ANALYSIS OF THE BEHAVIOUR LARGE HEADED STUD IN TERMS OF SHEAR RESISTANCE AND FAILURE MODE USING ABAQUS

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B. ENG (HONS.) CIVIL ENGINEERING

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ANALYSIS OF THE BEHAVIOUR LARGE HEADED STUD IN TERMS OF SHEAR RESISTANCE AND FAILURE MODE USING ABAQUS

TEH KAI YAO

Thesis submitted in fulfilment of the requirements
for the award of the degree of
B. Eng (Hons.) Civil Engineering

Faculty of Civil Engineering and Earth Resources
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JUNE 2016

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Dedicated to my family,

for their unending love and support

making me be who I am today

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ABSTRACT

Headed stud are quite popular type of shear connector that is often used in composite structure. Shear connectors were used to resist longitudinal shear forces on the surfaces between steel and concrete. An accurate non-linear finite element model of the push-out test has been developed to investigate the capacity of large stud shear connectors (25mm and above) and the failure mode. The main objective of this study is to discover the effect of changes in stud diameter affect the shear resistance and the failure model on headed stud. There were four model in this analysis which designated as PT 1, PT 2, PT 3, PT 4 and PT 5 with stud diameter size 22mm, 25mm, 27mm, 29mm and 30mm respectively. The load per stud for PT 1, PT 2, PT 3, PT 4 and PT 5 were 103.57kN, 133.08kN, 162.47kN, 195.07kN and 226.44kN respectively. Based on the FEA result, the larger size stud diameter, will produce higher shear resistance. The stress distribution of the model is shown in the failure mode of shear stud and it is located at the weld toes of the in the horizontal direction for the top row of headed stud.

ABSTRAK

Stud berkepala adalah sejenis penyambung ricih yang agak popular yang kerap digunakan dalam struktur komposit..Penyambung ricih digunakan untuk menahan daya ricih membujur pada permukaan antara keluli dan konkrit. Model finite element yang tepat untuk ujian “Push Out” telah dicipta untuk menyiasat kapasiti penyambung ricih stud besar (25mm dan keatas) dan mod kegagalan. Objektif utama kajian ini adalah untuk mengetahui kesan perubahan diameter stud dalam mempengaruhi rintangan ricih dan model kegagalan di stud kepala. Terdapat empat model dalam analisis ini yang ditetapkan sebagai PT 1, PT 2, PT 3, PT 4 dan PT 5 dengan saiz stud diameter 22mm, 25mm, 27mm, 29mm dan 30mm masing-masing. Beban setiap stud untuk PT 1, PT 2, PT 3, PT 4 dan PT 5 adalah 103.57kN, 133.08kN, 162.47kN, 195.07kN and 226.44kN masing-masing. Berdasarkan keputusan FEA, diameter saiz stud yang lebih besar, akan menghasilkan rintangan ricih yang lebih tinggi. Mod kegagalan menunjukkan stud model agihan tegasan dan ia terletak di jari kaki kimpalan daripada dalam arah melintang untuk baris atas stud berkepala.

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LIST OF SYMBOLS

%	Percentage
mm	Milimeter
kN	Kilo-Newton
mm^2	Millimeter square
Kg/m^3	Density
N/mm^2	Pressure
MPa	Mega pascal
E_{cm}	elastic modulus of concrete
$\mathbf{f_{ck}}$	compressive strength of concrete cylinders
h_{sc}	height of stud
f_y	Yield stress
ν	Poisson ratio

CHAPTER 1

INTRODUCTION

1.1 GENERAL

In the construction industry, steel and concrete are the vital and most used construction materials in this era. A lot of research had been done in order to determine the factors affecting the shear strength and relative slip of composite structure. The most important factor in a structure is the bonding between steel and concrete in it as they need to be strongly bonded into one unit in order to transfer load effectively to the sub-structure. Incorporating steel into concrete is a brilliant idea as concrete is strong in terms of compression but possess weak tensile strength, whereas steel has strong tensile strength where the incorporation steel into concrete produces stronger concrete with high tensile and compressive strength. In order to promote the bonding between concrete and steel, stud shear connectors are used where it resist longitudinal shear forces on the surface between steel and concrete, helps the concrete slab to bond stronger with the steel beam and prevent them from separating.

There are quite a few types of shear connectors used in the construction industry; headed stud connector, perfobond ribs, T-rib connector, T-connector, bar connector, and channel connector. All the connector can be category into two basic form, rigid and flexible where rigid shear connectors resist shear force using its front part by shearing and they have trivial deformations in the propinquity of ultimate strength. Unlike rigid shear connectors, flexible shear connectors use shearing, tension or bending at the connection point of steel beams to resist shear forces.

Headed stud is one of the flexible connector and is most commonly used in Malaysia. It contributes to the shear transfer and connect composite structure. This type of studs is installing by electronic welding which is easily installation and low cost. Much research has been carried out to determine the factor affecting the strength of headed stud. The push-out test were used to investigate the behaviour of headed stud in composite structure. In the high shear area, using the higher capacity shear connectors as large studs would reduce the number of studs and thus reduce welding time. Small number of large studs could help to reduce the deterioration of concrete slabs and enhance the safety of field workers because of the large space on the top flange.

1.2 PROBLEM STATEMENT

Nowadays, the bridge structure is very common in developing country. The composite structure is the main component for bridge structure. Shear connector is most important component present in composite structure where it connects the steel and concrete in the composite structure. According the statistics by OSHA, (2015) in United States, there is around 4579 workers killed due to their job in year 2014, which means every week, there is about 90 workers died due to site hazard and approximately 13 fatalities every day. However, the alarming fact is that out of the 4251 workers killed on their job in private industry on 2014, 20.5% of it is from the construction industry, which means 872 fatalities in construction industry in 2014. There are a lot hazards that leads to this large number of fatalities but one of the leading cause is due to lack of working space that leads to the fall of the workers that caused fatality.

There are a few solutions to this problem, one of it is using larger shear studs in composite bridge as using larger shear studs will reduce number of headed studs used which eventually provides more working space for the workers. According to Lee et al (2005), the use of headed stud greater than 25mm in diameter could provide considerable advantages and conveniences in composite bridges where in the high shear area, using the higher capacity shear connectors as large studs would reduce the number of studs and thus reduce welding time. However, the existing Eurocode 4 only can determine from 19mm to 25mm diameter.

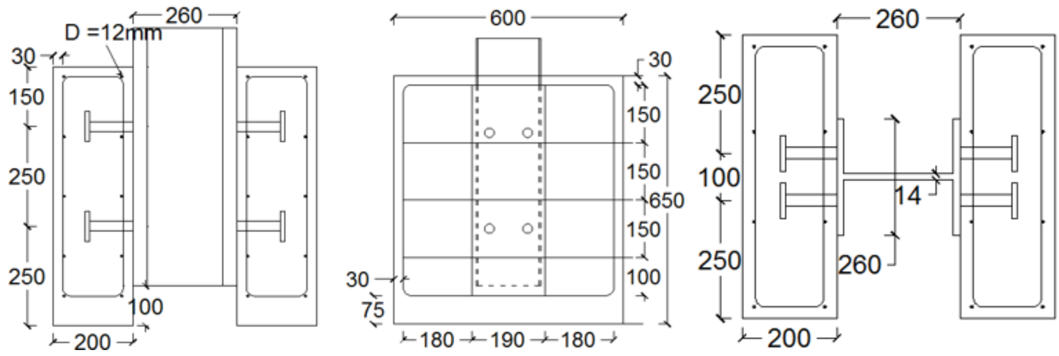
1.3 OBJECTIVES

The main purpose of conducting this research is to discover the effect of changes in stud diameter to the maximum shear resistance of stud.

i. To determine the shear resistance between concrete and steel structure connecting with difference size of headed stud.
ii. To analyses the stress distribution on different size of diameter and fatigue failure mode on headed stud.

1.4 SCOPE OF STUDY

The scope of study is mainly focus on the behaviour of the headed stud in composite structure. This research is conducted using Abaqus 6.14 student version software where finite element modelling is used to the modelling of steel concrete composite structure. There are 5 models of the pull-out test has been model with 22mm, 25mm, 27mm, 29mm and 31mm. The model is analysing by using ABAQUS version 6.14. The standard push out test model is set up according to the Eurocode 4 as shown in Figure 1.1. The size of concrete is 200mm x 300mm x 650mm and the model consist of 8 stud connectors. The steel reinforcement diameter is 12mm. The total height of stud is 150mm. The spacing between studs are 100mm and 250mm. The thickness of I beam is 14mm. The height and width of I-beam are 260mm. The concrete cover is 30mm.



(a) (b) (c)

Figure 1.1: Schematic diagram (a) Front view (b) Side view (c) Top view

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

The headed stud has been start research attention in the later 1950s and till 1960s. the early research work on headed studs was focused on applications in the concrete slab and steel beam composite structure. There were many studied had been done for headed studs. The first studied has been done is the behaviour of headed stud was studied by Viest (1956). He conducted a total of 12 push out test at the University of Illinois with varying effective depth to stud diameter ratios and observed three types of failures, which are concrete failure (concrete surrounding the stud get damaged), steel failure (headed studs reaches its yield point), and mix failure (both material) fail. He has recommended a formula to determine the shear resistance of headed studs. It has become the benchmark and fundamental on determining the strength and analysis the failure.

2.2 USE OF SHEAR STUD

Most of the time shear connector has been use in composite structure to combine the steel beam (strong in tensile strength) and reinforced concrete slab (strong in compressive strength). It uses to connect the bonding in between by providing the shear resistances. According to Johnson(2004), the present of shear connector will make the two member behave as one and the maximum bending stress is halved but the shear connection does not change the maximum shear stress. Figure 2.1 show the bending stress and shear stress of two components with shear connector (full interaction) and without shear connection (no interaction). When the presence of shear connector will prevents the slipping between the two members. Thus it achieves a much stiffer and stronger structure and can transfer the load effectively to the sub-structure.

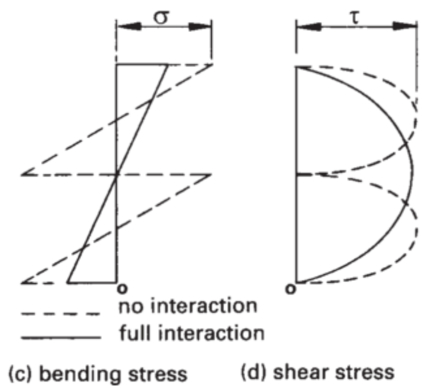


Figure 2.1: Effect of shear connection on bending and shear stresses

Source: Johnson 2004

2.3 TYPE OF FAILURE IN PUSH OUT TEST

According to Viest (1956), there is 3 types of most common failures in push-out test, which are shank shear failure of headed studs (steel failure), concrete splitting and crushing failure, and mixed failure. When the failure occurs, the maximum shear resistance can be determining.

2.3.1 Shank Shear Failure of Headed Stud

Shank shear failure occurred in push-out specimens with concrete slabs when the stud spacing was too large. The ultimate load is applied on the beam was reached, the failure will immediately occur which the characteristic feature of a shank shear failure is a total loss of interaction between concrete slab and the steel beam at failure (Chandrasekar Gnanasambandam, 1995). The load-slip curve of push-out test, which is shank shear failure has shown in Figure 2.2. This failure was happened when the headed studs reach its yield point and start to deformation. Fatigue failures occur at weld toes in the horizontal direction and fatigue failure modes of stud shear connector as shown in Figure 2.3.

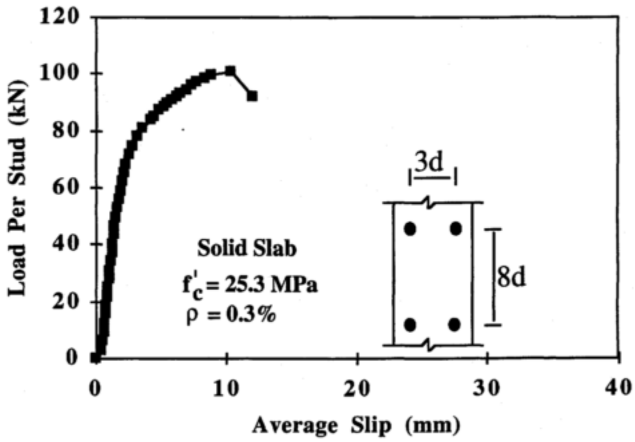


Figure 2.2: Load-slip curve for shank shear failure of headed studs.

Source: Chandrasekar Gnanasambandam 1995

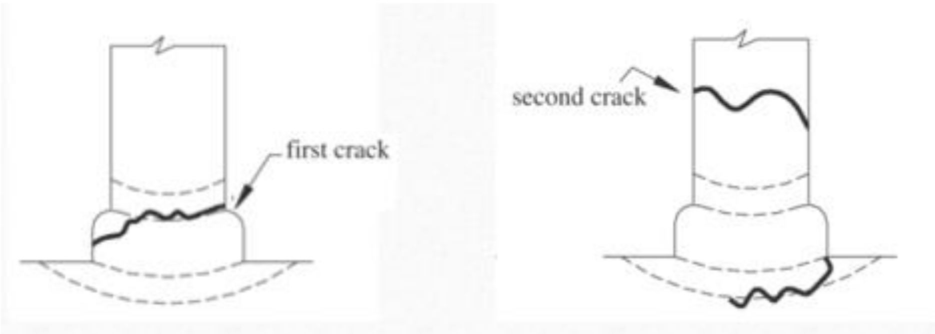


Figure 2.3: Fatigue failure modes of stud shear connector.

Source: Lee et al. 2005

2.3.2 Concrete crushing and splitting failure

Concrete crushing and splitting failure was happened in the specimens with solid slab and steel beam when the longitudinal stud spacing was too small or concrete strength is relative too lower than the ultimate tensile strength of stud *(Chandrasekar Gnanasambandam, 1995)*. For this failure mode, the longitudinal splitting is likely to originate at the inner face of the slab, from the root of the studs, and grows toward the surface of the slab. Then followed by crushing of the concrete in front of and in between the headed studs. The headed stud was undergoing bending, but do not have shank shear failure on it. The load-slip curve has shown in Figure 2.4 for concrete splitting and crushing failure. This curve shows the unloading part of the load unlike the curve show in Figure 2.2, that doesn't have unloading segment. Figure 2.5 shown typical concrete splitting and crushing failure in concrete slab.

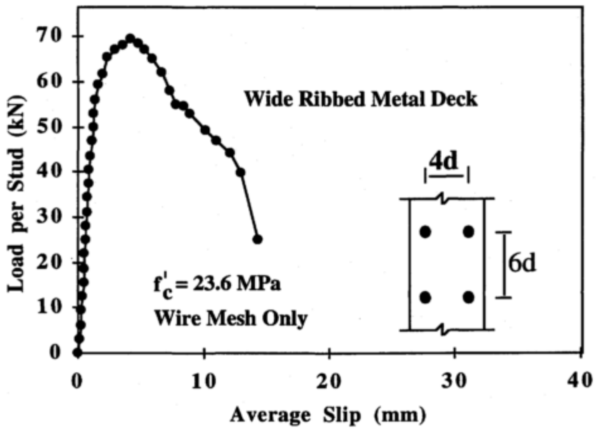


Figure 2.4: Load-slip curve for concrete splitting and crushing failure.

Source: Chandrasekar Gnanasambandam 1995

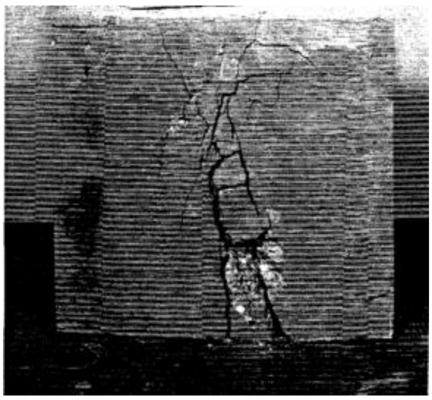


Figure 2.5: Typical concrete splitting and crushing failure in concrete slab.

Source: Chandrasekar Gnanasambandam 1995

2.3.3 Mixed failure

This types of failure are the combination of shank shear failure and concrete crushing failure occurred at same time in push-out specimen. The failed as a result of stud shank shear but only after considerable crushing of concrete at the root of the headed studs *(Chandrasekar Gnanasambandam, 1995)*. Figure 2.6 shown the load-slip curve for mixed failure in specimen. The highest point on the load slip curve represents the largest bending of the headed studs before shank shear failure of stud happened. The cracking noises was heard during the unloading stage and caused by headed studs shank shear. Figure 2.7 illustrated typical mixed failure on concrete and studs.

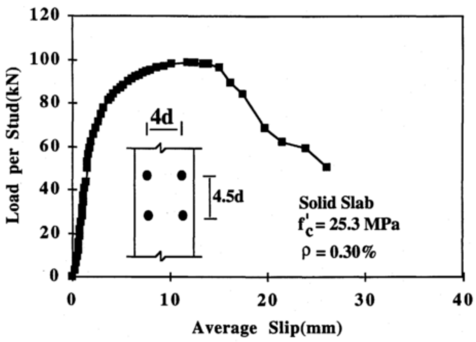


Figure 2.6: Load-slip curve for mixed failure.

Source: Chandrasekar Gnanasambandam 1995

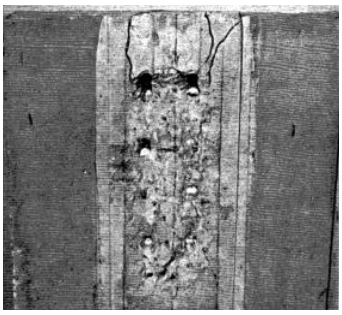


Figure 2.7: Typical Mixed failure.

Source: Chandrasekar Gnanasambandam 1995

2.4 PUSH OUT TEST

Push-out test is the most common way use to evaluate shear stud strength and composite beam behaviour typically utilized a push-out specimen to study shear transfer from concrete slab to the steel beam through the headed studs.(Anderson N. S., 2000) Headed studs were welded to both flanges in some prescribed pattern or spacing and embedded into a thin concrete slab. It was usually reinforced to stimulate a bridge deck. As shown in Figure 2.8, both the beam and two slabs were oriented vertically fitting conveniently into a universal testing machine.

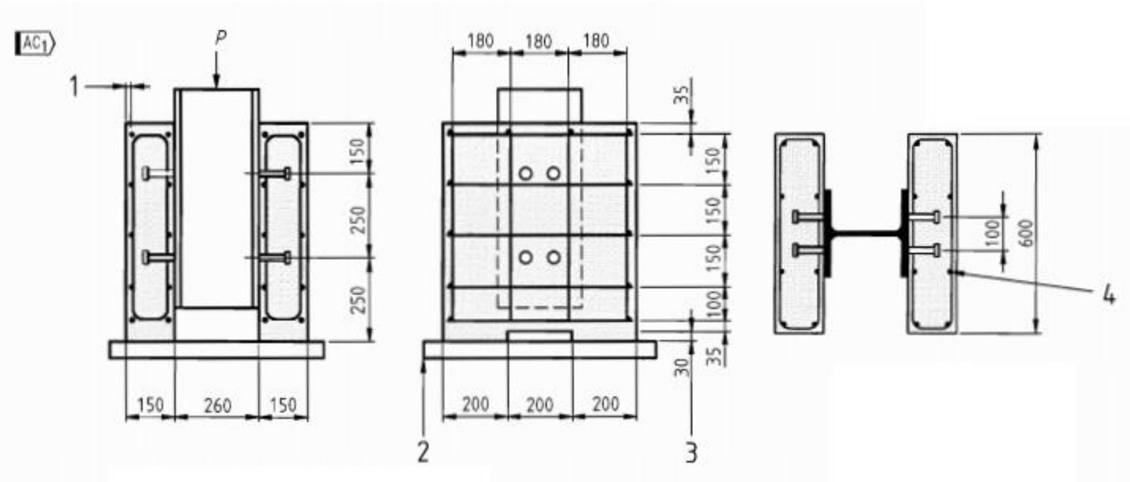


Figure 2.8: Standard Push out test specimen.

Source: Eurocode 2004

2.5 SHEAR RESISTANCE OF HEADED STUDS

According to Eurocode 4, the shear resistance of a headed stud can be determining by using Eq. (1) and (2). the maximum diameter of headed studs can be determining from 19mm to 25mm.

$$P_{Rd} = \frac{0.8 f_u \pi d^2/4}{\gamma_v} \qquad \text{(Eq.1)}$$

OR

$$P_{Rd} = \frac{0.29\alpha d^2\sqrt{f_{ck}E_{cm}}}{\gamma_v} \qquad \text{(Eq.2)}$$

Whichever is smaller,

$$\alpha = 0.2\left(\frac{h_{sc}}{d}+1\right) \text{ for } 3 \le h_{sc}/d \le 4$$

OR

$$\alpha = 1 \qquad \text{for } h_{sc}/d > 4$$

Where:

γ_v = the partial factor equal to 1.25;

d = diameter of the headed stud, $19mm \le d \le 25mm$;

E_{cm} = elastic modulus of concrete;

f_{ck} = compressive strength of concrete cylinders;

h_{sc} = height of stud.

Eq. (1) represents the shear failure of the shear connector and
Eq. (2) represents the concrete failure around the connector

2.6 SOLID (CONTINUUM) ELEMENTS

According to Xu, C., & Sugiura, K. (2013), Had concluded the steel beam, concrete and headed stud were suit using continuum elements for analysis and give accurate result. Continuum elements is used for three-dimensional modelling can be composed of a single homogeneous material and can include several layers of different materials for the analysis of laminated composite solids. This element is more accurate if not distorted. Continuum elements in Abaqus library can be used for linear analysis and for complex nonlinear analyses involving contact, plasticity, and large deformations. This element has three degrees of freedom at each node. The C3D8 element (8-node linear brick, reduced integration with hourglass control) was used for concrete slab, steel beam and headed studs. The reduced integration was used to make it take less time to run the analysis but it could have a significant effect on the accuracy of the element for a given problem. However, the slight loss of accuracy is counteracted by the improvement in approximation to real-life behaviour. Figure 2.9 shown three- dimension of continuum element.

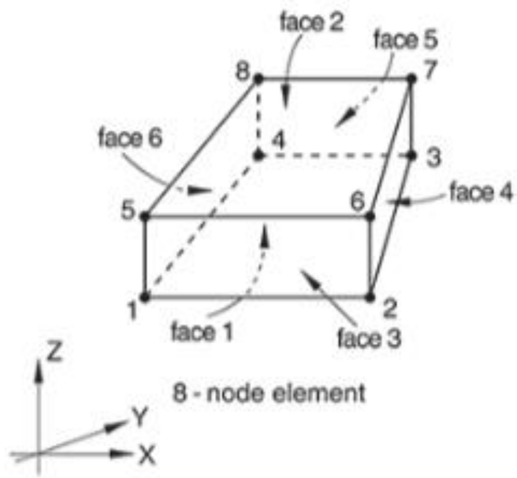


Figure 2.9: Three- dimension of continuum element.

Source: ABAQUS manual v6.14 2014

2.7 TRUSS ELEMENTS

As shown in Figure 2.10, truss element is used in two and three dimensions to model slender, line-like structures that support loading only along the axis or the centreline of the element. No moments or forces perpendicular to the centreline are supported. 2-node straight truss element, which uses linear interpolation for position and displacement and has a constant stress, is available in both Abaqus library.

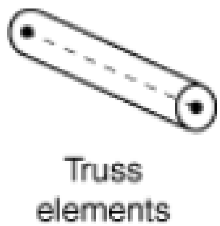


Figure 2.10: Truss element.

Source: Hibbitt, Karlsson, & Sorensen. (2001)

2.8 FINITE ELEMENT ANALYSIS COMPARE WITH EXPERIMENTAL TEST AND CURRENT CODE PRACTICE.

(Lam & El-Lobody, 2005) studied “Behaviour of Headed Stud Shear Connectors in Composite Beam” was concluded that the finite element model can accurately predicted all the mode of failure in push-out test. From the parametric study, it showed the formulas given in EC4 gave a good correlation with the experimental results and FE solutions. However, the BS5950 and AISC may have overestimated the shear resistance of the headed stud. The push-out tests for more than 22mm diameter headed stud need to further test should be carried out to verify the shear resistance. Figure 2.11 had shown the Codes comparison of shear capacity for 19mm X 100mm headed shear stud in various concrete strength.

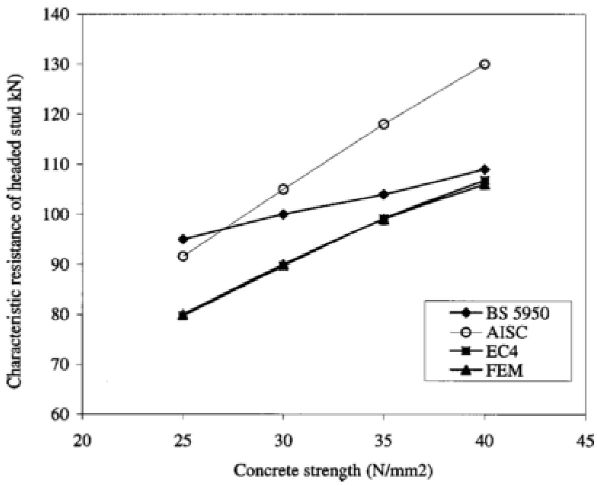


Figure 2.11: Codes comparison of shear capacity for 19mm X 100mm headed shear stud in various concrete strength.

Source: (Lam & El-Lobody, 2005)

(Ellobody & Young, 2006) studied “Performance of shear connection in composite beams with profiled steel sheeting”. The result for 44 push-out specimen with different profiled steel sheeting geometries, headed stud diameter and heights and concrete grade was stimulated using the finite element model with non-linear. The comparison of the shear connection capacities obtained from the finite element analysis and the design rules specified in the American Specification, British Standard and European Code have shown that, the American Specification and British specifications overestimated the capacity of shear connection with a maximum value of 27% and 25%, respectively. The design rules specified in the European Code were generally conservative, except for some cases that overestimated the capacity of shear connection with a maximum value of 11%.

2.9 FACTOR AFFECT THE SHEAR STRENGTH

There is many factor will decrease the headed studs shear resistance. These factors are the effect of concrete strength, effect of cross-section area of the stud shank, effect of the height to diameter ratio of the stud and effect of the longitudinal spacing of the studs on stud strength (Douglas .et al, 2012).

2.9.1 Effect of Concrete Strength on the Shear strength

An analysis about the effect of concrete strength om stud strength by means of numerical simulation was made in (J. Bonilla .et al,2009). It showed that the concrete strength directly proportional to the shear strength of connection. When the increased concrete strength, the capacity of shear connection increased. That fact is also consistent with (Ollgaard .et al, 1971).

2.9.2 Effect of Cross-section Area of the Stud Shank

From the studied (J. Bonilla .et al,2009), about the effect of the cross-section area of the stud shanks and the steel strength on the stud strength was carried out. As the cross-section area is increased, there is an increase in the shear resistance of connection. It shown a linear proportional relation between the cross section area and the shear resistance. On the other hand, the different of the ultimate tensile strength of the stud have little influence upon the connection bearing capacity. Therefore, this is not a very significant parameter.

2.9.3 Effect of the Height to Diameter Ratio of the Stud on the Shear Strength

According to J. Bonilla et al. (2012), a new factor (α) to reduce stud strength with h_c/d ratio variation is estimated. Which considers the influence of concrete strength and stud diameter variation. The reduction factor (α) is determined for each stud diameter from 9.52 to 25.40mm, according to concrete strength and h_c/d ratio. From the studied, h_c/d ratio more than 4 times at different concrete strength wont have any affect to the shear resistance of the headed studs.

2.9.4 Effect of the Longitudinal Spacing of the Studs on Stud Strength

When the stud connectors are too close to each other, the stress induced by the stud overlap and the connection bearing capacity decreases. The stud connectors calculation methods suggested in the international codes do not take into account this effect. A reduction factor (γ) of the capacity of shear connection was determined for cases when the connectors were closed to each other. (Douglas .et al, 2012). Due to this reduction factor has make the shear connector not efficiency to provide the maximum shear resistance.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

In this study, the finite element program ABAQUS v6.14 was used to simulate the push-out test. The main components influencing the behaviour of the shear connection in the composite beam are concrete the slab, steel beam, rebar and headed stud. There are five models with different diameter of headed stud in concrete grade 30. The models were named as PT 1, PT 2, PT 3 PT 4 and PT 5 with 22mm, 25mm, 27mm, 29mm, and 31mm respectively. The standard Push-out test model is set up according to Eurocode 4 The process of the analysis the push out test was separated into three steps which is pre-processor, post-processor and solution. The pre-processing was the modelling steps, while solution and postprocessor steps was applying the load and support condition and getting the result of the analysis respectively. Figure 3.1 and Table 3.1 show the dimension of stud and the size of stud was designed according to ISO 13918 (2008).

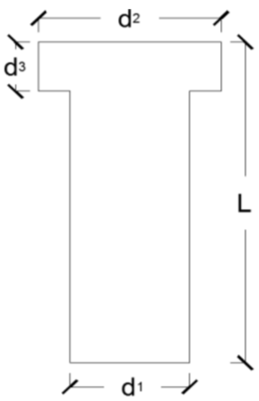
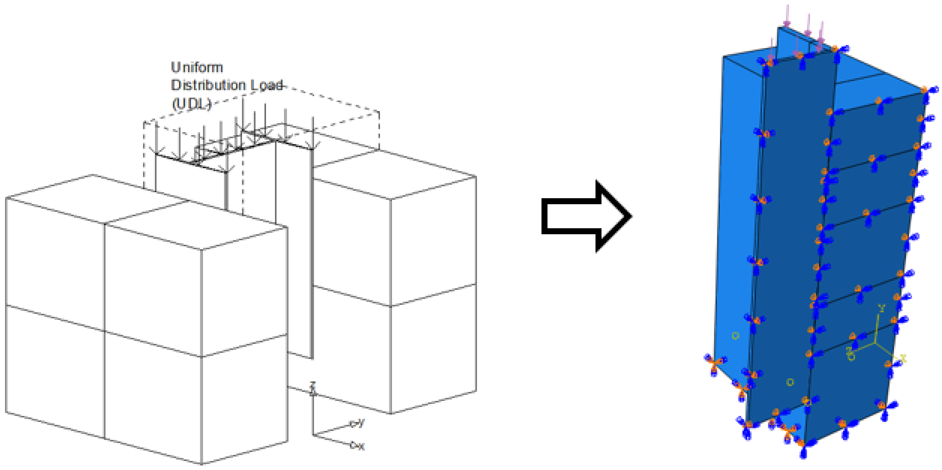


Figure 3.1: Dimension of Stud

Table 3.1: List of the detailing of the headed stud

Sample designated	Body diameter, d_1 (mm)	Head diameter, d_2 (mm)	Head height, d_3 (mm)	Length, L (mm)
PT 1	22	38	11	150
PT 2	25	38	11	150
PT 3	27	41	11	150
PT 4	29	43	11	150
PT 5	31	43	11	150

Figure 3.2(a) shown the full isometric view in model. There was only quarter of specimen was modelled in ABAQUS due to the symmetry of the specimen as shown in the Figure 3.2(b). Total force of 500kN had applied on the steel beam.



(a) (b)

Figure 3.2: Modelling (a) Isometric view (b) Quarter of model

3.2 FLOW CHART OF METHODOLOGY

Figure 3.3 shown the flow chart of this study, the process is separated into three parts: Pre-processor, Solution, and Post-processor.

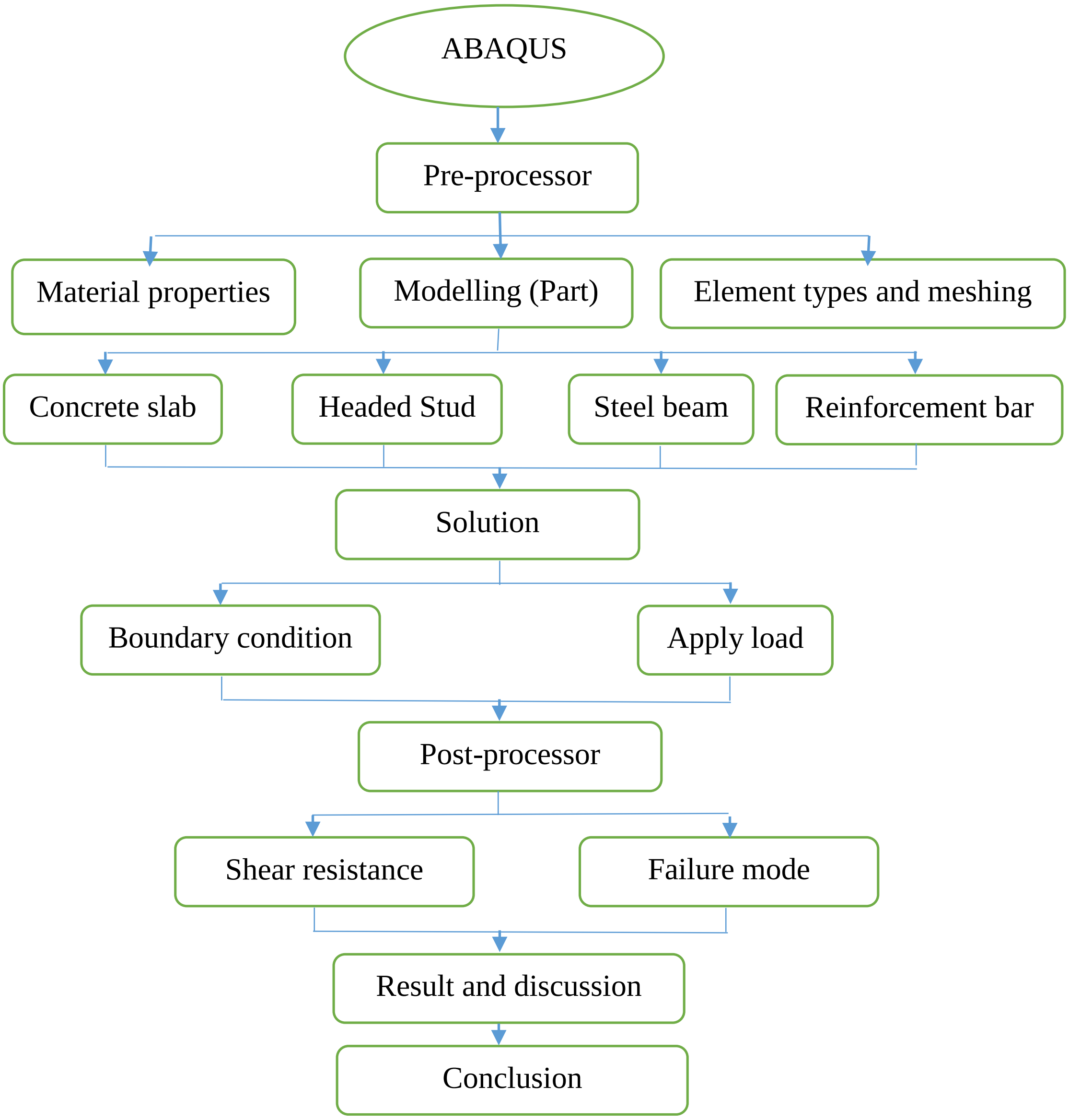


Figure 3.3: Flow Chart of the Analysis

3.3 PREPROCESSOR

In the pre-processor step, it considers inserting the element type, real constant for the material used, material properties value for the materials used.

3.3.1 Material properties

Table 3.2 show the material properties value used for the model. Concrete grade 30 was used for this study.

Table 3.2: Material properties

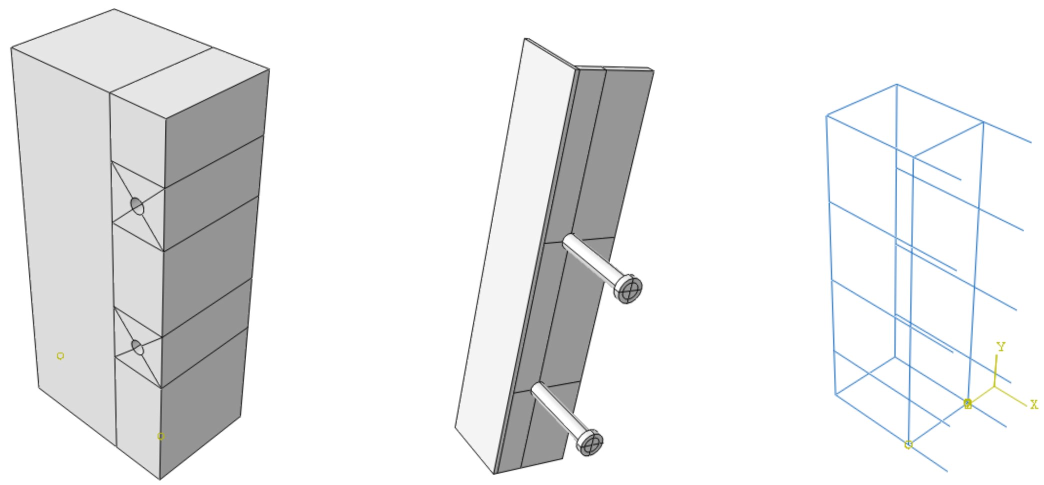
Properties	Values
Concrete	
Material model	Linear Elastic
Concrete grade	C30/37
Density (kg/m^3)	2400
Young's modulus (Gpa)	30
Poisson ratio, ν	0.2
Brittle cracking for concrete	
Direct stress after cracking	Direct cracking strain
1. 2.95	0
2. 0	0.01
For brittle shear	
Shear retention factor	Crack opening strain
1. 1	0
2. 1	0.001

Properties	Values
Stud connector, steel beam and rebar	
Density (kg/m^3)	7850
Young's modulus (Gpa)	210
Yield stress,f_y (Mpa)	355
Ultimate tensile strength,f_u (Mpa)	430

Concrete brittle cracking grade 30 were default value that given in ABAQUS manual. The stud connector, steel beam and rebar were used the same material properties.

3.3.2 Modelling (part)

As shown in Figure 3.4, this model consists of 4 part. There was concrete, headed stud, steel beam, and rebar. All the part is draw using millimetre unit. The steel beam and headed stud is combine together as one part for easy instances.

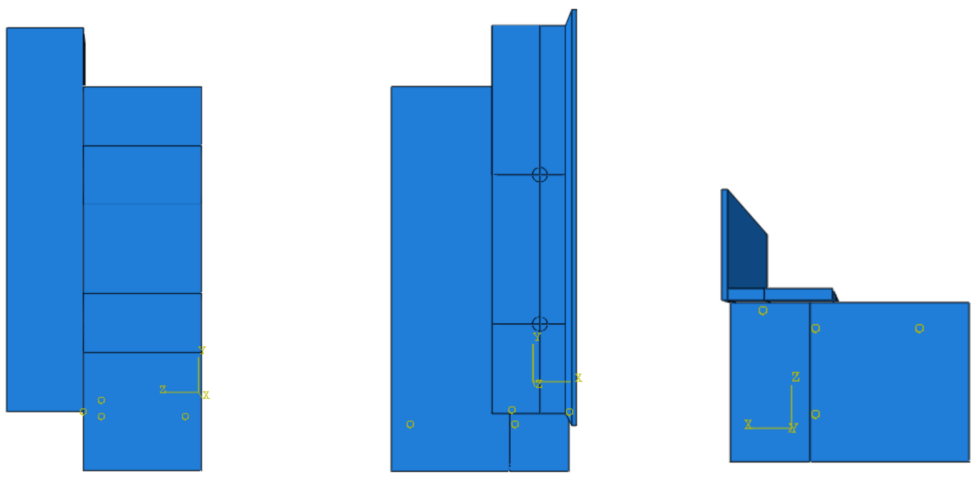


(a) (b) (c)

Figure 3.4: Part created for model (a) concrete (b) Steel beam (c) Rebar

3.3.2.1 Assembly of parts

After the part were created, the datum point was established on part. Datum point was used to assembly (instances) with other part as a coordinate system. Figure 3.5 shown the view after combine 3 parts.

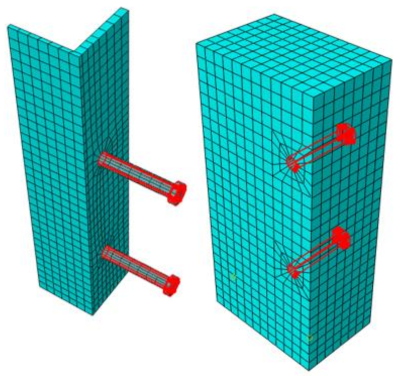


(a) (b) (c)

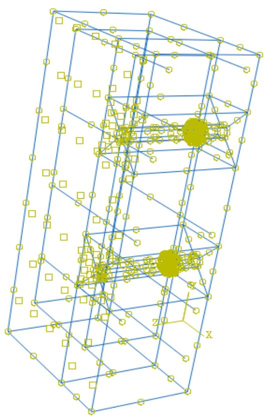
Figure 3.5: Assemble of model (a) side view (b) Front view (c) Top view

3.3.2.2 Constrain condition and interaction

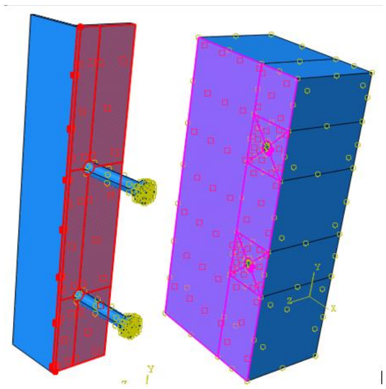
Appropriate constrains were used to describe the interaction between parts. As shown in Figure 3.6(a), the nodes on the surfaces of concrete slab around the studs were tied to the surfaces of the studs by the tie constrain. Using this constrain, the relative slip between these two surfaces was eliminated. Rebar were located inside the concrete slab as shown in Figure 3.6(b). The embedded constrain was applied to the rebar and concrete slab. In this constrain, the translational DOF of the nodes on the rebar elements were constrained to the interpolated values of the corresponding DOF of the concrete elements. The slip of the rebar was ignored. In the analysis, frictionless contact interaction was applied between concrete slab and steel beam surfaces shown in Figure 3.6(c).



(a) Surface in tie constrain between concrete and stud



(b) Embedded region with concrete and rebar



(c) Surface interaction contract of steel beam and concrete slab

Figure 3.6: Constrain condition and interaction

3.3.2.3 Analysis method (Step)

Step sequence provided a convenient way to capture changes in a model such as loading and boundary condition changes. The step of 'dynamic explicit' analysis method was used in this study. Dynamic explicit is time control method and it is used to show the failure of material and determine the shear resistance of stud. This step can use to limit the time interval and cut down the time for analysis. The time period was set as 1 second.

3.3.3 Element types and meshing

Table 3.3 show types of elements were used in this model. Concrete slab, steel beam, and headed stud were use C3D8R (continuum 3 dimensional reduce integration). The reduce integration element was used to shorten the time for analysis.

Table 3.3: Element types

Component part	Element
Concrete slab	C3D8R
Steel beam	C3D8R
Headed stud	C3D8R
Reinforcement bar	T3D2

The partition was created at the part as shown in Figure 3.4. Partition were used to create meshing. The overall mesh size was 25mm and the smallest size was about 15mm. The finite element mesh of the specimen is presented in Figure. 3.7.

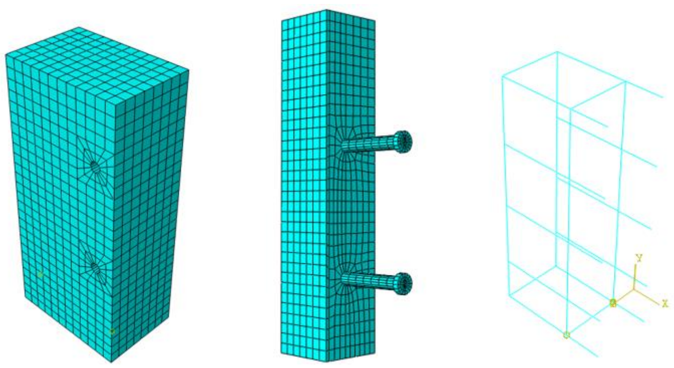


Figure 3.7: Meshing on part

3.4 SOLUTION

The boundary condition and applied load were located in the "Solution" stage. The load was defined by applying the structural types. The load was applied on the steel beam.

3.4.1 Boundary condition

Figure 3.8 shown the boundary condition of the model. The bottom of concrete slab surface, designated as surface 1. It has been fixed (pinned) support condition and is restrained from moving in all 3 directions. Surface 2 is taken as symmetric in X axis, therefore all the node on this surface is restrict in moving X-direction. Surface 3 is taken as symmetric in Y direction, which means all nodes located on the surface should be constrained in Y-direction.

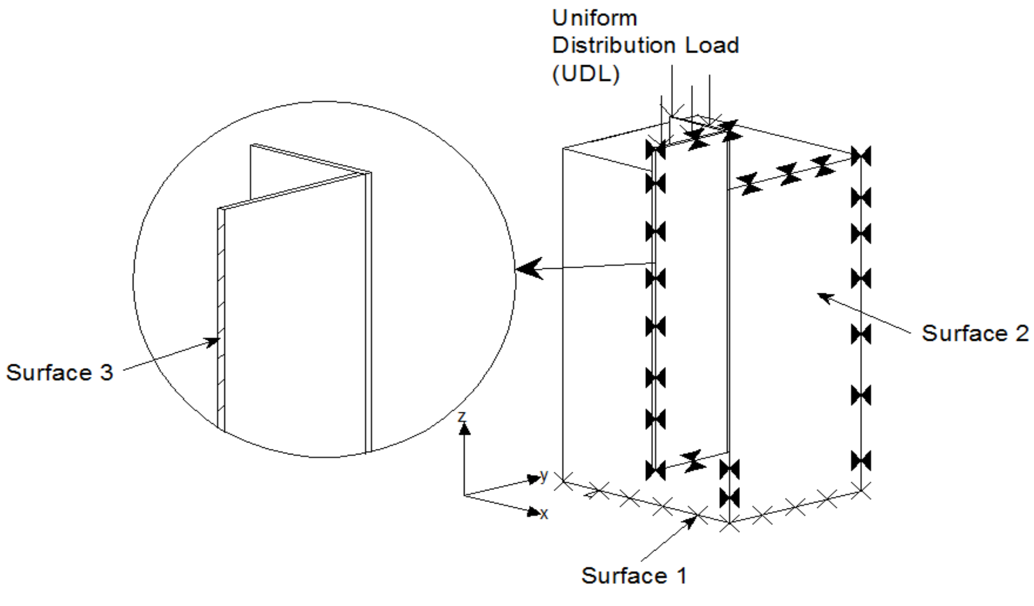


Figure 3.8: Boundary condition of model

3.4.2 Loading

Total force of 500kN was applied on the steel beam with an amplitude shown in Figure 3.9.

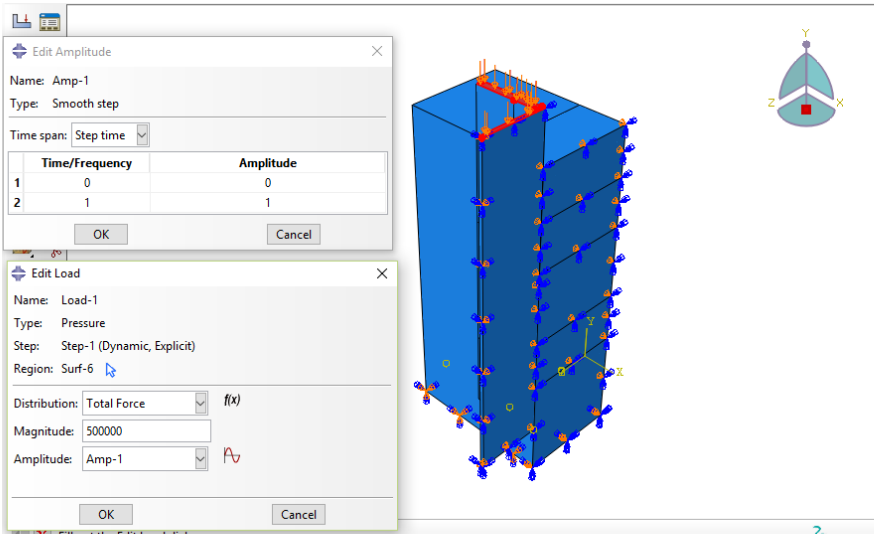
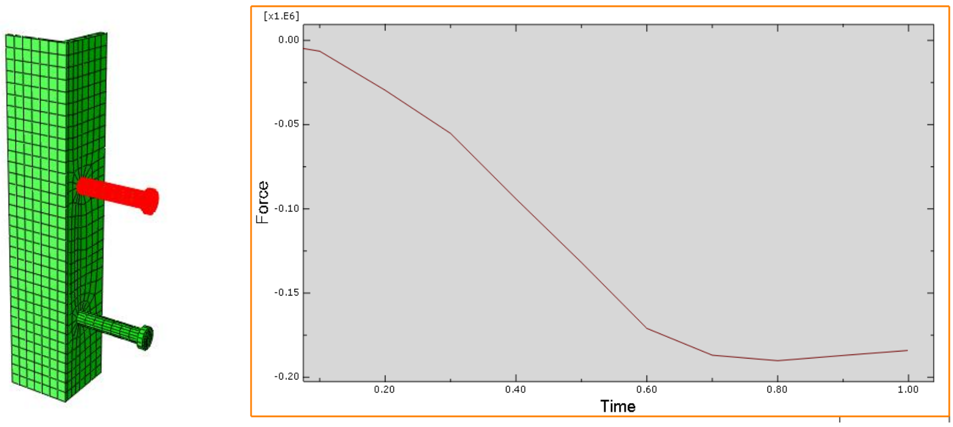


Figure 3.9: Loading on model

3.5 POST-PROCESSOR

In the general post-processor stage, the result was obtained and analysed. The result of the shear resistance and failure mode of the headed stud with different diameter was determined.

3.5.1 Shear resistance



(a) (b)

Figure 3.10: Result (a) Node of request history output (b) Force versus time graph

History output had been request the force/reaction in y-axis at the stud node as shown in Figure 3.10(a). The frequency of the analysis was set to be 0.1s for each interval. The result was show in a graph and maximum value was obtained shown in Figure 3.10(b). This step was repeated for all the model.

3.5.2 Failure mode

Concrete slab and rebar were removed before printed screen of the stress distribution of steel beam and to observe the failure location more clearly. The stress distribution limit had been set within certain range from 0 to 400N/mm^2 as shown in Figure 3.11.

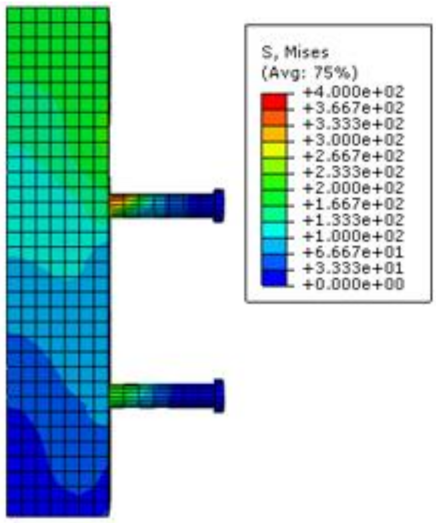


Figure 3.11: Stress distribution of model

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 GENERAL

In this chapter, there are 5 models of push out test with different opening size and location under different load that analysed by using ANSYS 12.0. The result will be analysis and discuss in this chapter. The applied of 500kN total force on the steel beam and analysis the push out test. The results are focus on the shear resistance of headed stud and failure mode on steel beam under different size of headed stud under uniform distributed load.

4.2 SHEAR RESISTANCE ON HEADED STUD

Shear resistance on headed stud is the maximum shear force withstand by the stud to prevent the composite component to sliding over each other. Table 4.1 had shown the shear resistance of headed stud or the load per stud. The result obtained from the ABAQUS v6.14 was verified by Eqn 1 and Eqn 2 in Eurocode 4. The theoretical calculation had shown in appendix. The lower value of shear resistance (P_{EC4}) calculated from Eqn 1 and Eqn 2 was chosen. The ratio of shear force from ABAQUS (P_{FEA}) and theory value (P_{Ec4}) is approximately 1 which is within acceptable range. Table 4.1 has showed comparison of shear resistance of headed stud.

From the Table 4.1 and Figure 4.1, the load per stud obtained from finite element analysis from PT 1, PT 2, PT 3, PT 4 and PT 5 are 103.57kN, 133.08kN, 162.47kN, 195.07kN and 226.44kN respectively. Theoretically value of load per stud calculated from EC4 were 104.62kN, 135.11kN, 157.59kN, 181.80kN and 207.74kN. The ratio of P_{FEA} and P_{CE4} are 0.990, 0.985, 1.031, 1.073 and 1.090 respectively and within the acceptable range. But for 31mm had slightly larger ratio value compared to the others. From the previous study only conduct until 30mm diameter headed. Therefore, stud larger than 30mm maybe can do future study on laboratory test and other factor may affect shear resistance of headed stud.

All the shear resistance was compared with the conventional stud PT 1. The stud diameter increase from 22mm to 25mm (13.64%), the shear resistance increased from 103.57kN to 133.08kN or 28%. Besides that, shear resistance increase from 103.57kN to 162.47kN or 56.9% for 22mm to 27mm (22.72%) diameter. Moreover, stud diameter 22mm to 29mm (31.82%), shear resistance increase from 103.57kN to 195.07kN or 88.35%. The shear resistance increase from 103.57kN to 226.44kN which is 118.63% for 22mm to 31mm stud diameter (40.91%). The 31mm stud diameter shows the maximum shear resistance and the value of shear force that can resist by 31mm stud diameter is double for the case of 22mm stud diameter. Thus, this prove that number of headed stud used in composite structure can be greatly reduce by using larger headed stud. Moreover, this study had shown the larger size of stud, was provided the higher of shear resistance.

From the study conducted by Barbie ss et all (2002) and Loh HY et all (2004), concluded that the larger headed stud was provided higher shear resistance than small headed stud with proper welding and design shear strength in Eurocode 4 gives conservative value for stud diameter up to 30mm.

Table 4.1: Comparison of shear resistance of headed stud.

Sample designated	**P_{FEA} (kN)**	**P_{EC4}, (Eqn 1) (kN)**	**P_{EC4}, (Eqn 2) (kN)**	**P_{FEA}/P_{EC4}**
PT 1	103.57	104.61	111.73	0.990
PT 2	133.08	135.11	144.27	0.985
PT 3	162.47	157.59	168.28	1.031
PT 4	195.07	181.80	194.13	1.073
PT 5	226.44	207.74	221.83	1.090

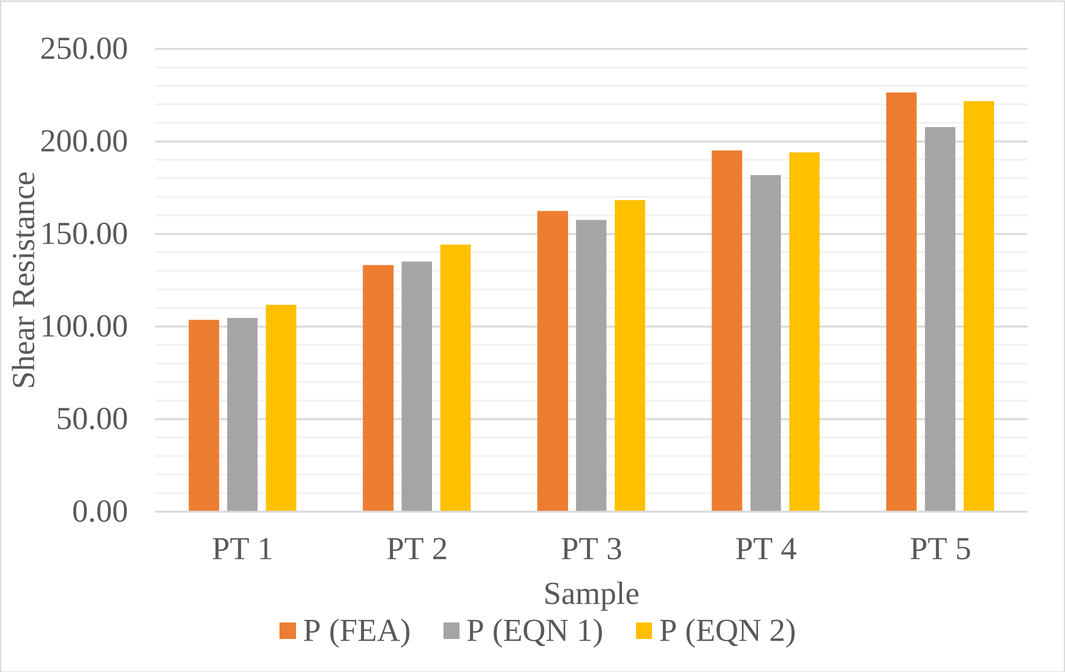


Figure 4.1: Shear force versus sample

4.3 FAILURE MODE ON HEADED STUD

Figure 4.2 shows stress distribution in the model. The highest stress distribution was located at corner body of the top stud (weld toes) for different size of and it indicate the location of shank shear failure of stud was occurred horizontally. Table 4.2 had shown the maximum stress distribution on each model. The maximum value of stress distribution at the critical point for specimen PT 1, PT 2, PT 3, PT 4 and PT 5 were 450N/mm^2, 401N/mm^2, 370N/mm^2, 352N/mm^2, and 340N/mm^2 respectively. The diameter of stud increase from 22mm to 25mm, the stress distribution decrease from 450N/mm^2 to 401N/mm^2 or 12.2%. Stress distribution decrease from 450N/mm^2 to 370N/mm^2 or 21.62%, diameter of stud increase 22mm to 27mm. Besides that, 22mm increase to 29mm diameter, stress distribution decrease 5% or 450N/mm^2 to 352N/mm^2 or 27.84%. Moreover, diameter of stud from 22mm to 31mm, stress distribution decrease from 450N/mm^2 to 340N/mm^2 or 32.35%. Thus, larger headed stud can greatly reduce the stress located on the stud. From the Figure 4.2 in all model, the shrank failure of headed stud had happened on the top row of stud and follow by the bottom row due to the top row of stud withstand higher stress.

Schijve, Jaap (2001) had found an object is strongest (lowest stress distribution) when force is evenly distributed over larger area. Therefore, the larger diameter of stud was provided high area and distribute the load evenly.

Table 4.2: Maximum stress distribution on model

Sample designated	Stress (N/mm^2)
PT 1	450
PT 2	401
PT 3	370
PT 4	352
PT 5	340

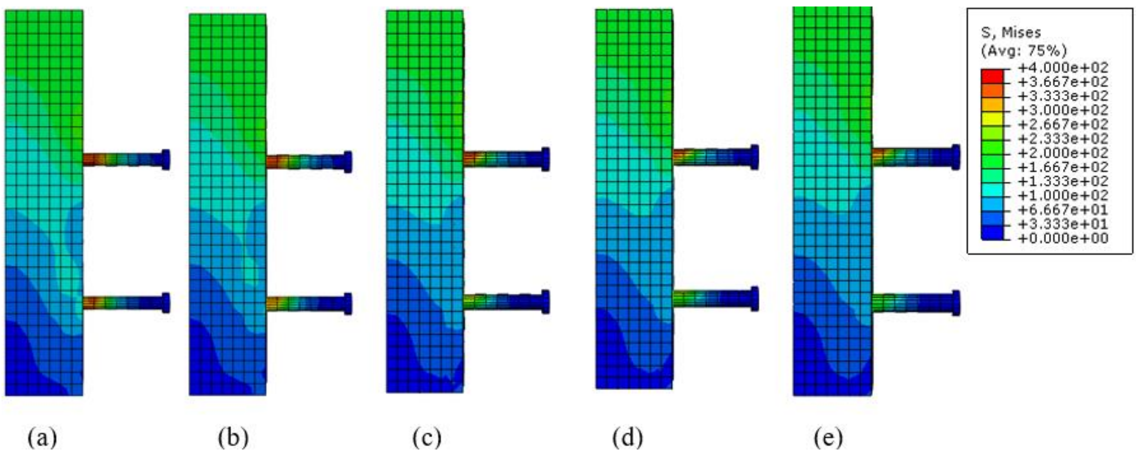
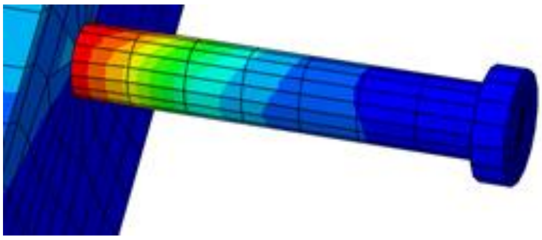
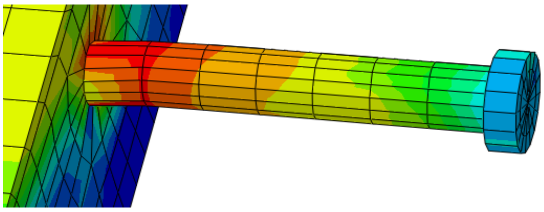


Figure 4.2: Stress distribution for (a) PT 1, (b) PT 2, (c) PT 3, (d) PT 4 and (d) PT 5

From the Figure 4.3, starting of failure of headed stud till the end had been studied. The first cracking occurred at the weld toes horizontally of the stud at 0.1s for top row of stud. At t = 0.8s, the second cracking of stud occurred at the body of stud and the welding part of steel beam and stud. All the model show the same stress distribution. From the pass study conducted by Lee et al. (2005), about the ‘static and fatigue behaviour of large stud shear connectors for steel-concrete composite bridges’ concluded that fatigue failures occur at weld toes in the horizontal direction and Figure 2.3 shows the fatigue failure modes of a stud shear connector and the large stud has a larger cross-sectional area, welding required a power source with higher amperage. From this study, the location of shark failure had been determine and occurred at the top row of headed stud.



(a) Stress distribution at t = 0.1s for PT 1



(b) Stress distribution at t = 0.8s for PT 1

Figure 4.3: Failure mode on the headed stud PT 1

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

In this study, there are five model was generating using ANSYS 12.0. There was total force 500kN applied on all the model with different size of diameter of headed stud. Accurate non-linear finite element models of push-out specimen have been developed to investigate the capacity of large stud shear connectors embedded in solid slab. The models took into account the non-linear material properties of the concrete, steel beam, stud and reinforcement bar. ABAQUS software gives the result of shear resistance of headed stud and failure mode of stud. There are few concluded that can be made:

i. The larger diameter of headed stud, the larger shear resistance. Therefore, larger stud is practical in the high era construction site to withstand high shear force and greatly reduce the number of headed stud needed. Hence, the working space will be larger and reduce the chance of fatality.
ii. The time required for welding and cost required were deceases when the number of headed stud lesser.
iii. 31mm of headed stud can resist higher shear force and 226.44kN of load per stud can withstand, which is much larger than the conventional stud.
iv. The failure mode of shear stud and location was determined from the ABAQUS software and determine the stress distribution at the stud.
v. The larger area provided by headed stud, the stress was distributing more evenly and withstand larger shear force.

5.2 RECOMMENDATIONS

For the purpose of the future study, there are some recommendation that will contribute to the accuracy of the analysis:

1. Conduct the laboratory testing where the model of push out test was scaled and compare the result obtained from ABAQUS v6.14

2. Conduct the push-out model with different spacing between stud, to analyse the effect on shear resistance.

3. Conduct the push out test with different ratio of headed diameter and body diameter, to analyse the effect on shear resistance.

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Appendix

Calculation for Table 4.1, PT 1 model

22mm diameter headed stud

For Eq. 1 (shear failure of headed stud)

$$P_{Rd} = \frac{0.8 f_u \pi d^2/4}{\gamma_v}$$

$$P_{Rd} = \frac{0.8(430)\pi(22)^2/4}{1.25}$$

$$P_{Rd} = 104.61kN$$

For Eq. 2 (concrete failure)

$$P_{Rd} = \frac{0.29\alpha d^2\sqrt{f_{ck}E_{cm}}}{\gamma_v}$$

$$h_{sc}/d > 4 \quad , \therefore \alpha = 1$$

$$P_{Rd} = \frac{0.29\times1\times22^2\times\sqrt{30\times10^3\times33\times10^6}}{1.25}$$

$$P_{Rd} = 111.73kN$$

Calculation for Table 4.1, PT 2 model

25mm diameter headed stud

For Eq. 1 (shear failure of headed stud)

$$P_{Rd} = \frac{0.8 f_u \pi d^2/4}{\gamma_v}$$

$$P_{Rd} = \frac{0.8(430)\pi(25)^2/4}{1.25}$$

$$P_{Rd} = 135.11kN$$

For Eq. 2 (concrete failure)

$$P_{Rd} = \frac{0.29\alpha d^2\sqrt{f_{ck}E_{cm}}}{\gamma_v}$$

$$h_{sc}/d > 4 \quad , \therefore \alpha = 1$$

$$P_{Rd} = \frac{0.29\times1\times25^2\times\sqrt{30\times10^3\times33\times10^6}}{1.25}$$

$$P_{Rd} = 144.27kN$$

Calculation for Table 4.1, PT 3 model

27mm diameter headed stud

For Eq. 1 (shear failure of headed stud)

$$P_{Rd} = \frac{0.8 f_u \pi d^2/4}{\gamma_v}$$

$$P_{Rd} = \frac{0.8(430)\pi(27)^2/4}{1.25}$$

$$P_{Rd} = 157.59kN$$

For Eq. 2 (concrete failure)

$$P_{Rd} = \frac{0.29 \alpha d^2 \sqrt{f_{ck} E_{cm}}}{\gamma_v}$$

$$h_{sc}/d > 4 \quad , \therefore \alpha = 1$$

$$P_{Rd} = \frac{0.29 \times 1 \times 27^2 \times \sqrt{30 \times 10^3 \times 33 \times 10^6}}{1.25}$$

$$P_{Rd} = 168.28kN$$

Calculation for Table 4.1, PT 4 model

29mm diameter headed stud

For Eq. 1 (shear failure of headed stud)

$$P_{Rd} = \frac{0.8 f_u \pi d^2/4}{\gamma_v}$$

$$P_{Rd} = \frac{0.8(430)\pi(29)^2/4}{1.25}$$

$$P_{Rd} = 181.8kN$$

For Eq. 2 (concrete failure)

$$P_{Rd} = \frac{0.29\alpha d^2\sqrt{f_{ck}E_{cm}}}{\gamma_v}$$

$$h_{sc}/d > 4 \quad , \therefore \alpha = 1$$

$$P_{Rd} = \frac{0.29\times1\times29^2\times\sqrt{30\times10^3\times33\times10^6}}{1.25}$$

$$P_{Rd} = 194.13kN$$

Calculation for Table 4.1, PT 5 model

31mm diameter headed stud

For Eq. 1 (shear failure of headed stud)

$$P_{Rd} = \frac{0.8 f_u \pi d^2/4}{\gamma_v}$$

$$P_{Rd} = \frac{0.8(430)\pi(31)^2/4}{1.25}$$

$$P_{Rd} = 207.74kN$$

For Eq. 2 (concrete failure)

$$P_{Rd} = \frac{0.29\alpha d^2\sqrt{f_{ck}E_{cm}}}{\gamma_v}$$

$$h_{sc}/d > 4 \quad , \therefore \alpha = 1$$

$$P_{Rd} = \frac{0.29\times1\times31^2\times\sqrt{30\times10^3\times33\times10^6}}{1.25}$$

$$P_{Rd} = 221.83kN$$