Behaviors of Polymer Concrete Composite Castellated Beam with Different Openings Shape

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ABSTRACT: *The difference between normal and polymer concrete not contain a hydrated cement phase. In present work, investigations of the behavior of the polymer concrete composite castellated beam with different openings shape by experimental approach. Ultimate load strength capacity and deformations of the composite beams specimens are explorations. Different parameters are considered such as shape of openings of the castellated beam and composite interactions as full and partial. Test results showed that the hexagon opening shape gave more strength capacity and less deflection and slip. The percentages increase around 19% as strength capacity and the comparisons between same specimens but differ in partial and full interaction, the full interaction gave more strength capacity and less deflection and slip. Decrease in slip in case of full interaction than partial are 34.13 and 82.08% for hexagon and rectangular openings respectively.*

KEYWORDS: *Castellated Composite Beam, Ultimate Strength, PolymerConcrete, Web Openings, Openings Shapes.*

I. INTRODUCTION

The functions of structural elements such as beam, slab, column and shear walls are to providing strength and resistance against loadings based on the material properties. Concrete, steel and composite structures are the main buildings around the worlds. Composite structure made from two or more different structural material that differs by modulus of elasticity and Poisson's ratio. Two theories that adapted to discussed the behavior of composite actions as structure. First, full interaction between the different structural materials that are means there are full bond between them and there is no slip. Second, partial interactions that is mean there are slips developed but within limits. The presence of openings within the beams allowed the services pipes and ducts that reduce the total height of floors and then less the whole height of buildings. A lot of researchers discussed the composite action, **Johnson** [1], explained the behavior of simply supported composite beam tacked into accounts two cases as full and partial interactions. A castellated steel beam is the beam in which contains spread a standard rolled steel section in such a way that a predetermined pattern is cut on section webs and the web opening may circular, hexagonal or octagonal. The two halves are joined reversal together by welding together so that the modulus section increased. The advantages of castellated steel beam are high strength to weight ratio, cost wise and lighter section in additions it can be using the opening for servicing and mechanical ducts. The polymer concrete classified as composite material. The aggregate of polymer concrete is bounded with each other by means of polymer binder. The difference between normal and polymer concrete not contain a hydrated cement phase. The polymer concrete differ than ordinary concrete in which the mechanical properties such as compressive strength, splitting tensile strength, modulus of rupture and also modified the concrete modulus of elasticity. **Rangan** et al [2], showed that the behavior of geopolymer concrete same as ordinary concrete but differ in mechanical properties and strength. **Kumar** [3], showed that there are enhancements in strength capacity of columns due to the presence of fly ash. **Dattatreya** et al. [4], Test results showed that the strength load capacity in cases of geopolymer concrete was higher than normal and high strength concrete**. Ruby et al**, [5], Based on test results, the polymer concrete gave better behavior than the normal concrete in case of same compressive strength. **Poojidha and Nirmalkumar**[6], test results showed that there are improvements inmechanical properties of polymer concrete. **Shaikh, and Autade** [7], Test results showed that the increased of stress in the direction of edge of web openings. **Wakchaure** et al, [8], tested castellated steel beams with varied web depth under four point loads. Based on test results, the authors concluded that the castellated steel beam behaved satisfactory for serviceability when the opening size was less. **Galambos** et al. [9], the researchers concluded that the ultimate load increased as the depth of steel beam increased.

II. AIM AND OBJECTIVES OF RESEARCH

Different tests for composite castellated steel beams with different shapes of web openings. Many researchers tested composite castellated steel beams but little or no investigations of geopolymer concrete that casted above the castellated steel beam. The aims and objectives of present study are to investigate the behaviors of polymer concrete composite castellated beam with different openings shape under the effect of four point's static loadings. Different web opening shapes such as hexagon and rectangular are adapted and the concrete slab type is polymer concrete in addition to the control beam without opening for comparisons. Composite beams capacity, deflections and slips for all tested specimens are recorded and discuses.

III. EXPERIMENTAL PROGRAM

The materials that adopted in present study are explains and summarize below

Geopolymer concrete: The geopolymer concrete prepared by replaced full thecement by geopolymer. Geopolymer concrete is made by reacting aluminate and silicate bearing materials with a caustic activator. The adapted material in present study as follow:

Metakaolin: The methodology and processes to converting kaolinite tometakaolin relay on the applied temperature in which (100-200 C^o) the most quantity of water will be loss and (500-700 C^o) loss all water. Chemical, physical and the requirements based on the ASTM C618 [10] properties of metakaolin are lists in Table 1, 2 and 3 respectively.

Table 1: Chemical properties of metakaolin

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na2O	K_2O	K_2O	TIO_2
%Content	54.20	39.00	0.92	1.37	.15	0.45	0.22	0.27	0.71	0.80

Table 2: Physical Properties of metakaolin

Physical Property	Physical form	Color	Specific gravity	Surface area, (m^2/g)
Results	Powder	Off-white	2.64	13.30

Table 3: Chemical requirements based on ASTM C618 [10]

Composition of Oxide	Pozzolans, Class N	Metakaolin
% min SiO_2+Al_2O_3+Fe_2O_3	70.00	94.12
% max SO_3	4.00	0.45
% max Loss on ignition	10.00	0.71

Sodium silicate: The brand of sodium silicate adapted in present studymanufactured in United Arab Emirate with properties by weight lists in Table 4.

Table 4: Sodium Silicate's Properties (supplier brochure)

Description	SiO_2/ a_2O	%H2O	%Na2O	%SiO2	Density	Specific Gravity	Viscosity
Value	2.4± .05	55.10	13.10 – 13.70	32– 33	51± 0.5	1.534 – 1.551	600– 200

Sodium hydroxide: The sodium hydroxide is the most important item toprepare the geopolymer concrete. The sodium hydroxide prepared by dissolved caustic soda flakes in water. The chemical reaction between sodium hydroxide and water was an exothermic component after that the compositions cool in air for two hour. Table 5 lists the test results and compare with the requirements based on ASTM E 291-09 [11].

Table 5: Properties sodium hydroxide

Appearance	Test results	Specification ASTM E291-09 [11]
%Sodium hydroxide (NaOH)	98.14	≥ 97.5
%Sodium carbonate (Na_2CO_3)	0.36	≤ 0.40
Sodium chloride (NaCl), (P_{Pm})	70.00	≤ 200
Iron as Fe^{+3}, (P_{Pm})	4.50	≤ 10
Sulphates as Na_2SO_4, (P_{Pm})	70.00	≤ 200
Copper as Cu^{+2}, (P_{Pm})	0.10	≤ 4.00
Nickel as Ni^{+2}, (P_{Pm})	2.42	≤ 5.00
Manganese as Mn^{+2}, (P_{Pm})	0.02	≤ 4.00
Silicate as SiO_2, (PPm)	14.00	≤ 20.00
Water Insoluble, (PPm)	60.00	≤ 200.00

The methodology that adapted to prepared alkaline solution by prepared from the (NaOH) and (Na_2SiO_3) by dissolve flaky high purity sodium hydroxide more or equal to (98%) in distilled water. One litter solution was prepared by mixed (560 g) of (NaOH) with (826 ml) water so that the concentration by weight is (0.404). The Molarity (mole/l) for adopted mix was (14) and the weight of (NaOH) flakes is (404 g). The preparation of alkaline liquid by mixed one litter from (NaOH) with (3.5 litter) from (Na_2SiO_3). The adopted time mix was (1 day) before use the final mixture. The adapted methodology for geopolymer concrete that producing by mixing silica and aluminum oxide in the Metakaolin that react with the alkaline (that is mean composition of Na_2SiO_3 with NaOH) to produce the geopolymer that slips between the fine and coarse aggregates to male them as unity.

IV. Mechanical properties:

The mechanical properties of geopolymer such as compressive strength, splitting tensile strength, modulus of rupture and modulus of elasticity are explored; Table 6 lists the summary of mechanical properties.

Table 6: Summary of mechanical properties - geopolymer concrete

Age (Days)	Compressive strength *fc'* (MPa)	Splitting tensile strength (MPa)	Modulus of rupture (MPa)
28	32.60	4.55	4.46

Castellated beams and slab reinforcement

Layout and details of castellated composite beams is shown in Figure 1. To investigate the mechanical properties of steel section, three specimens are cuts to check out the yield and ultimate strength in addition to modulus of elasticity for castellated beam specimen. Table 7 lists the mechanical properties of castellated cross section and Figure 2 show the specimen test setup. Reinforcement for concrete slab with diameters (6 mm) is adapted based on the design of composite castellated beam that designed before tests. All specimens were casted in galvanize mold with (1.6 mm) in thickness. The concrete deck slab were connected to the castellated steel beams by means of smooth shear stud connector with diameter (8 mm) and total height (40 mm) and upper head diameter (13 mm) is adapted. The height to diameter ratio is (5) that matching with the BS 5400 [12] requirements. The specimens are classify and lists in Table 8.

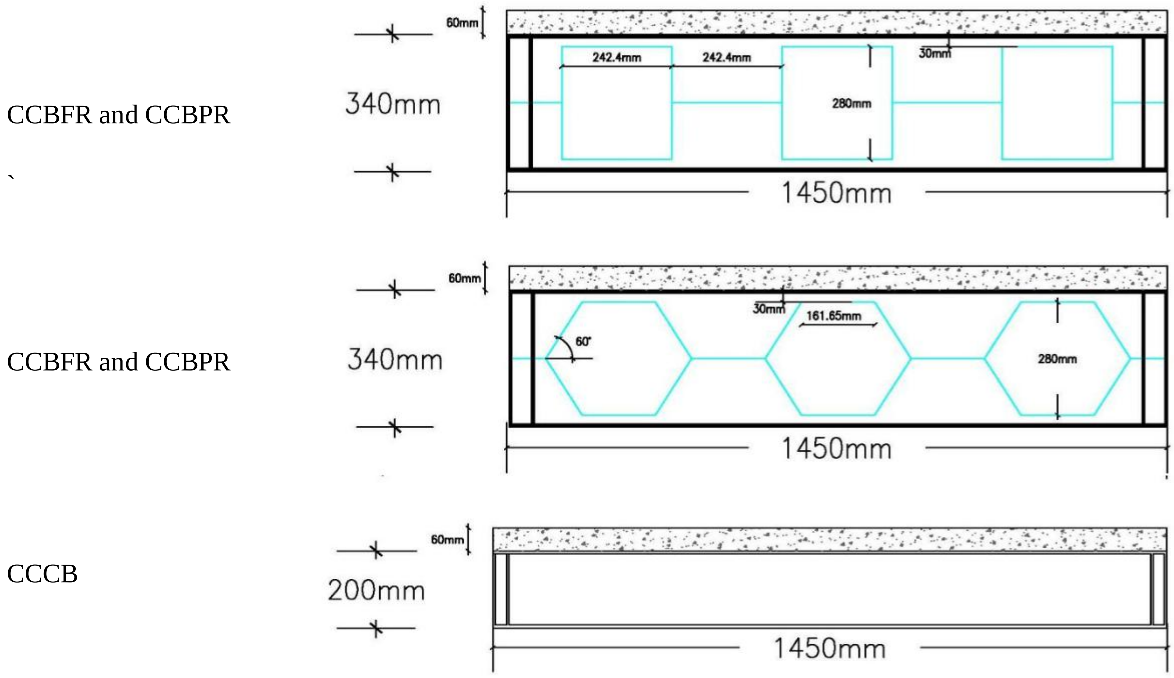

Figure 1: Layout and details of composite castellated beams

Table 7: Steel section geometry and mechanical properties

Flange (mm)		Web (mm)		Modulus of Elasticity (MPa)	Yield Strength f_y (MPa)	Ultimate Strength f_u (MPa)
Width	Thickness	Height	Thickness			
100	8	184	5	207000	376	517

Figure 2: Specimen setup

Table 8: Specimens classifications

Specimen mark	Opening shape	Composition action
CCCB	Solid	Full
CCBFH	Hexagon	Full
CCBPH	Hexagon	Partial
CCBFR	Rectangular	Full
CCBPR	Rectangular	Partial

CCCB: Composite Castellated Control Beam, H: Hexagon, R: Rectangular, F: Full, P: Partial(70%full)

The applied load incrementally in step initially (5 kN) up to (20%) from ultimate load and the deformations such as deflection, strain and slips are record. Load increments and record all values with step of (4 kN) up to (40%) and then the test continue with loads increments as (3 kN, 2 kN) up to (75% and 90%) respectively. Load – deflection behavior for all specimens quarter, mid span are shown in Figures 3and 4. Load –slip (average) at the end of the composite beams are plotted in Figure 5 in which there is symmetrical around y-axis.

V. TEST RESULTS

All specimens are tests under four point loads up to failure. Table 9 lists the ultimate load, first crack loads and the ratio of first crack load to the ultimate load for each specimen.

Table 9: Ultimate load, first crack load and the ratio of first crack load to the ultimate load

Specimen mark	First crack load (kN)	Ultimate load (kN)	% (First crack load/ Ultimate load)
CCCB	31.50	143.0	22
CCBFH	44.00	212.5	20.70
CCBPH	25.45	192.5	13.22
CCBFR	55.00	177.5	30.98
CCBPR	35.00	155.0	22.58

Table 10 lists the maximum deflections at quarter and mid of the composite beam span and the recorded slips at the end of the specimens.

Table 10: Maximum deflection at quarter and mid span with maximum slip at the end span of all specimens

Specimen mark	Maximum deflection at quarter (mm)	Maximum deflection at mid (mm)	Maximum slip (mm)
CCCB	3.12	7.80	1.50
CCBFH	2.88	9.36	1.48
CCBPH	2.95	9.16	1.67
CCBFR	3.25	8.87	1.58
CCBPR	3.75	12.12	2.12

VI. LOAD - DEFLECTION

The behaviors of all specimens under the effect of applied static loadings are discussed in term of deflection. Load-deflection curves of the tested specimens at quarter and mid span at all stages of loading up to failure are constructed and shown in Figures 3 and 4. In general, all specimens were tested up to failure in which the failure occurred in concrete slab due to cracks propagations. The specimens behaved as linear started from zero up to load that caused first crack in concrete slab that rely on the concrete type, full or partial interaction and opening web of steel beam percentage. The behavior of the specimens after the point of inflection become nonlinear due to change in modulus of elasticity that influenced by increase in load that cause increase in strain that reflect in reduce on the magnitude of modulus of elasticity so that the specimen stiffness become less. Increases in load make the slop of the load - deflection less that indicate reduce in specimen stiffness due to increase in load and deflections. The deflection at the mid span gave the maximum value due to the curvature of the beam increase started from zero deflection at supports.

The reference specimen CCCB solid web without openings casted by geopolymer concrete with number of stud shear connectors make the composite beam as full interaction, the ultimate load capacity is 143 kN and the corresponding deflection at mid span is 7.80 mm. The behavior of reference CCCB start from zero up to 31.50 kN that represent the load caused first crack is linear. The maximum deflection at the mid and quarter of the CCCB is 7.80 and 3.12 mm respectively. The specimen CCBFH, the load capacity is 212.50 kN compared with the CCCB there was reduced in strength and approximately same maximum deflection. The specimen CCBPH compare with CCBFH, the strength capacity is less due to the effect of slips that reduce the resistance and increase the deflection. The specimen CCBFR that gave strength capacity 177.50 kN with maximum deflection 8.87 mm that greater than the control specimen with higher strength capacity. The partial interaction of specimen (CCBPR) with ultimate load capacity (155.00 kN) gave less load capacity than CCBPR due to the partial interaction between steel and concrete that lead increase in deflection.

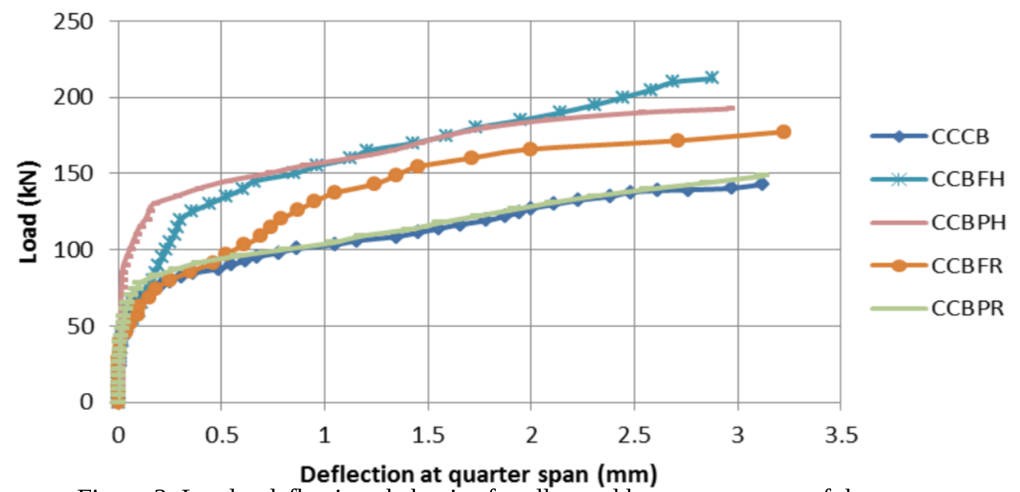

Figure 3: Load – deflections behavior for all tested beams at quarter of the span

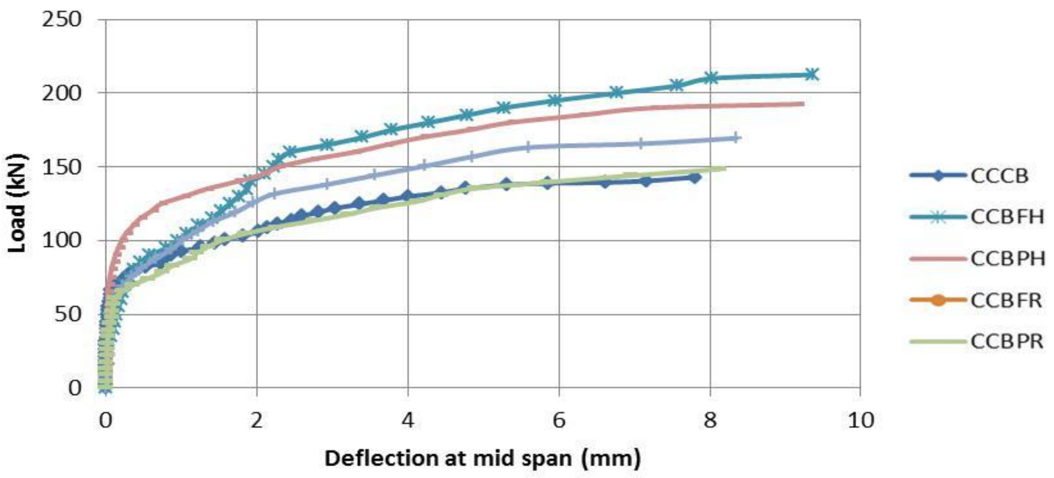

Figure 4: Load – deflections behavior for all tested beams at mid span

SLIP

Even the number of shear stud connectors that provided to connect the two different materials as concrete and steel sufficient to working as unity, still there are slip developed at the interface surface. The behavior of slip for all specimens are shown in Figure 5 in which the slips distribution symmetric about the origin (mid span) with reversal in sign. The maximum slip values ranged between 1.48-2.12 mm rely on full or partial interaction. The load – slip behavior at mid span is zero due to the change in directions of shear flow (shear load) that developed due to applied load. The slips are very small at the early applied load and then increase at the load that caused more shear flow. In case of partial interaction, the slips are greater than that of full due to the magnitude of distributed shear flow more that caused slip at the interface in presence of friction that reduce the slip value because the frictional force direction in opposite direction of shear flow.

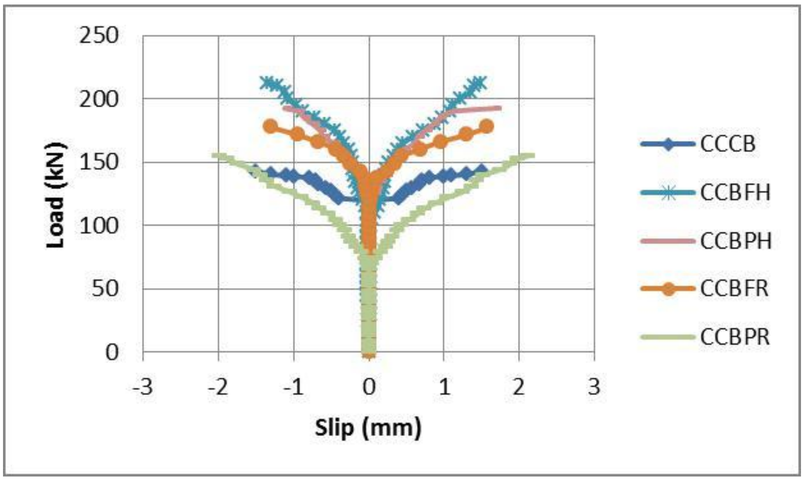

Figure 5: Load – slips behavior for all tested beams at the end of the span

STRAINS

Strains were measured at the location at middle of bottom flange, mid web and mid reinforced concrete slab. The functions of measured strains that developed in steel section and concrete are to evaluate the strain behavior of the reinforced concrete composite castellated beams under the effects of static loadings and find out which material yield first. Figure 6 shows the load - strain behavior for all specimens. All behavior starts as linear with small increments in strain up to approximately (75%) from the ultimate load. the behavior of the models become nonlinear (curve) when the load reaches the ultimate load capacity. All recorded strain in the tension zone not reach the yielding strain (0.00175) so that the steel section not yield and still in the elastic zone. Figure 7 represents the full behavior of the load – strain for all specimens that recorded in the middle web of steel section. The mid Points of web lie in the tension zone of the composite castellated beam and all strains within the elastic range that not exceeded the yielding strain that mentioned above. All loads – strain behave as elastic up to ultimate load for each specimen. Figure 8 shows the load – strain at the middle of the reinforced concrete slab for each specimen. The behavior of load – strain starts as linear up to nearly first crack that rely on the each specimen specification. After first cracks of each specimens, the behaviors become nonlinear but still in elastic range. All specimens not reach the maximum strain in concrete (0.003) based on ACI-318 – 2019 [13] except specimen CCBFR that explained the failure due to heavy cracks.

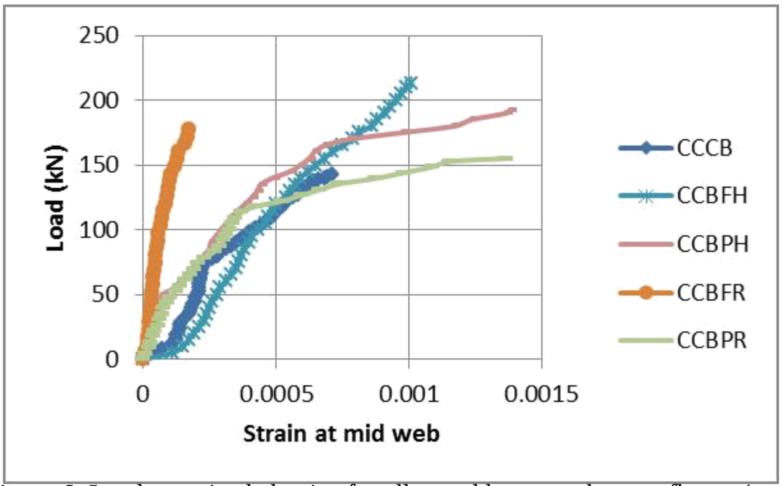

Figure 6: Load – strains behavior for all tested beams at bottom flange (steel beam)

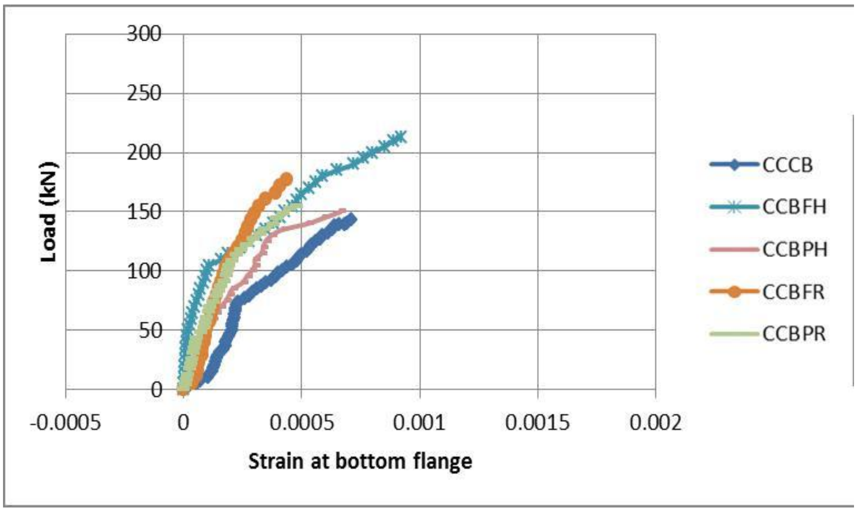

Figure 7: Load – strains behavior for all tested beams at mid web (steel beam)

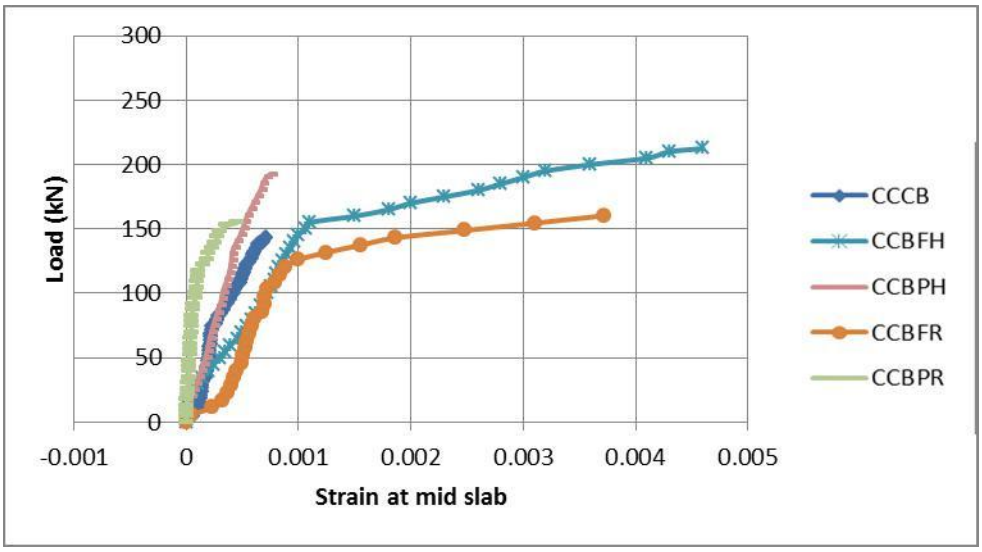

Figure 8: Load – strains behavior for all tested beams at mid concrete deck slab

VII. CRACK PATTERN AND MODE OF FAILURE

Concrete material such as geopolymer concrete classified as weak in tension resistance due to that the concrete is a brittle material. The cracks developed and progress when the load applied cause stress in tension zone more than the modulus of rupture in flexural test. When the applied load increased till reach to developed first crack that is mean the internal stress that inside the concrete in tension zone become near the value of modulus of rupture. The magnitude of first crack load relies on different parameters such as compressive concrete strength and geometry of concrete member. In case of partial interaction the load caused first crack less than that in full interaction due to the presence of slip that increase the deflection and not make the concrete and steel section worked as unity so that the full stiffness of composite castellated beam reduce and make the internal stress in tension zone high to reach the limit of modulus of rupture of concrete. A Figure 9 to 13 shows the cracks propagations and failure modes for all composite castellated beams. No pull – out of concrete slab failure and there are no cut of any headed stud shear connectors during test up to ultimate loads for each specimen. The specimen CCCB is shown in Figure 9 in which the cracks at failure stage shows nearly vertical and parallel to slab thickness started from the locations of applied loads toward slab bottom. The whole composite castellated beams bend to the direction of applied load and the mode of failure is flexural due to concrete cracks. The specimen CCBFH is shown in Figure 10 has cracks at failure more than CCCB due to the presences of openings. The specimen CCBPH has less cracks than CCBFH due to the shape of openings. Figure 11 represent the specimen CCBPH, this specimen carried out less ultimate load due to partial in connection. Figure 12 for specimen CCBFR in which the load capacity at failure for less than CCBPH even these specimens are full interaction but the diagonal distance of web opening is more so that the shear stress become high that lead to produced more cracks near the ends. Figure 13 shows the flexural failure mode and the cracks propagations of specimen CCBPR at failure stage. The amounts of cracks intensity with low failure load indicated that this specimen fail when the cracks in the slab growth more quickly due to weakness of the composite castellated beam due to large openings size.

Figure 9: Composite beam CCCB at failure stage

Figure 10: Composite castellated beam CCBFH at failure stage

Figure 11: Composite castellated beam CCBPH at failure stage

Figure 12: Composite castellated beam CCBFR at failure stage

Figure 13: Composite castellated beam CCBPR at failure stage

VIII. Discussions

According to the experimental investigation with different parameters that adopted in present work, followings are discussions due to observations and test results. Table 11 lists the comparisons between the specimens as a function of opening shape, hexagon and rectangular. In case of rectangular opening, the diagonal distance between the edges of opening greater than that in hexagon so those large openings reduce the strength load capacity of whole section. The forms of hexagons especially (oblique) the diagonal works like rib that increase the strength and stability of the section.

Table 11: Effects of opening shape on ultimate load, deflection and slip of composite castellated beams

Specimen mark	Ultimate load (kN)	% Increases in ultimate load	Maximum deflection at mid (mm)	% Decrease in deflection	Maximum slip (mm)	% Decrease in slip
CCBFR	177.5	---	8.87	---	1.58	---
CCBFH	212.5	19.72	3.86	56.48	0.75	52.53

Partial and full interaction theories are applied on the design of composite castellated beams to evaluate the full capacity, mid span deflection and slip. Table 12 lists the effects of composite action on ultimate load, deflection and slip of composite castellated beams. In case of full interaction between the reinforced concrete slab and the castellated steel section the whole system act as unity. In case of full interaction the number of shear stud connectors becomes more so that the shear flow transfer between the two contact surfaces distributed to the shear connectors less that lead to reduce slip and deflection and the composite beam capacity become more than partial system.

Table 12: Effects of composite action on ultimate load, deflection and slip of composite castellated beams

Specimen mark	Ultimate load (kN)	% Increases in ultimate load	Maximum deflection at mid (mm)	% Decrease in deflection	Maximum slip (mm)	% Decrease in slip
CCBPH	192.5	---	9.16	---	1.67	---
CCBFH	212.5	9.41	5.31	42.03	1.1	34.13
CCBPR	155.0	---	12.12	---	2.12	---
CCBFR	177.5	14.52	4.18	65.51	0.38	82.08

Conclusions

Based on the results from experimental tests, followings are the important conclusions points:

1. The specimens haves rectangular opening, the diagonal distance between the edges of opening greater than that in hexagon so those large openings reduce the strength load capacity of the composite castellated beams.

2. The shape of hexagons gave more stiffness to the web and works similar to rib that increase the strength and stability of the section.

3. Full interaction between the two contact surface as top of steel castellated beam and reinforced concrete slab worked and act as unity. In case of full interaction the number of shear stud connectors becomes more so that the shear flow transfer between the two contact surfaces distributed to the shear connectors less that lead to reduce slip and deflection and the composite beam capacity become more than partial system.

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