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Finite Element Analysis of Plain Cement Concrete Slab with and Without Opening

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Abstract: In modern construction practices, plain cement concrete (PCC) slabs are often designed with openings to accommodate services such as electrical conduits, plumbing, and ventilation ducts. However, the introduction of openings leads to significant changes in the structural behavior of slabs, including increased deflections, stress concentrations, and potential early cracking. This research presents a comprehensive finite element analysis (FEA) study on PCC slabs with and without openings, considering different concrete grades (M20, M30, M40, and M60). The slabs were modeled under simply supported conditions and subjected to a uniform distributed load. Various parameters were analyzed, including opening size and location.

I. INTRODUCTION

Plain Cement Concrete (PCC) slabs are foundational elements in modern construction, known for their simplicity, durability, and cost-effectiveness. These slabs form the backbone of floors, pavements, and structural decks in diverse construction projects. While PCC has proven its effectiveness over decades, the ever-evolving demands of the construction industry have encouraged researchers to explore innovations that enhance material efficiency and performance. One such innovation involves incorporating pre-designed hollow openings within PCC slabs panel. Pre-designed hollow openings in PCC slab panel serve multiple purposes. Structurally, they reduce the self-weight of the slabs, leading to more efficient designs and reduced costs in high-rise structures where dead load is a critical consideration. Additionally, these openings allow for the seamless integration of mechanical, electrical, and plumbing (MEP) systems, eliminating the need for post-installation drilling that could compromise the structural integrity of the slab. From a sustainability perspective, reducing the volume of cement and aggregate in slabs contributes to lower embodied carbon, aligning with global efforts to minimize the environmental footprint of construction materials.

However, the introduction of hollow openings alters the stress distribution and load-bearing capacity of PCC slab panel. Concentrated stresses around the edges of the openings can lead to crack propagation and potential structural failure if not properly addressed. These challenges necessitate a detailed investigation of the mechanical behavior of PCC slab panel with hollows, combining experimental testing and numerical simulations.

A. Characteristics of PCC slab

- Material Composition: Cement, water, fine aggregate (sand), and coarse aggregate (gravel or crushed stone).
- No Reinforcement: Unlike reinforced concrete slabs, a plain concrete slab does not have rebar or steel mesh inside for extra tensile strength.
- Thickness: Typical thickness ranges from 4 to 6 inches for residential floors or driveways, but this can vary depending on the load requirements.
- Uses: Ideal for light-load applications like sidewalks, driveways, patios, or flooring in areas with limited load-bearing demands.

B. Advantages of PCC slab panel

- Cost-effective: As no reinforcement is required, the materials are less expensive, and the process is faster.
- Durability: When properly designed, PCC can withstand heavy loads and environmental conditions like water and frost.

C. Limitations

- Low Tensile Strength: Plain concrete can crack under tensile stresses because it has limited capacity to resist bending or stretching.
- Cracking: Susceptible to cracking due to temperature changes, settlement, or loads if not properly designed or supported.

D. *Components of PCC*

- Cement: Acts as the binding agent that holds the aggregates together when mixed with water. It undergoes hydration, which hardens and gains strength over time.
- Fine Aggregates: Sand is used to fill the voids between coarse aggregates, providing bulk to the mix.
- Coarse Aggregates: Generally, gravel or crushed stone, these materials give the slab its compressive strength and durability.
- Water: The water-cement ratio is crucial, as it determines the workability and strength of the concrete.

E. *Purpose and Applications of PCC slab panel*

PCC slab panels are typically used for flooring, paving, and subbases in construction projects. Due to the absence of reinforcement, these slabs are more cost-effective and easier to install compared to reinforced concrete slabs. Common applications include:

- Pavements and walkways: Providing a solid, durable surface for pedestrian traffic.
- Sub-base for foundations: Acting as a base layer for structures such as buildings and roads.
- Flooring in industrial or residential spaces: Often laid as a flat surface for areas where loads are primarily compressive.
- Low maintenance: PCC slab panels require minimal upkeep, making them suitable for long-term applications in various settings.

II. LITERATURE REVIEW

Jofriet and Gregory, (1971) did the finite element analysis of RCC slab for bending stress. The analysis concentrates on the nonlinear behavior due to progressive cracking of a slab and does not include post-yield behavior. The Branson and Beeby methods are explored for estimating the rigidity of a cracked concrete region. The latter is found to yield better results. In order to deal with cracking in any arbitrary direction, suggestions are made for the transformation of the matrix of flexural rigidities and for the determination of equivalent steel areas with respect to the orientation of the cracks in a region. Some results are presented to demonstrate the proposed method.

Mosallam & Mosalam, (2003) presented an experimental and analytical investigation for evaluating the ultimate response of unreinforced and reinforced concrete slabs repaired and retrofitted with fiber reinforced polymer (FRP) composite strips. A uniformly distributed pressure was applied to several two-way large-scale slab specimens using a high-pressure water bag. Both carbon/epoxy and E-glass/epoxy composite systems were used in this study. In predicting the behavior of the repaired slabs, the finite element method was used. Comparison between the experimental and the analytical results indicated the validity of the computational models in capturing the experimentally determined results for both the control and the rehabilitated slabs. For repair applications, test results indicated that both FRP systems were effective in appreciably increasing the strength of the repaired slabs to approximately five times that of the as-built slabs. For retrofitting applications, use of FRP systems resulted in appreciable upgrade of the structural capacity of the as-built slabs up to 500% for unreinforced specimens and 200% for steel reinforced specimens.

Foster et al., (2004) This paper presents the results from 15 small-scale tests conducted on horizontally unrestrained slabs which were subjected to large vertical displacements. All the tested slabs showed a load-carrying capacity far greater than the design capacity using the well-established yield-line theory. The purpose of these tests was to investigate the influence of isotropic and orthotropic reinforcement, together with reinforcement bond strength, on the degree of mobilization of tensile membrane action, and thus on the load capacity of the slab. The results of the tests have been compared to a previously developed design method which incorporates membrane action of composite floor slabs into the estimation of their load capacity in fire, where large vertical displacements are acceptable provided that compartmentation is maintained. This comparison shows that the design method compares well with experimental results and is generally conservative, although it is in need of development to account for the bond characteristics of reinforcement and changes of failure mode for some orthotopically reinforced slabs.

Thanoon et al., (2005) suggested that crack is one of the most common defects observed in reinforced concrete slabs and beams. Major cracks in concrete structures may occur due to overloading, corrosion of reinforcement or differential settlement of support. To restore the structural capacity of the distressed elements, retrofitting and/or strengthening are needed. There are different techniques available for retrofitting and strengthening of different reinforced concrete structural elements reported in the literature. This paper investigates the structural behavior of cracked reinforced concrete one-way slab, which is repaired using different techniques. Five different techniques are used for the purpose of repair in the cracked concrete slab namely; cement grout, epoxy injection, ferrocement layer, carbon fiber strip and section enlargement.

The slabs were loaded to failure stage and the structural response of each slab specimens have been predicted in terms of deflection, variation of strain in concrete and steel, collapse loads and the failure modes.

The efficiency of different repair and strengthening techniques and their effects on the structural behavior of cracked one-way reinforced concrete slab had been analyzed. It was observed that the type of repair technique used will affect the load carrying capacity of the slab and will lead to a redistribution of the strains and hence stresses in both concrete and steel reinforcement. All repair techniques are found to be able to restore or enhance the structural capacity of cracked concrete slabs.

El-Sayed et al., (2005) evaluates the shear strength of one-way concrete slabs reinforced with different types of fiber-reinforced polymer (FRP) bars. A total of eight full-size slabs were constructed and tested. The slabs were 3,100mm long×1,000mm wide×200mm deep. The test parameters were the type and size of FRP reinforcing bars and the reinforcement ratio. Five slabs were reinforced with glass FRP and three were reinforced with carbon FRP bars. The slabs were tested under four-point bending over a simply supported clear span of 2,500 mm and a shear span of 1,000 mm. All the test slabs failed in shear before reaching the design flexural capacity. The experimental shear strengths were compared with some theoretical predictions, including the JSCE recommendations, the CAN/CSA-S806-02 code, and the ACI 440.1R-03 design guidelines. The results indicated that the ACI 440.1R-03 design method for predicting the concrete shear strength of FRP slabs is very conservative. Better predictions were obtained by both the CAN/CSA-S806-02 code and the JSCE design recommendations.

III. METHODOLOGY

1) Experimental Analysis: In this section 500x200x50 mm slab panels were cast using M40 grade of concrete in the lab and tested after 28 days of curing under flexural testing machine. The arrangement of three-point load test is shown in Figure1.

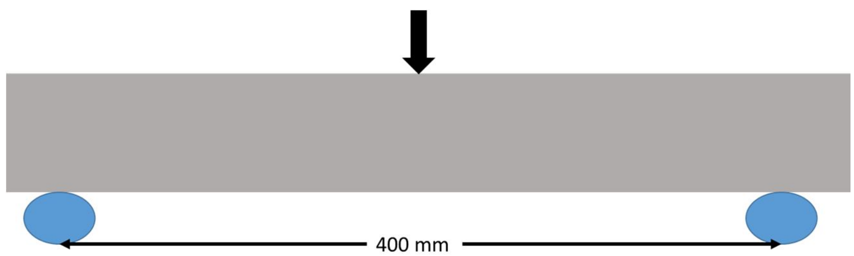

Figure 1 Three-point load arrangement

For casting slab panel M40 grade of concrete is used. The ratio of the mix proportion ingredient of concrete shown in Table 2. The testing machine should be equipped such that the load may be applied without shock and be increased continuously at a rate of 1.8 kN/min for 10 x 10 x 50 cm specimens lS:9399 - 1979.

2) Numerical Analysis (Finite element method): In this section the methodology adopted to create the three-dimensional (3D) model of plain slab is discussed. The modeling of plain concrete slab is done using Finite element analysis. The Finite element modeling of plain concrete slab is carried out using ABAQUS 6.14 finite element software. The analysis procedure and various elements of the software are also discussed in this chapter.

3) FEM modeling procedure: Finite Element Method (FEM) is a numerical technique used to solve complex problems in engineering and physics that involve structural, thermal, fluid, and multi-physics simulations. The FEM modeling process involves discretizing a continuous physical system into smaller, simpler elements and solving for the unknowns (e.g., displacements, stresses, temperatures, etc.). The procedure for FEM modeling can be broadly broken down into several key steps, each of which ensures that the solution is accurate and reliable.Below is a typical FEM modeling procedure, often followed in software tools such as ABAQUS, ANSYS, COMSOL, and others.
4) Stages in finite element analysis

The finite element analysis consists of the following stages:

a. Pre-processing:
b. Processing:
c. Post processing:

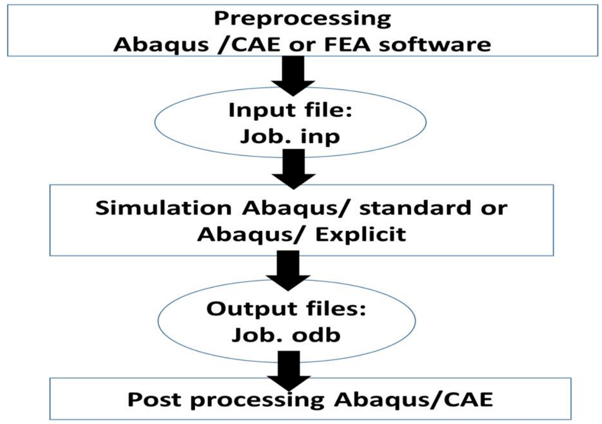

Figure 2 Flow chart for FEM modeling

IV. PROBLEM STATEMENT

Plain Cement Concrete (PCC) is widely used in construction for pavements, foundations, and flooring due to its simplicity in construction and cost-effectiveness. However, despite its extensive use, PCC suffers from significant limitations, particularly in tensile strength, leading to cracking and failure under load or environmental stresses. The presence of different types of opening in PCC reduce its tensile strength and cracking resistance Thus, this research seeks to explore innovative solutions to address these limitations, aiming to develop a numerical model of plain cement concrete slab to measure the effect of different types of opening. The focus will be on effect of different types of grade of concrete on load carrying capacity of PCC slab with different types of opening.

V. RESULTS & DISCUSSION

Table 1 Effect of Grade of concrete on load carrying capacity of slab

Grade of Concrete	Load (N)	% – increment in load
M20 PCC solid slab	744	0
M30 PCC solid slab	1261	69.48
M40 PCC solid slab	2310	210.48
M60 PCC solid slab	4798	544.89

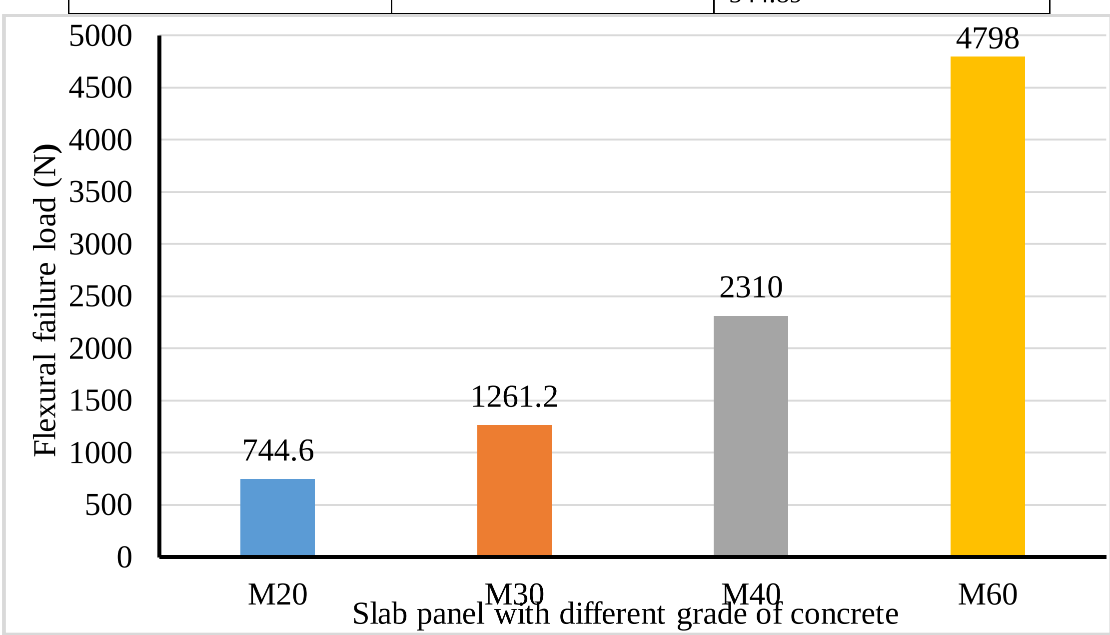

Figure 3 FEA results of PCC slab panel with different grades of concrete

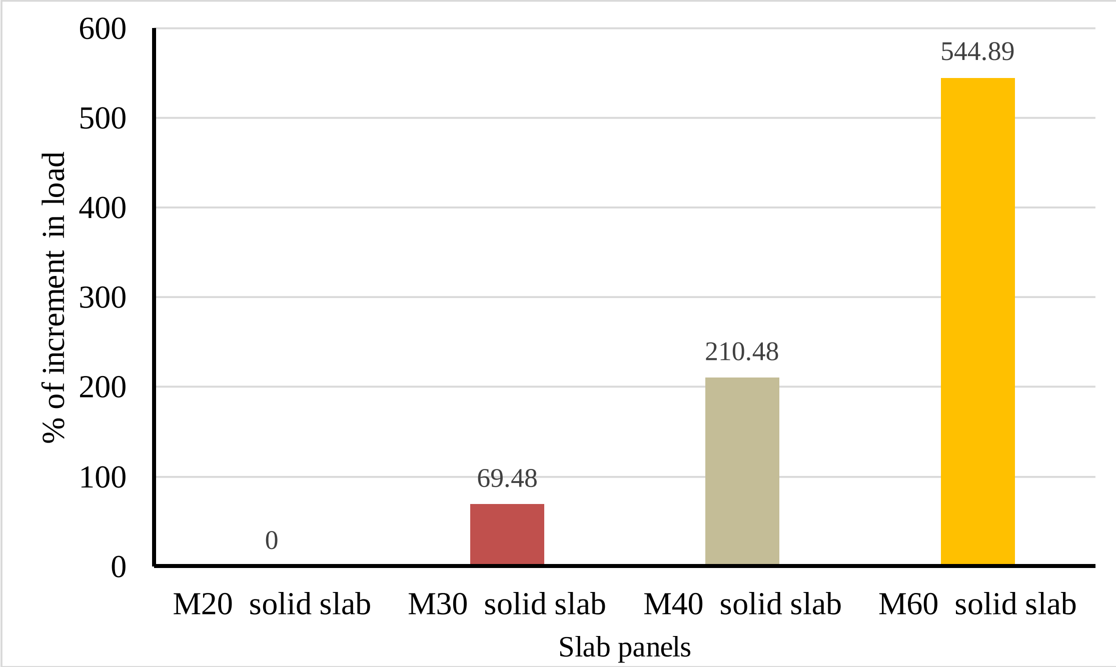

Figure 4 Percentage increment in load of PCC slab panel with different grade of concrete

Effect of opening on load carrying capacity of slab

Table 2 M20 grade of concrete slab with opening

Grade of Concrete	Load (N)	% of decrement in load
M20 solid slab	744	0
M20 with opening (10mm Dia) at NA	706.6	5
M20 with opening (10mm Dia) at 12.5mm below NA	682	8.33
M20 with opening (20mm Dia) at 12.5mm below NA	200	73.11

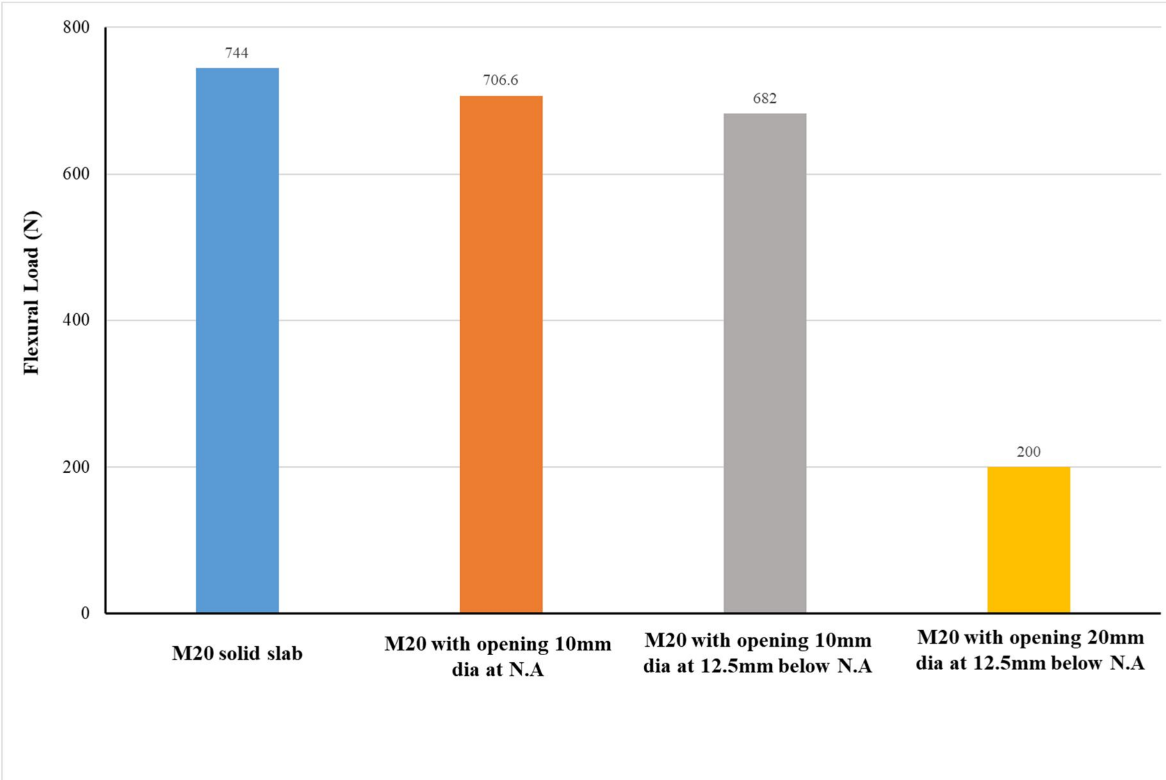

Figure 5 FEA results of M20 grade of PCC slab panel with opening

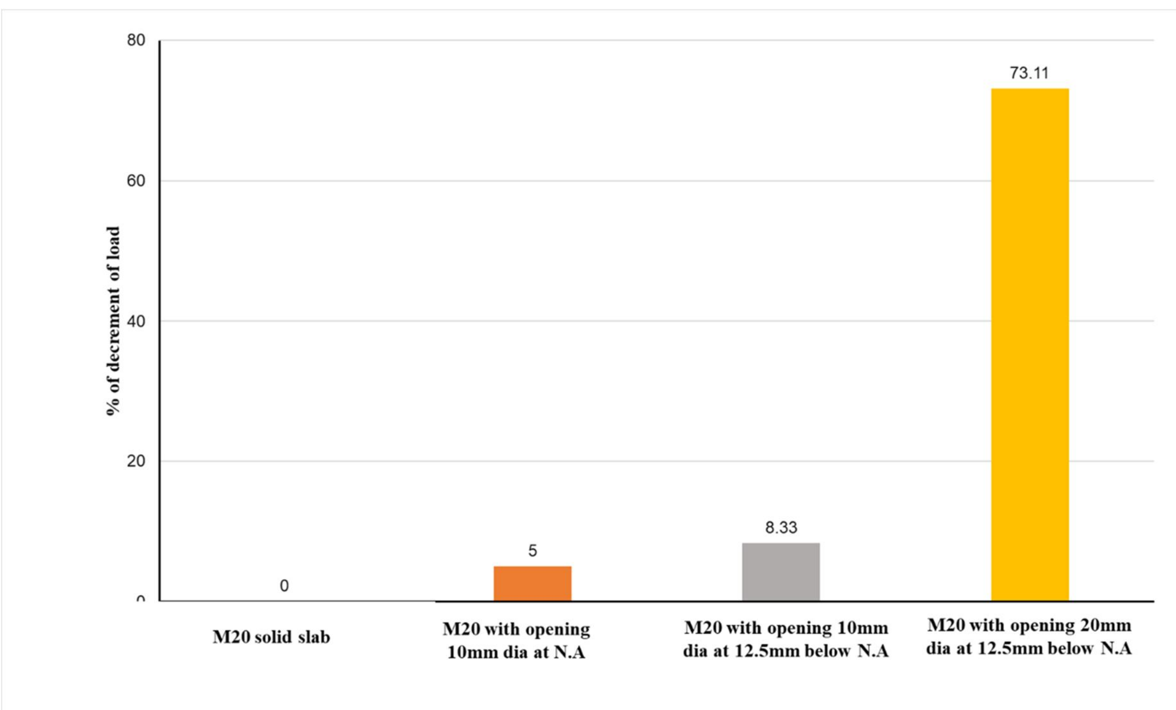

Figure 6 Percentage of decrement of load in M20 PCC slab panel with opening

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Table 3 M30 grade of concrete slab with opening

Grade of Concrete	Load (N)	% of decrement of load
M30 solid slab	1261	0
M30 with (10mm Dia) opening at NA	1069	15.23
M30 with (10mm Dia) opening at 12.5mm below NA	1038	17.68
M30 with (20mm Dia) opening at 12.5mm below NA	800	36.56

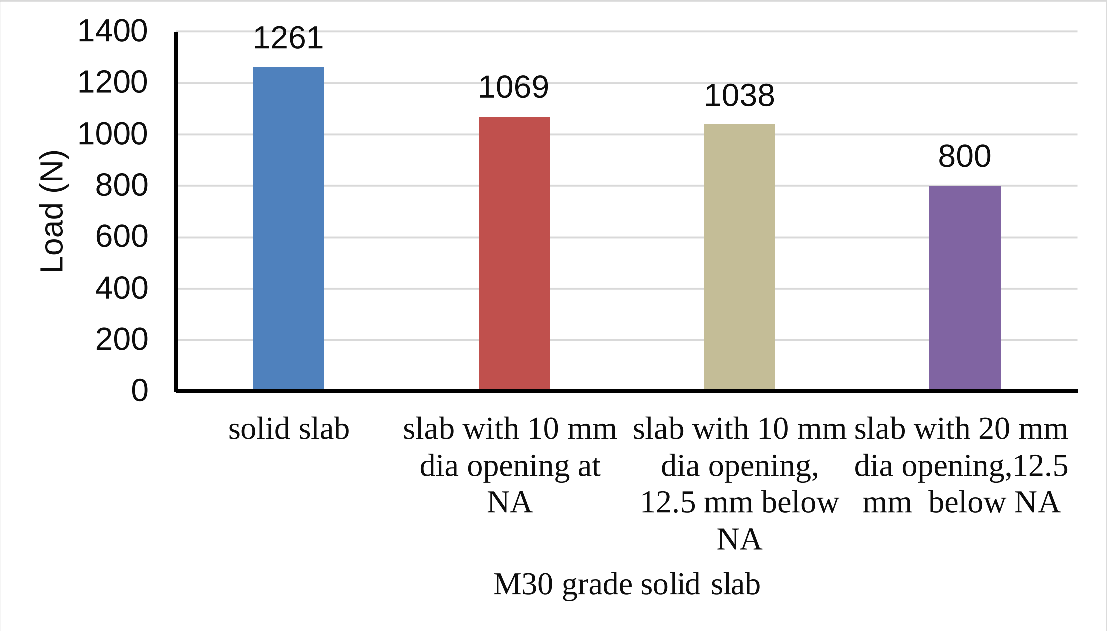

Figure 7 FEA results of M30 grade PCC slab panel with different opening

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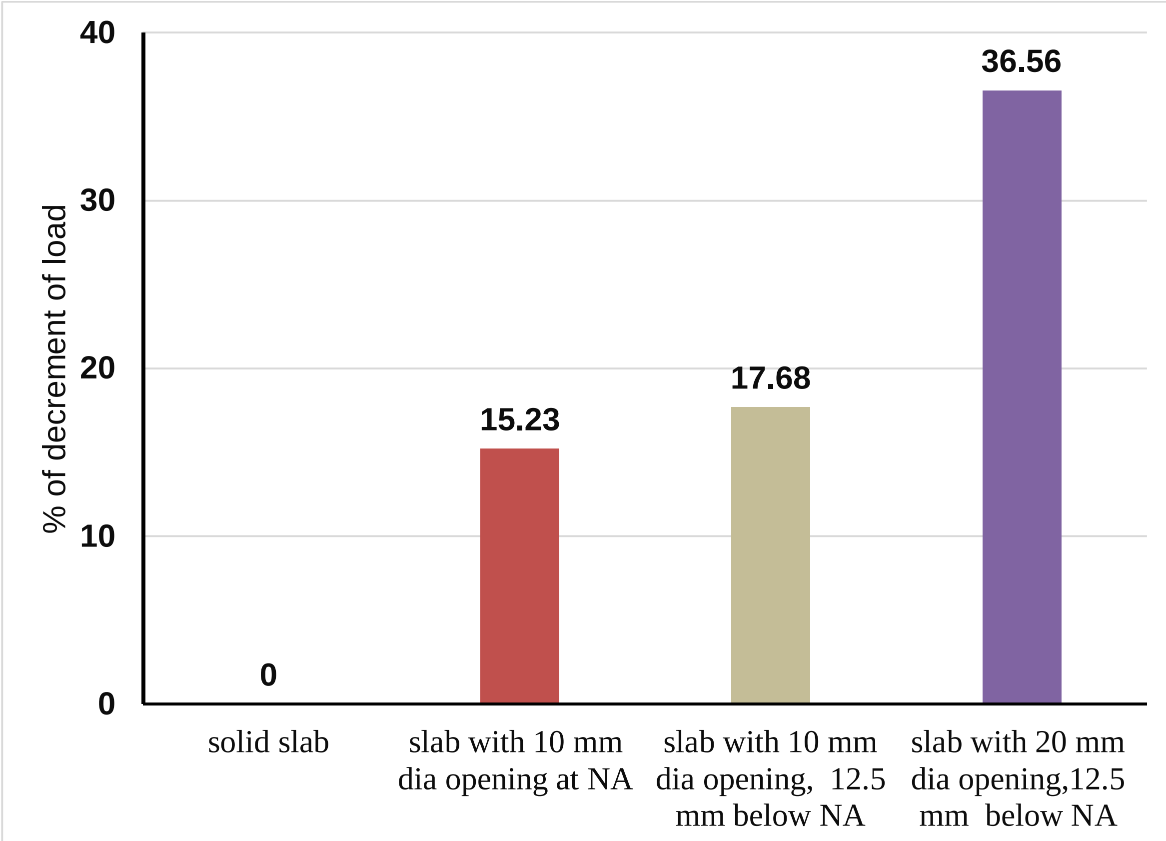

Figure 8 Percentage of decrement of load in M30 PCC slab panel with opening

Table 4 M40 grade of concrete slab with opening

Grade of Concrete	Load (N)	% of decrement in load
M40 solid slab	2310	0
M40 with opening (10mm Dia) at NA	1900	17.75
M40 with opening (10mm Dia) at 12.5 below NA	1750	24.24
M40 with opening (20mm Dia) at 12.5 below NA	1500	35.06

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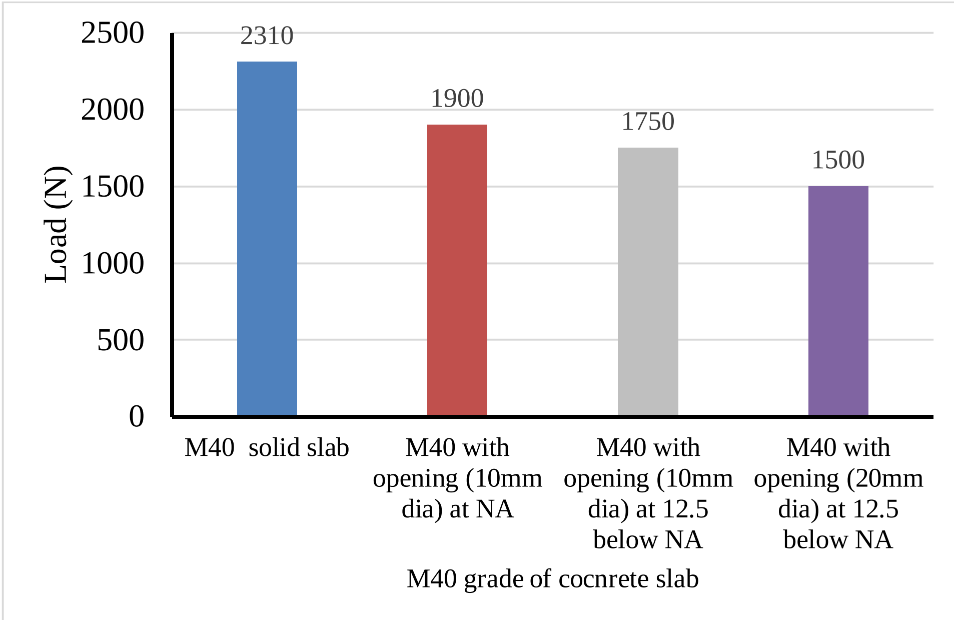

Figure 9 FEA results of M40 grade of PCC slab panel with opening

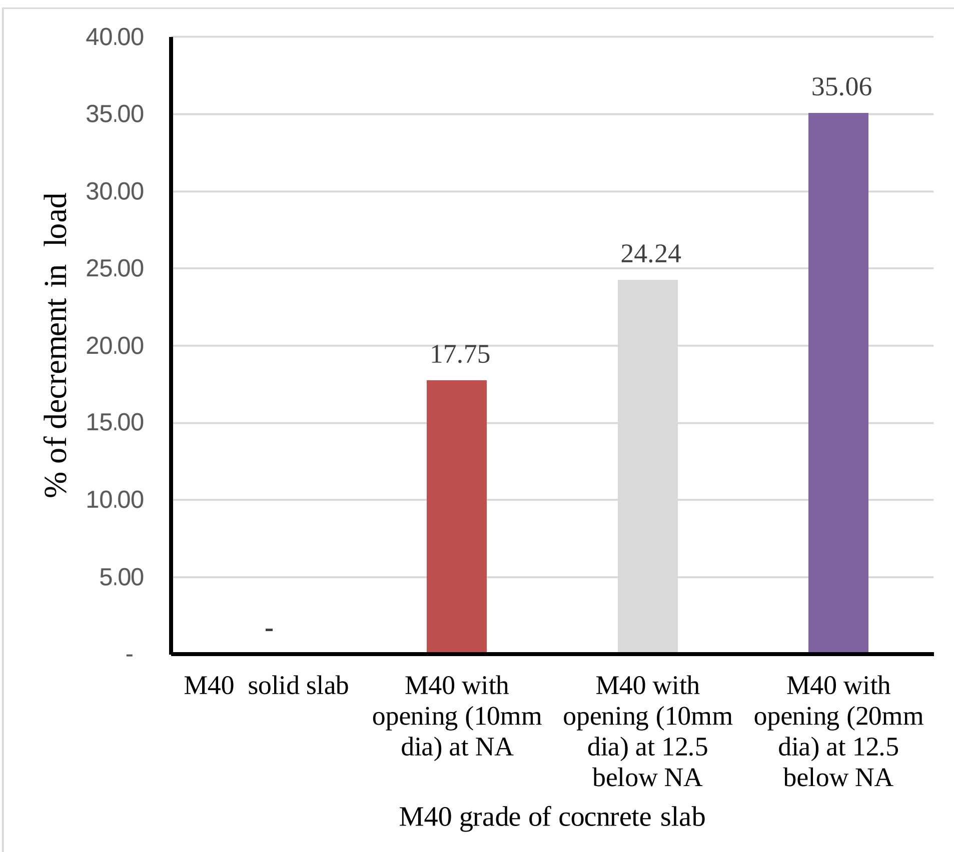

Figure 10 Percentage of decrement of load in M40 PCC slab panel with opening

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Table 5 M60 grade of concrete slab with opening

Grade of Concrete	Load (N)	% of decrement in load
M60 solid slab	4798	0
M60 with opening (10mm Dia) at NA	4300	10.38
M60 with opening (10mm Dia) at 12.5mm below NA	4100	14.55
M60 with opening (20mm Dia) at 12.5mm below NA	3700	22.88

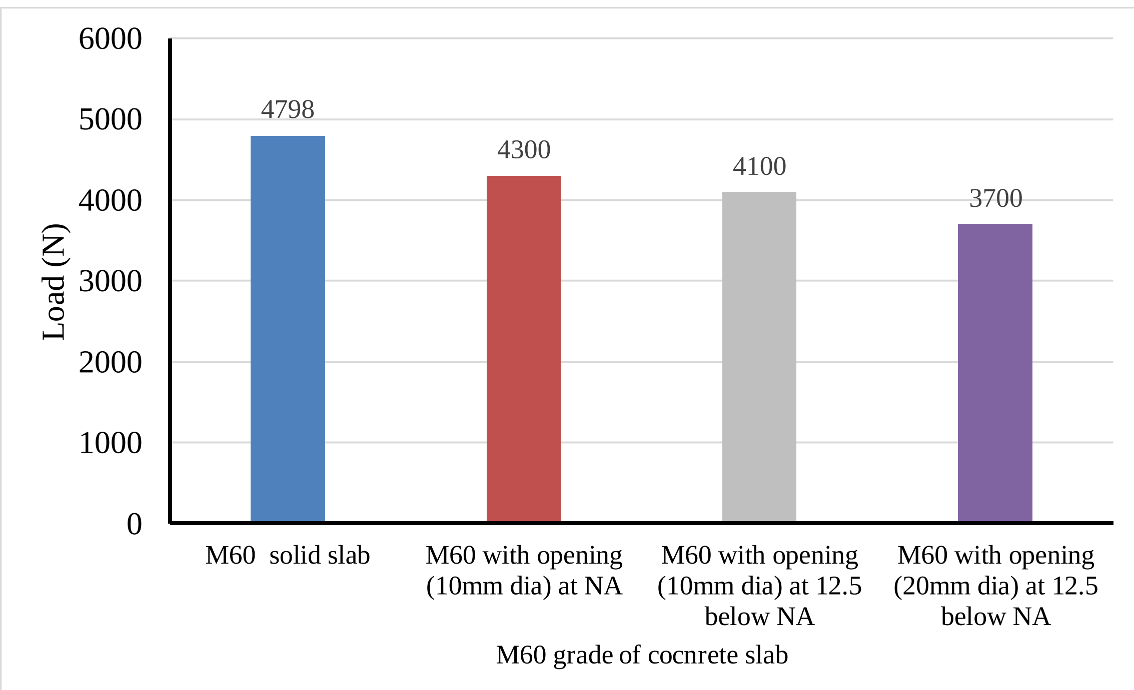


Figure 11 FEA results of M60 grade PCC slab panel with opening

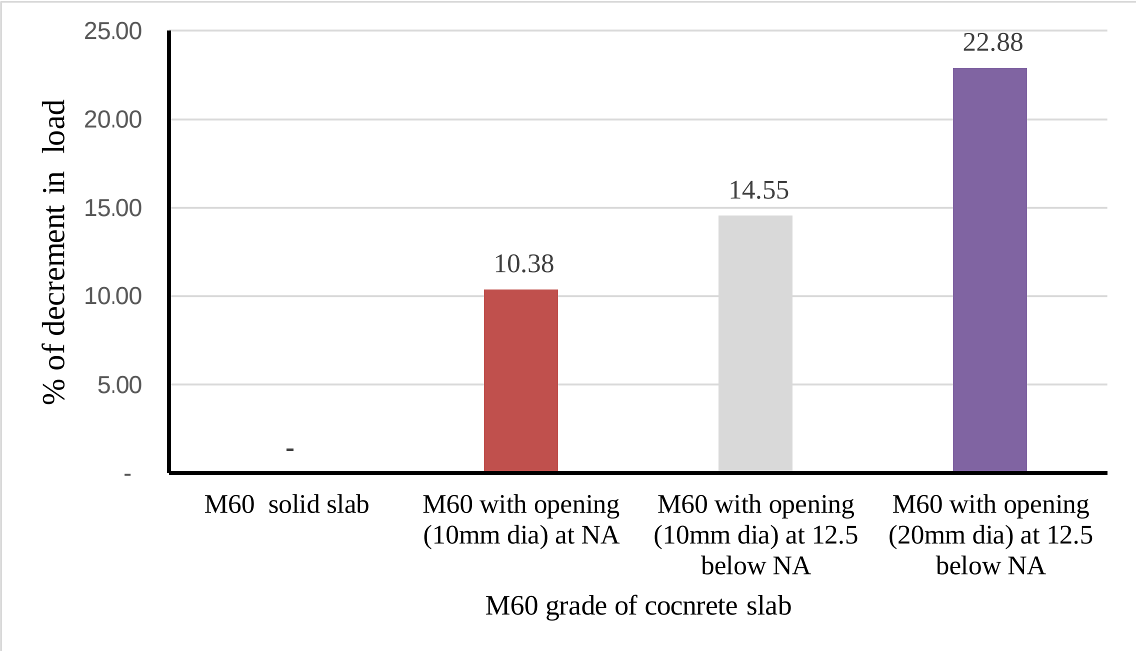


Figure 12 Percentage of decrement in load for M60 PCC slab panel with opening

VI. CONCLUSION AND FUTURE SCOPE

This study provides a comprehensive analysis of the impact of openings on the load-carrying capacity of P.CC slab, offering practical insights for improving precast P.C.C panel and construction practices. The FEA approach enables a deeper understanding of structural behavior, contributing to the development of more P.C.C slab panels.

- By increasing the grade of concrete on the P.C.C slab the load carrying capacity of P.C.C slab also increases.
- Circular openings at different locations lead to a reduction in the load-carrying capacity of P.C.C slab, and by increasing the size of opening a significant decrease in load carrying capacity is also observed.
- Reduction of area on concrete in tension zone also leading to greater reductions in load carrying capacity of P.C.C slab panel.
- The location of opening also affects the load carrying capacity of P.C.C. slab panel.
- Higher grades of concrete slab panel have higher resistance against opening as compared to lower grade of P.C.C slab panel.
- Opening at or near NA gives better results compared to openings away from NA.

The following are the suggestions for further study of the present work:

- The analysis can be made on P.C.C slab panel with wire mesh, poly vinyl fiber and other types of tensile strength improving material with openings.
- The analysis can be made on P.C.C slab panel with openings above NA.
- The analysis can be made on P.C.C slab panel with openings that are rectangular in shape instead of circular.

REFERENCES

[1] Jofriet, Jan C. and G. M. Mcneice. (1971). "Finite Element Analysis of Reinforced Concrete Slabs." *Journal of the Structural Division* 97 (1971): 785-806.

[2] Bureau of Indian Standards. (1979). *IS 9399:1979 - Specification for flexible polyurethane foam for domestic mattresses*. New Delhi: Bureau of Indian Standards.

[3] Bureau of Indian Standards. (2000). *IS 456:2000 - Plain and reinforced concrete – Code of practice*. New Delhi: Bureau of Indian Standards.

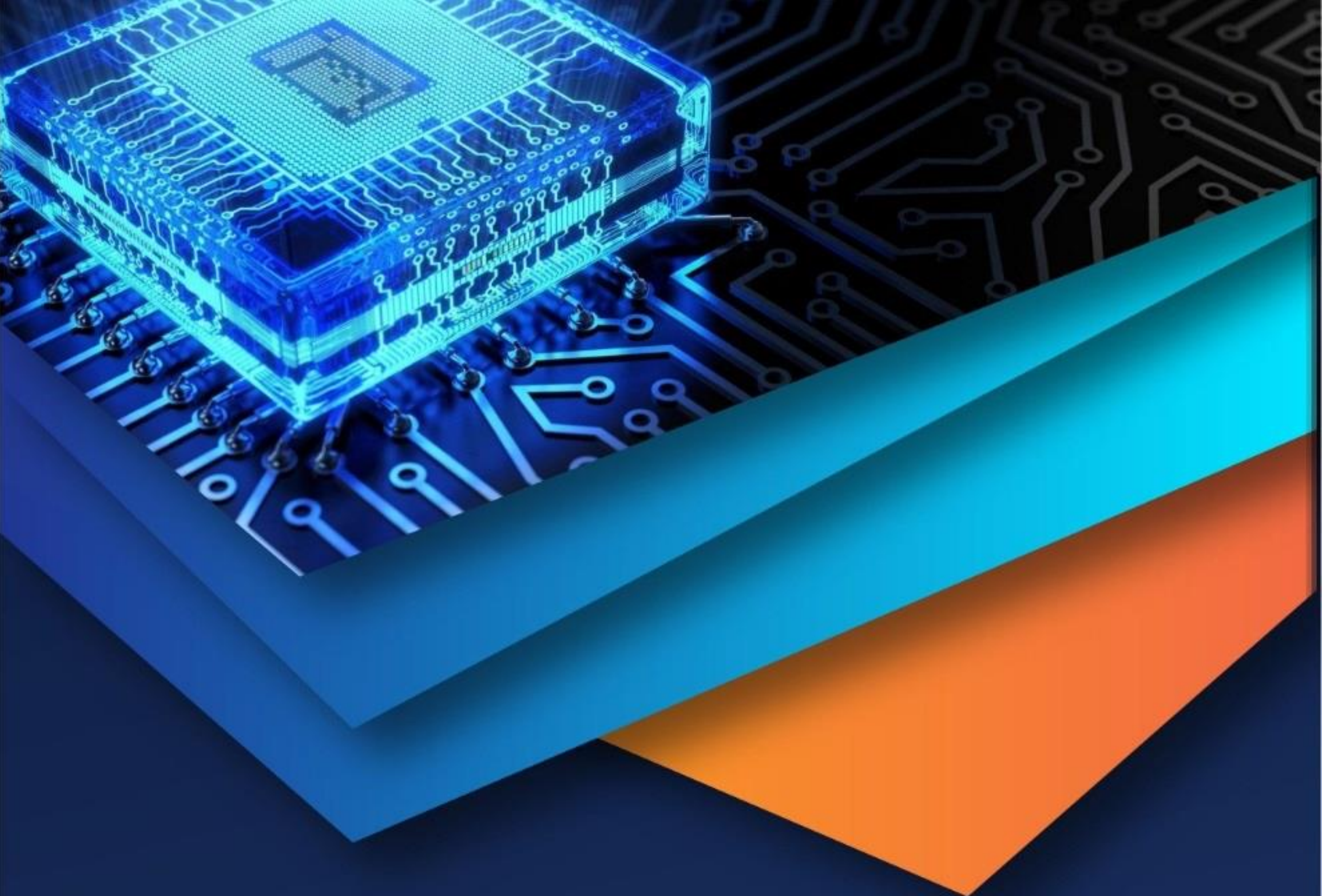
[4] Mosallam, A. S., & Mosalam, K. M. (2003). Strengthening of two-way concrete slabs with FRP composite laminates. Construction and Building Materials, 17(1), 43–54. https://doi.org/10.1016/S0950-0618(02)00092-2

[5] Foster, S. ., Bailey, C. ., Burgess, I. ., & Plank, R. . (2004). Experimental behavior of concrete floor slabs at large displacements. Engineering Structures, 26(9), 1231–1247. https://doi.org/10.1016/j.engstruct.2004.04.002

[6] Thanoon, W. A., Jaafar, M. S., A. Kadir, M. R., & Noorzaei, J. (2005). Repair and structural performance of initially cracked reinforced concrete slabs. Construction and BuildingMaterials, 19(8), 595–603. https://doi.org/10.1016/j.conbuildmat.2005.01.011

[7] El-Sayed, A., El-Salakawy, E., & Benmokrane, B. (2005). Shear Strength of One-Way Concrete Slabs Reinforced with Fiber-Reinforced Polymer Composite Bars. Journal of Composites for Construction, 9(2), 147–157. https://doi.org/10.1061/(ASCE)1090-0268(2005)9:2(147)

[8] Bureau of Indian Standards. IS 516 (2021)- *Flexural testing of concrete beams – Code of practice*. New Delhi: Bureau of Indian Standards.



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