Shear Resistance Analysis of Rebar Connector in RC Stocky Wall Panel Using Lusas 3D Modelling

Noraspalela Abdullah, Mohd Suhelmiey Sobri and Siti Hawa Hamzah

Abstract Reinforced concrete (RC) stocky wall panel is a new innovation to the construction industry. To-date, studies on the RC stocky wall panel are under progress. This paper is analyzed shear resistance of rebar connector in RC stocky wall panels using LUSAS 3D model. Four (4) number of model have been analyzed using finite element analysis with varies size of rebar connector which is T12, T16, T20 and T25. These models of RC stocky wall panel was constructed in same dimension, 125 mm × 1,000 mm × 500 mm (Thickness:Length:Height). This paper was concerned with a finite element model to determine the maximum deflection of the RC stocky wall panel in resisting lateral load. These four (4) models are being analyzed to observe its deflection, stress and strain. The result was illustrated and discussed in graphs namely stress-strain relationship and also load versus displacement contour. The size of rebar connectors are affected the shear resistance results in term of lateral deflection, stress and strain. From this study, it can be concluded that, the larger diameter of rebar size has give the less displacement in model.

Keywords RC stocky wall panel · Rebar connector · Shear resistance · Deflection

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1 Introduction

Wall can be categorized in many types with different function. The reinforced concrete (RC) wall is one of the type walls that is categories as load bearing or non-load bearing. Load bearing wall caters the load from its own weight and the load from the main structure such as beam and slab followed by transmitting the load to the foundation. Non-load bearing wall only uphold its own weight, then all load transfer to the column and proceed to the foundation.

In Malaysia the wall panels are widely used and have already been used in numerous projects, including the construction of residential houses, hotels and commercial buildings. RC wall panel is usually design and manufacturer in rectangular shape. The RC stocky wall panels are same like shear wall panels in term of function but different in dimension size of wall.

Nowadays the Industrialised building system (IBS) is compulsory to be used in all the Malaysian government's projects which must not be less than 70 % of the all building works. Based on the structure scopes IBS can be divided into five major parts;

- Precast concrete framings, panel and box systems,—The common group of IBS products is the pre-cast concrete elements which is precast concrete columns, beams, slabs, walls and lightweight precast concrete and etc.
- Steel framework systems; example of steel framework systems are tunnel forms, tilt-up systems, beams and columns moulding forms, and permanent steel formworks (metal decks).
- Prefabricated timber framings systems—Commonly used with pre-cast concrete slabs, steels columns and beams, steel framing systems.
- Framing systems—Among the products listed in this category are timber building frames and timber roof trusses.
- Blockwork systems—The construction method of using conventional bricks has been revolutionized by the development and usage of interlocking concrete masonry units (CMU) and lightweight concrete blocks.

The RC stocky wall panels can be categorized as precast concrete and are one of the elements in the IBS. The stocky wall panels was categories as precast concrete framings, panel and box systems. The products of IBS are encouraged to be used in the construction industries to speed up the delivery time and built affordable and quality of project.

The precast RC wall panels are manufactured in factories, and mobilized to the site. Generally to easier mobilize to the site, the manufacturer will design the components of wall with a certain fixed length and shall be connected at the site. The workers at site must connect the RC wall to the main structure such as column and beam. The connection from one wall panel with other panel is importance because the lower workmanship at final work will make the lower performance in structure serviceability.

The innovation in stocky wall panels as load bearing wall have been most helpful in the construction industry to achieve that short time frame in work and on the other hand will make much energy efficiency benefits in construction. The minimum wastage on the rebar used in the site project will contribute to energy efficiency. The use of rebar's to link these stocky wall panels as the main wall structures is the main focus of this study.

Rebar also known as reinforcement bar, reinforcing steel or deformed bar. Normally rebar formed from the carbon steel, the normal reinforcement bar used in Malaysia's industries is mild steel round bar (Grade 250) and high tensile deformed bar (Grade 460) but in certain special construction, the contractor was used special grade of high tensile bar for minimize the number of reinforcement bars example Grade 500.

The RC stocky wall panels with rebar connector is a newbie in construction industries, which is more research should be done to this wall in order to make it useable to construction industries in future. The new finding and research about the RC stocky wall panels will make the industries become more effective and competitive.

2 Theoretical Wall Design Using British Standard (BS 8110: Part 1: 1997)

According to BS 8110, a wall is defined as a vertical load- bearing member whose length on plan exceeds four times its thickness and on the other hand the member can call as a column [1]. A reinforced wall with minimum amount of vertical reinforcement used can be categorised as plain concrete wall. According to BS 8110 (clauses 3.9.4), it recommends that the design ultimate axial force in a plain concrete wall may be calculated on the assumption that the members transmitting forces on the walls are simply supported. Summary for design requirement for reinforced concrete wall are given in Table 1.

3 Finding from Previous Research

RC Wall panel is commonly used in construction industries. Basic functions of wall are partition of area, separator for interior space, some time as fire wall and etc. RC walls have three main structural functions where are listed below;

- Resist gravity loads applied through floor framing systems.
- Resist lateral loading imposed by earth pressure or liquid pressure.
- Resisting lateral resistance from wind or earthquake forces and/or promotes lateral stability to a building.

Table 1 Data properties preparation

	Area of steel reinforcement ($A_{sc} \geq 4$ h mm^2/m)
Unbraced walls	**Effective Height**
	l_e to be determined as for columns (refer BS 8110, Clause 3.8.1.6.1)
	Stocky Wall (l_e/h ≤ 15, where h is wall thickness)
	Design unit length of wall as a short column bent about the minor axis, with $e_{min} = 0.05$ h ≤ 20 mm (refer to BS 8110 design chart for rectangular column)
	Alternatively, for a wall supporting an approximately symmetrical arrangement of slabs (uniform load and spans differing by no more than 15 %)
	Design ultimate axial load per unit length is given by
	Slender Wall (15 < l_e/h ≤ 40 for A_{sc} < 10 h, 45 otherwise)
	Design unit length of wall as a slender column bent about the minor axis. If only one layer of centrally placed reinforcement is provided, double the additional moment
Unbraced walls	**Effective Height**
	l_e to be determined as for columns (refer BS 8110, Clause 3.8.1.6.1)
	Stocky Wall (l_e/h ≤ 10, where h is wall thickness)
	Considered as for braced column
	Slender Wall (10 < l_e/h ≤ 30)
	Design unit length of wall as a slender column bent about the minor axis. If only one layer of centrally placed reinforcement is provided, double the additional moment due to slenderness

RC wall Panel is suitable for using as components in Industrialize Building System (IBS). Steel fibre reinforced concrete wall panel with aspect ratio (h/l) and slenderness ratio (h/t) are 1.5 and 20 respectively shall be sustained more capacity and advantages in terms of crack compared with the normal reinforced concrete wall, [2]. The reinforced concrete stocky wall panel by using recycled aggregate with double layers steel fabric can achieved high ultimate strength compared with the theoretical results [3].

Study on the nonlinear behavior of reinforced concrete slit wall with shear connection using finite element software ANSYS 12. The study has founded that the finite element analysis was simulated accurate and realistic the behavior of the reinforced concrete walls [4]. On the other hand, the slender and stocky reinforced concrete walls shall be started flexural and deform when the walls nominal shear strength of approximately twice the lateral force [5]. The nonlinear behavior of composite shear walls with vertical steel encased profiles is believed that the shear failure can be avoided if the composite elements in the shear wall are designed to bending and shear at the associated shear force of the capable bending moment [6]. On the contrary, the nonlinearities are caused by the steel yielding which occurred in steel profiles and vertical reinforcement, plastic deformations occurred in concrete, steel concrete connection and due to shear stud connector's behavior [7]. The ultimate shear resistance of the multiple shears key connection mainly depends on the load was acted to the connection, and the hearing stresses and shear friction along the slip surfaces [8].

4 Methodology

Generally, this research was used LUSAS software version 14.7 to identify the solutions and get the results and achieve the objective for this research.

4.1 Analysis

The main focus of this research to investigate and analysis the behavior of rebars connector in RC stocky wall panel by using Finite Element Method (FEM) in non linear method. From the analysis, the maximum deflection, maximum stresses and strains of the RC stocky wall panel using LUSAS 3D has been discussed. Finite element methods can make advanced computing facilities in obtaining safe and optimum building solutions without the need for expensive and time consuming laboratory testing and at the same time his was stated that the finite element method is innovative and efficient building products [9].

4.2 Computer Modelling Using LUSAS Software

Linear and nonlinear finite element analysis can be prepared using LUSAS computer program. The LUSAS program shall be capable to provide 3-Dimensional graphical modeling for the sample of RC stocky wall panel. Finite Element Analysis was modeling in three (3) stages of works, which is:

1. Pre-Processing/Modelling
2. Finite Element Solver/Running the analysis
3. Results-Processing/Viewing the results

4.3 RC Stocky Wall Panel

Four (4) models of Reinforced concrete (RC) Stocky Wall Panel with dimensions 125 mm × 1,000 mm × 500 mm (Thickness:Length:Height) has been modeled by using LUSAS 3D program. The RC stocky wall panel was modeled by using concrete Grade 30 ($fcu = 30$ N/mm^2) and double layer steel fabric types B385 (B7) as the main reinforcement. Rebar connector with sizes of T12, T16, T20 and T25 are defined in the four numbers of RC short wall panel models respectively. The rebar connector has been modeled in vertically between the two RC stocky wall panels and analysed using the LUSAS software. Figure 1 shows the detailed models dimensions of RC stocky wall panel. The lateral global load distributed 0.2858 kN/m was used in the modeling. The load is converted based on the basic wind speed 100 years return periods for Ipoh. The data from Ipoh was used because their give

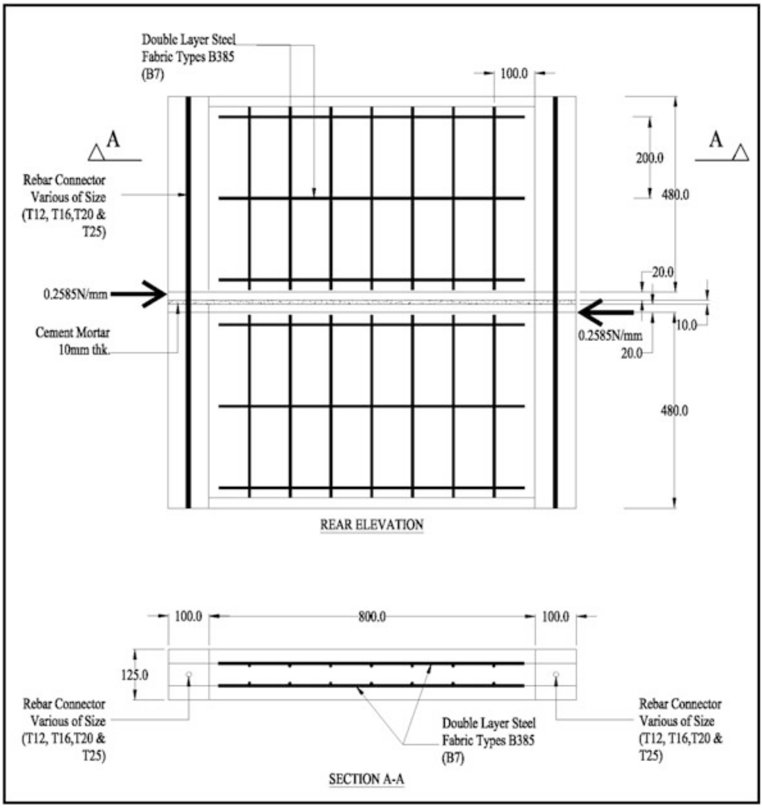


Fig. 1 RC stocky wall detailing model with rebar connector of various size

critical values for wind speed in Malaysia. The data has been founded from the Jabatan Meteorologi Malaysia.

4.4 Data Used in LUSAS Modeling

The double layer of rectangular steel fabric mesh type B385 or B7 with 7 mm diameter of wire has been used to reinforce the samples [10]. The mesh size nominal pitch of wires for main wire is 100 mm spacing centre to centre and for the cross wire is 200 mm centre to centre. The cross section area per meter width for the main wire is 385 mm^2 and for the cross wire is 193 mm^2. The yield stress for the steel fabric mesh and the reinforcement bars is 485 and 460 N/mm^2 respectively. Furthermore, the other properties of the materials used for the steel fabric mesh and rebar connector are the Young's modulus specified as 209,000 N/mm^2, Poisson's

Table 2 Data properties preparation

1. Grade of concrete	30 N/mm^2
2. Grade of reinforcement	
(a) Nominal reinforcement	460 N/mm^2
(b) Welded steel fabric	485 N/mm^2
3. Density of concrete	24 kN/mm^3
4. Dimension of wall	125 mm × 1,000 mm × 500 mm (Thickness:Length: Height)
5. Concrete cover to reinforcement	25 mm
6. Reinforcement bar @ rebar connector size	
(a) Model 1	12 mm
(b) Model 2	16 mm
(c) Model 3	20 mm
(d) Model 4	25 mm
7. Steel fabric types	B 385 (B7) 7 mm diameter
8. Selfweight-gravity load	9.81 N/mm^2
9. Mortar thickness	10 mm

ratio 0.3, mass density specified as 7,800 kg/m^3 and coefficient of thermal expansion 0.011E−3. Tables 2 are shown the data that used in LUSAS Modeling.

The concrete properties material has been assigned based on the BS 8110 for concrete Grade 30 with Young's modulus specified as 26,000 N/mm^2, Poisson's ratio 0.2, mass density specified as 24 kg/m^3. Mortar with 10 mm thickness was used in the model as a join for RC stocky wall panels. The properties materials used for mortar are the Young's modulus specified as 15,000 N/mm^2, Poisson's ratio 0.25, mass density specified as 24 kg/m^3. LUSAS elements are classified into groups according to their function. Two types of elements has been used in modeled RC stocky wall panels, there are bar element, BRS2 and 3D continuum element, HX8M. The bar elements BRS2 were selected for the steel fabric mesh while on the other hand the elements HX8M were used for the concrete section. BRS2 are three-dimensional bar elements comprising of 2 nodes each with 3 degrees of freedom and the geometric properties of this element is constant along the length of the bar. In the analysis, BRS2 can be deformed perfectly. HX8M elements are three dimensional solid hexahedral elements comprising 8 nodes each with 3 degrees of freedom moreover the HX8M elements are linear with respect to geometry. The displacement contour variations along the length of the element are linear axial, linear rotational and cubic transverse displacement contour. Figure 2 shows the LUSAS element used in modeling the RC stocky wall panel. All the RC stocky wall panels have been assigned with fully fixed supports at the top and bottom of the wall. Figures 3 and 4 show the support conditions, load applied location on wall panel and mortar location that has been modeled in LUSAS software.

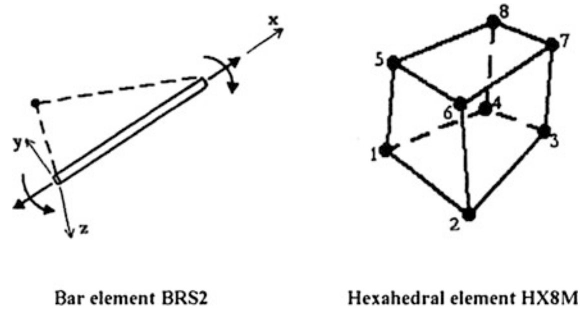


Fig. 2 LUSAS elements used in modelling

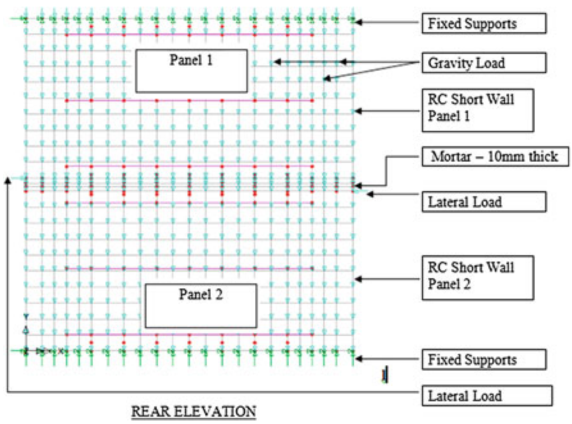


Fig. 3 RC stocky wall panel-LUSAS model

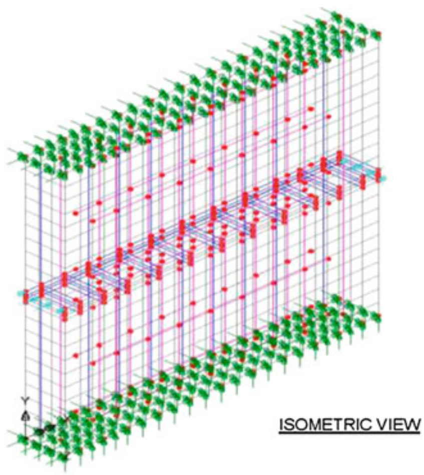


Fig. 4 RC stocky wall panel-LUSAS model

5 Result and Discussion

Four (4) models of RC stocky wall panels was modeled and analysed under horizontal load condition. All the models was modeled using difference size of rebar connector which is T12, T16, T20 and T25 and the cross section area of reinforcement bar is 113.10, 201.061, 314.161 and 490.871 mm^2 respectively. RC stocky wall panel Model 1, Model 2, Model 3 and Model 4 are representative the RC stocky wall panels with the rebar connector size T12, T16, T20, and T25 respectively. Tables 3, 4 and 5 shown the maximum displacement in x-direction, maximum and minimum stress in x-plane, and maximum and minimum strain in x-plane was occurred on Model 1, Model 2, Model 3 and Model 4.

5.1 *Graph of Load Versus Displacement*

Figure 5 show load in x-direction versus displacement in x-direction for Model 1, Model 2, Model 3 and Model 4 as model with T12, T16, T20 and T25 respectively.

Table 3 Maximum displacement in x-direction

Model number	Elastic condition − max displacement in x-direction (mm)	Plastic condition − max displacement in x-direction (mm)
Model 1	0.0392×10^{-3}	0.242
Model 2	0.0382×10^{-3}	0.243
Model 3	0.0373×10^{-3}	0.213
Model 4	0.0366×10^{-3}	0.239

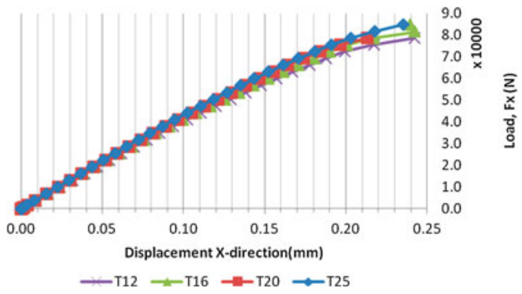
Table 4 Maximum and minimum stress in X-plane

Model number	Elastic condition − max stress in x-plane (N/mm^2)	Elastic condition − min stress in x-plane (N/mm^2)	Plastic condition − max stress in x-plane (N/mm^2)	Plastic condition − min stress in x-plane (N/mm^2)
Model 1	3.236e−3	−8.200e−3	36.729	−65.918
Model 2	3.180e−3	−9.815e−3	64.262	−80.845
Model 3	2.556e−3	−9.093e−3	64.262	−80.845
Model 4	2.035e−3	−8.665e−3	18.125	−47.557

Table 5 Maximum and minimum strain in X-plane

Model number	Elastic condition − max strain in x-plane (N/mm^2)	Elastic condition − min strain in x-plane (N/mm^2)	Plastic condition − max strain in x-plane (N/mm^2)	Plastic condition − min strain in x-plane (N/mm^2)
Model 1	0.067e−6	−0.267e−6	0.469e−3	−1.698e−3
Model 2	0.068e−6	−0.316e−6	0.844e−3	−2.048e−3
Model 3	0.066e−6	−0.295e−6	0.642e−3	−1.790e−3
Model 4	0.068e−6	−0.281e−6	0.591e−3	−2.246e−3

Fig. 5 Load displacement relationship of RC stocky wall panel for model 1, 2, 3, and 4

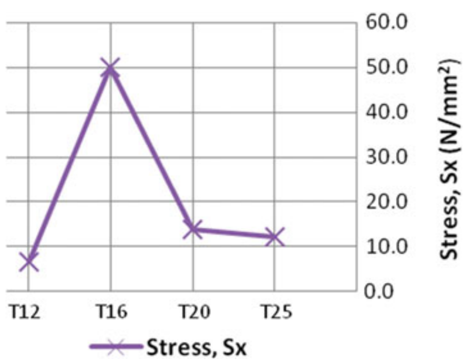


From the graph, the rebar connector T25 give less displacement on the higher load. The maximum load for model 1 (T12), model 2 (T16), model 3 (T20), and model 4 (T25) before the model yielded are 78.64, 81.765, 78.64 and 84.89 kN respectively. When comparing displacement with size of rebars connector, it can clearly be seen that the bigger size of rebar connector will give less displacement.

5.2 *Graph of Stress Versus Strain*

Figures 6 and 7 are showing the graph of stress-strain curve for RC stocky wall panel for all models. However in Fig. 6 shows the graph of maximum stress and size of rebar connector relationship. The maximum stress occurred on model with the rebar connector of size T16 and the value 49.895 N/mm^2. In the other hand, the Fig. 7 shows the graph of stress in Sx-plane versus strain in Ez-plane. Based on the analysis, these three types of plane give the maximum value of stress and strain because the shear resistance was occurred in this plane area. From the analysis the maximum stress and strain was occurred at the location of the applied load position. When the RC stocky wall panel was loading beyond the proportional limit, the elongation increases more rapidly and reached the elastic limit.

Fig. 6 Maximum stress versus size of rebar connector



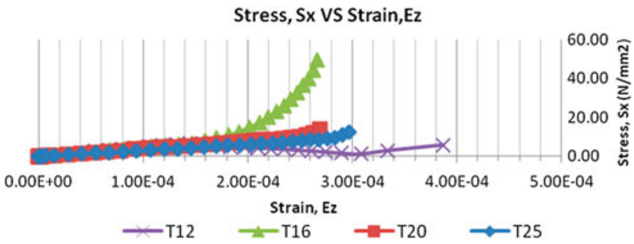


Fig. 7 Graph of stress (Sx) versus strain (Ex) of RC stocky wall panel for model 1, 2, 3 and 4

6 Conclusion

From this study, it can be concluded that there are some differences of structural behavior of reinforced concrete shear wall by using different size of rebar connector. In this paper the parameter of different size of rebar has been considered with function as rebar connector between the top and bottom connection of RC stocky wall panels. Based on the lateral load applied to the RC stocky wall models, the displacement contour were determined in all directions, and the maximum is found to be 0.243 mm which occurred in x-direction. The maximum displacement occurred in model 1 with rebar connector of size T12. Based on the results the maximum values for stress is 49.895 N/mm^2 > 30 N/mm^2 and occur in x-plane of model 2 with rebar connector T16.

From this research, it can be concluded that the size of rebar connector used in the model of RC stocky wall panels affect the values of displacement, stress and also strain. Based on the results, RC stocky wall panels size 125 mm × 1,000 mm × 500 mm (Thickness:Length:Height) with rebar connector size T20 is suitable to be used in the design because the stress from the modeling is 13.793 N/mm^2, which is not exceed the concrete strength has been used (30 N/mm^2) in this design and moreover at same time to avoid crack problem to the RC stocky wall panel. Based on calculation using BS 8110, the shear stress for model 3 with rebar connector T20 is 1.258 N/mm^2 and less than the maximum shear stress which is 5 N/mm^2 or $0.85\sqrt{fcu}$. The shear resistance of RC stocky wall panel with rebar connector T20 also fulfills the requirement was stated in BS 8110.

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