexpected failure modes. Plan irregularities are anomalies in the horizontal arrangement of the building, such as torsional imbalance, re-entrant corners, or asymmetry that can have a negative effect on the seismic performance and structural behaviour of a structure.

1. Re-entrant Corners

Under lateral stresses, re-entrant corners—like those in L-, U-, or T-shaped buildings—introduce stress concentrations in the inner corners. These geometries act as several intersecting wings, which could lead to significant damage at junctions due to differential displacement and deformation incompatibility.

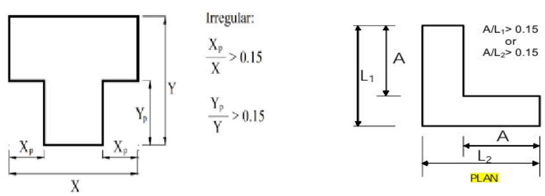

Fig- 3 Re-entrant Corner

4. Vertical Irregularity

Significant variations in stiffness, strength, mass distribution, or geometry along a building's height are referred to as vertical irregularity in structures. Stress concentrations and discontinuities in load transmission systems are frequently the result of these abnormalities' complex dynamic responses during seismic or lateral loading events.

Standards like IS 1893 (Part 1): 2016 and international guidelines such as FEMA P-154 and ASCE 7-16 classify vertical irregularities into distinct categories, including:

1. Mass Irregularity: Occurs when the mass of adjacent floors changes significantly, frequently as a result of different uses, the presence of large machinery, or storage spaces.

2. Stiffness Irregularity (Soft Storey): Distinguished by a sharp decrease in lateral stiffness in one story as opposed to the preceding stories. This phenomenon can result in a soft-storey mechanism during earthquakes and usually occurs in open ground floor structures (such as parking levels).

3. Geometric Irregularity: Results of abrupt modifications to the structure's elevation profile or design, such as setbacks, overhangs, or irregular vertical components like walls or columns.

4. Discontinuity in Load Path: Occurs when vertical structural elements such as columns or walls do not align continuously from foundation to roof, thereby disturbing the force transfer path.

5. In -Plane Discontinuity: Disruption in the lateral force-resisting system within the vertical plane of the structure.

Such irregularities can amplify inter-story drift, increase torsional effects, and reduce the overall seismic resilience of a building. Hence, early identification and appropriate structural detailing or redesign are essential during the planning and analysis phase to mitigate performance deficiencies under lateral loading.

II. LITERATURE REVIEW

Research articles published by various authors in different papers have been studied and are summarized in the following section:

Salman I. Khan and Ashok R. Mundhada,(2015) [1] In this study, the authors investigate the seismic performance of flat slab and grid slab reinforced concrete (RCC) buildings in India through dynamic analysis of G+12, G+15, and G+18 storey structures. The research compares the seismic behaviour of multi-storey buildings with flat and grid slab systems under varying earthquake intensities. Key parameters analysed include base shear, storey displacement, storey drift, and natural time period. The findings indicate that base shear in flat slab buildings increases with height, showing a variation of approximately 3–4%. Maximum lateral displacement is observed at the terrace level, with flat slab buildings exhibiting higher values than grid slab structures. Additionally, storey drift is more pronounced in flat slab buildings, leading to increased moment demands. The natural time period also rises with building height, with a significant difference of about 23% between flat and grid slab systems.

Latha M.S, Pratibha K (2020)[2] In the present study, a G+12 storey structure was analyzed in both symmetric and asymmetric configurations, considering regular, plan irregular, and vertical irregular forms. The analysis was conducted for both conventional slab and grid slab systems under gravity and lateral load conditions, in accordance with relevant IS codes. ETABS software was used for the structural modeling and analysis. Key parameters evaluated included storey drift, base shear, slab deflection, and storey displacement. Results showed that the maximum deflection in the slab of a regular structure was approximately 9.3% higher in conventional slabs compared to grid slabs, while for irregular structures, the deflection was around 4.7% higher. Storey displacement was found to be greatest in grid slab systems and lowest in conventional slabs, regardless of structural regularity. However, conventional slabs exhibited higher storey displacements overall. Storey shear was observed to be highest in conventional slab systems with irregularities, particularly in symmetric and plan irregular structures, while grid slab systems and vertically irregular configurations showed comparatively lower shear values.

CH. Lokesh Nishantha, Y. Sai Swaroopa, Durga Chaitanya Kumar Jagarapua, Pavan Kumar Jogi (2020)[3] In the present study, a commercial building was analyzed and designed using various slab systems, including conventional slabs, flat slabs, grid/waffle slabs, and load-bearing walls. The analysis was performed using ETABS software, following the guidelines of IS 456:2000 and IS 875-Part 5 (2015) codes. Load combinations were considered based on a wind speed of 55 m/s and an earthquake zone 5 location. The study focused on key structural factors such as storey drift, base shear, and storey displacement, which significantly influence the building's performance. The results indicated that conventional slabs exhibit 92.6% greater storey displacement than load-bearing walls, while base shear in conventional slabs is 44.5% higher compared to flat slabs. However, when considering costs, the study found that the concrete quantity required for load-bearing walls is 21% more than that for flat slab systems.

Akshata Barkade, Prof. U.L.Deshpande (2021) [4] In this paper, a comparative study is conducted to analyse and design three types of slab systems conventional, flat, and grid slabs by examining a G+10 commercial building. The building is analysed across seismic zones IV and V. Key parameters considered in the analysis include storey drift, base shear, and storey displacement. The findings show that the grid slab design provides a safer and more cost-effective solution for storey displacement when compared to conventional and flat slab systems, with improvements of up to 90% and 70%, respectively. The conventional slab exhibits a higher storey shear value of 6.6% compared to the grid slab in seismic zones IV and V, with a 0.67% increase in flat slab shear. Storey drift is highest for conventional slabs, while flat slabs have maximum displacement. Grid slabs have minimum displacement.

Soha Khanam, Swathi. V(2022) [5] This study focuses on the structural analysis of various slab systems, including conventional slabs, flat slabs, waffle slabs, and ribbed slabs, using ETABS software for modelling and evaluation. They had analysed a G+12 structure for Zone-III and comparison for commercial building and also, study the behaviour of the commercial structure under different types of slab conditions. The study found that the ribbed slabs have the highest Story Displacement and Base Shear, making flat slabs more suitable for high-rise structures. The paper concludes that a flat slab is more effective for multi-storey buildings, while conventional slabs offer increased stiffness, weight carrying ability, safety, cost-effectiveness, and economics. Waffle or Grid and Ribbed slabs are stable and economical for high-rise structures due to their more resisting moment capacity

III. OBJECTIVES

- To analyse and study the multi-storey Plan & vertically irregular building under seismic loading.
- To compare the performance of multi-storey building with regular Slab arrangement.

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IV. METHODOLOGY

Seismic analysis is carried for the RCC Buildings with and without irregularities for different Slabs.

- The Etabs software is used to conduct the study through modeling and analysis different slab arrangements.
- To assess the building's structural performance, maximum storey displacement, storey drift, storey stiffness, and base shear were plotted and examined for buildings with various slab configurations.
- Evaluate the and comparing the results with regular Slab arrangement.

A. Structural Modelling of Buildings

Table 1 has Structural Data which has been used for the Modelling. Setback Irregularity is introduced to building according to IS 1893:2016 and other references.

Structural Details	
No. of Stories	G+8
X Direction Width	30 M
Y Direction Width	25 M
Storey Height	3 M
Live Load	3 KN/m2
Floor Finish	1.5 KN/m2
Importance Factor	1
Wall Thickness	230 mm
Wall Height	2.1 M
Parapet Wall Height	1 M
Concrete Grade	M 25
Steel Grade	Fe 500
Slab Thickness	200 mm
Beam Size	300 x 900 mm
Column Size	600 x 600 mm
Drop Panel	400mm

Table -1: Structural Modelling Details

RCC Building is modeled is ETABS without any irregularities then different types of vertical geometric irregularities were introduced for other two model.

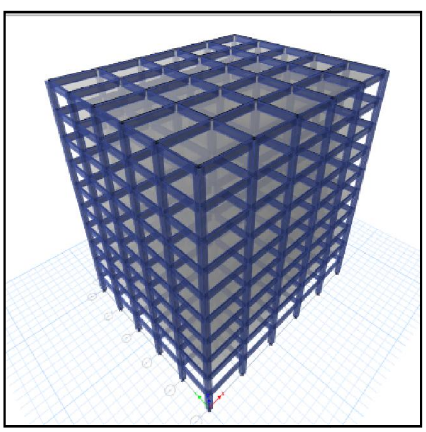

Fig -4: Isometric View for Model 1

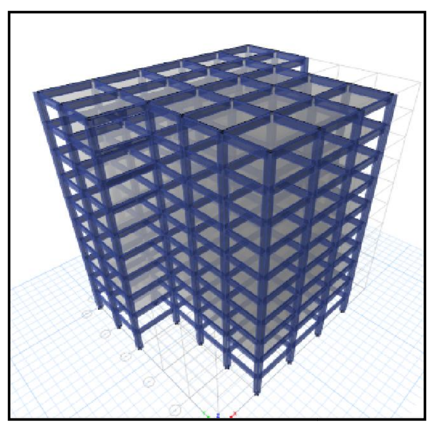

Fig -5: Isometric View for Model 2

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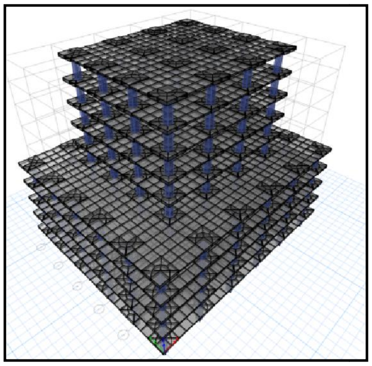

Fig -6: Isometric View for Model 3

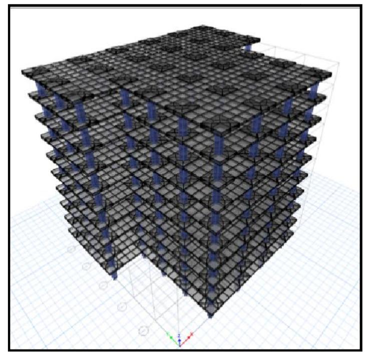

Fig -7: Isometric View for Model 4

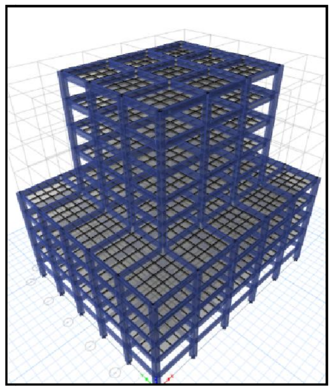

Fig -8: Isometric View for Model 5

V. RESULTS

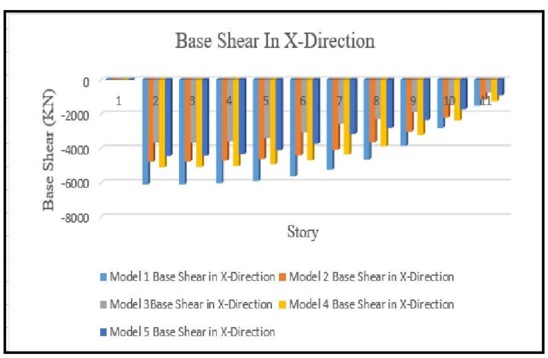

Fig -9: Base Shear in X-Direction

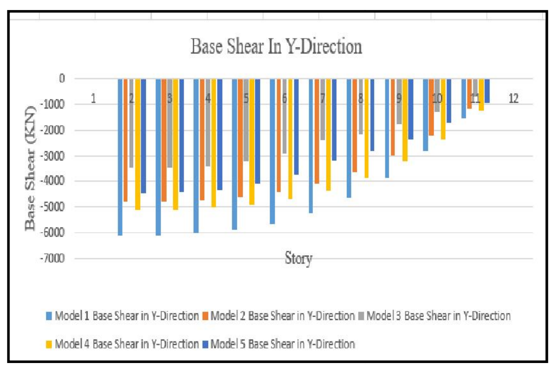

Fig -10: Base Shear in Y-Direction

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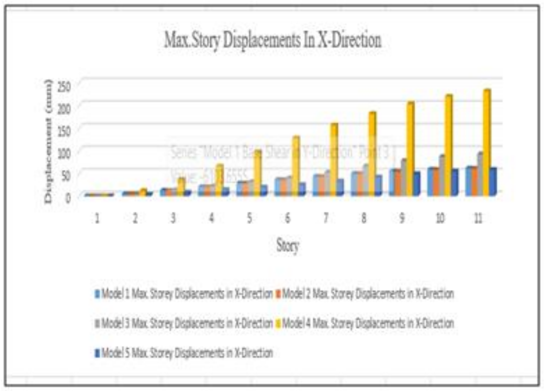

Fig -11: Max. Story Displacement in X-Direction

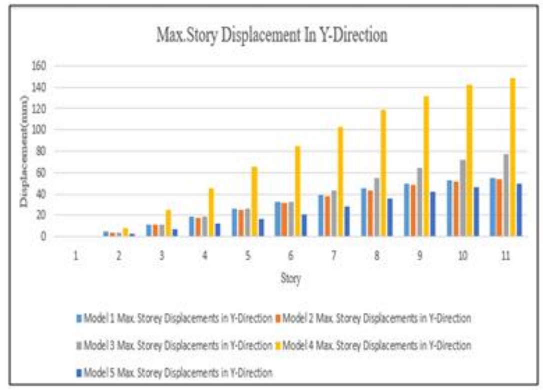

Fig -12: Max. Story Displacement in Y-Direction

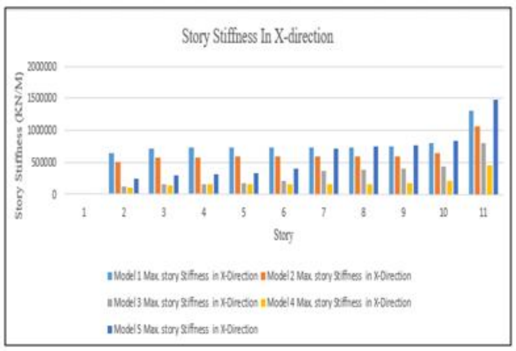

Fig -13: Story Stuffiness in X-Direction

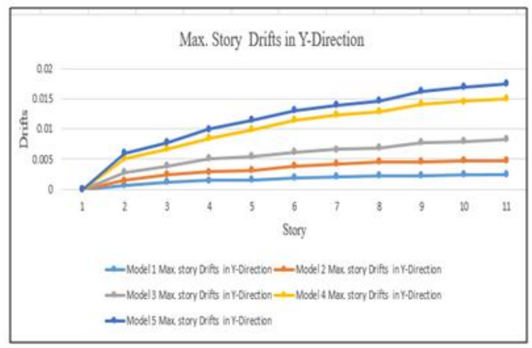

Fig -14: Story Stuffiness in Y-Direction

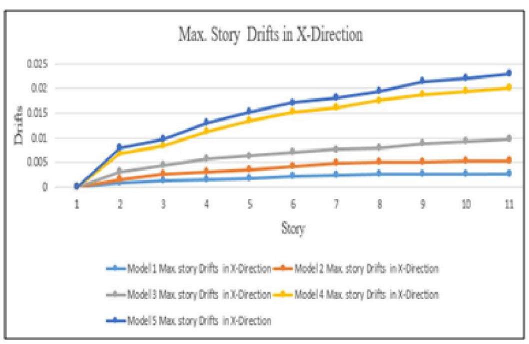

Fig -15: Max. Story Drift in X-Direction

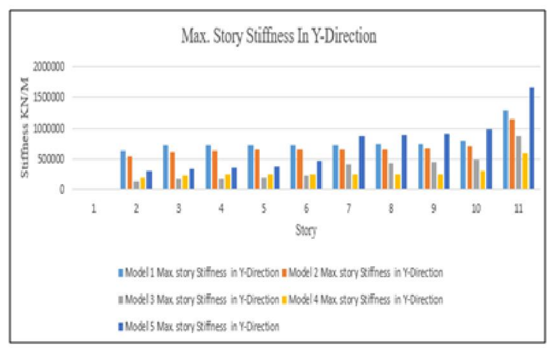

Fig -16: Max. Story Drift in Y-Direction

From above tables and figures we found out that,

The seismic analysis revealed that Model 1 was more resistant to lateral forces than the other models, as evidenced by the highest storey shear in both the X and Y directions, with a peak value of 6110.2 KN.

In comparison to other models, Model 4 had the greatest storey displacement, measuring 232.096 mm in the X-direction and 148.965 mm in the Y-direction. This suggests that Model 4 has greater lateral flexibility.

In the seismic analysis, Model 5 exhibited the highest storey stiffness in both the X and Y directions, with values of 1,479,385.485 KN/m and 1,655,747.228 KN/m, respectively, indicating superior resistance to lateral deformation.

The maximum storey drift was recorded in Model 3 for the X-direction and in Model 4 for the Y-direction, with respective values of 0.004268 mm and 0.006685 mm, indicating higher lateral deformation in these models under seismic loading.

VI. CONCLUSION

From the above study, the conclusions can be made as follows:

The regular structure with a conventional slab showed the highest base shear of 6110.2 kN. Plan and vertical irregularities led to reductions of 5.3% and 6.2%, while flat slab systems showed smaller drops of 4.7% and 3.9%. This indicates a slight decrease in lateral force resistance with irregularities and slab changes.

Models with plan irregularity, vertical irregularity, and flat slabs with irregularities all exhibit a considerable increase in story displacement; the flat slab with drop panels that have plan irregularity exhibits the largest displacement, 95% higher than the conventional slab.

The flat slab with drop panels showed the largest improvement in maximum storey stiffness when compared to the normal conventional slab, increasing by about 84.9% in the X-direction and 84.0% in the Y-direction. The investigation shows that structural imperfections and slab layout have a significant impact on lateral stiffness. While conventional slab systems demonstrated the least amount of stiffness, especially in seismic zone conditions, plan irregular and vertical irregular slab systems demonstrated the most rigidity.

The plan irregular conventional slab exhibits a moderate increase in storey drift when compared to the regular conventional slab. While the plan irregular flat slab with drop panels exhibits at about 91% increase in the Y-direction, the vertical irregular conventional slab has a roughly 71% higher drift in the X-direction. This suggests that under seismic loads, drift is greatly increased by structural imperfections.

Conflict of Interest Statement: On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Author contributions

In this study all authors have contributed by providing their valuable inputs in preparing this manuscript. The SBP and RRK collected the required data through rigorous review.

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Data Availability: This study do not involve the generation or analysis of any datasets.

Declarations:

Competing interests the authors declare that there are no competing interests.

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