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# Finite Element Analysis of Punching Shear in Flat Slabs: A Review

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**ABSTRACT:** Punching shear failure occurs in reinforced concrete flat slabs due to the creation of a three-dimensional state of stresses around the column generated by high transverse and in-plane strains. Many efforts are being worked on by researchers to identify and increase punching shear strengths in flat slabs. This article covers some of the methodologies and strategies pioneered by previous studies, as well as their success in increasing punching shear strength. This research also considers the effects on slab column joints. The efficacy of a new strengthening solution for existing flat slab interior slab-column connections employing steel angle plates and high strength steel bolts is also discussed. The evolution of the concrete and steel contributions in shear-reinforced flat slabs is explored in depth, and a technique for estimating and analysing both contributions is discussed. The current study includes comparison flat slab strengthening with Externally Bonded Reinforcement "On Grooves" (EBROG) and "In Grooves" (EBRIG) FRP strips to those of Externally Bonded Reinforcement (EBR) FRP strengthening. The potential scope of future work is also highlighted.

**KEYWORDS:** Flat Slabs, Finite element analysis, Punching shear, slab-column connection, strengthening, crack pattern, Flat plate, FRP.

## INTRODUCTION

Flat slab structural systems have gained favour in the construction of multi-story commercial buildings over the last few decades due to various advantages the system provides in terms of depth solution, flat soffit, and flexibility in design arrangement. In flat slab designs, the slab column connections are extremely vulnerable to punching shear failure, which can occur suddenly and without notice. Such collapse may be ascribed to faulty structural design, building flaws, or a change in the usage of the present structure with increased floor loads. Pure shear punching occurs when a high reinforcement ratio is used, resulting in rapid failure at a small displacement, whereas flexural punching demonstrates ductile deformation at a large displacement where the failure mode is intermediate; neither pure flexural nor pure punching shear occurs. Flat slabs without shear reinforcement, on the other hand, are especially sensitive to brittle failure types. When punching happens, the column and the slab physically separate from one other, disrupting the structural system's balance and eventually leading to structural collapse. These failures result in serious human fatalities unless enough reinforcement is supplied, highlighting the need of correct details and design improvement.

Efforts have been made in recent decades to improve the punching shear strength of flat slabs. Many design guidelines and strengthening solutions for the slab-column connections of new flat slabs have been documented in the past. Shear reinforcements such as bent-up bars were investigated. Some of the recommendations and strategies made by various researchers to increase the punching strength of flat slabs are described in this study.

## II. LITERATURE REVIEW

Aikaterini S. Genikomsou, Maria Anna Polak [1] performed finite element analyses (FEA) in order to investigate the effect of the compressive membrane action in flat concrete slabs by comparing results from isolated specimens and continuous floor systems. finite element analyses (FEA) are performed in order to investigate the effect of the compressive membrane action in flat concrete slabs by comparing results from isolated specimens and continuous floor systems. They used model SB1 from previous research and considered it as continuous by applying various boundary

conditions. The adopted continuous model for the slab SB1 is as shown in [fig. 1](#). The result they obtained are displayed in [Fig.2](#) and the statistics is presented in [table 1](#).

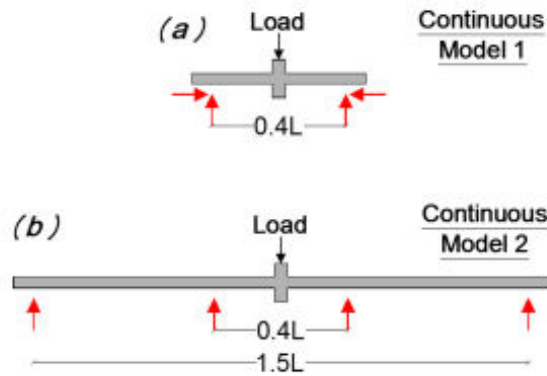


Fig. 1: Adopted Continuous models for the slab SB1 by Aikaterini S. Genikomsou and Maria Anna Polak [1]

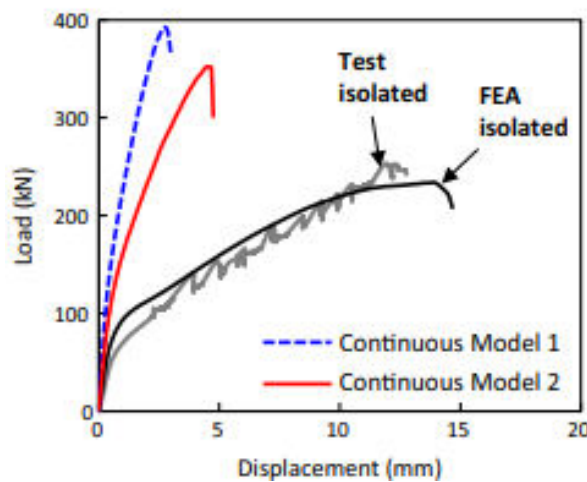


Fig. 2: Load-deflection curves of the continuous slabs (comparison with the simply supported isolated ) [1]

Table 1: Finite element analysis results. [1]

Specimen	Failure Load (kN)	Displacement at failure (mm)
Isolated	234	13.9
continuous model 1	392	2.7
continuous model 2	352	4.5

Their research conclude that the deflections of all simulated continuous specimens are less than those of the isolated simply supported slab due to the membrane action effect. As a result, the continuous specimens have lower crack widths and the crack patterns are localised around the region of the column rather than spreading to the slab margins. As a result, continuous slabs have greater punching shear strength. The whole floor system study reveals that the actual slab has a 24% greater punching shear resistance than the isolated simply supported slabs. This punching shear strength is lower than that obtained for continuous slabs. As a result, the continuous models overstate the compressive membrane action effect and its contribution to punching shear strength.

H.R. Taresh, M.Y.M. Yatim, and M.R. Azmi [2] investigated the behaviour of inner slab-column connections using steel angle plates and high strength bolts in a series of experiments on reinforced concrete flat slabs. At both tension

and compression sides, the angle plates were fastened to the column faces and slab. The steel plate dimensions is shown in Fig. 3(a). The shorter leg of the angle plate linked to the column face functions as an equivalent concrete width column capital, while the longer leg functions as an equivalent concrete depth drop panel. Four practical-sized flat slabs were built and tested to failure under shear force delivered via the column. Non-linear finite element models were built, examined, and validated against test results, only to discover that both findings were in good accord. A parametric analysis was conducted to explore the effects of bolt strength, bolt spacing, and angle plate dimensions on the ultimate load behaviour of the slab. A simple theoretical technique based on yield line theory for predicting the flexural capacity of the reinforced slab is also described. In addition, the tests and numerical results are compared to the values anticipated by the ACI design code. The test setup is shown in fig 3 (b).

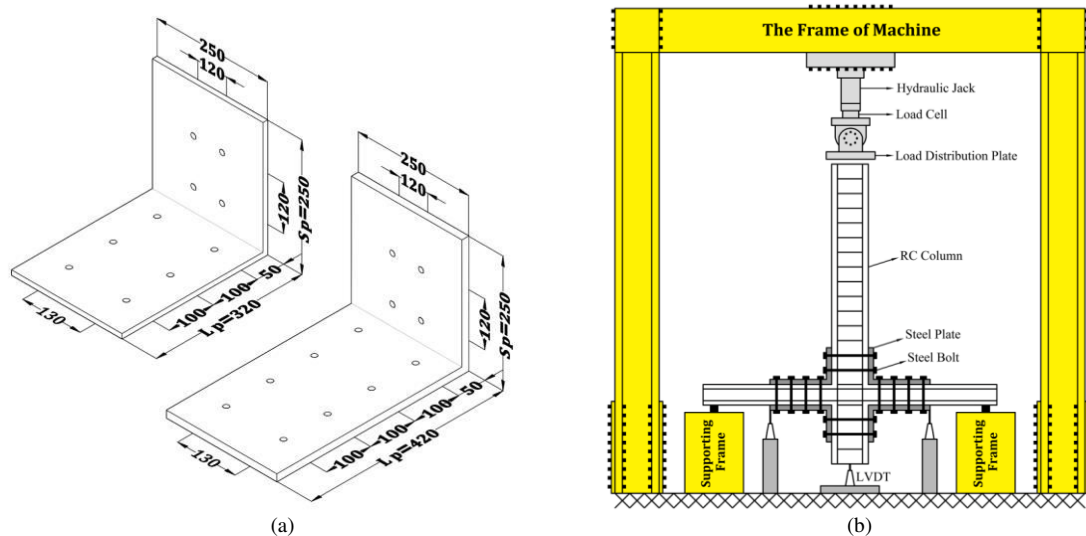


Fig. 3: H.R. Taresh, et. al. [2] (a) Dimensions of steel plates used, (b) Test setup

They concluded that the average increase in failure load, deformation capacity, stiffness, and energy absorption achieved by the reinforced slabs was roughly 51%, 20%, 24%, and 209%, respectively, over the control specimen. This huge improvement can be due to confinement pressure on the concrete mass along the column, which results in an increased critical section from the column perimeter to the outside of the reinforced sections.

Philipp Schmidt, Dominik Kueres, and Josef Hegger [3] studied the evolution of the concrete and steel contributions in shear-reinforced flat slabs in depth and offered a technique for computing and assessing both contributions. The evolution of concrete and steel contribution based on the quantity of shear reinforcement is examined and compared to the design provisions of Eurocode 2, Model Code 2010, and the draught (as of April 2018) of the next generation of Eurocode 2. They also proposed that by taking into account the tested range of parameters, more progressive design concepts, particularly for low and medium degrees of shear reinforcement, may be produced. Fig. 4 show the development of concrete and steel contribution.

The conclusion of this study is that the semi-empirical design approach of EC2 assumes a constant concrete contribution and a linearly rising steel contribution proportional to the quantity of shear reinforcement for the punched design of shear reinforcement. In contrast, the physically-based regulations stated in MC2010 and prEC2 take into account a diminishing concrete contribution and a rising contribution of shear reinforcement with increasing shear reinforcement ratio. Because a direct measurement of the concrete contribution to punching capacity is not possible, the concrete contribution of a flat slab at failure can be computed as the final punching shear failure force less the predicted steel contribution.



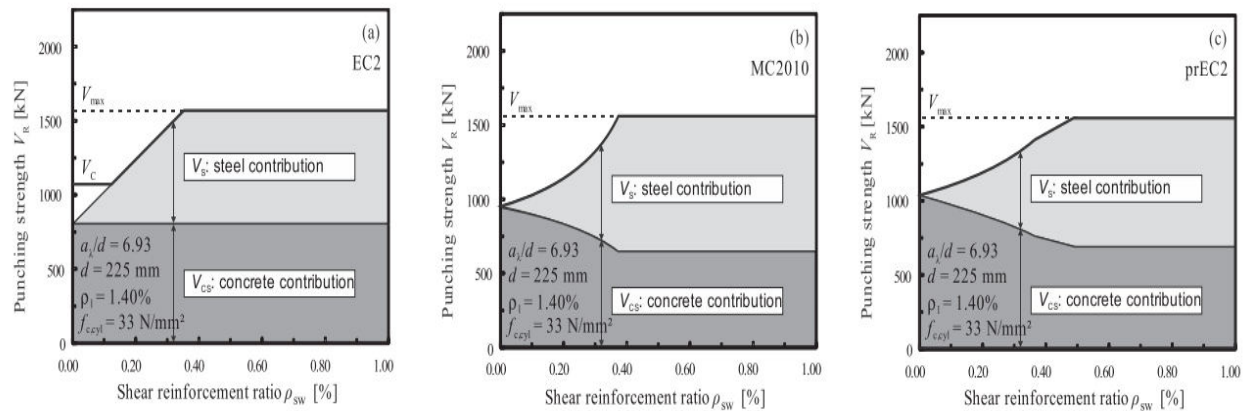


Fig. 4: Development of concrete and steel contribution according to EC2, MC2010, and prEC2 as a function of the shear reinforcement ratio by Philipp Schmidt, et al. [3]

Brisid Isufi, Ildi Cismasiua, Rui Marreiros, António Pinho Ramos, Válder Lúcio [4] Horizontal cyclic loading studies on flat slab-column specimens show that inserting punched shear reinforcement significantly improves drift capacity. Seismic design codes, on the other hand, either do not suggest or do not include structures with flat slabs as part of the major lateral load resisting system. The goal of this work is to contribute to a better understanding of the advantages and disadvantages of utilising punched shear reinforcement in seismic performance of such structure. To that goal, nonlinear static analyses and a set of fragility functions are developed for two reinforced concrete three story frame models. To reduce modelling errors, the numerical models are calibrated using two laboratory specimens (one without punched shear reinforcement and one with headed studs) evaluated under reversed horizontal cyclic loads. Fig. 5. Shows Adopted model for the specimens and the flat slab-column connections and fig. 6 shows the model for equivalent frames.

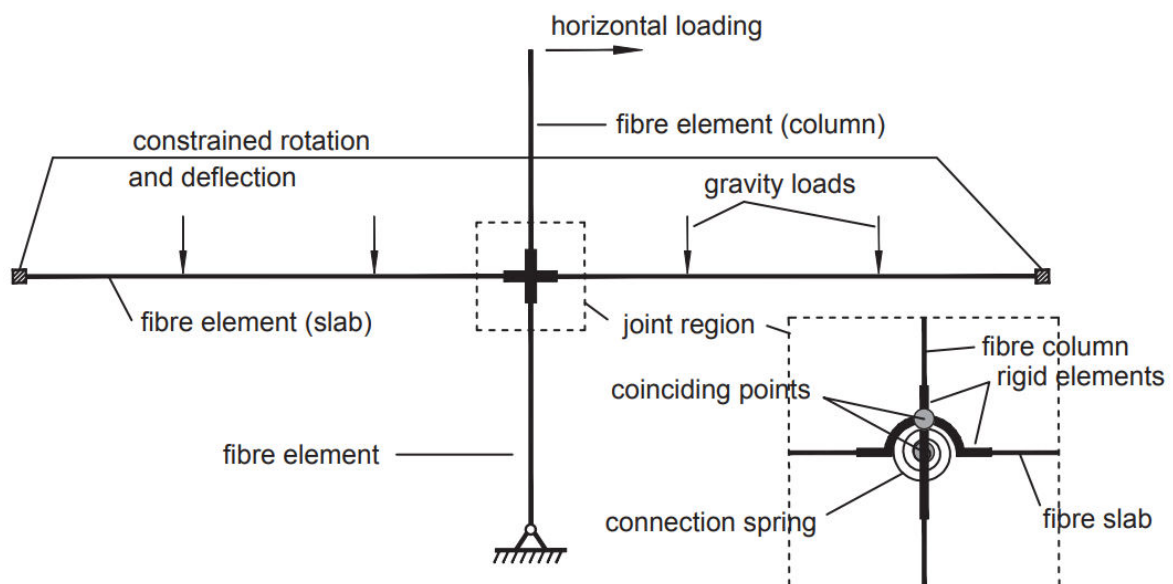


Fig. 5 : Adopted model for the specimens and the flat slab-column connections. by Brisid Isufi, et al. [4]

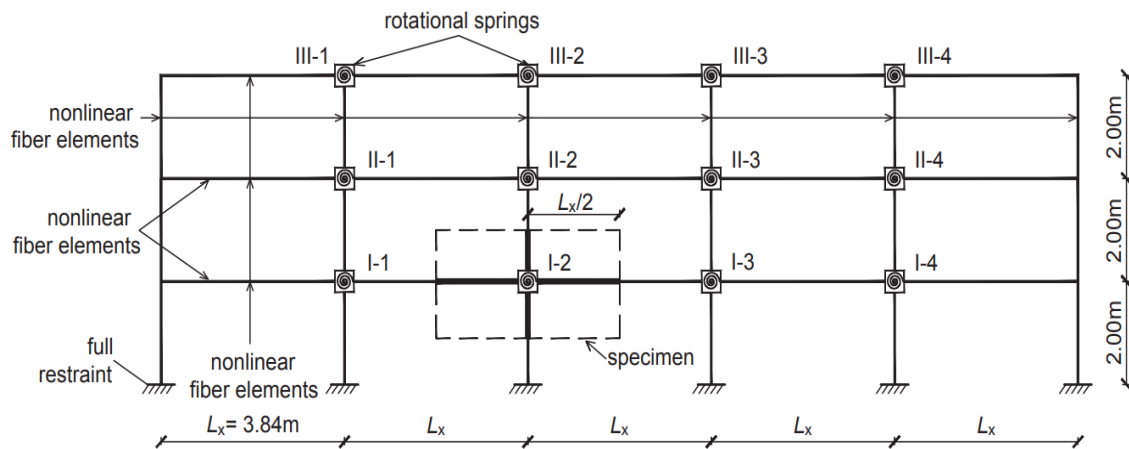


Fig. 6 : Model of the equivalent frames by Brisid Isufi, et al. [4]

The results demonstrate that incorporating punched shear reinforcement can increase the performance of the frames. However, it is demonstrated that the intrinsic flexibility of slab-column connections under lateral stress remains a limiting factor even when punching shear reinforcement is used.

Marcus Ricker, Tania Feiri, Konstantin Nille-Hauf, Viviane Adam, Josef Hegger et. al [5] offered a comprehensive analysis of the state-of-the-art of dependability approaches in which the safety level of design provisions for punching shear resistance without shear reinforcement is studied. This study focuses on three reliability analysis techniques: Mean-Value First Order Second Moment Method (MVFOSM), First-Order Second Moment Method (FOSM), and Monte-Carlo simulation with Importance Sampling (MC-IS). Reliability indices are employed as a practical assessment of the safety level by expressing failure probability. The parameters impacting punching shear capacity without shear reinforcement were modified to span the region of practical concern. , the study demonstrates that the application of the approaches FOSM and MC-IS appears adequate for calculating the likelihood of failure of the design equation for the punched shear capacity without shear reinforcement. The work emphasises the possibility of employing the aforementioned reliability analysis methodologies and emphasises the significance of calculating the uncertainties for an accurate structural safety evaluation of flat slabs without shear reinforcement. Reliability indices are presented in fig 7 and fig 8.

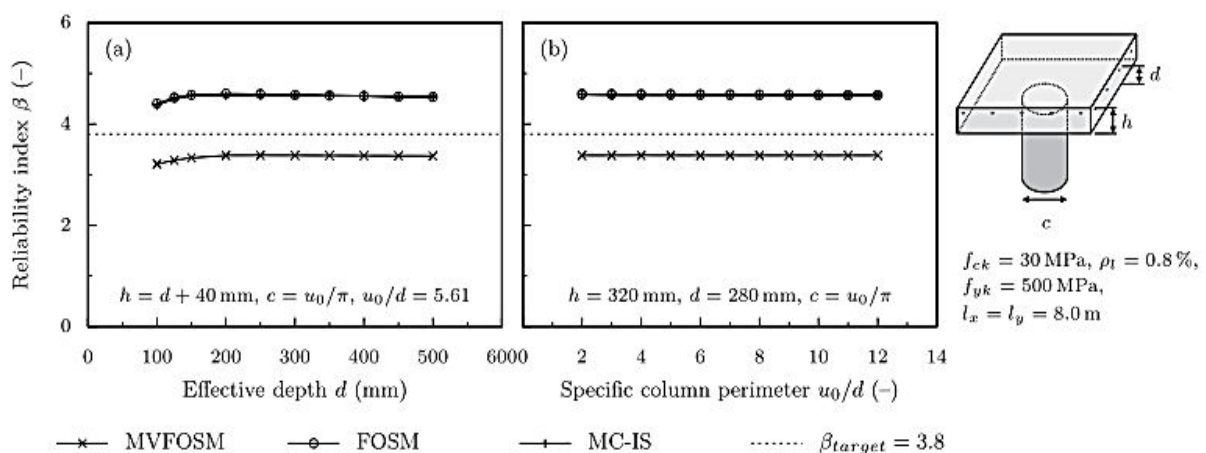


Fig. 7: Reliability indices in dependence of (a) effective depth and (b) column dimensions by Marcus Ricker, et al. [5]

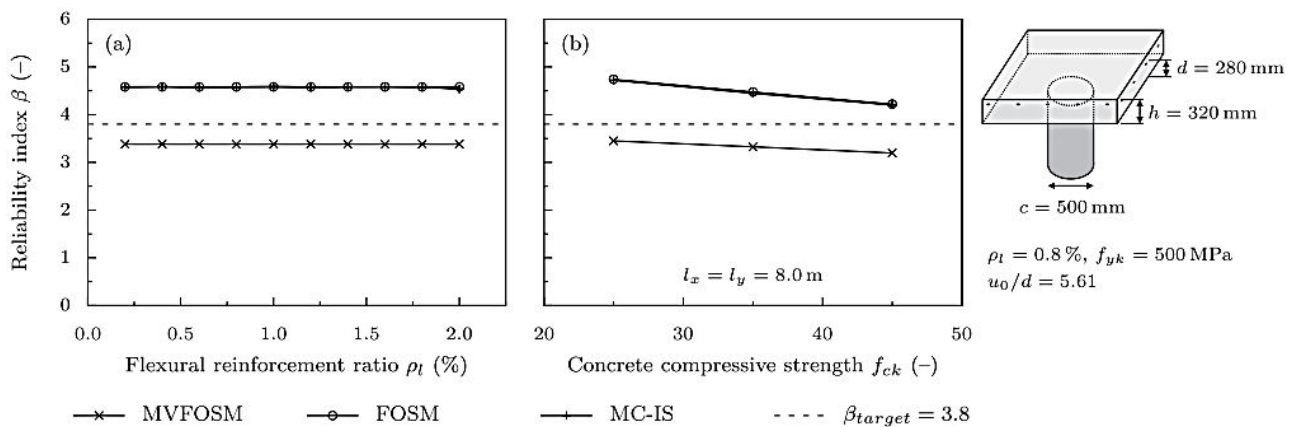


Fig. 8: Reliability indices in dependence of (a) flexural reinforcement ratio and (b) concrete compressive strength. [5]

The study found that the limit state function is more sensitive to the variable expressing model uncertainty than to any other variable, emphasising the need of accurately estimating and minimising the uncertainties in the resistance model. On the opposite end of the spectrum, the study found that the flexural reinforcement ratio had no effect on the safety level of the punching shear resistance model.

Somayeh Amiri, Sayed Behzad Talaeitaba [6] researched and compared the strengthening of flat slabs using Externally Bonded Reinforcement "On Grooves" (EBROG) and "In Grooves" (EBRIG) FRP strips to Externally Bonded Reinforcement (EBR) FRP strengthening. Nonlinear analysis was used to define and examine 28 slabs, one control and 27 strengthened. The EBRIG and EBROG reinforcing layouts had 1- or 2-layer FRP strips under slabs on two grooves of 4 or 8 mm width and 8, 10, or 12 mm depth. First, the findings of the finite elements (FE) analysis were validated against experimental results from the literature, confirming that the FE nonlinear analysis can be utilised to estimate the behaviour of reinforced slabs. The findings of the study of EBR, EBRIG, and EBROG strengthened samples revealed that FRP strengthening of slabs in EBRIG and EBROG format enhanced the punching capacity of the slab by up to 60%, while EBR strengthening increased this capacity by around 28%. The Bond-Slip models of EBR, EBROG, and EBRIG reinforced samples are depicted in fig 9.

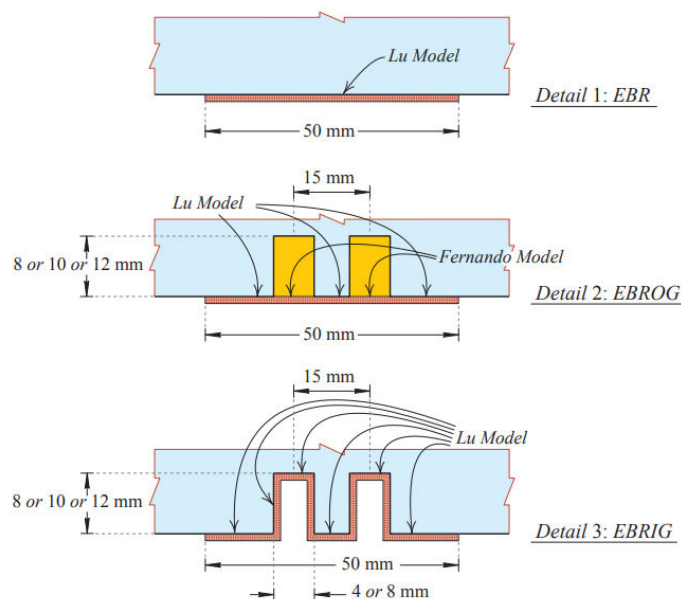


Fig. 9: Bond-Slip models of EBR, EBROG and EBRIG strengthened samples in FE analysis by Somayeh Amiri, Sayed Behzad Talaeitaba [6]

### III. CONCLUSION

After reviewing all the previous researches, we found out that 3D nonlinear finite element methods may be employed efficiently in punching shear simulations to assess the continuity of reinforced concrete floor systems. The outcome of this compressive membrane action is an increase in the flexural and shear capacity of a slab. The existing punching shear design requirements do not take the membrane action impact into account. The calibrated concrete damaged plasticity model in ABAQUS properly predicts the reactions of the continuous and isolated slabs. Full actual floor systems can be analysed using FEA; however, they need more computing time than isolated slabs. The modification of these factors affects the punching shear capacity; consequently, this influence should be addressed and examined in future study effort.

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