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Assessment on the performance of flat slab under service load and ultimate load using ABAQUS

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Abstract. The research carried out to study on the performance of the flat slab under the design load. The design loads consist of service load, 14.68 kN/m² and the ultimate load, 21.31 kN/m². The justification on the design load was from the car park. The Three-Dimensional (3D) Finite Element Analysis (FEA) were conducted to investigate their failures modes with the appropriate modelling of element, mesh and concrete parameter. The size of flat slab was 1200 mm x 1200 mm x 175 mm while the material parameters were the Grade 25 for concrete and S275 for steel. It is found that the improvements more than 20% to the strength of model flat slab with shear reinforcement. Another outcome of the study indicated that the punching shear location using the FEA was less than 250 mm from column perimeter which is within the two times the depth (2d) from column face as proposed by the Eurocode 2: Design of Concrete Structures.

1. Introduction

Flat slab building is a structure component where it is supported by the column. It is different from the conventional slab which the slab is supported by the beam and column. The aesthetical value of this type of construction is very good but need to be careful with a huge punching shear experienced by the flat slab as the load is directly distributed to the column [1]. Flat slab construction can lead to high shear stresses around supporting columns, which can cause abrupt punching shear failures at loads well below the slab flexural strength. Traditionally, to prevent shear failure, reinforcement is provided either at an angle or perpendicular to the main flexural reinforcement [2]. The flat slab is widely used in commercial building, hotels, parking spaces and other buildings which are less depending on beam support. Figure 1 shows the difference between the conventional slab and flat slab. For ordinary structure, the beams are used to support the slab as shown in Figure 1(a). The loading from the slab including the self-weight of the slab is distributed along the beams and the loading is directly transfer to the column. Meanwhile, for the flat slab as Figure 1(b), first the perspective view of flat slab is very impressive and elegant. There is no usage of beams in between column to column. The slab actually distributes its weight and self-weight directly to the column, where the column will receive the load directly from the slab [3].



The advantages of the flat slab are flexibility in room layout and can introduce partition walls anywhere required. It can change the size of room layout and at the same time omit false ceiling. At the same time it can save building height with lower storey height and it can reduce building weight approximately 10% in vertical members. Furthermore, it can reduce foundation load.

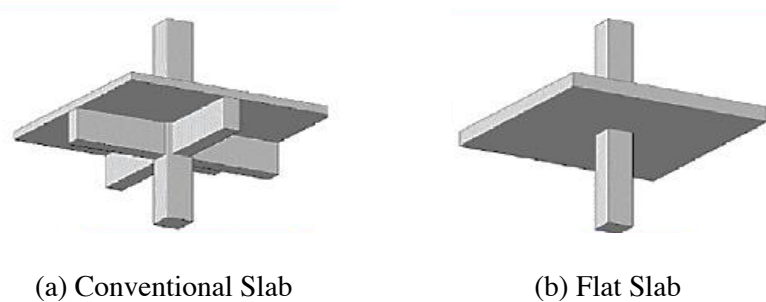


Figure 1. Types of slab structures.

This study is conducted using ABAQUS which offered a coupled damaged-plasticity model for 3D finite element analysis adopted for the representation of concrete [4]. Analyses of reinforced concrete structures using finite element method (FEM) give a great advantage and a perfect view in term of finite element analysis (FEA) to show the critical part of the model. FEA is very sensitive as it adopted the representation of the tensile concrete behaviour [5]. The assessment on the failure of the flat slab were evaluated based on the performance of the flat slab that have been analysed.

The punching shear around the column is the critical considerations in flat slabs. Eurocode 2 gives details about the control perimeter for circular and rectangular columns. The control perimeter is at a distance of $2d$ from the column perimeter as shown in Figure 2 [6].

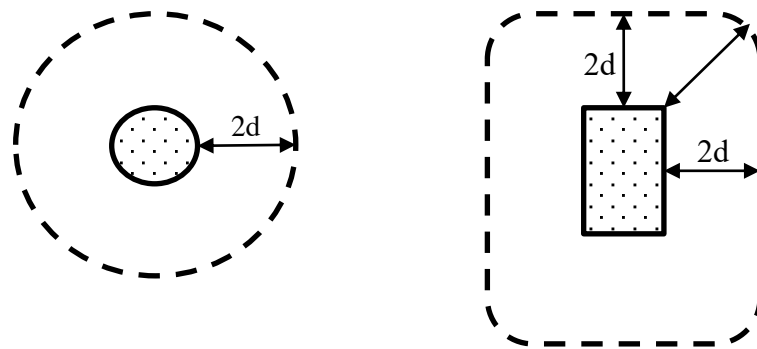


Figure 2. Control perimeters for circular and rectangular columns.

2. Materials and Methods

This study considered model named as Model 1 and Model 2. Both models have the same parameter as shown in Table 1.

Table 1. Proposed design parameter for the flat slab analysis.

No	Item	Description
1.	Concrete grade	The grade of concrete is G25
2.	Slab Thickness	The slab thickness is 175mm which identical for all model
3.	Bar diameter	The bar diameter is 12mm
4.	Type of BRC	The BRC type is A8 which is 8mm for diameter with square spacing of 200mm
5.	Concrete cover	The concrete cover is 25mm
6.	Young Modulus	The young modulus is to be include in the ABAQUS parameter as 25000 N/mm ² (Concrete) & 210000 N/mm ² (Steel)
7.	Poisson Ratio	The Poisson Ratio is to be include in the ABAQUS parameter as 0.20 (Concrete) & 0.30 (Steel)

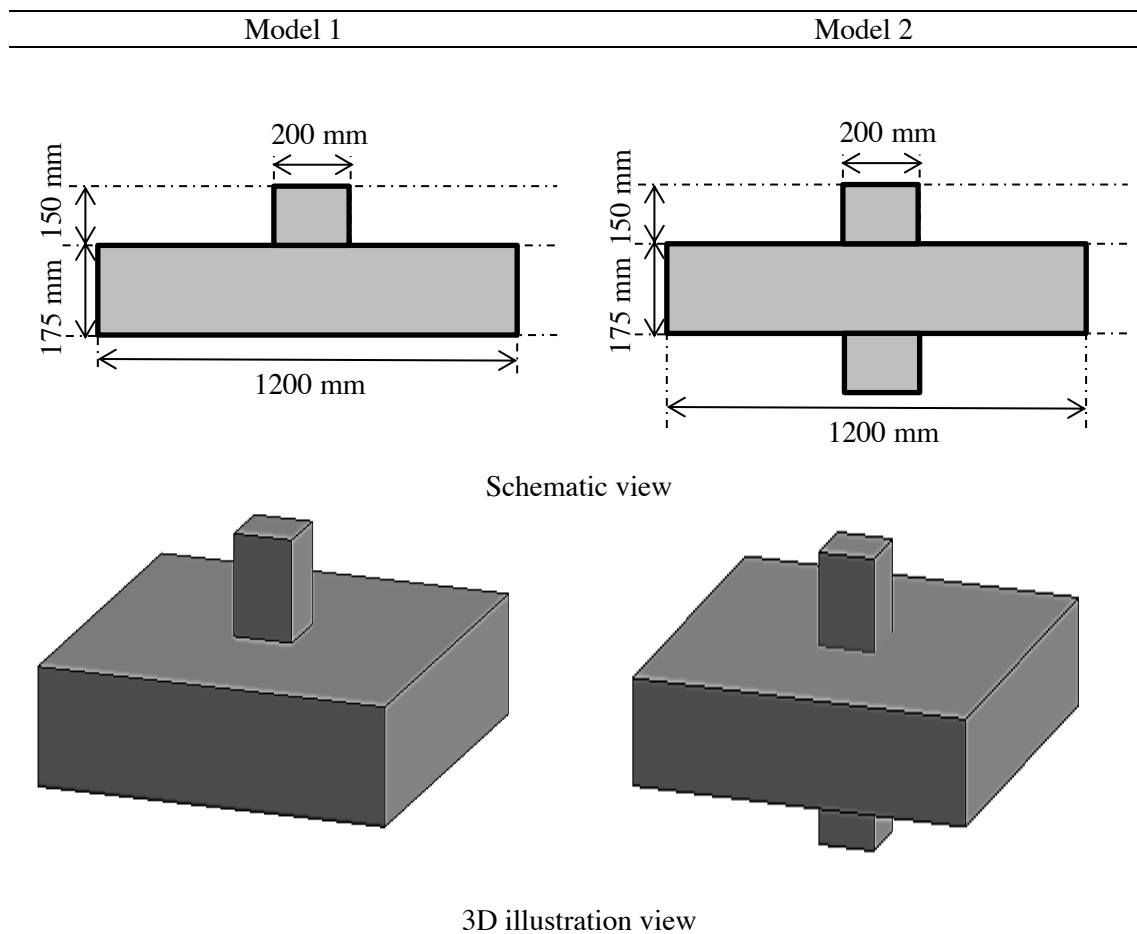
Table 2 present detail of Model 1 and 2. The size of flat slab is 1200 mm x 1200 mm x 175 mm. The calculated service load used is 14.68 kN/m² based on total permanent load, G_k and variable load, Q_k from car park while ultimate load is 21.31 kN/m² refer to MS EN 1991: Eurocode 1 – Actions on Structures.

For simulation purposes, the parameter in Table 1 was used for developing the model in ABAQUS software. There were two models of flat slab and each model will be experienced two different load cases (CASE 1 & CASE 2). Meanwhile, the load cases consist of two (2) different loading. Thus, there will be 2 models for Model 1 and 2 models for Model 2 were tested. All models were simulated in the ABAQUS and produced the load-displacement curve for each model. Each of the load case were imposed with two different loading as shown in Table 3.

Table 2. Model name with load cases.

Model	Load case	Model name
Model 1	Service load design over slab (CASE 1)	M_1_SER
	Ultimate load design over slab (CASE 2)	M_1_ULT
Model 2	Service load design over slab (CASE 1)	M_2_SER
	Ultimate load design over slab (CASE 2)	M_2_ULT

The embedded method been implemented to simulate the connection between the reinforcement and concrete to get a perfect bond. While for the loading support, the fixed support is used at the bottom edges. Stud type is applied for shear reinforcement model for analysis.

Table 3. The model of flat slab.

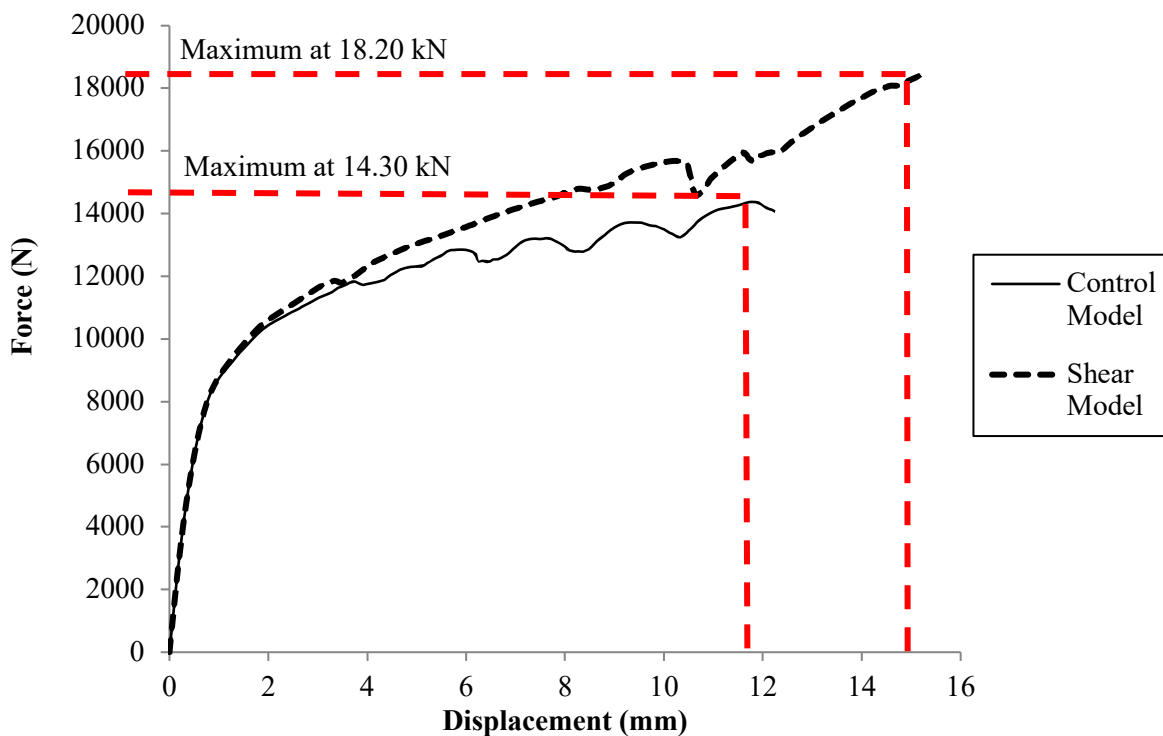
3. Results and discussions

This research investigated the effect of the service load and ultimate load on the strength of the flat slab. The control model for the service load design, M_1_C_SER design gives 14.30 kN maximum load while for the ultimate load design, M_1_C_ULT gives 15.48 kN as shown in Table 4. There was a significant value which the ultimate load design gives a huge value compare to the services load design since the parameter for both models were same.

For the services load design with shear reinforcement (M_2_S_SER), the model can cater up to 18.20 kN when there were shear reinforcement compare to the control model (M_1_C_SER) that was 14.30 kN as shown in Figure 3. The increment of 3.90 kN was also the significant value for the services load design model when there was shear reinforcement that improve the strength of the flat slab. In term of the displacement, the control model reaches the displacement at 12.00 mm when the maximum load reaches meanwhile for the shear reinforcement model the displacement reaches at 15.00 mm.

Table 4. The analysis result in term of maximum load applied.

Cases	Slab name	Maximum Load (kN)	Maximum deflection at the centre column until crack (mm)	Percentage difference of maximum load between control sample
Control Model	M_1_C_SER (Service)	14.30	12.00	-
	M_1_C_ULT (Ultimate)	15.48	17.20	-
Shear Reinforcement Model	M_2_S_SER (Service)	18.20	15.00	22.01 %
	M_2_S_ULT (Ultimate)	19.85	18.80	21.43 %

**Figure 3.** Graph force versus displacement curve of services load design.

Meanwhile, for the ultimate load design with shear reinforcement (M_2_S_ULT), the model can cater up to 19.85 kN when there were shear reinforcement compare to the control model (M_1_S_ULT) only 15.48 kN as shown in Figure 4. The increment of 4.37 kN was the significant value in which the application of shear reinforcement can increase the strength of the flat slab. In term of the displacement, the control model reaches the displacement at 17.20 mm when the maximum load reaches meanwhile for the shear reinforcement model the displacement reaches at 18.80 mm. These displacements actually reflect the failure of the flat slab models and shows the maximum deflection at the centre of column until it crack.

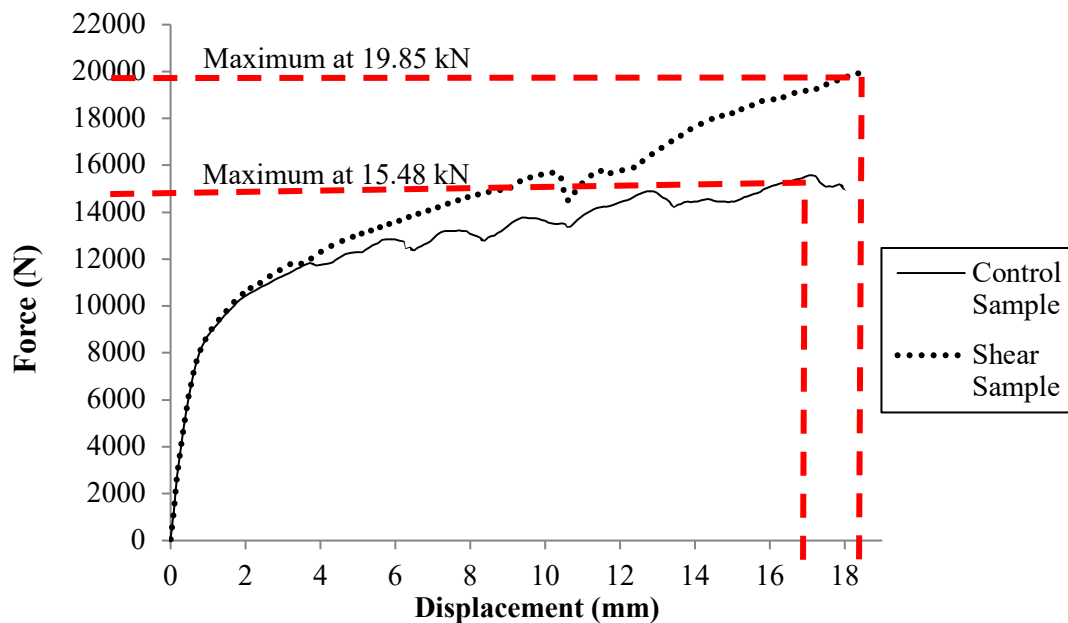


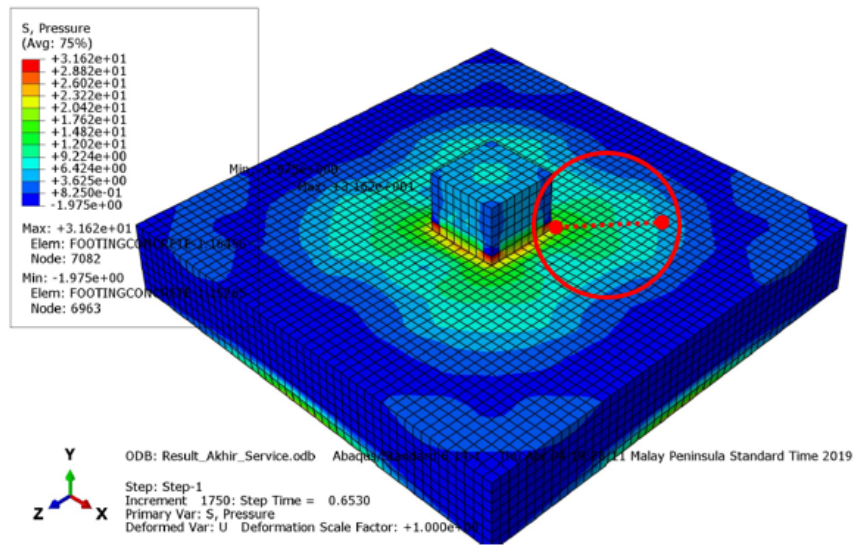
Figure 4. Graph force versus displacement curve of ultimate load design.

It is found that Model 2 are better because of installing the shear reinforcement bar to the flat slab. Thus, the result for the strength of the flat slab was improved by 27 % and 28 % for service load design and ultimate load design respectively. It is because after the development of the inclined shear cracks, shear reinforcement transfers much of the shear force across the shear crack and delays the further widening of the shear crack, thus increasing the punching shear capacity and ductility of the slab [7].

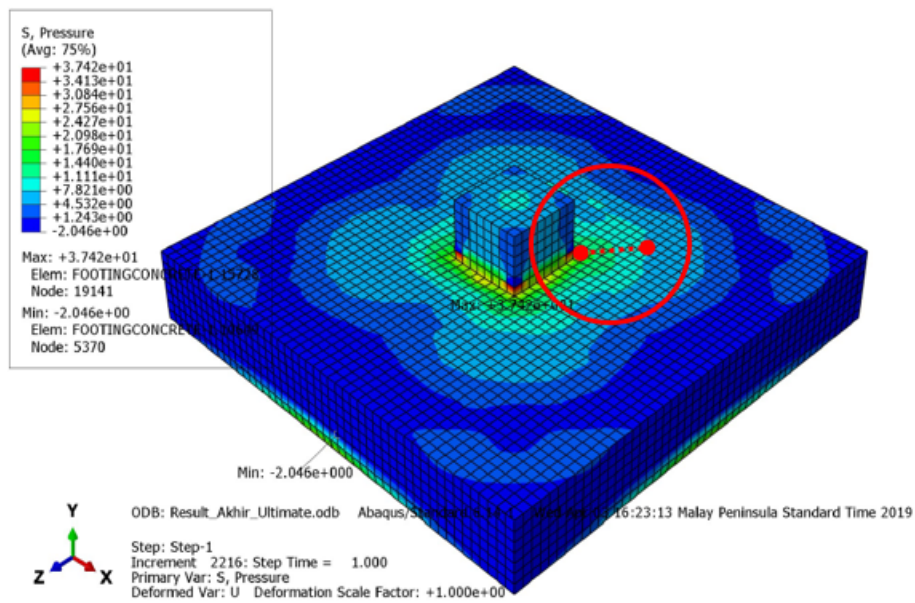
In this study, the location for the implementation of the shear reinforcement based on the punching shear area. It can be identified through the same mode of stresses component at the integration point, S. The area covered around the column or the punching shear perimeter shows a contour of the stress distribution all over the model the value shows in Table 5. Moreover, Figure 5(a) to Figure 5(d) clearly shows the critical perimeter within the distance of $2d$ from the column perimeter which is less than 250 mm.

Table 5. The maximum pressure exerted on the model and location covered.

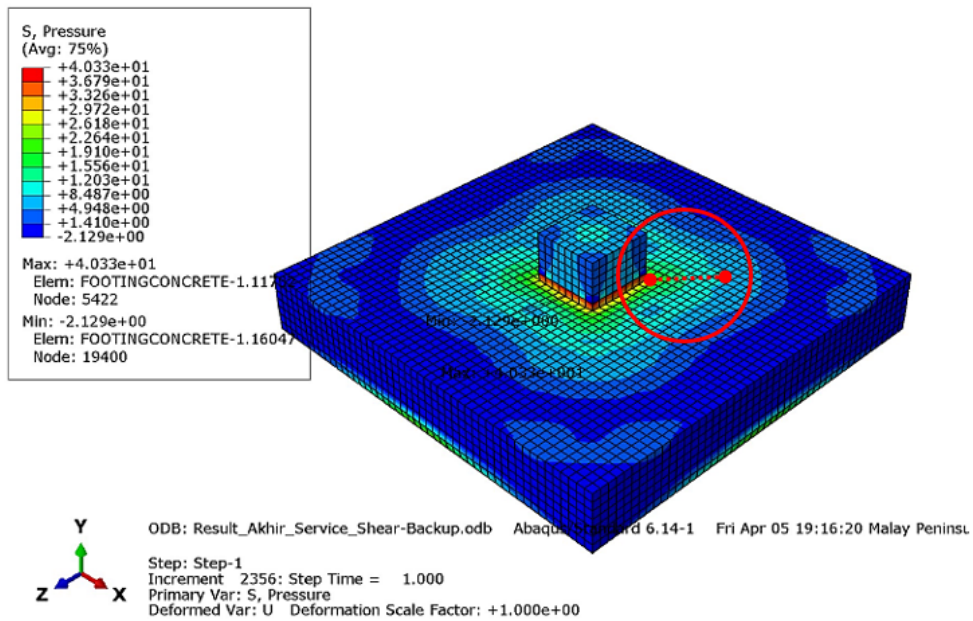
Slab name	Maximum pressure exerted on the model (kN/m ²)	Location covered for maximum pressure from column edge (mm)	Percentage increment of maximum pressure
M_1_C_SER	31.6 x 10 ³	245	15.5%
M_1_C_ULT	37.4 x 10 ³	175	
M_2_S_SER	40.3 x 10 ³	210	2.66%
M_2_S_ULT	41.4 x 10 ³	140	



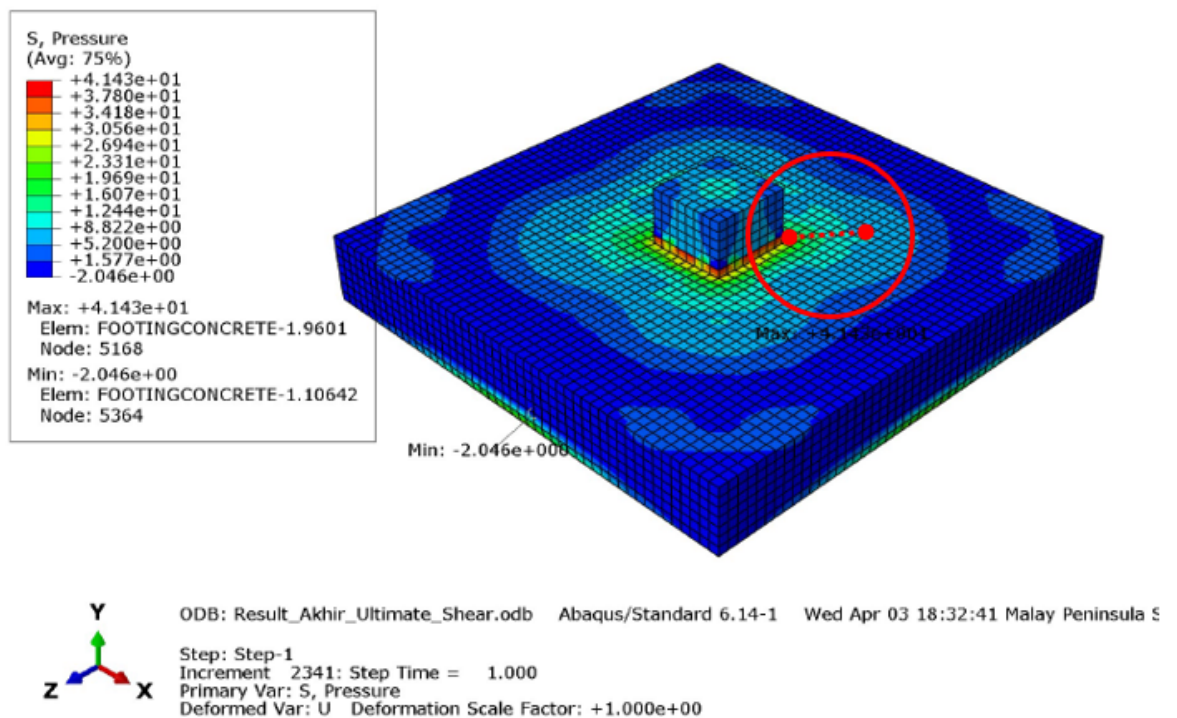
(a) Stress contour shows the stress distribution for service-type model (M_1_C_SER)



(b) Stress contour shows the stress distribution for ultimate-type model (M_1_C_ULT)



(c) Stress contour shows the stress distribution for service-type model (M_2_S_SER)



(d) Stress contour shows the stress distribution for ultimate-type model (M_2_S_ULT)

Figure 5. The critical perimeter base on stress contour.

4. Conclusion

The finding of the research on the effect of service design load and ultimate design load produced a significant value. It is found that the service load design gives smaller design load compared to the ultimate design load. The service design load flat slab model with shear reinforcement (M_2_S_SER) improved up to 21.43% compared to the control model (M_1_C_SER). Meanwhile, the ultimate design load model with shear reinforcement (M_2_S_ULT) improved up to 22.02% compared control model (M_1_C_ULT). This confirms that the implementation of shear reinforcement on both flat slab models can increase the strength of flat slab and can cater both service and ultimate design load. While, the critical perimeter distance from the column perimeter is less than 250 mm which is within the two times the depth (2d) as proposed by the Eurocode 2: Design of Concrete Structures. Overall, the objectives that has been stated for this research was achieved.

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