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Application of SCC (Self Compacting Concrete) on the Joint of Beam-Columns Cause of Vertical Loads

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Abstract: SCC (Self Compacting Concrete) is a self-compacting concrete with a high enough slump. SCC has a high flowability so that it can flow, meet the formwork and solidify by itself. Structural failures that generally occur in the joint of beam-column occur due to weak shear resistance and low ductility. The difficulty of mixing concrete into the joint of section perfectly fills the tensile spacing distance, it's becoming the principal idea of applying SCC concrete to beam-column joints by utilizing high flowability.

The specimens used are cylindrical concrete with dimensions of diameter 15 cm; height 30 cm and joint of beam-column with dimensions of 20x20x125 cm for columns; 20x25x100 cm for the beam. Reinforcement tensile used on the beam is 2D13. With a FAS value of 0.44 for SCC and normal concrete, compressive strength was performed; concrete uniformity; and concrete behavior against the vertical force on the joint of beam-column. CTM (Compression Test Machine) used on cylinder concrete, hammer test used on cylinder concrete and joint of beam-column concrete that divided into several test segments, and structural test with frame set with load cell for loading and LVDT to record displacement occurring on the beam when giving the maximum load on the joint of beam-column speciment.

From the result of the research, ratio of normal concrete compressive strength to the same FAS value 21% greater than the compressive strength ratio of SCC. The reflected value generated on the joint of beam-column is relatively the same in each segment. Normal concrete has a smaller displacement from SCC that can be seen from normal concrete displacement values that are smaller than SCC (BKN 0.6; 47.42 <BKS 0.6; 70.54). The value of normal concrete strain on equal load is smaller than SCC (BKN 0.6, 0.00139 <BKS 0.6, 0.00268), modulus elasticity of SCC is smaller than normal concrete (28066,37 Mpa <29263,30 Mpa) so that SCC concrete is easier to have extension or shortening. Based on the value of strain on the two types of test on the joint of beam-column that has not reached the maximum value of concrete strain (0.003), then the type of collapse that occurs is over-reinforced. The first experimental crack rate ratios (Pcr) against the theoretical crack loads for the of BKN 0.6 and BKS 0.6; are 1.291 and 0.948; . The ratio of the experimental ultimit moment to the ultimate moment of calculation based on theory for the test of BKN 0.6 and BKS 0.6 are 1.73 and 1.52.

Keywords: scc concrete, CTM test, hammer test, crack load, displacement

1. Introduction

In general, many structural failures are caused by beam-column connections that result from poor shear resistance and low planned ductility. Block-column connections are an important part of the structure of multi-storey buildings. In recent decades, intensive research in the field of structural engineering has provided a good understanding of the behavior of structures, especially the behavior of reinforced concrete structures due to both bending and shear load (Anggraini, et al, 2016).

Concrete is a material comprising cement, coarse aggregate, fine aggregate, water and additives when necessary. In general, normal concrete is widely used in the construction process because the manufacturing process is relatively easy and also considered more economical. However, it is not uncommon to find constraints in the normal concrete casting process that is the separation between fine aggregate, cement, and water with coarse aggregate (segregation) due to the distance between bars too tightly. Therefore, in its development, the normal concrete continues to change according to the needs of existing construction. One of them is the development of concrete SCC (Self Compacting Concrete).

SCC (Self Compacting Concrete) is a concrete that can solidify itself with a fairly high slump. In the process of placing on the volume of formwork (placing) and compaction process, SCC does not require the process of vibration as in normal concrete. SCC has high flowability so that it can flow, meet the formwork, and reach its own highest density (EFNARC 2005). Concrete SCC (Self Compacting Concrete) was first developed in Japan in the mid-1980s and began to be used in concrete construction in the early 1990s (Okamura et.al. 2003). Unlike in Japan, SCC in Indonesia is still not growing rapidly. The development of SCC in Indonesia is still limited to the mix design trial method that will be used on the concrete. One of the chemicals that affect the ability of SCC to flow is the superplasticizer. Superplasticizer dosage, cement type, concrete mix design composition determines the superplasticizer's ability to react.

The purpose of this research is to know the compressive strength of concrete SCC (Self Compacting Concrete), evaluate reflected value on SCC concrete segment, and to know the behavior of structures that occur in SCC concrete. This research was conducted in Structural and Materials Laboratory Faculty of Engineering University of Mataram. The test is a compression test on a cylindrical concrete with a height dimension of 30 cm and a diameter of 15 cm, a hammer test on cylindrical concrete and beam-column connections, as well as structural testing on column beam joints. The planned compressive strength is 25 MPa.

2. Literature Review

Abrar et al (2015) in his study of bending strength of beams in reinforced concrete beam-column connection with 3 variations of repeating ratios, ie 0.0059, 0.0087 and 0.0147. From the results of his research showed that the greater the reinforcement ratio, the stronger the beam hold the load and the smaller the displacement occurs.

Citrakusuma (2012) in his research on SCC compressive strength test with the addition of various superplasticizer resulted that the test on fresh concrete, superplasticizer variations are 1.2%, 1.3%, 1.4%, 1.5% and 1, 6% meet the requirements set by SCC. Supplementary ingredients such as superplasticizer viscocrete10 can serve as a high water reducer and on compressive strength testing at 14 days of age. Addition of superplasticizer 1.6% produces the highest compressive strength.

Akmaluddin (2011) in his research on the effect of reinforcement ratio in the effective moment of reinforced concrete beam inertia for short-term deflection calculation with 150x250 mm cross-section beam and variation of reinforcement ratio 0.72, 1.08 and 1.80, illustrated graph of the relationship between moment and deflection to analyze crack moment (Mcr), melting steel moment (My) and ultimate moment (Mu). The research results in the greater the ratio of reinforcement, the greater the value of crack moment generated. Thus the reinforcement ratio affects the effective moment of inertia of lightweight reinforced concrete beams.

2.1 Modulus Elasticity of Concrete

The general benchmark of the elastic properties of a material is the modulus of elasticity, which is the ratio of the pressure applied to the change in form per unit length, as a result of the pressure applied (Maria, 2008). Modulus Elasticity is a constant material that has a certain value for a particular material. The smaller the modulus of elasticity of an object, the easier it will be for the material to undergo an extension or a shortening. Similarly, the greater the modulus of elasticity of an object, the more difficult it will be for the material to undergo an extension or a shortening

In accordance with SNI 2847-2013 section 8.5, the formula of the modulus of elasticity of concrete is as follows:

E = 〖w_c〗 ^ 1.5.0,043√ (f'c) .... (1)

with,
E c = modulus of elasticity of concrete (MPa)
w c = the weight of concrete
f'c = compressive strength of concrete (MPa)

This empirical formula applies only to concrete with a fill weight ranging between 1440 and 2560 kg / m3. For normal density concrete with a weight of ± 2.3 ton / m3 we can use the following values:

Ec = 4700√ (f'c) .... (2)

with,
Ec = modulus of elasticity of concrete press (MPa)
f'c = compressive strength of concrete (Mpa)
Crash Modulus and Crash Charges
The concrete tensile strength represents the collapsing modulus (fr). For normal concrete fr value is determined as Eq. (2-4) below.

$$f_r = 0.62\sqrt{f_c^{'}}$$ …………………………………………………………………. (3)

When the voltage that occurs beyond the tensile stress of concrete (tensile strength) then the concrete will experience a crack. In other words when the load (moments) that work beyond the load (moment) cracks, then the concrete cross section is cracked. The first cracking moment can be calculated by Eq. (2-5) below.

$$M_{cr} = \frac{f_r \, I_g}{y_t} \quad (4) \qquad (4)$$

with Ig is the moment of inertia of intact cross-section and yt = 1/2 h.
In the case of the specimen it is known that for the beam part,

$$M = P\,L \ \text{atau} \ M_{cr} = P_{cr}\,L \qquad (5)$$

So the load that causes the first crack in the beam can be predicted using:

$$P > P_{cr} \qquad (6)$$

$$P > \frac{0.62\sqrt{f_c^{'}}\ bh^2}{6L} \qquad (7)$$

where b is the width of the beam body, h is the cross-sectional height of the beam and L is the net length of the cantilever beam.

Bending Beam Mom

In the analysis and planning of multiple reinforcement bars, the nominal strength of the reinforced concrete section is considered to be the accumulation of two internal coupling moments acting due to the horizontal force component of the Tension (T) reinforcement, the compressive force of the concrete compressive stress block C and the compression force steel reinforcing press (Cs) as shown in Figure 1,

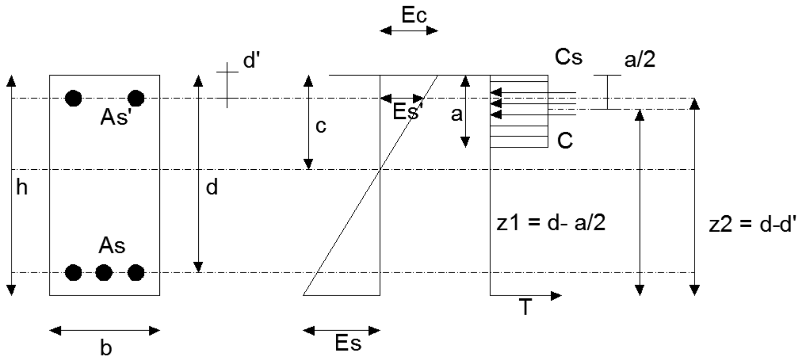

Figure 1. Distribution of tensile double-stranded square bars and strains

The first component is an internal coupling moment formed by the Pull (T) force on the tensile strength section of As1 = As - As' and the compressive force in the block diagram of the equivalent concrete compressive stress (C) with the sleeve length of z1 = d - a / 2.
The second component is the internal coupling moment formed by the compressive force on the asbestone rebound member and the tensile strength of the tensile strength steel (T) as wide as As2 = As '= As-As1, with the sleeve length of z2 = d - d'.
The nominal capacity of the cross section can be calculated as the sum of the components of the first and second coupling moments, as stated in the following equation:

$$Mn = Mn_1 + Mn_2 \qquad (8)$$

$$Mn_1 = (As - AS').fy\ (d - \frac{a}{2}) \qquad (9)$$

$$a = \frac{(As - As').fy}{(0{,}85.f'c.b)} \qquad (10)$$

$$Mn_2 = As'.fy\ (d - d') \qquad (11)$$

So the nominal capacity of the cross section can also be expressed in the following equation:

$$Mn = (As - As').fy\ (d - \frac{a}{2}) + As'.fy\ (d - d') \qquad (12)$$

The above equation is applicable only if the tensile reinforcement (As') has melted, if the melting stress has not been reached then the beam is regarded as a tung repeating beam. If the molten reinforcing steel then,

$$(\rho - \rho') \geq \left(\frac{0{,}85.\beta_1.f'c.d'}{fy.d}\right)\left(\frac{600}{600-fy}\right) \quad \ldots\ldots \quad (13)$$

If the tensile reinforcement (As') has not been melted then the actual voltage can be calculated for,

$$fs' = 600\left(1 - \frac{0{,}85.\beta_1.f'c.d'}{(\rho-\rho').fy.d}\right) < fy \quad \ldots\ldots \quad (14)$$

This fs' value can be used for the initial approach to the strain control for the nonstick tap press state. To ensure ductile behavior on reinforced concrete beams, the maximum allowable reinforcement ratios for double tensile beams are set to:

$$\rho \leq 0{,}75.\underline{\rho} + \rho' \frac{fs'}{fy} \quad \ldots\ldots \quad (15)$$

If the rebound press (As') has not been melted then the height of the equivalent compressive stress block shall be calculated using the actual stress on the compressive reinforcement obtained from the tensile reinforcement strain (ε_s), so that:

$$a = \frac{As.fy - As'.fs'}{0{,}85.f'c.b} \quad \ldots\ldots \quad (16)$$

Thus the nominal moment capacity in equation (2-18) changes to:

$$Mn = (As.fy - As'.fs')(d - \frac{a}{2}) + As'.fs'(d - d') \quad \ldots\ldots \quad (17)$$

3. Methodology

The method used in this research is the experimental method that is by directly experimenting the test object (destructive and non-destructive). There are three kinds of testing conducted in this research : stress test (destructive), hammer test (non-destructive) and structure test with set frame tool with hydraulyc jack, load cell and LVDT.

3.1 Test Objects

For the variety of specimens and their needs can be seen in Table 1,

Table 1 The number of test specimens

Specimen	Specimen Value	Column Tensile	Beam Tensile		Stirrup Tensile
			Press Tensile	Reinforcement Tensile	
BN	3	-	-	-	-
BS	3	-	-	-	-
BKN 0.6	1	4D16	2D10	2D13	Ø10-100
BKS 0.6	1	4D16	2D10	2D13	Ø10-100

3.2 Set Up Test Objects

To set up the specimens in the study were conducted on the frame set with LVDT aids. In Figure 2 can be seen set up testing in this study.

Figure 2. Set Up testing

4. Results and Discussion

4.1 Testing of Concrete Material

Prior to making the specimens material testing to ensure the achievement of a mix design that has been planned previously. The material examination results are presented in Table 2,

Table 2. Material testing results

Materials Test	Result of Materials Test
Unit Weight of Sand	
a. Loose unit weight	1,304 gr/cm^3
b. Dense unit weight	1,490 gr/cm^3
Unit Weight of Gravel	
a. Loose unit weight	1,360 gr/cm^3
b. Dense unit weight	1,453 gr/cm^3
Fine Modulus of Sand	3,130
Fine Modulus of Gravel	6,803
Mud Content in the Sand	3,075 %
Density of Sand	2,558
Density of Gravel	2,692

4.2 Mix Design

Mixed design in this research using trial and error method with compressive strength plan 25 MPa. Trial and error method is used because there is no reference for SCC. From the trial and error results, the comparison of SCC concrete with the addition of a superplasticizer of 0.8% is 450 kg of cement: 789.75 kg of sand: 965.25 kg of crushed stone: 200 liters of water. For a normal concrete mix using a mixture of 510 kg of cement: 922.2 kg of sand: 667.8 kg of crushed stone: 225 liters of water

4.3 SCC Testing

To ensure that concrete is made as qualified as SCC concrete, it is necessary to test fresh concrete. The tests include: slump flow spread, slump time (t50), j-ring test, j-ring time, j-ring height and sieved stability test.

The results of fresh SCC concrete testing can be seen in Table 3.

Testing Method	**Requirement**	**Average Result**
Slump flow spread	65-80 cm	68,2 cm
Slump time (t50)	2-5 dt	2,6 dt
J-ring test	60-80 cm	63,5 cm
J-ring height	0-1 cm	1,1 cm
		0,9 cm
		1,15 cm
J-ring time	2-5 dt	4,1 dt
Sieved stability test	< 20%	14,46%

Table 3. Results of fresh SCC concrete testing

And in Figure 3 showed the results of running the slump flow spread test,

Figure 3. Results of slump flow spread test

4.4 Test Hammer

The Hammer test is performed on cylindrical concrete and joint of beam-column that are divided into several segments. For the hammer testing point on the joint of beam-column and cylindrical concrete specimen showed in Figures 4 and 5 below,

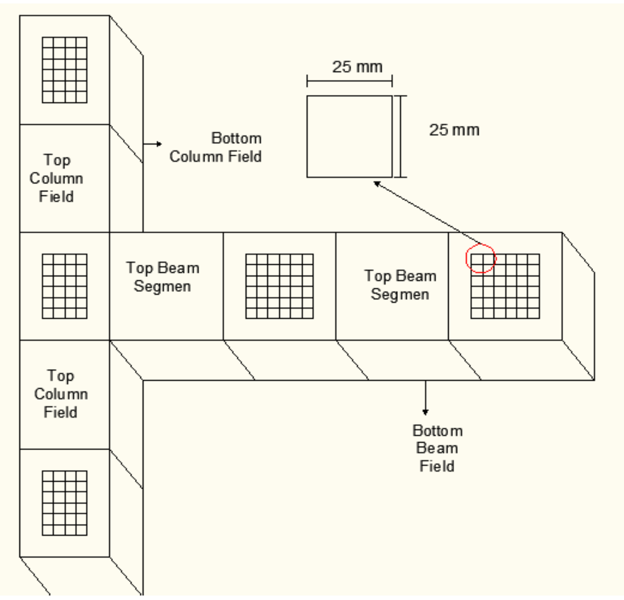

Figure 4. The hammer test point on each segment

Figure 5. Test the hammer on a concrete cylinder

For hammer test results presented in Tables 4 and 5 below,

Table 4 Results of normal concrete hammer test and SCC

Specimen	Specimen Shape	Reflection Value (R)		Average
		Top	Bottom	
BN	Cylinder 1	28	33	31
	Cylinder 2	29	32	31
	Cylinder 3	28	33	31
BS	Cylinder 1	27	31	29
	Cylinder 2	27	30	29
	Cylinder 3	28	31	30

Table 5. Hammer test results for normal concrete and SCC on the joint of beam-column segment

No.	Specimen	Section Properties	Reflection Value		
			Top	Bottom	Average
1	BKN 0.6	Peak of Beam	29	36	33
		Center of Beam	29	33	31
		Joint of Beam-Column	29	33	31
		Column	30	30	30
2	BKS 0.6	Peak of Beam	26	35	30
		Center of Beam	27	33	30
		Joint of Beam-Column	26	31	29
		Column	26	30	28

4.5 Compressive Test

The compressive test is performed using CTM (Compression testing machine). Tests were performed on cylindrical concrete at 28 days. The test results are presented in Table 6 below,

Table 6. Test results of CTM

Specimen	Compressive Strenght (f'c) (MPa)	Average (f'c) (MPa)	Ratio
BN 1	38,446		
BN 2	39,067	38,766	1,00
BN 3	38,783		
BS 1	31,010		
BS 2	30,734	30,626	0,79
BS 3	30,135		

Based on the compressive strength test results, known that the ratio of normal concrete compressive strength to the same FAS value is 21% greater than the compressive strength ratio of SCC.

4.6 Modulus Of Elasticity

Based on the mix design that has been made, we got the weight of normal concrete contents of 2.325 kg / m3 and SCC of 2.405 kg / m3. The concrete quality value (f'c) is 38,766 MPa for normal concrete and 30,626 MPa for SCC concrete. Using equation 2-2 and 2-3, we get the normal elasticity modulus value of 29263,30 MPa and SCC concrete is 28066,37 MPa.

4.7 First Crack Loads

In this research, the average value of concrete quality (f'c) is 38,766 MPa for normal concrete and 30,626 MPa for SCC. So the modulus collapsed in this study will occur in the voltage,

$fr \ = 0,62\sqrt{f'c}$

$= 0,62\sqrt{38,766}$

$= 3,860\ N/mm^2$ (MPa)

In the same way, the collapse modulus of SCC is 3.431 MPa. Then for the crack moment value on the cross section of BKN 0.6 is equal,

$$M_{crack} = \frac{I_g * fr}{yt}$$
$$= \frac{1/12 \times 200 \times 250^3 \times 3{,}860}{125}$$
$$= 8042219{,}97 \ \frac{N}{mm}$$

For the results of Mcrack calculations on the other samples are presented in Table 7.

Table 7. Crack moments on each specimen

Specimen	fr (N/mm2)	Ig (mm4)	yt (mm)	Mcrack (Nmm)	Momen Distance(mm)	First *Crack* Load, *Pcr (kN)*
BKN 0.6	3,860	260416666,7	125	8042219,97	1000	8,042
BKS 0.6	3,431	260416666,7	125	7148181,83	1000	7,148

The Pcr value above can be used to predict value of the load at the time of the first crack.

4.8 Structural Testing

Structural testing was performed using frame sets with LVDT and strain gauge tools installed on concrete. From the results of the test, drawned graph of the relationship between load - displacement and load - strain of concrete. In this test the load is given with an increase of 1.25 kN. The loading is given until the specimen is no longer able to accept the load (collapse) and or exceed the capacity of the test equipment. Graph of the relationship between load - displacement and load - concrete strain shown Figures 6 and 7.

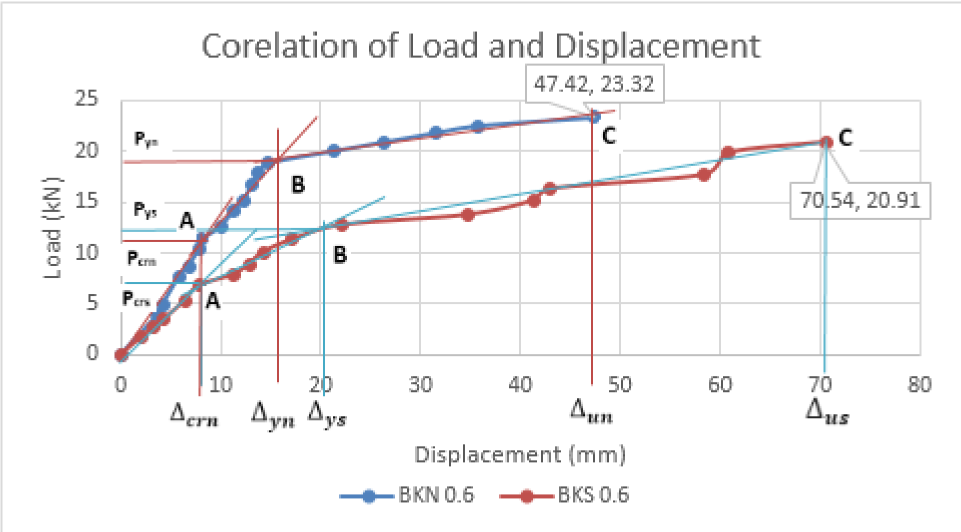

Figure 6. Load relationship and normal concrete displacement - SCC

BKN 0.6 collapsed when receiving the maximum load of 23.32 kN with displacement of 47.42 mm. And then BKS 0.6 collapsed when receiving the maximum load of 20.91 kN with displacement of 70.54 mm. From the graph known that the displacement value that occurs in SCC is greater than the normal concrete (70.54 mm> 47.42 mm). Point A is the point of change of the curve line (first linear boundary) with that point can be known the value of Pcr which is the load when the first crack occurs. Based on the graph, the first crack BKS 0.6 (Pcrs) occurs at 6.78 kN and BKN 0.6 (Pcrn) loading of 10.38 kN. The cracking continues until it reaches point B. At this point the melting reinforcement begins at the load value called Py. The value of Py BKS 0.6 (Pys) is 12.45 kN and BKN 0.6 (Pyn) of 19.12 kN. Then from point B to point C concrete plastic behavior that also shows the ductility of the specimen.

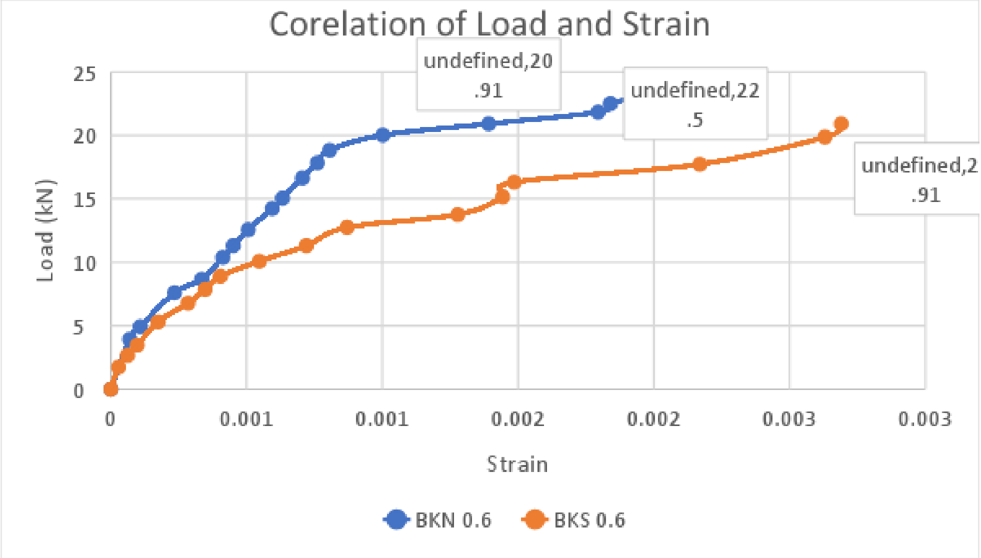

Figure 7. Load and strain relationship on SCC and concrete beam concrete beam concrete joints

On the SCC maximum strain occurs at load 20.91 kN with a strain value of 0.00268. Whereas in normal concrete strain occurs at load 23,32 with strain value equal to 0,00201. When the maximum load on the collapse of SCC is 20.91 kN which is observed in normal concrete, the strain occurring is 0.00139. The strain value of SCC is greater than normal concrete in accordance with the modulus of elasticity value of SCC concrete which is smaller than normal concrete (28066,37 Mpa <29263,30 Mpa), so that concrete SCC is easier to extend or shorten. Based on the value of strain on the two types of test object joint of beam-column that not reached the maximum value of concrete strain (0.003) at the time of collapse, it known that type of collapse that occurs is over-reinforced.

Based on the result of the plot of the graph of the load-displacement relationship known that the first crack load value which will be compared with the first crack value of the theoretical calculation results in Table 8.

Table 8. Experimental and theoretical first crack load values

Specimen	Pcr Theoretical (kN)	Pcr Experimental (kN)	Pcr Experimental Ratio to the Theoretical	Explanation
BKN 0.6	8,042	10,38	1,291	collapse
BKS 0.6	7,148	6,78	0,948	collapse

Based on the Table 8 known that the ratio of Pcr experimental to Pcr theoretical. The resulting ratio is relatively small with the experimental crack load value approaching the theoretical crack load value. Thus it can be said that equation 7 yields the value of first crack load is quite valid.

Then from the results of running tests, obtained value of moment experimental results which will be compared with the ultimate moment of the calculation results. The results of the calculation of ultimate moments and experimental moments are presented in Table 9 below,

Table 9. Ultimate moments of calculation and experimental results

Specimen	Mu Theoretical (kNm)	Mu Experimental (kNm)	Explanation	Ratio 5=3/2
1	**2**	**3**	**4**	**5**
BKN 0.6	13,46	23,32	Collapse	1,73
BKS 0.6	13,7496	20,91	Collapse	1,52

Based on the experimental and theoretical ultimate moment, known that the experimental moment of BKN 0.6 and BKS 0.6 has met the estimated theoretical calculated ultimate moment with ratio of more than 1 (> 1).

5. Conclusions and Recommendations

5.1 Conclusion

From the analysis of laboratory test results to normal concrete and SCC, it can be concluded that:

1. The ratio of normal concrete compressive strength to the same FAS value is 21% greater than the compressive strength ratio of SCC,
2. The reflected value generated on the beam-column connection beam is relatively the same in each segment,
3. Normal concrete has a smaller displacement from SCC that can be seen from normal displacement values of smaller concrete compared with SCC (BKN 0.6; 47.42 <BKS 0.6; 70.54). The value of strain on equal load is greater than that of concrete SCC (BKN 0.6, 0.00139 <BKS 0.6, 0.00268), the modulus of elasticity of SCC is smaller than normal concrete (28066,37 Mpa <29263,30 Mpa) so that SCC concrete is easier to be extension or shortening. Based on the value of strain on the two types joint of beam-column that has not reached the maximum value of concrete strain (0.003) at the time of collapse, then the type of collapse that occurs is over-reinforced.

The first experimental crack rate ratio (Pcr) to the theoretical crack loads for the test specimens of BKN 0.6; BKS 0.6; is 1.291; 0.948.

Ratio of the experimental ultimate moment to the ultimate moment of calculation for the specimen of BKN 0.6 and BKS 0.6are 1.73 and 1.52. Based on the experimental and theoretical ultimate moment, known that the experimental moment of BKN 0.6 and BKS 0.6 has met the estimated theoretical calculated ultimate moment with ratio of more than 1 (> 1).

5.2 Suggestion

Based on the process of this research, there are some suggestions that can be given for the next research, as follows:

1. We recommend to more variations of mixed design for SCC concrete to get better results,
2. Accuracy is necessary for good research results,
3. To avoid lack of data due to failure in the test, the research specimen for each variation should be more than one.

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