Punching Shear Behavior on High Strength Concrete

Cut Yusnar
Civil Engineering Department, Politeknik Negeri Lhokseumawe

E-mail: cut_yusnar@pnl.ac.id

Abstract. An experiment was conducted to investigate the behavior of punching shear on connection between column and slab as the effect of axial loading. Four test specimens that consist of high strength concrete slab and normal concrete slab were tested with axial loading. Test result indicated that the capacity of load deflection as behavior of punching shear on a connection of column and slab as the effect of axial loading on high strength concrete slabs higher than load deflection on normal strength concrete slab.

1. Introduction
Most of the problem of slab structure was the presenting of punching shear on a connection between columns and slab. The presenting of punching shear Guandalini, S. (2004) reported that the failure caused of punching shear on connection between column and slab were steadily rigid. While to insert the shear reinforcement on the connection of column and slab was very hard on the application. One of the innovative technologies to strengthen the connection of column and slab based on ACI 03-2847-2002 is to use high strength concrete and to increase the thickness of the slab to anticipate punching shear failure. Kinnunen, S. (1980) suggested that to anticipate punching shear by increasing slab thickness. Recently the application of high strength reinforced concrete has been increasing significantly due to its attractive properties such as high tensile strength, load deflection resistance and ductility of a slab.

According to Ramon, L. et al. (1981) high strength concrete has been defined as that having a compressive strength in the range 41 – 83 MPa. High strength concrete is significantly different from ordinary strength material. Carassquillo, et al. (1980) founded that the stress-strain curve in uniaxial compression is steeper and more nearly linear to higher stress to strength ratio for high strength concrete than for normal strength. It was indicated that more brittle failure and much faster release of the load. Ngo, D.T (2001) founded that high strength concrete increased the capacity of punching shear. However, very limited test has been conducted to study the punching shear behavior especially on the connection of column and slab. With using material high strength concrete this research focused on the behavior of punching shear on connection of column and slab with axial loading.

2. Experimental Program
An experiment was conducted to investigate the punching shear load of high strength concrete slabs. The parameter studied included the ratio of reinforced steel and concrete compressive strength.

2.1. Test specimen
As in Table 1, four specimens were designed and fabricated to simulate the interior slab-column connections. The test specimens were 1400 x 1400 x 120 mm square slabs with the stub column, 200 x
200 x 200 mm, at the center of the slab, which was cast monolithically. The properties of the specimens were shown in Table 1. Two specimens designed with normal concrete, one of them made without shear reinforcement (SR0). Two specimens made from high strength concrete. One with shear reinforcement and another one without shear reinforcement. Specimens were designed to have steel ratio 0.01%. D12 were used to distribute with equal spacing in both directions for high strength concrete slabs and D10 for normal strength concrete slabs. The tested yield and ultimate strength of D12 and D10 bar were 240 MPa. Average concrete compressive strength from 150 mm x 300 mm cylinders during the test of the cylinder was 30 MPa for normal strength concrete and 60 MPa for high strength concrete.

The additive material (silica fume and super plasticizer) were used to produce high strength concrete. The percentage of additive silica fume was 8%, and super plasticizer were 2% of cement weight (Aulia 1999). The function of additive was to keep water-cement ratio constant, but the workability of admixture possible to implicate in simulated form.

| Slab Number | Compressive strength (MPa) | Bar size, Spacing (mm) | Steel Ratio (%) |
|-------------|-----------------------------|------------------------|-----------------|
| FC30 EsSR0  | 30                          | D10@100                | 0.01            |
| FC50 EsSR1  | 30                          | D10@100                | 0.01            |
| FC60 EsSR0  | 60                          | D12@100                | 0.01            |
| FC60 EsSR1  | 60                          | D12@100                | 0.01            |

2.2. Test Set Up and Procedure
The specimens were designed to be simply supported along the edges and to be loaded centrally at the stub column. The pin to pin distance was 1000 mm. The monolithically load was applied to the stroke control of the testing machine to capture the post maximum load behavior. During the testing, the deflection of the slab was measured using linear variable differential transducers (LVDTs) at five points indicated in Figure 2. To provide additional strain information of reinforced bars, strain gauges were mounted to measure the strains. The location of strain gauges was at a distance of d = 200 mm from column face at both directions and at tension side of the slabs.

Figure 1. Description of specimen’s test
Figure 2. Transducer placements
Figure 3. Strain gauge placement
3. Results and Discussion

3.1. Observed behavior

(a) Cracking on tension face starting

(b) Cracking line become bigger

(c) Cracking line spread to edge of the slab

(d) A few cracking lines getting exfoliate

(e) Column and slab still hold on

(f) Most concrete at cracking area exfoliated, except column surface still hold on

(g) Slab concrete surround column starting

(h) Column starting pull out detached

Figure 3. Observation of concrete

Barely specimens FC30E0SR0 failed in flexure. While the specimens reached the maximum load, the failure was not so significant as the punching shear failure. Figure 3(a) until (h) showed the fully developed yield lines appear on the tension face of the specimen.

High strength concrete slab observed during the test. Monitored the load-deflection curve during the test showed that the specimens behaved relatively linearly at the beginning of the test. While the
maximum punching load capacity was reached a loud noise was heard and the concrete was gradually broken. After the slabs failed in punching, the load resistances were decreased immediately to about 20 – 50 % of maximum load depending on the concrete compressive strength and steel ratio.

After the conclusion of the test, the area surrounds the punching failure on the surface of the tension face of the slab was observed. The punching failure surface was away from the column and the shape of the failure surface nearly circular. The diameter of the failure surface was around 600 – 750 mm that represented 3 – 4d distance from the column face on high strength concrete specimens, and 200 – 400 mm that represented 0.5d – 2d on normal strength concrete (ACI 318.CSA A.23.3). The extent of failure surface indicated that in the presence of high strength made the failure surface became bigger than 2d. Figure 4 depicts the failure surface on normal concrete strength, while Figure 5 indicates the failure surface on high concrete strength.

3.2. Load-deflection characteristic

The load-deflection measured at the center of the slab shown in Figure 6 and 7 were the deflection of high strength concrete slabs. Figure 8 and 9 were the deflection of normal strength concrete. The load deflection on the center of the slab on normal strength concrete (specimen FC₆₀E₀SR₀) bigger than deflection on high strength concrete. The deflection had caused by flexural failure due to the low ratio of reinforcing steel and their deflection curves along the horizontal plateau. Specimens FC₆₀E₀SR₀ demonstrated gradual softening behavior after reached the maximum capacity due to the effect of reinforcement and high strength concrete. Specimen FC₆₀E₀SR₁ showed the characteristic of punching shear failure and load-deflection diagram exhibited a sharp peak followed by a much lower resistance.
3.3. Failure loads
Table 2 summarized the test result. The maximum punching shear load shown in Table 2 is the average values of the maximum load of the slabs.

| Slab Number  | Maximum punching load (T) | Percent increased (%) | Mode of Failure |
|--------------|---------------------------|-----------------------|-----------------|
| FC₃₀𝐸₀SR₀   | 32.55                     | -                     | Flexure         |
| FC₃₀𝐸₀SR₁   | 42.55                     | 30.72                 | Punching shear  |
| FC₆₀𝐸₀SR₀   | 35                        | -                     | Punching shear  |
| FC₆₀𝐸₀SR₁   | 50                        | 42.86                 | Punching shear  |

3.4. Deflection and Strain Measurements
Typical load – vertical deflections, measured at five points of the slabs as indicated in Figure 2 are shown in Figure 10. Since the slabs were tested with simply supported along four edges, the corner of the slabs was free to lift off. The extensive yielding of the reinforcing bar occurred in the specimens FC₃₀𝐸₀SR₀ that fail in flexure. The specimens failed caused of punching had passed of flexure failure. The strain of concrete and steel are shown in Figure 11, 12 and 13, respectively.

The strain measured from slab indicated that the high strength concrete slabs failed to reach their ultimate strain and only developed less than 10 % of the full strength.

3.5. Effect of parameters
High concrete compressive strength affected the stiffness of the slab. At some load stage, increased the strength of the concrete slab. Therefore, the deflection at center of slab reduced. The maximum punching load increased up to 42.86 %.
4. Conclusion

Based on the observed behavior and test results the following conclusions are reached regarding the reinforced concrete slabs strengthening by using high strength concrete:

1. The using of high strength concrete increases the punching shear capacity of slab-column connection.
2. By increasing the punching shear capacity, increased the stiffness of concrete slab and load capacity.
3. The deflection on the surface of columns reduced compared than deflection on the slab.
4. The characteristic of punching shear failure exhibited a sharp peak followed by a much lower resistance.
5. The extent of failure surface indicated that in the presence of high strength concrete made the failure surface bigger than 2d (d = the distance from column surface to the edge of failure surface).

References

[1] ACI 318, 2002. Building Code Requirement for Structure Concrete and Commentary: ACI 318-2002, American Concrete Institute, Farmington Hill, MI.
[2] Aulia 1999, Ductility of High Strength Concrete and Normal Strength Concrete, Engineering Faculty Leipzig Unvisited.
[3] Carasquillo, 1980 An Experimental Study on the Punching Shear Behavior of reinforced Concrete Slab, Journal ACI
[4] Guandalini, S and Muttoni 2004 Symmetric Punching Test on Reinforced Concrete Slab without Shear Reinforcement, Text Report, EPFL, Lausanne, Switzerland
[5] Kinnunen, S, Nylander, H and Tolf 1980 Influence of Slab Thickness on the Strength of Concrete Slab on Punching: Test with Rectangular Slab, Test Report, Royal Institute of Technology, no.137, Stockholm, Sweden