SIMULATION STUDY ON THE EFFECT OF ECCENTRICITY LOAD ON THE BEHAVIOUR OF PRECAST WALL PANEL IN TERMS OF STRESS DISTRIBUTION AND LATERAL DISPLACEMENT

M.R. Shyazril, M.A. Sulaiman, R. Othman

Abstract

This research studies on behaviour precast wall loaded with a different eccentricity of load using finite element method. Seven (7) models of the wall were developed and analysed using ABAQUS software. All samples are designed with a dimension of 3000 mm height x 3000 mm length and 150 mm thickness by using the main material, which is reinforced concrete. Steel bar reinforcement for all model precast walls was provided with T10-200 in the vertical section and T10-300 in the horizontal section. The concrete grade used for the design of the precast wall in this study is the C35 with a longitudinal steel support of deformed steel reinforcement bars with a nominal yield strength of 460 MPa and for the mild steel is of 250 MPa. The study shows the decrease in deformation shape curve when the eccentricity value increases up to 10 mm. The study also reveals no significant effect on stress distribution regarding the location of stress under different eccentricities of load.

Keywords Behaviour wall panel, Finite element method, Various eccentricity load, Stress distribution, Lateral displacement.

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Introduction

The rapid development of Malaysia in the city centre, even in rural areas with various forms of structural architecture, can be seen everywhere in Malaysia due to the growing economic and human growth. Thus, engineers need to develop innovative and fast-paced new construction techniques in line with economic and human growth to produce cost-effective solutions rather than the traditional construction practices currently in use (Yee & Eng, 2001).

A load-bearing region is defined by a wall, which is both a structure and a surface, and provides security, shelter, soundproofing or aesthetic value. There are many different types of walls, such as those in structures that serve as a foundation for the superstructure or to separate internal rooms, occasionally for fire safety, defensive walls in fortifications, retaining walls that keep back soil, stone, water or noise, and many others. All are either load bearing or non-load bearing walls in terms of their purpose. A load bearing wall is a part of the building foundations. It holds the building up. A non-load bearing wall is just a partition that separates the different spaces in the buildings. A non-load bearing wall can demolish the wall, but it is not so for a load bearing wall. Figure 1 shows the general behaviour expected on the wall panel under loading.

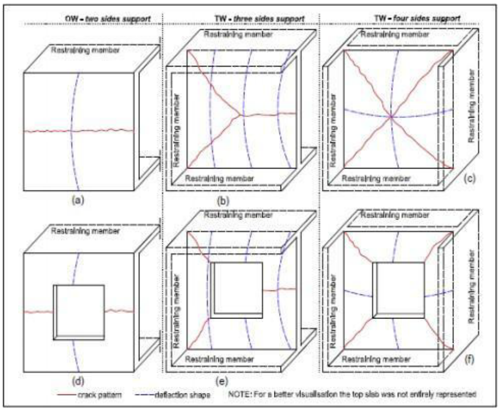


Figure 1: Wall with and without side support (Popescu et al., 2015b).

Reinforced concrete wall panels or precast walls are innovative new techniques developed by engineers working in this domain that need to be commercialised. With reinforced concrete wall panels, this technology can save construction time, reduce manpower and indirectly save construction costs, which are very different from traditional construction that previously used old methods such as in-situ walls that take a long time to complete (Brzev & Perez 2010).

This paper aims to investigate and understand more about the effect of eccentricity load on the behaviour of wall panels in terms of stress distribution and lateral displacement. From the previous study, the effect on eccentricity on the wall panel is not well understood. However, studies confirm that load eccentricity affects both the ultimate load stress and the displacements of the wall. Eccentric axial loads provide a bending moment on the wall that may significantly increase after a second-order effects caused by out-of-plane curvature. The eccentricity, e, is the initial eccentricity when the load is applied. When out of plane displacements start, an additional eccentricity occurs, thus second-order effects appear (Johan Jansson & Sebastian Svensson, 2016). Very few researchers have studied the effect of variation of eccentricities, both for one- and two- way walls. Most of them have a constant eccentricity of tw/6, (Popescu et al., 2015).

According to a study by Kuddus (2010), the concrete wallpanel was exposed to a uniformly distributed axial force with the same eccentricity of tw/6 in most prior studies. Based on a research from Doh (2002), only eccentric loads act on wall panels in practice, as previously stated. Only in theory can the centrically load be applied. Because eccentricity affects the kind of failure of the wall panel, it must be considered during the design process. A catastrophic collapse scenario occurs when a substantial curvature in a narrow wall is paired with a high eccentricity. According to Doh (2002), the centric loading's failure load was more than double that of the eccentric loading.

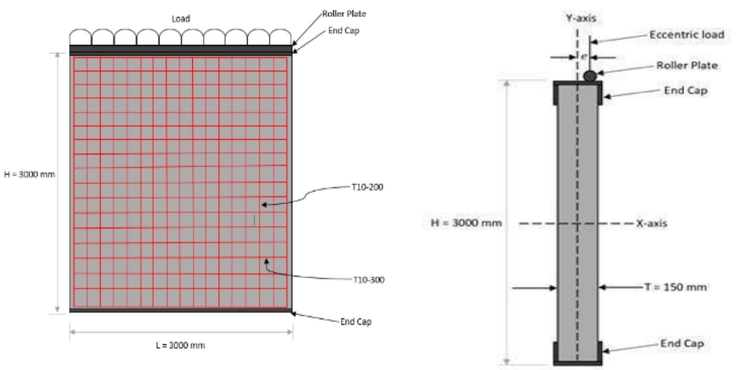
Methodology

The impact of eccentricity load on the behaviour of the wall is investigated using ABAQUS software and Abaqus/Standard with Static/General Structural linear analysis. This is because the applied forces and displacements in a linear static analysis are linearly related. In reality, this is true for structural issues when stresses remain within the material's linear elastic range. The stiffness matrix of the model is constant in a linear static analysis, and the solution method is comparatively quick compared to a nonlinear analysis on the same model.

For this, a solid wall panel with dimensions (Height, H x Length, L x Thickness, tw), 3000 mm x 3000 mm 150 mm is modelled and validated. All samples were loaded with eccentricity load of 10mm, 20mm, 30mm, 40mm, 50mm, 60mm and 70 mm, and designated as PW1, PW2, PW3, PW4, PW5, PW6 and PW7, respectively. Figure 2 is just a schematic diagram, the FE model does not include end cap and roller. As shown in Figure 3, (a) shows a dimension of the wall and the arrangement of reinforcement, and (b) shows a position of eccentricity load loaded on the wall. All samples were designed with a concrete cover of 25mm, and slenderness ratio and aspect ratio were 20 and 1.0, respectively, for this precast wall model.

Table 1 shows the model detail. The reinforcing bars are spaced 300 mm and 200 mm centre to centre in the horizontal and vertical directions, respectively. The bars are 10 mm in diameter. Table 2 shows the material characteristics allocated to steel and concrete in the workbench. Throughout this project, the specimen's property is maintained. The concrete used in this study was designed for 28 days with concrete grade C35 equivalent to 35 MPa. Deformed steel bars with a nominal yield strength of 460 MPa and mild steel with a yield strength of 250 MPa were used as longitudinal steel reinforcement, but in this study, nominal yield strength and mild steel are not included because this study focuses on linear static analysis only. For FE model, the element used in shape solid and type extrusion for precast wall, and element for reinforcement bar are shape wire and type planar.

Meshing for FE model used for this study is 30 mm. Łukasz Skotny (2019) stated that the correct mesh size for FE model is 30mm, 25mm and 10mm. Usually smaller mesh means more accurate results, but the computing time gets significant as well, depending on the computer's capabilities. Next, Taher Nalawala (2016), on the study of Reinforced Cement Concrete Beam Analysis using Abaqus, used the same meshing, which is 30mm.



(a) **(b)**

Figure 2: Design Model Wall Panel (a) reinforcement arrangement (b) position of eccentric load.

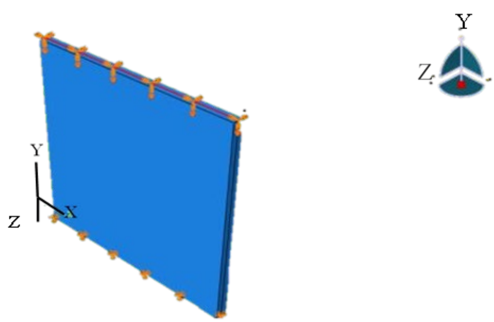


Figure 3: FE Model

Table 1: Model details with eccentricity differences.

Wall Code	Size of wall	Slenderness Ratio	Aspect Ratio	Eccentric load, (kN/mm)	Eccentricity, (mm)
PW1	3000*3000*150	20	1	125	10
PW2	3000*3000*150	20	1	125	20
PW3	3000*3000*150	20	1	125	30
PW4	3000*3000*150	20	1	125	40
PW5	3000*3000*150	20	1	125	50
PW6	3000*3000*150	20	1	125	60
PW7	3000*3000*150	20	1	125	70

Table 2: Material properties of concrete and steel

Material no	Material	Material property
1	Concrete	Density = 2,400 kg/m3
		Young’s modulus, E = 25,000 MPa
		Poison’s ratio = 0.2
		Compressive strength = 35 MPa
2	Structural steel	Density = 7,800 kg/m3
		Young’s modulus, E = 200,000 MPa
		Poisson’s ratio = 0.3

The boundary condition is done for all models. Young's modulus and Poisson's ratio of concrete are calculated and taken using compressive strength based on the equations in EC2 and the properties of steel based on EC3. The constraint is imposed to one-way wall panels at the top and bottom of the panels. Displacement is halted in all directions of X, Y and Z at the top, and in all directions X, Y and Z at the bottom. Z denotes a direction perpendicular to the paper's plane and parallel to the wall's thickness direction. In ABAQUS, an evenly distributed load is delivered as a line pressure at the chosen eccentricity.

Result and Discussion

Lateral displacement

The lateral displacement of the wall model is done by applying the same load, which is 125 kN/mm. Five points were taken for all models which at 0, L/4, L/2, 3L/4 and L of the wall height. Table 3 shows the displacement at the specific point. The displacement at the top and bottom of the wall is 0 mm, and the highest displacement is recorded at the mid height of the wall model. The displacement at point 3L/4 is the highest compared to point L/4. This means the maximum lateral displacement occurred in between point L/2 and 3L/4. Table 4 shows the detail of maximum lateral displacement for each model. Figure 3 shows the lateral displacement profile for all wall models. It shows that all models were deflected in the same pattern, which is single curvature.

Figure 4 shows the maximum point of the lateral displacement for all models. It shows the maximum point moving near the top, by decreasing the eccentricity. However, it is vice versa when eccentricity is more than 40 mm. This result was agreed by Kudus (2010). Based on Table 3, each precast wall has a different lateral displacement. This is because the eccentric distance applied to each wall is different and this shows that different eccentricity distances are strongly influencing the behaviour of the wall in terms of lateral displacement. Referring to Jansson and Svensson (2016), they stated that different eccentricity and opening sizes may affect the structural behaviour in a different way.

Next, based on Table 3, the wall buckling graph made is only at 5 points selected, not including the maximum value for buckling a wall. This is because the distance to the maximum buckling point of a wall is not the same for every wall. Table 4 shows the maximum value of buckling for all wall models along with the maximum displacement position on the wall.

Table 3: The result of lateral displacement.

Eccentricity (mm)		0 mm (0)	750 mm (L / 4)	1500 mm (L / 2)	2250 mm (L / 3) 4	3000 mm (L)
		Lateral Displacement				
PW1	10	0	99.426	308.942	314.611	0
PW2	20	0	96.989	301.551	308.505	0
PW3	30	0	118.894	311.012	282.829	0
PW4	40	0	114.785	300.701	275.141	0
PW5	50	0	111.828	293.227	269.619	0
PW6	60	0	132.32	298.489	242.376	0
PW7	70	0	128.539	290.491	237.337	0

Table 4: Maximum displacement position.

Wall Code	Eccentricity (mm)	Maximum Displacement Position (mm)	Displacement (mm)
PW1	10	1920	352.609
PW2	20	1920	344.807
PW3	30	1830	337.748
PW4	40	1830	327.232
PW5	50	1830	319.625
PW6	60	1740	312.712
PW7	70	1740	304.793

Referring to Table 4, all 7 models have different maximum buckling values, as well as the maximum displacement position. All models have the same range maximum displacement position distance, which is between 1500 mm (L/2) and 2250 mm (L/4/3). This shows that the maximum buckling occurs in almost the same area. Next, the high buckling distance is 352.609 mm, which occurs on wall PW1 and for wall PW7, the buckling distance is

304.793 mm, which is the smallest buckling distance between all models. Next, Figure 5 describes the data from Table 3 and Table 4 in the form of graphs.

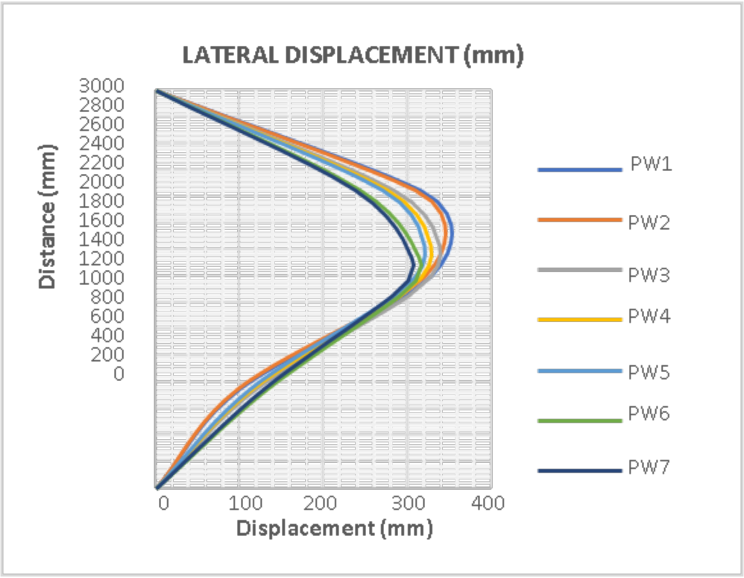
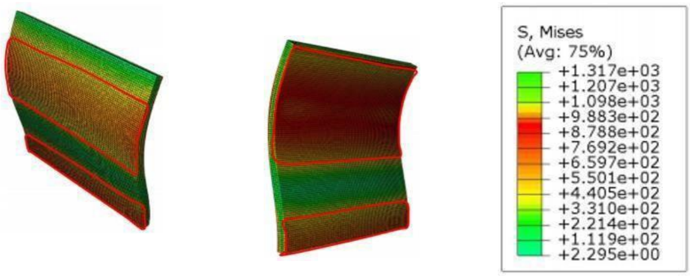


Figure 4: Comparison of lateral displacement for all models PW1 until PW7.

Based on Figure 4, it is interesting to relate to the statement from Doh et al. (2002), that indicated that the eccentricity is a sensitive parameter when designing walls. Another test on two-way walls with different load eccentricity shows that the failure load and lateral displacement increased dramatically with decreased eccentricity.

Stress distribution

All models show the same stress distribution pattern in term of location. The concentrated stress occurred at 2 parts in each wall, as shown in Figure 5(a) and 5(b) in area red line. Although the stress distribution is at the same position on all wall models, it has a different critical stress due to the curvature stress. This is because the axial load applied is according to the eccentric distance of each wall with guided pigment colour. Hence, the backside of the wall shows more concentration compared to the front side. Figure 5(c) jobs information for stress. Based on Kuddus (2010), the concentrated stress occurred at the middle of the wall.



(a) **(b)** **(c)**

Figure 5. Stress distribution location and crack pattern (a) front side (b) backside (c) job information for stress.

Doh et al. (2005) stated that eccentricity also affects the failure type in the wall. Higher eccentricity gives a more brittle and sudden failure than a lower eccentricity, due to maximum stress distribution at higher eccentricity at the back of the buckling wall. This statement is also supported by Kuddus (2010) in his study, which described the position of stress that occurs at the back of the curve when buckling occurs on the wall, as shown in Figure 6. He also described the vertical triangle shading as a form of stress that would increase and become bigger if eccentricity increased.

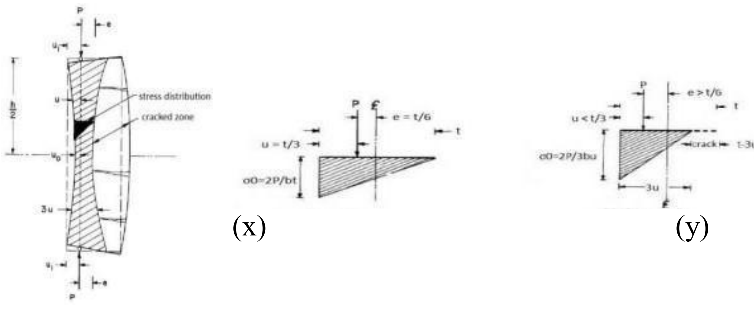


Figure 6: Stress distribution in wall units (a) Stress distribution location (b) The resulting stress distribution (x) corresponds to a t/6 eccentricity, whereas (y) relates to a larger than t/6 eccentricity (Kuddus, 2010).

Next, a one-way action solid panel is deflected in a single curve in the vertical direction, with the greatest deflection occurring between mid-height and 2/3 of the wall height, depending on the eccentricity. Next, based on a study Doh and Fragomeni (2006), predetermined load found a crack location on the front of wall buckling at mid-height of span, as shown in Figure 7. In the vertical direction, the one-way action solid panel is deflected in a single curve, with maximum deflection near the panels' mid-height centre. The fracture patterns were horizontal (perpendicular to the loading direction), with bending failure occurring around the
centre of the panels.

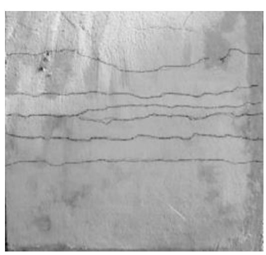


Figure 7. Crack pattern on solid wall with tw / 6 eccentricity (Doh et al, 2006).

Conclusions

The following conclusions are based on the result obtained from the simulation Abaqus, by comparing the displacement and cracking pattern due to stress distribution of the sample wall for all seven models, respectively:

i. Lateral displacement would decrease if the eccentricity applied to the model increases.
ii. The maximum deflection position rises progressively above the middle height of the wall up to 10 mm and 20 mm of eccentricity for PW1 and PW2.
iii. The stress distribution increases critically when the eccentricity applied to the model increases, and this shows that various eccentricities will affect the behavior wall. All model shows the critical stress distribution occurs at the middle of the wall.
iv. The stress distribution on the backside of the wall is more concentrated than on the front side of the wall.

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