Hybrid Precast Concrete Column and Sandwich Concrete Beam under Static Loading

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Hybrid Precast Concrete Column and Sandwich Concrete Beam under Static Loading

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Abstract

This paper discusses structural behaviour of hybrid precast concrete column under static loading. Comparison between the hybrids precast concrete and ordinary cast in-situ concrete columns are also discussed. The column and sandwich concrete beam connection were tested represent typical construction of conventional housing. Experimental investigation was conducted on 5 hybrid concrete column and 6beam-column connection to evaluate the load-displacement characteristic, failure mode, and moment capacity. Test results showed that the ratios of experimental moment capacity to the theoretical one were1.27and 1.68 for 40 mm and 60 mm eccentric loads respectively. The results indicated that the moment capacity under eccentric load can be accurately estimated using the theoretical formula. However, under concentric load the coefficient of 0.67 should be added. It has also been found that the additional anchor to the shear reinforcement of the beam gave a significant increase of the load bearing capacity of the beam.

Keywords: column; concrete; hybrid; sandwich.

1. Introduction

The application of precast concrete for tall buildings and bridges has been widely used and studied intensively in terms of its seismic resistance. Significant findings of previous study results (Xue and Yang 2009) on two-story hybrid concrete frame tested on half-scale model stated that maximum load carrying capacity under cyclic loading

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was approximately equal to that under monotonic loading. It was also found that displacement ductility under monotonic loading was approximately 10% larger than the corresponding value under cyclic loading. Other studies have also been carried out with regard to seismic resistance of precast concrete building (Rodrigues and Blandon 2005), precast beam-column connection (Stone et al. 1995) and prestressed precast concrete columns (Yamashita and Sanders 2009). These previous studies gave the inspiration to conduct research on precast concrete columns for low-income housing, particularly the hybrid system. It was intended to reduce the price of housing by combining the precast and cast in-situ concrete column construction. As for the beam construction, it has been made by combining ordinary concrete and pumice lightweight concrete to form a sandwich beam. Thus, the aims of this study are (1) to determine the behaviour and load carrying capacity of the hybrid column under static loading and (2) to explain experimental behaviour of the sandwich-beam hybrid-column connection with various shear reinforcement spacing and also effect of additional diagonal anchor on the joint. This study has also indirectly introduced the model of permanent mould for the construction of concrete column so that the house price could be affordable.

2. Literature Review

In designing the column it is expected that the cross-sectional of reinforced concrete column should be met minimum criterion to withstand the working load of maximum axial load, P_u, and moment, M_u. These criteria are summarized as follows (Leet at al. 1997): $P_u \le \phi P_n$ and $M_u \le \phi M_n$ where ϕ = 0.70 for spiral column and 0.65 for tied columns. When the column loaded under axial load only, P_0, therefore maximum P_n must be taken as 0.85 P_0 and 0.80 P_0 for spiral columns and tied column respectively. P_0 is given in Equation (1) below.

$$P_0=0.85f'_c\left(A_g\text{-}A_{st}\right)+A_{st}f_y \quad (1)$$

where, $0.85f'_c$ is maximum concrete stress, A_g is gross area of the section (concrete and steel), A_{st} is total area of the reinforcement in the cross section and f_y is yield strength of the reinforcement. In terms of column loaded under axial and moment load simultaneously then Figure 1 below was used to obtain maximum load carrying capacity of the column section.

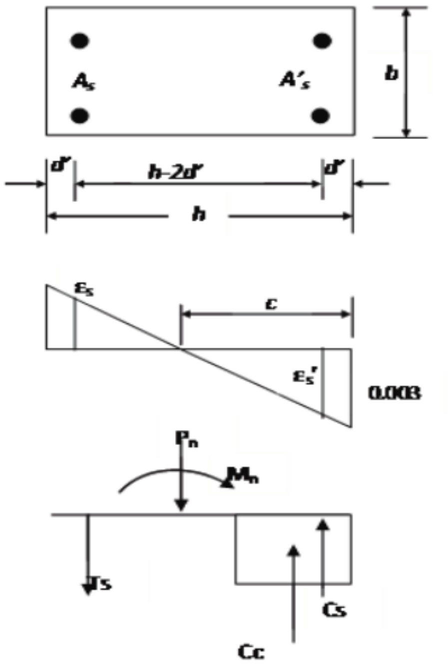

Figure 1. Stress and strain diagram in column cross section.

By referring to Figure 1, under ultimate condition, compression reinforcement will reach the yield stress, except when either the load is small or relatively small column dimension. In general, it is assumed that the steel compression reinforcement is yield. Therefore, $f'_s = f_y$ so the equation for nominal axial load capacity becomes:

$$P_n = 0.85f'_c\,a\,b + A'_s f_y - A_s f_s \tag{2}$$

By taking moments about the centroidal axis of the section, then nominal moment capacity, $M_n = P_n e$, can be written as Equation (3) below:

$$P_n e = 0.85f'_c\,a\,b\left(d - \tfrac{1}{2}h - \tfrac{1}{2}a\right) + A'_s f_y\left(d - \tfrac{1}{2}h - d'\right) + A'_s f_s d'' \tag{3}$$

where e is load eccentricity, f'_c is compressive strength of concrete cylinder, f_y is yield stress of reinforcing steel, f_s is stress in tensile steel reinforcement, A_s is tensile reinforcement area, A'_s is area of compression reinforcement.

In terms of balanced load capacity (P_b, M_b), Equation (2) and (3) can be applied by replacing a in the equation with a_b as given in Eq. (4) and f_s replaced with f_y.

$$a_b = \beta_1 c_b = \beta_1 \frac{600}{600 + f_y} d \tag{4}$$

with $\beta_1 = 0.85$. Failure criteria of the column can be determined by comparing P_u and P_b. When $P_u < P_b$ means column fail in tension otherwise the column fail in compression. When the latter condition occurs then stress in tensile steel reinforcement should be determined through Eq. (5).

$$f_s = 600\frac{\beta_1 d - a}{a} \quad (5)$$

In short the failure zone can be illustrated in interaction diagram as in Figure. 2.

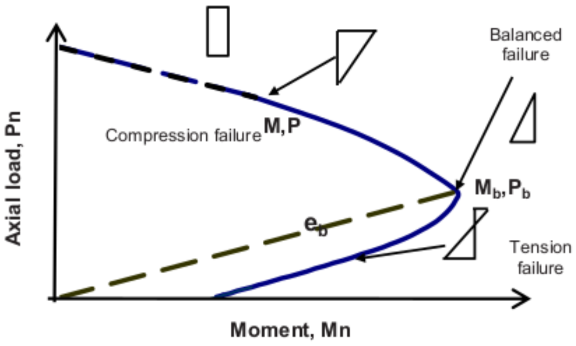

Figure 2. Interaction diagram of rectangular column cross section.

3. Experimental Program

3.1. Specimen Design

Specimen were prepared for column and beam-column connection study. The design of the column specimen was based on practical column dimension of 150x150 mm and column height of 1000 mm. The column was constructed by combining precast concrete skin as a permanent mould and cast in-situ concrete core. The detail of the column skin is shown in Figure 3. The T-shape of the column-beam connection was also prepared with similar size of the column and connected with short sandwich concrete beam of 120x200 mm and 600 mm length. The core of the sandwich beam was made from lightweight concrete. Ordinary concrete, however, was used for the hybrid column and skin of the sandwich beam.

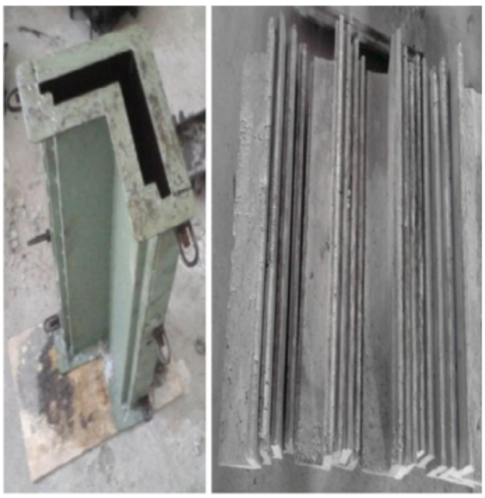

Figure 3. Mould and skin column specimen.

Table 1 presents a concrete design mixture for 1 m^3 of lightweight concrete and normal weight concrete with w/c ratio of 0.5 and 0.49 respectively.

Table 1. Concrete mix design

No.	Material	LWC (12 MPa)	NWC (20MPa)
		w/c = 0,5	w/c = 0,49
1	Water (kg)	203	190
2	Cement (kg)	406	388
3	Sand (kg)	523	739
4	Pumice max 10 mm (kg)	428	-
5	Course aggregate max 10mm (kg)	-	1108

LWC = Lightweight concrete
NWC = Normal weight concrete
w/c = Water to cement ratio

3.2. Specimen Fabrication

The specimen was constructed by match casting. The maximum aggregate size of 10 mm was used for both pumice and course aggregate. The normal concrete was planned to have a 20 MPa compression strength and lightweight concrete of 12 MPa. Plain bar of 250 MPa yield strength was also used. Base of the specimen made of similar concrete strength to the column. The column specimen preparation is shown in Figure 4 below.

Figure 4. Column specimen preparation.

Table 2 presents 11 number of specimen which divided into 2 parts. Five specimens were planned for column study and the rest were prepared for studying beam-column connection. Four steel of 8 mm plain bars with 6 mm links were used as column reinforcement. Whilst, 5 reinforcement with 10 mm plain bars were also prepared. 3

bars placed on top and 2 bars on the bottom beam representing tension and compression reinforcement respectively.

Table 2. Specimen designation and number

Sample	**Column type**		**Beam-column Connection**		**Total sample**
	HC	NC	S	S+A	
NC e(4)		#			1
HC e(0)	#				1
HC e(4)	#				1
HC e(6)	#				1
HC-H	#				1
BCJ-60			#		1
BCJ-100			#		1
BCJ-150			#		1
BCJ-60A				#	1
BCJ-100A				#	1
BCJ-150A				#	1
Total					11

3.3. Test Set-up

The column specimen was placed on the steel frame and clamped in such a way as shown in Figure 5. Load cell was employed on the top of the column through 3 mm steel cap thickness. "Enerpac" hydraulic jacks of 1000 kN capacity was applied and connected to the load cell. Two dial gauges were put on top and middle of the column to measure horizontal deformation. Each loading was given at such incremental, deformation or deflection measurements were taken at the top and the middle of the column. Figure 5 and 6 show method of the column testing under axial loading and lateral loading respectively.

Figure 5. Set-up column under axial load.

Setting-up test for beam column connection was also carried out in similar place and applied similar equipment as for column testing. However, two hydraulic jack were employed in this specimen with constant loading of 20 kN for the column and varies loading applied in the beam. Dial gauge was attached on the beam under parallel direction with the load acting. Figure 7 shows setting-up beam-column joint test in this study

Figure 6. Set-up column under lateral load.

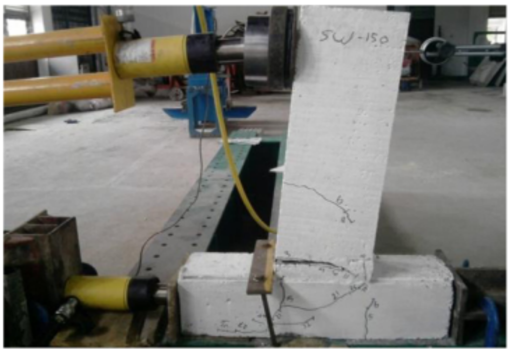

Figure 7. Typical beam-column joint test.

4. Result and Discussion

4.1. Column behaviour

Test result of the column subjected to axial load acting concentrically on the top of the column behaves as elaborate below. In the early stage of loading around 50 kN deformation on the top and the middle of the column has similar horizontal deflection about 1.5 mm. However, with the increasing of the load the top column experience such compression which is transferred into the bottom part of the column then by the time compression on the top similar with compression in the bottom. Therefore, the middle of the column experience buckling. This can be seen as increasing deformation in the middle while deformation on the top decreased. For this typical hybrid column as shown in Figure 8 has capacity of 220 kN which produce lateral deflection of 8 mm.

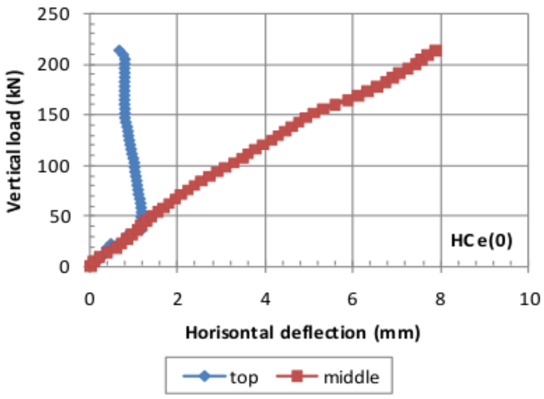

Figure 8. Hybrid column under concentric axial load.

4.2. Comparison between normal and hybrid column under eccentric loading

Conventional column and hybrid column with eccentric loading of 40 mm were prepared. The eccentricity was achieved by adding spacer at the bottom end of column base until produce 40 mm distance axis between column base and end top of the column. Figure 9 and Figure 10 show the behaviour of the column under 40 mm load eccentricity of normal column and hybrid column respectively. Comparing the two figures, it can be seen that normal column has higher load carrying capacity than hybrid column. Maximum load carrying capacity of the normal column is 310 kN whilst hybrid column gives 257 kN. This indicates that there is a reduction of load capacity of 53 kN or about 17 % on hybrid column. This has been realised as the hybrid column was made from several precast concrete functioning as permanent mould. The weak connection between the moulds could reduce the strength of the column system. Connection between precast concrete was not design specifically but using mortar traditionally instead.

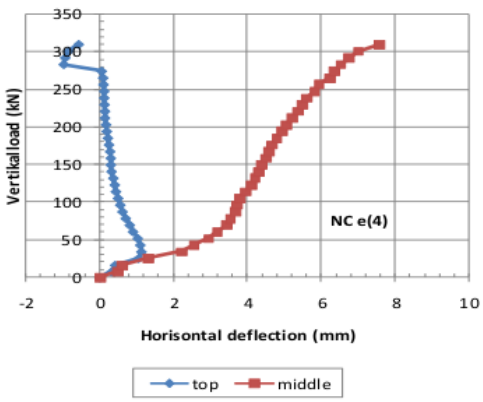

Figure 9. Normal column under 40 mm eccentric loading.

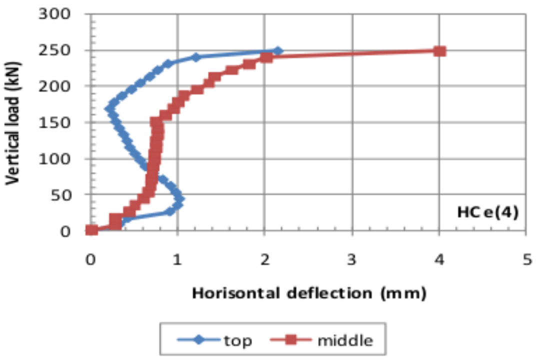

Figure 10. Hybrid column under 40 mm eccentric loading.

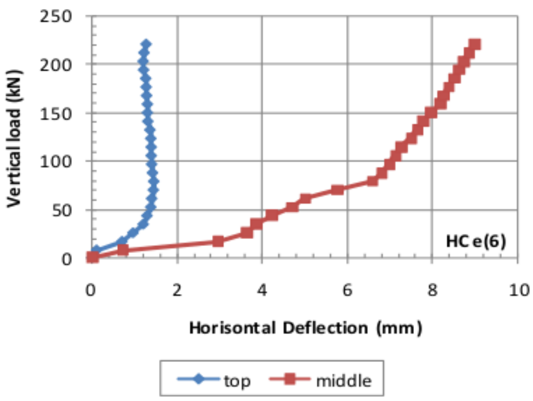

Figure 11. Hybrid column under 60 mm eccentric loading.

Based on Figure 9 and 10 it can be seen that the more eccentricity of load given the capacity of the column was decreased. In another word, the eccentricity is inversely proportional to load carrying capacity of the column. However, the figures do not represent moment capacity of the column so the presentation of test result is given in Table 3 for all column specimens tested.

Table 3. Test results of all column specimens

Specimen	e (mm)	Experiment		Prediction		Rasio	
		$P_{u(exp)}$ (kN)	$M_{u(exp)}$ (kNm)	P_u (kN)	M_u (kNm)	P_u	M_u
(1)	(2)	(3)	(4)	(5)	(6)	(7)=(3)/(5)	(8)=(4)/(6)
NC e(4)	40.00	311.50	12.46	202.16	8.08	1.54	1.54
HC e(0)	0.00	214.90	0.00	320.00	0.00	0.67	-
HC e(4)	40.00	257.21	10.29	202.16	8.08	1.27	1.27
HC e(6)	60.00	230.29	13.82	137.34	8.18	1.68	1.69

Referring to the table above, it can be seen that all columns have load carrying capacity experimentally higher than that obtained theoretically using Equation (2) and (3). Normal column as a column reference has a load carrying capacity ratio of 1.54 whilst hybrid columns have 1.27 and 1.68 for column with eccentricity of 4 cm and 6 cm respectively. However, there was a phenomena for column loaded centrically, where experimental value lower than the theoretical one and the load capacity ratio of 0.67 was obtained. This indicated that theoretical coefficient for column with axial load should be evaluated. Therefore, from this result it is suggested to use coefficient reduction of 0.65 for evaluating hybrid column with concentric loading. For more convenient and more comprehensive discussion then presentation is given in load-moment interaction diagram as shown in Figure 10. Figure 10 show that marker points represent the experimental value whilst the curve shows representation of the theoretical one. When the points located on the outside of the curve, this indicates that the column test results meet the theoretical requirement. Therefore, the formula to evaluate column can be used. Otherwise, the points inside the curve mean that test results have lower value than the theoretical one.

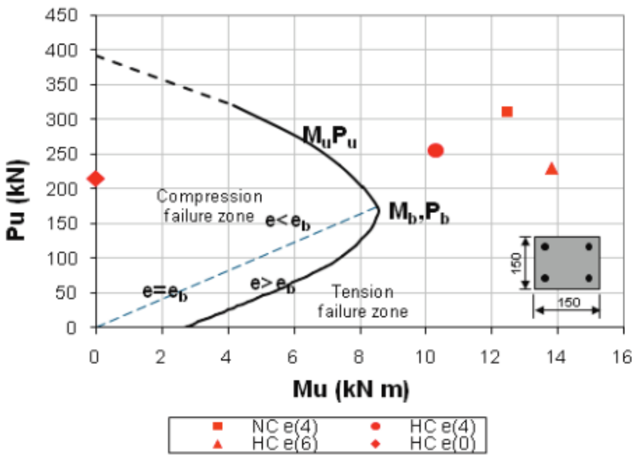

Figure 12. Interaction diagram of column.

If this happen the theoretical equation is questionable. The figure also gives two zones divided by a line represented loading acting on the balance eccentricity ($e = e_b$). It has been found that for such column has e_b = 4.89 mm. When the zone located on the top of the line represent compression zone (e $<e_b$) and the zone under the line correspond to tension failure (e $>e_b$). From the figure it can be seen that only one point is located inside the curve i.e. hybrid column under concentric load, HCe(0). As for all eccentrically loaded columns are beyond the sheath interaction diagrams. This indicates that the capacity of the column experimentally is greater than that of the theoretical value.

The linier line can be used as a constraint to classify the failure mode. When the linier line is extended in Figure 12, therefore, it can be seen that all the columns with load eccentricity of 4 cm fail under compression whilst column loaded eccentrically with 6 cm collapse under tension. This was as expected. Thus, formula to predict column capacity can be used for column under eccentric loading. For the column with concentric loading must be taken into consideration to use factor of 0.65 times the theoretical value.

Laterally loaded column have the same behavior as the beam loaded. For this hybrid column has maximum shear force capacity of 30 kN with produced about 8.5% drift ratio. However by limiting drift ratio to 4% then the maximum shear force capacity of the column is 17 kN as shown in Figure 13.

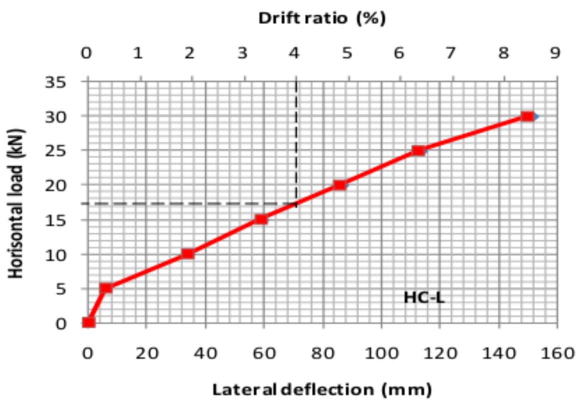

Figure 13. Hybrid column loaded laterally.

4.3. Beam column connection

Figure 14 shows that the 100 mm spacing stirrups as a shear reinforcement of the beam at the beam-column connection gave nearly 17 kN load bearing capacity, while the 60 mm and 150 mm stirrups spacing can withstand loadings of 15 kN and 12.5 kN respectively. The figure also shows that the last two connections gave better ductility to the structures compare to the first connection. Although theoretically, connections with smaller spacing of the shear reinforcement will give bigger load-resistance to the structure, the above phenomenon happens probably caused by the differences of concrete strength between column and beam.

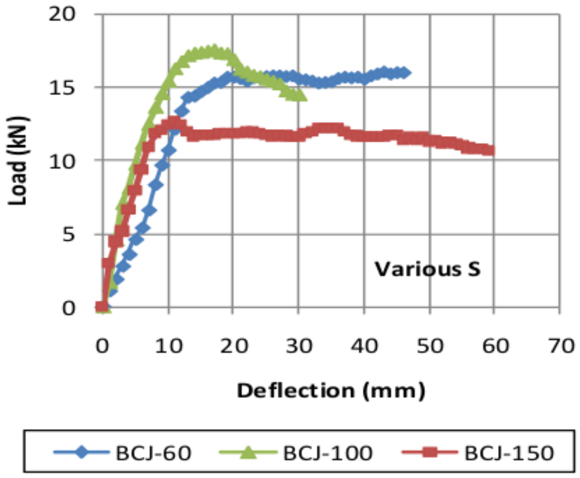

Figure 14. Effect of stirrups spacing on behaviour of Beam-column connection.

Result of using similar varieties of stirrups spacing and additional two diagonal anchors fixed in the joints as shear reinforcement is presented in Figure 15. The result shows no significant effect of additional diagonal shear reinforcement to the 60 mm and 150 mm stirrups spacing. However, in the case of 100 mm spacing stirrups, the additional of diagonal shear reinforcement will improve the beam's ductility although no significant improvement occurs to the joint strength.

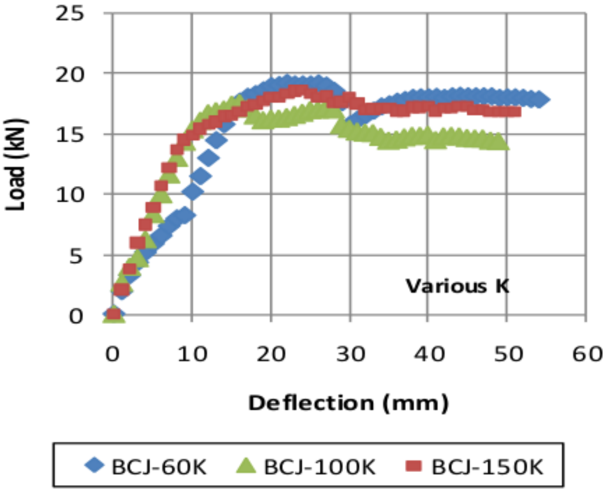

Figure 15. Effect of diagonal anchor on behaviour of Beam-column connection.

5. Concluding Remarks

This experimental investigation can be concluded in the following:

- The balanced eccentricity, e_b, of the column is 4.89 cm. Column with eccentricity load of 4 cm (e/e_b<1) has experienced compression failure, whilst eccentricity load of 6 cm (e/e_b>1) has suffered tension failure.
- The maximum axial load capacities of hybrid column were 214.9 kN, 257.21 kN, and 230.29 kN for the load eccentricity of 0, 4 cm, and 6 cm, respectively.
- Moment resistance capacity of hybrid column (partially precast) were 0 kNm, 10.29 kNm, and 13.82 kNm for the load eccentricity of 0, 4 cm, and 6 cm, respectively.
- The ratio of experimental moment capacity to the theoretical moment capacity of Hybrid columns is 1.27 and 1.68 for 40 mm and 60 mm eccentric loads respectively. Whilst the ratio of 0.67 has been found for concentric load.
- From the above conclusion, the results indicated that the moment capacity under eccentric load can be accurately estimated using the theoretical formula. However, under concentric load the minimal coefficient of 0.65 should be added.
- The 100 mm spacing stirrups as a shear reinforcement of the beam at the beam-column connection gave about 17 kN load bearing capacity, while the 60 mm and 150 mm stirrups spacing can withstand loadings of 15 kN and 12.5 kN respectively.
- Additional two diagonal anchors fixed in the joints as shear reinforcement increase resistance capacity of 1.82 kN, i.e. from 15.98 kN to 17.8 kN for 60 mm of spacing stirrups. For 100 mm spacing stirrups, the additional diagonal anchors have no significant effect to the joint strength although the ductility of the beam improve significantly. The significant improvement occurs to the 150 mm spacing stirrups where the joint strength improve 6.23 kN, i.e. from 10,64 kN to 16.87 kN.

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