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Finite Element Analysis of Plain Cement Concrete Slab With and Without Opening: A Review

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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. In this paper, we are conducting a literature review regarding analysis of plain cement concrete slab
Keywords: Finite Element Analysis (FEA), Plain Cement Concrete (PCC), Concrete slab, Load carrying capacity

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.

II. LITERATURE REVIEW

REVIEW OF LITERATURE

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.

Peter Marti et al., (1990) reviewed the mechanisms of transverse shear transfer in reinforced concrete slabs. A truss-model-based design procedure is developed for transversely reinforced labs, and its application is illustrated for the case of a large transfer plate in a high-rise building.

Kojima et al., (1991) described a series of missile impact tests of reinforced concrete slabs. The primary objective was to investigate the local behavior of slabs. The method of testing consists of making steel missiles collide against reinforced concrete slabs. A total of 12 tests were performed varying the targets and missile conditions. The following conclusions were obtained in the tests: (1) the degree of damage from a soft-nosed missile is less than that of a hard-nosed missile; (2) steel lining is effective in preventing scabbing; (3) the impact resistance of a double reinforced concrete slab is inferior to that of a single reinforced concrete slab in case of a hard-nosed missile, and almost equal in case of a soft-nosed missile; and (4) the existing formulae for evaluating critical thicknesses against perforation and scabbing give slab thicknesses on the conservative side.

Marzouk and Hussein, (1992) investigated the deformation and strength characteristics of punching shear failure of high-strength concrete slabs. The tested specimens had different slab depths and reinforcing ratios varying between 0.49 and 2.33 percent. Test results revealed that high-strength concrete slabs exhibit a more brittle failure than normal strength concrete. Experimental results indicated that as the level of reinforcement is increased, the punching strength of the slabs is also increased. It was found that using the cubic root of the concrete compressive strength to predict the punching resistance of the concrete slabs generally yields better results than the square root expression used in North American codes.

Matthys & Taerwe, (2000) use of fiber-reinforced polymer (FRP) grid reinforcement for concrete slabs has been investigated, considering the behavior of the slabs in one-way bending and under concentrated loading. The behavior under the latter loading type will be considered in this second part of a two-part paper. From the performed punching tests and the analysis, a fairly strong interaction between shear and flexural effects was noted for most of the tested slabs. For the FRP-reinforced slabs with an increased reinforcement ratio or an increased slab depth (needed to fulfill the serviceability criteria in bending), the punching strength was similar to or higher than the tested steel-reinforced reference slabs. For most slabs, slip of the bars occurred resulting in higher deflections at failure. The calculation of the punching failure load according to empirical-based models (from different codes), a modified mechanical model, and an analytical model is evaluated.

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.

Khaloo & Afshari, (2005) suggested a influence of length and volumetric percentage of steel fibers on energy absorption of concrete slabs with various concrete strengths is investigated by testing 28 small steel fiber reinforced concrete (SFRC) slabs under flexure. Variables included fiber, volumetric percentage of fibers and concrete strength. Test results indicate that generally longer fibers and higher fiber content provide higher energy absorption. The results are compared with a theoretical prediction based on random distribution of fibers. The theoretical method resulted in higher energy absorption than that obtained in experiment. A design method according to allowable deflection is proposed for SFRC slabs within the range of fiber volumetric percentages used in the study. The method predicts resisting moment–deflection curve satisfactorily.

Jeffery R. Roesler, et al., (2006) investigated the large-scale load testing was completed on both plain and fiber reinforced concrete slabs-on-ground. The fiber-reinforced concrete used a new synthetic microfiber. Although the synthetic fibers did not alter the tensile cracking load of the plain concrete slab, the flexural cracking load of the plain concrete slab was increased by 25 and 32% with synthetic fiber addition of 0.32 and 0.48% by volume, respectively, for the center loading configuration. Similarly, synthetic fibers at 0.48% volume fraction increased the flexural cracking load of plain concrete slab under edge loading by 28%. The ultimate load capacity of the plain concrete slab under center loading was increased by 20 and 34% with the addition of 0.32 and 0.48% synthetic fibers, respectively. Embedded strain gauges in the concrete slabs and deflection profile measurements indicated the fibers effectively distributed the load throughout the slab volume as cracking progressed, resulting in the increased concrete slab flexural and ultimate capacities.

Roesler and Jeffery et al., (2006) used synthetic microfiber in concrete slab and concluded that microfiber enhanced the strength properties of concrete slab. The results of the load testing showed that the failure behavior of plain concrete slabs was significantly modified with the addition of synthetic fibers, but that the synthetic fibers did not change the tensile cracking load of the plain concrete slab. Strain gauges embedded in the concrete slabs indicated the fibers distributed the load-carrying capacity throughout the slab volume, increasing the concrete slab flexural and ultimate capacities.

Roesler et al. (2006) suggested that microfiber can enhance the strength properties of plain and fiber- reinforced concrete slab on ground. The structural behavior of fiber-reinforced concrete slabs under interior and edge loading conditions were tested. The results of the load testing showed that the failure behavior of plain concrete slabs was significantly modified with the addition of synthetic fibers, but that the synthetic fiber did not change the tensile cracking load of plain concrete slab. Strain gauges embedded in the concrete slabs indicated the fibers distributed the load-carrying capacity throughout the slab volume, increasing the concrete slab flexural and ultimate capacities.

Schladitz et al., (2012) suggested that of textile reinforced concrete (TRC) is a very effective method for strengthening reinforced concrete (RC) constructions and researched was carried out on, strengthening the bending load capacity of existing concrete or reinforced concrete components. As a rule, the experimental research was done at small format reinforced concrete slabs with span widths of 1.60 m and slab thicknesses of 0.10 m strengthened with TRC. At the same time calculation models were developed to predict the maximum bending load capacity of the reinforced components amongst others.

This article describes the experimental and theoretical research reassessing the assignability of the results gained until now to large scale reinforced concrete slabs with a span width of 6.75 m and slab thickness of 0.23 m. By using textile high-performance carbon reinforcements based on so-called heavy-tow-yarns very high strengthening levels can be realized. The results show significant load bearing capacity increases compared to unreinforced reference slabs. Thus the safe use of bending reinforcements consisting of TRC could be demonstrated for components with even large span widths and high reinforcement degrees. Simultaneously a distinct decrease of deflection with growing reinforcement degree was verified at a comparable load level. Calculation results of the presented simplified calculation model for the estimated bending measurement are consistent with the load carrying capacities determined experimentally. Using the finite element method (FEM) not only the load bearing capacities but also the deformations were calculable keenly.

Yin et al., (2017) tested to investigate the behavior of nine rectangular specimens composite reinforced concrete (RC) slabs strengthened with ultra-high performance concrete (UHPC). The specimens were two series with various UHPC strengthening configurations. The first, a rehabilitation series, tested UHPC as patch material for repairing deteriorated concrete structures. The second, a UHPC overlay series, was used to retrofit soffits of RC members. The results showed that using the rehabilitation series, the UHPC reduced diagonal cracking and developed more flexural cracks as compared to RC slabs with no UHPC strengthening. The UHPC exhibited excellent energy absorption with extensive deflection hardening and ductility during the post cracking range. In the UHPC overlay series, each slab showed diagonal shear cracks and debonding modes. The UHPC overlay delayed the development of shear cracking. As the overlay thickness increased, the ultimate load increased; but the tendency for the UHPC to undergo fracture failure also increased.

Earij et al., (2017) developed a nonlinear finite element model, to predict the short-term behavior of reinforced concrete slabs under transverse service loads. The model is based on small deflection plate bending theory and uses a layered 16-degree-of-freedom rectangular plate bending element. The sources of material nonlinearity in reinforced concrete slabs are examined and accounted for in an incremental nonlinear solution procedure. Various methods are considered for treating the tension stiffening effect that occurs between the cracks in the tensile concrete in regions close to the reinforcement. Numerical calculations are used to assess the relative merits of these methods and to test the validity of the model. A simple treatment of the tension stiffening effect is proposed in which a modification is made to the tensile stress-strain diagram for the reinforcing steel. This produces accurate results with relatively economic use of computer time.

Mali & Datta, (2018) used reinforced concrete structural members subjected to static gravity loads. The conventional steel reinforcement is used to provide additional tensile strength and energy absorption capacity to concrete members. But conventional M.S. (Mild steel) or HYSD (High Yielding Strength Deformed) bars are heavy in weight, costly, nonrenewable and un-ecofriendly material. Aiming to mitigate this concern a sustainable, renewable, ecofriendly material like bamboo has been used as substitute to steel in the present work. Bamboo-concrete Bond behavior was first studied through a series of pull-out tests. Bond strength investigation has resulted in a unique bamboo strip profile along with a surface treatment the combination of which exhibited maximum bond strength under uniaxial loading. This new bamboo strip is further used as main reinforcement in concrete slab panels. Feasibility and effectiveness of this unique bamboo profile used as reinforcement was investigated through experimental testing of concrete slab panels. A total 15 concrete slab panels were fabricated and tested as per Eurocode EN-1448-5 (2006). The effect of total replacement of main steel reinforcement by bamboo on the flexural behavior of slabs in terms of load-deformation characteristics, energy absorption capacity, crack patterns and failure modes have been studied. Test results show that there is improvement in the load carrying and deformation capacity when proposed bamboo strip is used as reinforcement in concrete slab panels as compared to that of PCC (Plain Cement Concrete) and RCC (Reinforced Cement Concrete) slabs. Interestingly the structural behavior of slabs using newly developed bamboo reinforcement has shown significant improvement in flexural performance and it was marginally better than the RC slabs having M.S. bars as main reinforcement.

Abbas et al., (2022) suggested that the ions of lead of wastewater loaded into rice husks can be used as an additive for plain concrete slabs to improve the flexural strength, as well as the workability of plain concrete slabs (or walls), which are produced by using Lead-loaded rice husk material as an additive substance in protective shields for the establishment of hospital radiology rooms. The results show that flexural strength for plain concrete slabs begins with a relative increase until it reaches breakdown. The results at age of 28 days also show that by increasing the proportion of Lead-loaded rice husk added to plain concrete slabs, the flexural strength gradually increases until it reaches one-third of the value of reference plain concrete slabs at a specific ratio, then decreases sharply until the slabs fail. These results provide a novel approach to managing toxic waste and propose an easy, simple, effective, economical, and environmentally friendly way to get rid of more than one type of waste and reach the concept of zero residue level.

III. CONCLUSION

Here in this paper, we are concluding several research papers regarding plain cement concrete slabs.

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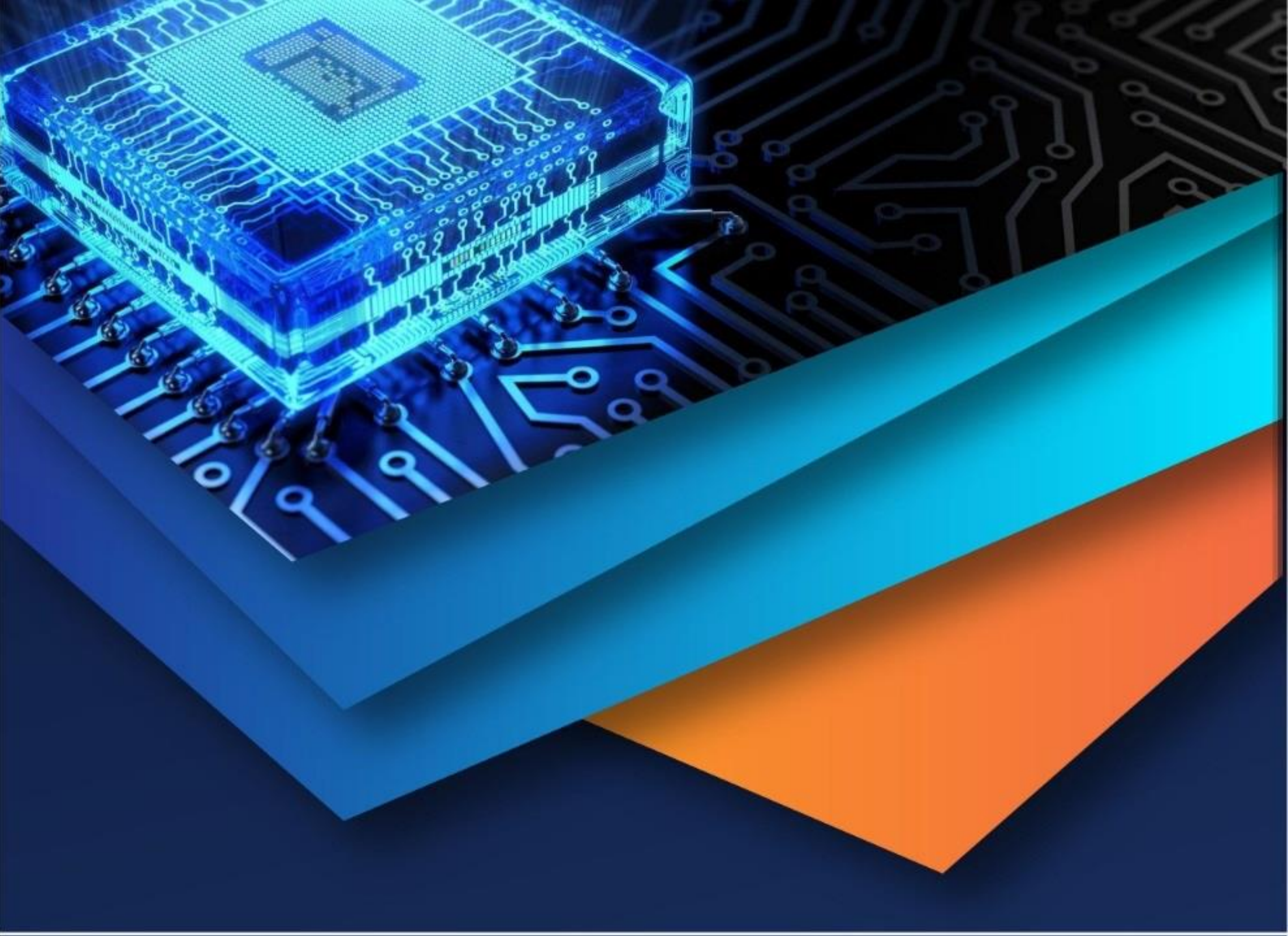

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