Recent Trends in Civil Engineering and Built Environment Vol. 2 No. 1 (2021) 042–051

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

Effect of Bolt Diameter on The Bearing Capacities of Bolted Fibre Cemboard: A Numerical Modelling Using FEM

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DOI: https://doi.org/10.30880/rtcebe.2021.02.01.005
Received 30 January 2021; Accepted 28 April 2021; Available online 30 June 2021

Abstract: Fibre cemboard is one of the most important meterials used in the construction of buildings. The application of fibre cemboard has led to the prefabricated and build-up system known as bolted-fibre cemboard to be used as floor system. However, the knowledge about bearing capacity of bolted-fibre cemboard is not readily available. Therefore, this study aim to numerically investigate the bearing capacity of bolted-fibre cemboard in term of bearing resistance, slip-displacement and failure mode. The numerical modelling of two-layer bolted-fibre cemboard with size 210mm length x 210mm width will be conducted using the Finite Element Method (FEM). The diameter of bolted-fibre cemboard is caries from 10mm up to 24mm. The mesh that will be used in the numerical modelling is based on four-noded tetrahedral element. Plasticity material model with hardening properties will be define in the fibre cemboard and steel bolt, respectively as the constitutive laws. The loading that will be applied is based on push out test in term of stroke-time history. Furthermore, the relation of diamerter bolted-fibre cemboard with ultimate load and maximum displacement was also establish. It was found that the larger steel bolt diameter is used, the bearing capacity increased steadily compared to deformation that as the steel bolt diameter is increased, the slip-displacement decreases gradually. Overall, the final result of this study shows that bolted-fibre cemboard has a good potential as a structural member due to exelent serviceability.

Keywords: Fibre Cemboard, Bearing Capacity, Slip Displacement, Numerical Modeling.

1. Introduction

Fibre cemboard has been widely used and become more reliable in the construction of buildings. The application of fibre cemboard includes internal partition, plank, roof sarking, solid panel for wall and slab as well as gable end cover. Figure 1 shows the application of fibre cemboard as solid panel for wall and slab. However, fibre cemboard is asbestos-free as it basically manufactured from cement

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cellulose fibre, ground sand and water [1]. One of famous fibre cemboard in Malaysia is known as Superflex by UAC Berhad and Primaflex that produced by Hume Industries Sdn Bhd.

According to [2], the main attributes of fibre cemboard are flexible, durable and resilient to fire and water, good sound insulation, high impact resistant, dimensionally stable, termite free, rust proof and green product. The performance of fibre cemboard as floor system are shorter construction time, less dependent on heavy equipment on job site, simplified utility installation, simplified utility installation, environmentally intelligent, reduce on-site labour time and costs and less wastage of materials [3]. Fibre cemboard has been widely used and become more reliable in the construction of buildings.

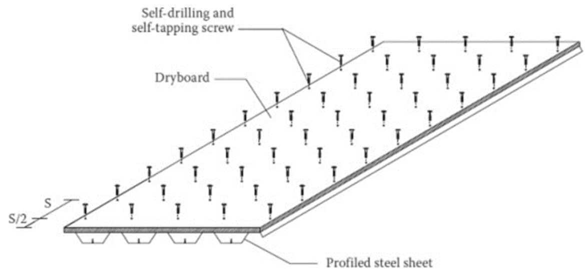


Figure 1: The multi-layer fibre cemboard

In heavyweight floor, multi-layer fibre cemboard is required to provide adequate load carrying capacity and bearing resistance toward imposed actions for the whole life span. Multi-layer fibre cemboard can be constructed by combining several layers of fibre cemboard using bond mechanism such as glue adhesive or steel bolt. [4] mentioned that joining through steel bolt provides significant increase in durability, thus become an ideal solution to increase the performance of bolted-fibre cemboard. If glue adhesive is applied between fibre cemboard, the strength will be good but the resistant between fibre cemboard is small.

1.1 Problem Statement

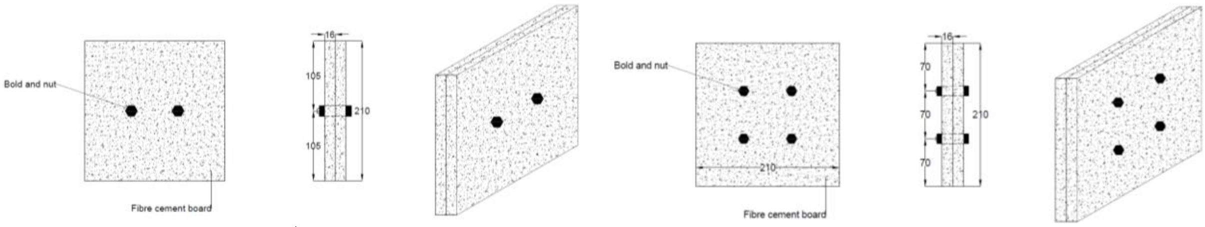
Major concern of bolted-fibre cemboard is the bearing capacity and slip-displacement that may affecting its performance under horizontal circumstances. The failure such as cracking and splitting are often happening at the surrounding joint of fibre cemboard and steel bolt. Long term problems in bolted-fibre cemboard is detachment and delamination that require specific repairing and strengthening methods. [5] stated that the design and performance of bolted-fibre cemboard mostly governed by the diameter of steel bolt. Therefore, the study on bolted-fibre cemboard is necessary to deeply understand about its performance. [6] suggested the push-out test to be implemented in order to obtain the bearing capacity and slip-displacement. However, such experimental study is tedious and costly because of large number of specimens need to be prepared. Besides that, it requires repetitive works and detailed observation to ensure the accuracy of results. Therefore, numerically modelling is suggested as alternative to the experimental study. Numerical modelling is a great tool to simulate various physical problems precisely and effectively. Furthermore, the numerical modelling an provide effect constrain and contact surface that govern the failure mode of bolted-fibre cemboard.

1.2 Objective

This paper is written for the objective as to perform model bolted-fibre cemboard under push-out test using finite element method program called WELSIM. It should be emphasized here that the main aim of this study is to analyse the bearing capacity, slip-displacement and failure mode of bolted-fibre cemboard as well as to evaluate the effects of different steel bolt diameters. It also can be prove by comparing the result between numerical and experimental study.

2. Materials and Methods

The bolted-fibre cemboard consists of two-ply fibre cemboard that connected using steel bolt as bond mechanism. The dimension of bolted-fibre cemboard is 210 mm length, 210 mm width and 16 mm thickness. The steel bolt with mild-strength characteristic (grade 4.6) and stainless hexagon (head and nut) is used to attach the fibre cemboard. The length of steel bolt is 60 mm. Five different steel bolt diameters were used as parametric studies; 10 mm, 12 mm, 16 mm, 20 mm and 24 mm. The location of steel bolt was setup to asymmetry corner. Figure 2 shows the schematic design of bolted-fibre cemboard. Two models were prepared; fibre cemboard with two steel bolts (FC2B) and fibre cemboard with four steel bolts (FC4B). The end distance and spacing of steel bolt are allocated with same value of 70 mm at the horizontal and vertical directions, except for model FC2B that has end distance of 105 mm at the vertical direction.



a) **b)**

Figure 2: Schematic design of bolted-fibre cemboard, a) Model FC2B (fibre cemboard with two steel bolts), and b) Model FC4B (fibre cemboard with four steel bolts)

2.1 Experimental study

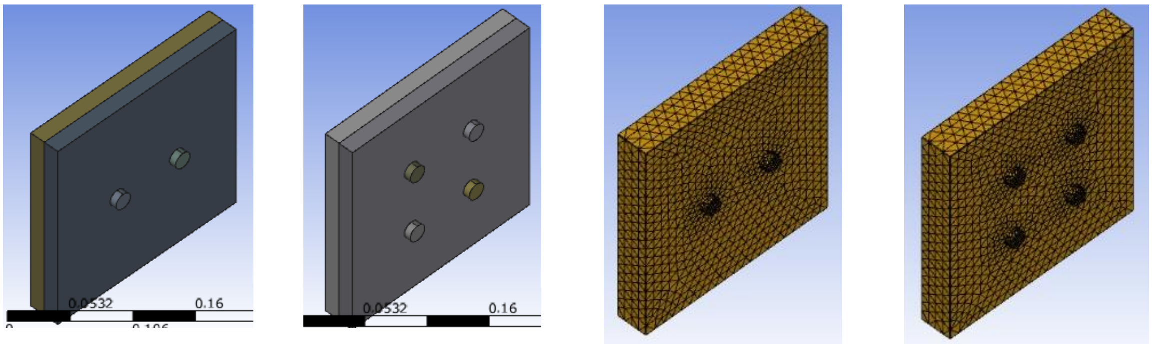
The numerical modelling of bolted-fibre cemboard was conducted as similar as the push-out test. For the purpose of validation, this study follows the experimental study by [7]. Basically, the push-out test is conducted to determine the bearing capacity and slip-displacement. During the experimental study, the top and bottom sides of bolted-fibre cemboard is slotted with metal plate. The function of metal plate is to support the bolted-fibre cemboard and replicate the partial-fixed type of constraint. The metal plate at the bottom side holds the bolted-fibre cemboard, while metal plate at the top side was imposed by an incremental axial compression load in term of stroke with speed rate of 1.0 mm/minute.

2.2 FEM modelling

The bolted-fibre cemboard under push-out test was modelled using the finite element method program known as WELSIM. The numerical modelling was performed as described in the experimental study. After the validation of results between numerical modelling and experimental study, further investigation was conducted by using parametric studies. In WELSIM, the numerical modelling was conducted based on the explicit analysis taking into the account the non-linear and plastic behaviour. Consequently, the geometry, material properties, constraint, contact surface and loading are important consideration that requires properly creation and definition.

2.3 Geomatry

The bolted-fibre cemboard was modelled in three-dimensional and defined with tetrahedral element. This type of mesh is classified as solid element with four nodes. Tetrahedral element can fit better complex geometry. When integrate the shape functions with points of Gauss, it is less accurate than hexahedral element. Figure 3 shows the geometry of bolted-fibre cemboard and the discretization. Mesh size used in this study is 10 mm. This mesh size was determined based on the convergency analysis (mesh sensitivity test) and the critical time step. Therefore, strength prediction output is independent from mesh refinement effects.



a) **b)**

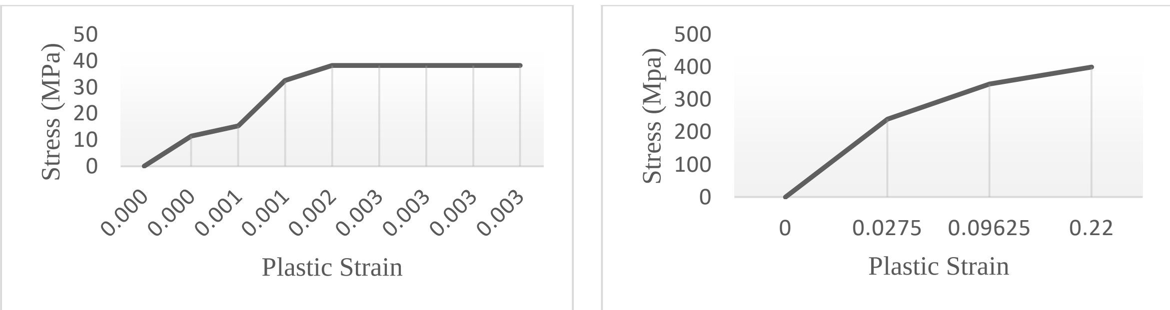
Figure 3: a) Geometry of Bolted-Fibre Cemboard, b) Discretization of Bolted-Fibre Cemboard

2.4 Materials properties

The bolted-fibre cemboard consist of two distinguish components known as fibre cemboard and steel bolt. In order to create the non-linear plasticity in the numerical modelling, the material model needs to be defined with elastic material properties, strength parameters and hardening properties. The elastic material properties and strength parameters of fibre cemboard and steel bolt can be referred in Table 1. In term of hardening properties, multilinear kinematic hardening is associated to fibre cemboard. On the other hand, trilinear isotropic hardening is defined for steel fibre. The hardening properties require the definition of plastic strain and true stress that derived theoretical from engineering strain and engineering stress. Figure 4 shows multilinear kinematic hardening and trilinear isotropic hardening.

Table 1: The elastic material properties and strength parameters

Properties	Elastic material properties for fibre cemboard	Elastic material properties for steel bolt
Young's modulus, E (GPa)	30	200
Poisson Ratio, v	0.18	0.3
Density, ρ (kg/m^3)	1300	7850
Bulk Modulus, k (GPa)	15.625	166.7
Shear Modulus, G (GPa)	12.712	76.92
Tensile strength, σ_t (MPa)	6.37	-
Isotropic Thermal Conductivity, (W/m/C)	0.24	-
Specific Heat, (J/kg/C)	780	-



a) b)

Figure 4: a) Multilinear kinematic hardening for fibre cemboard, b) Trilinear isotropic hardening

2.5 Constrain

Constraint is used in the numerical modelling to the support and translational control. Under push-out test, the bottom side of bolted-fibre cemboard is supported by metal plate. In the numerical modelling, the bottom side of bolted-fibre cemboard was defined with fixed support that mimicking the actual condition as in the experimental study. Therefore, the constrain was setup true in all directions (x, y and z axis) and no movement is allowed. Meanwhile, the top side of bolted-fibre cemboard is restricted in the horizontal direction but able to move in the vertical direction. has been allowed to move in the vertical direction. Moreover, to assemble this method the proper step is needed to be follow to run the model smoothly without any error.

2.5 Contact Surface

In the numerical modelling, contact surface represent the interaction between different components. In this study, there are two conditions of contact surface that occur on the bolted-fibre cemboard such as imply between fibre cemboard to fibre cemboard and fibre cemboard to steel bolt. The contact surface between fibre cemboard to cemboard is considered as perfect bonded due to the presence of polyurethane glue. On the other hand, the contact surface between fibre cemboard to steel bolt is assumed as partial bonded. It is demanding the friction parameters as tabulated in Table 2. As partial bonded, target contact and master contact were imposed to fibre cemboard and steel bolt, respectively.

Table 2: Friction parameters for partial bonded

Properties	Value
Friction Coefficient	0.1
Friction Penalty Stiffness	1.0
Formulation	Lagrange
Normal Direction Tolerance	10-5
Tangential Direction Tolerance	0.001
Normal Direction Penalty	10000
Tangential Direction Penalty	1000

2.6 Loading

The loading that was imposed on the bolted-fibre cemboard is setup as similar as measured during the push-out test. In the numerical modelling, an axial compression load was defined at the top side of bolted-fibre cemboard. The shear load was transferred to the lower interface through bolts. The loading is based on the displacement-time history as can be seen in Figure 5. This loading was converted from the stroke-time history of Universal Testing Machine that truly reflects the speed rate of 1.0 mm/minute. It should be emphasized here that the maximum load that can be reached through this loading was capped at 100 kN.

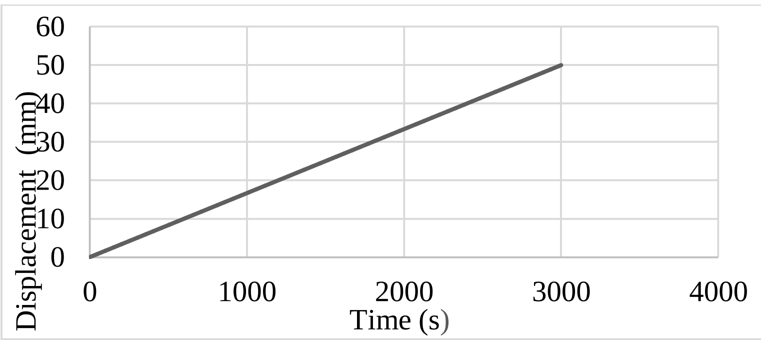


Figure 5: Stroke-time history

3. Results and Discussion

In the numerical modelling, the results in term of stress-force curves and stress-displacement curves were obtained directly from WELSIM software. The parametric studies involve different steel bolt diameter ranging from 10 mm to 24 mm. There are models involve in this study; fibre cemboard with two bolts (FC2B) and fibre cemboard with four bolt (FC4B). It should be emphasized here that the main aim of this study is to analyse the bearing capacity, slip-displacement and failure mode of bolted-fibre cemboard, as well as to evaluate the effects of different steel bolt diameters.

3.1 Appraisal and Validation

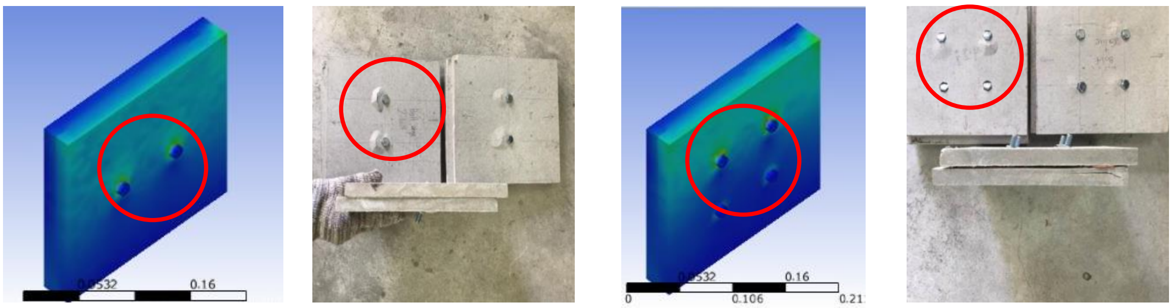
As described in material and method, the numerical modelling of bolted-fibre cemboard was conducted in three-dimensional. The explicit analysis with non-linear plasticity was adopted in the numerical modelling taking into account the geometry, material and contact nonlinearities. It is requiring the definition of mesh, material properties, constrain, contact surface and loading. Consequently, the tetrahedral solid elements were used in the discretization, while constitutive law is governed by multilinear kinematic hardening for fibre cemboard and trilinear isotropic hardening for steel bolt. The size of mesh is 10 mm for fibre cemboard and 3 mm for steel bolt. With the presence of polyurethane glue in between to surface of fibre cemboard, the partial perfect bonded was employed with friction definition. Results between numerical modelling and experimental study are compared as tabulated in Table 3.

Table 3: Results between numerical modelling and experimental study

Parameter	Experimental Study	Numerical Modelling	Error (%)
Model FC2B (steel bolt diameter of 8 mm)			
Bearing Capacity (kN)	35.44	42.00	15.62
Slip-displacement (mm)	4.31	4.37	1.37
Model FC4B (steel bolt diameter of 8 mm)			
Bearing Capacity (kN)	39.73	45.5	12.68
Slip-displacement (mm)	4.36	5.95	26.65

It should be noted here that the experimental study is based on [7]. According to [8] the push-out test is implemented in order to obtain the bearing resistance and slip-displacement. Based on the results, it was found that model FC2B able to resist axial compression load of 42.00 kN, which is 15.62% higher than experimental study. Similarly, model FC4B has higher bearing capacity in numerical modelling as compared to experimental study. In numerical modelling, model FC2B able to sustain axial compression load up to 45.50 kN, whilst in experimental study it only has 39.73 kN. This creates approximately 12.68% errors. On the other hand, the slip-displacement of model FC2B has less than 2% difference between numerical modelling and experimental study. On the other hand, slip-displacement for model FC4B is 5.95 mm and 4.36 mm for numerical modelling and experimental study, respectively.

Although there is discrepancy of results between numerical modelling and experimental study, the errors are still in the acceptable range. Therefore, the results of numerical modelling can be accepted. This reflects that the methodology, especially the mesh, material properties and contact surface, used in the numerical modelling is appropriate. On the other hand, a validation on numerical modelling is performed based on qualitative measurement. In this case, the damage based on stress contour is compared with that obtained from experimental study. Figure 4.1 shows the damage for model FC2B, whilst Figure 4.2 shows the damage for model FC4B. It was observed that damage occurs at the surrounding steel bolt. In experimental study, the damage can be identified by flaking of fibre cemboard. In numerical modelling, the damage can be detected as high stress accumulation at the particular area. However, the damage is identical.

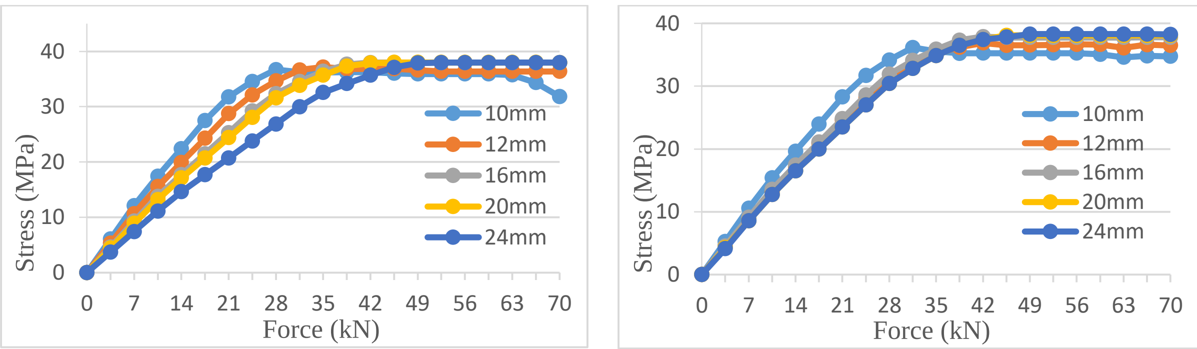


a) b)

Figure 6: Numerical modelling and experimental study, a) FB2C, b) FB4C

3.2 Stress-Force Curve

Prior to the successful of numerical modelling, models FC2B and FC4B were simulated under parametric studies. The results of stress-force curves for different steel bolt diameters; 10mm, 12 mm, 16 mm, 20 mm and 24 mm are plotted as can be seen in Figure 7. The force obtained from numerical modelling is considered as bearing capacity. It can be observed that the pattern of stress-force curve is similar for all parametric studies and imply both models. The stress is increased as correspond to the force and remain constant when it reaches the yield stress. Under push-out test, fibre cemboard is solely resist the stress that induced by axial compression load until it experiences failure. Although all parametric studies display similar yield stress, the stiffnesses indicated by the gradient of stress-force curves and ultimate loads at the initial point of yield stress are diverse.



a) b)

Figure 7: Stress-force curves, a) FB2C, b) FB4C

3.3 Stress-Displacement Curve

Figure 8 (a) displays the stress-displacement curves for model FC2B. There are five different curves that represent the parametric studies of steel bolt diameters in 10 mm, 12 mm, 16 mm, 20 mm and 24 mm. The displacement measured at the initial point of yield stress is considered as slip-displacement due to the axial compression load. Under the axial compression load, the bolted-fibre cemboard move down until certain limit. However, the movement is hold by polyurethane glue that act as bond mechanism. When the detachment occurs, steel bolt took place in resisting the movement. The stress is increase as correspond to the displacement and constant when it reaches the yield stress. Under push-out test, fibre cemboard solely resist that induced by axial compression load until the length between fibre cemboard can measured. As on the data, the increase of bold diameter will affect the less displacement measured on the fibre cemboard. The subtraction on displacement between parametric studies also show more noticeable base on the data bellow.

Figure 8 (b) displays the stress-displacement curves for model FC4B. The fibre cemboard react the same situation as model FC2B. The increase of bold diameter will affect the less displacement measured on the fibre cemboard. The subtraction on displacement between parametric studies also show less noticeable base on the data bellow. Based on this statement, the connection bonded on model of FC2B less than FC4B and will react less to the displacement.

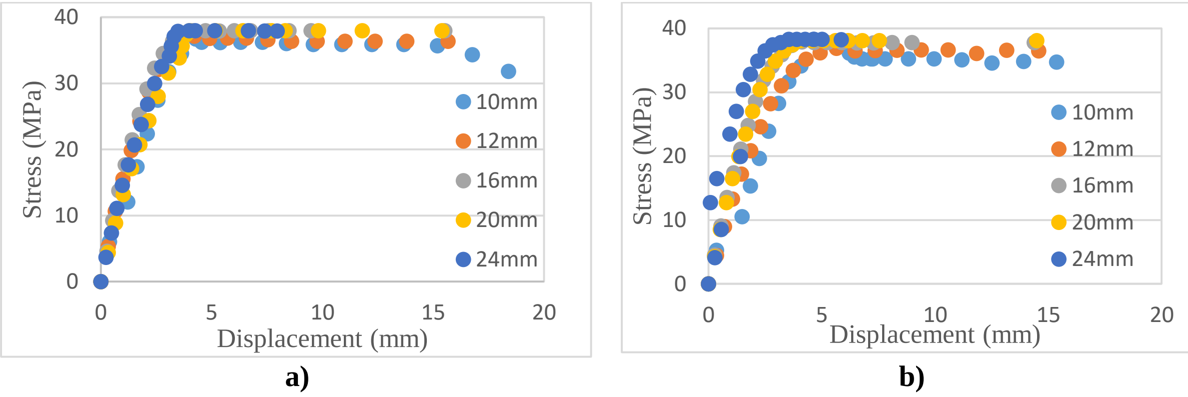


Figure 8: Stress-displacement curves, a) FB2C, b) FB4C

3.4 Failure Mode

[9] stated that for plate with bolt connection, the plate fails in tension. The plate is deformed as the in-plane load added and increased, whilst the edge fold over and bolt hole become plastic deformed. Similar behaviour was observed happen to bolted-fibre cemboard. Figure 9 illustrated the damage occurs on model FC2B and FC4B. It can observed that regardless the steel bolt diameter, the damage occur at the surronding area of steel bolt. The damage is identified as flaking in which that if sudden force is imposed, it will cause spalling and fracture. Another damage that can be observed is bending where fibre cemboard deforms in such as shape of semi-buckling. Although the slip-displacement is confirmed, it cannot be visualized herein can only be measured.

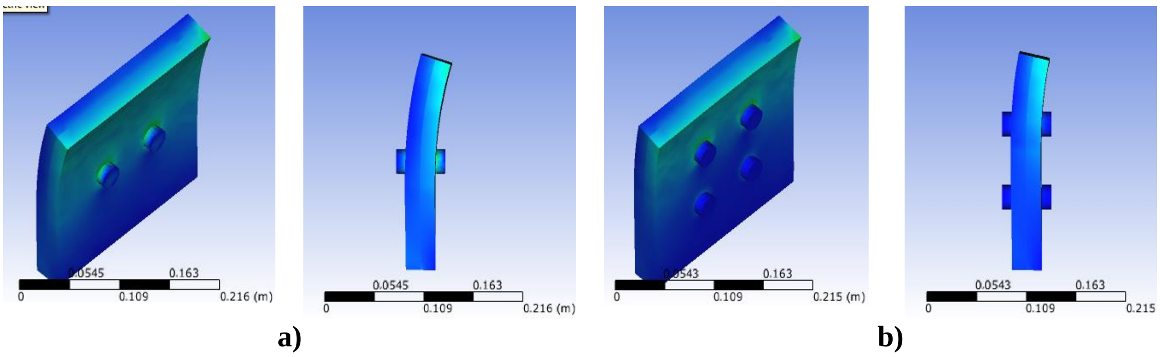
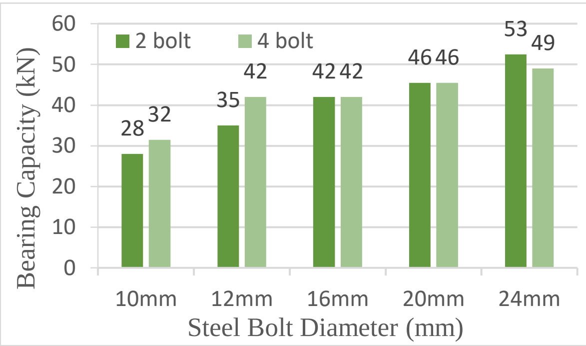


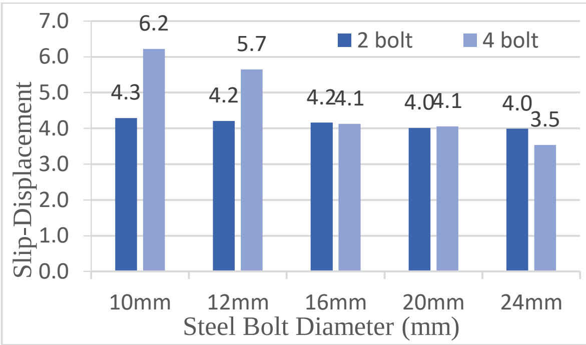
Figure 9: Damage on model isometric and side view, a) FB2C, b) FB4C

3.5 Effects of Steel Bolt Diameter

Figure 10 (a) shows the variant of bearing capacity between models FC2B and FC4B in term of steel bolt diameter. When larger steel bolt diameter is used, the bearing capacity increased steadily. [5] stated that the performance of plate is mostly governed by steel bolt diameter. This because in real fact, when the bigger size of connector is used, it will increase the strength of two specimen. [4] proved that the presence of steel bolt as bond mechanism able to increase the stiffness. For model FC2B, the increment of bearing capacity is around 10% to 25%. On the other hand, model FC4B has 10% to 30% increment of bearing capacity in correspond to the steel bolt diameter. In most cases, model FC4B shows higher bearing capacity than model FC2B except for fibre cemboard with steel bolt diameter of 24 mm. The difference of bearing capacity between models FC2B and FC4B is small, hence justify that number of bolts per row does not contribute to the better performance.

The effects of different steel bolt diameters on the slip-displacement of bolted-fibre cemboard is statistically depicted in Figure 10 (b). It can be observed that as the steel bolt diameter is increased, the slip-displacement decreases gradually. A comparison of slip-displacement between models FC2B and FC4B shows insignificant difference, except for fibre cemboard with steel bolt diameter of 10 mm and 12 mm. These bolted-fibre cemboard indicate higher slip-displacement due to the higher rate of damage. Although the use of bigger steel bolt diameter contributes to better performance of bearing capacity, unlikely not to the slip-displacement. According to [4], the use of steel bolt as connector may contribute to the unexpected events such as high stress accumulation, delamination and cracking. Therefore, slip-displacement become important indicator to detect any unlawful behaviour.





a) **b)**

Figure 10: a) Bearing capacity of fibre cemboard with different steel bolt diameters,

b) Slip-displacement of fibre cemboard with different steel bolt diameters

4. Conclusion

From this study, the model also has been compared with the experimental result and achived lowest error until 1.37% on quatitative comparison. The qualitative comparison also similar to the experimental study as the figure on result and discussion that has been explained regarding to the failure mode of the model and specimen. In this result, the model has achieved objectives which was the bolted-fibre cemboard has been succesfuly modelled. From the data of modelling, it also can analyse the ultimate force, maximum displacement and failure mode that happen from the model. This has been prove from the data that showed on result and discussion. This data also helps industry to apply bolted-fibre cembord in construction. As the result from result and discussion, the increase the diameter of bolt will lead a good performance of ultimate force. On the other hand, the increase of bolt will convey a less displacement to the model. From this study, the optimum size diameter for both FC4B and FC2B is 16mm. This because the result of both data were almost similar. This optimum size also can lead to economical, save cost and satisfactory in term quality of strength.

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