Performance of RC Beams Cast using Normal and Self-Compacting Concretes with Different Reinforcement Ratios Compared with ECP and ACI

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Abstract - *Self-compacting concrete like a construction material needs more treatises to explorer its structure performance. Performance of normal concrete with under, balanced and over reinforcement ratios is very clear but for self-compacting concrete is still unknown. Deflections corresponding to the same loads for the same structure element are different from code to another. In this research normal concrete and self-compacting concrete beams with under, balanced and over reinforcement ratios were tested to scout the self-compacting concrete structure performance. The tested beams were analyzed using both Egyptian Code of Practice ECP 203-2017 and American Concrete Institute ACI 318-2014 to verify the difference between deflections computations. Trial mixes for both normal and self-compacting concretes were proportioned, and tested in fresh and hardened states to elect suitable mixes for casting the reinforced concrete beams with under, balanced and over reinforcement ratios. A comparative study was performed between the tested beams to scout the structure performance of the self-compacting concrete related to normal concrete. Another comparative investigation was performed to scout the difference in deflection computation for both the Egyptian Code of Practice and the American Concrete Institute.*

Key Words: Normal, Self, Compacting, Concrete, Reinforcement, Under, Balanced, Over.

1. INTRODUCTION

Self-compacting concrete SCC is identified as a type of concrete has distinguished segregation opposition and deformability. SCC is capable of stream through its own weight and capable of filling the entire framework even inside serried reinforcement. The SCC is analogous to the normal concrete hardened properties such as condense, homogenous and substantiality [1, 2]. SCC has the identical constituents as normal concrete, that are binding material, fine aggregate, coarse aggregate and water, in the company of variable ratios of mineral admixture and chemical admixture [3]. SCC has verified advantageous and economic features such as more rapid construction, manpower reduction in erection field, preferable concrete face finish, placing facility, enhanced durability, enlarge flexible design, delicate concrete sections, low noise standard and vibration lack [4, 5]. Till now, there is no specified design for SCC mixes but only guidelines differ from agency to other [5, 6]. SCC is implemented by decreasing the volume proportion of aggregate to binding cementitious substance, augmenting the paste content and utilizing diverse superplasticizers and viscosity enhancing element [7,8, 9].

There is a great leakage about the structural performance of the SCC. The first aim of this research is to investigate the structure performance of self-compaction concrete beams with under, balanced and over reinforcement related to normal concrete beams. The second aim is to verify the difference between deflections equations of both Egyptian of Design and Practice of Concrete Structures ECP 203-2017 and American Concrete Institute ACI 318-14 considering the tested beams.

2. EXPERIMENTAL PROGRAM

2.1 Materials and Mixes

A normal strength ordinary Portland cement C which meets both Egyptian specification ESS 4756-1/2013 CEM I 42.5N and European standards BS EN 197-1:2011 CEM I 42.5N demands was used a binding material. Clean, well graded and smooth texture natural sand S was used a fine aggregate. Standard sieve No. 4 was used to remove larger grains and harmful loam. Crushed dolomite CD of lime stone which was sieved using sieve No. 2 to maintain nominal maximum size equals 20 mm was used a coarse aggregate. Potable water W was used for casting both normal concrete mixes, self-compacting concrete mixes and reinforced concrete beams.

Two concrete additives were used in this investigation for production of self-compacting concrete, whereas the first admixture was fly ash FA and the second admixture was superplasticizer SP. The fly ash is a new generation spherical particles in tender powdered form [10]. Fly ash is high performance third generation additive for homogenous concrete production [10]. Superplasticizer confirms with both ASTM-C-494 Type G and F, and BS EN 934 part 2:2001 demand was used as high-range water-reducer [11].

Trial nine normal concrete mixes were proportioned to select a concrete mix with plastic consistency and suitable compression strength. The nine mixes had constant cement content equals 350 kg, water cement ratios ranging from 0.46 to 0.54, and both crushed dolomite and sand were calculated using absolute volume equation. Table 1 shows normal concrete mixes proportion.

Table -1: Normal Concrete Mixes Components

Mix	Concrete Mix Components (kg/m^3)			
	C	S	CD	W
MNC1	350	777	1165	161
MNC2	350	773	1159	164.5
MNC3	350	769	1153	168
MNC4	350	765	1147	171.5
MNC5	350	762	1143	175
MNC6	350	758	1137	178.5
MNC7	350	754	1131	182
MNC8	350	751	1126	185.5
MNC9	350	747	1120	189

For self-compaction concrete mix design, there is no standard method. In this investigation the directions of the Technical Specification for Self-Compacting Concrete, 2012 [12] were considered in the self-compacting concrete mixes proportions. For self-compacting concrete mixes proportions, cement content was constant and equals 350 kg, water cement ratio W/C was constant and equals 0.4, fly ash contents were 25, 30 and 35% of cement content [10], superplasticizer contents were 1, 1.5 and 2% of cement content by volume [11], and both sand and crushed dolomite were calculated applying absolute volume equation. According to ETS [12], sand content was assumed equals to crushed dolomite content. Table 2 shows nine self-compacting concrete mixes proportions considering the variables mentioned above.

Table -2: Self-Compacting Concrete Mixes components

Mix	Self-Compacting Concrete Components (kg/m^3)					
	C	S	CD	W	FA	SP
MSCC1	350	935	935	140	87.5	3.67
MSCC2	350	924	924	140	105	3.67
MSCC3	350	914	914	140	122.5	3.67
MSCC4	350	933	933	140	87.5	5.51
MSCC5	350	922	922	140	105	5.51
MSCC6	350	911	911	140	122.5	5.51
MSCC7	350	930	930	140	87.5	7.35
MSCC8	350	920	920	140	105	7.35
MSCC9	350	909	909	140	122.5	7.35

2.2 Fresh and Hardened Properties

For normal concrete, mixes were tested in slump test and compression test for fresh and hardened properties evaluation. Concrete with slump value ranging from 3 to 12 cm is set a plastic consistency concrete. For compression test both 7-day and 28-day compression strengths were measured for normal strength mixes. Normal concrete mix MNC4 had a slump nearest to the average of plastic consistency range. Therefore normal concrete mix MNC4 was chosen for casting the tested RC beams.

For fresh properties of self-compacting concrete, Concrete has passingability, fillingability and segregation resistance properties is set a self-compaction concrete. Passing ability, filling ability and segregation resistance characteristics are evaluated by applying slump flow, J-ring and V-funnel tests, respectively. For slump flow test, average diameter of concrete in two orthogonal directions $d_{average}$ and time for concrete to get to 50 cm in diameter circle $t_{50\ cm}$ were measured. For j-ring test, difference in concrete height between outside and inside the ring Δ_h, average diameter of concrete in two orthogonal directions $d_{average}$ and time for concrete to get to 50 cm in diameter circle $t_{50\ cm}$ were measured. For segregation resistance, time between trap door opened and light seen from the top the funnel $t_{V\text{-funnel}}$ and time between trap door opened and light seen from the top the funnel after 5 minutes $t_{V\text{-funnel-5}}$ were measured. For hardened properties, each self-compacting concrete mix was tested in compression test after 7 days and 28 days.

The acceptance limits of the slump test are $d_{average}$ is ranging between 600 to 800 mm and $t_{50\ cm}$ is ranging between 2 to 5 second [12]. The acceptance limits of the J-ring test Δ_h is ranging between 0 to 20 mm, and both $d_{average}$ and $t_{50\ cm}$ are not available [12]. The acceptance limits of the V-funnel test are $t_{V\text{-funnel}}$ is ranging between 6 to 12 sec and $t_{V\text{-funnel-5min.}}$ is ranging between ($t_{V\text{-funnel}}$+0) and ($t_{V\text{-funnel}}$+3) second [12]. Self-compacting concrete mix MSCC6 gave fresh tests results near to the average of the acceptance ranges of the measured terms. Self-compacting concrete MSCC6 gave suitable early and late compression strengths. Therefore, self-compacting concrete MSCC6 was chosen for casting the RC beams.

2.3 Reinforced Concrete Beams

Six reinforced concrete beams were cast, curing and tested up to failure. The six reinforced concrete beams were 200 cm in length, 30 cm in height and 15 cm in width. Three reinforced concrete beams were cast using normal strength concrete with under, balanced and over reinforcement ratios. Also, three reinforced concrete beams were cast using SCC with under, balanced and over reinforcement ratios. Table 3 shows reinforcement details and compression strengths for each beam. Figures 1 to 6 show the tested RC beams.

Table-3: Reinforcement Details and Compression Strengths of the Tested Beams

Beam Code	Reinforcement Ratio	Longitudinal Reinforcement	Shear Reinforcement
BNCU	Under	2Φ12 mm	10Ø8/m\
BNCB	Balanced	6Φ12 mm	8Φ10/m\
BNCO	Over	6Φ16 mm	9Φ10/m\
BSCCU	Under	2Φ12 mm	10Ø8/m\
BSCCB	Balanced	6Φ16 mm	10Φ10/m\
BSCCO	Over	6Φ16 mm + 2Φ12 mm	8Φ12/m\

Table-3 (Cont.): Reinforcement Details and Compression Strengths of the Tested Beams

Beam Code	Compression Strength f_{cu} (MPa)	
	Average $f_{cu\ 7\text{-}day}$	Average $f_{cu\ 28\text{-}day}$
BNCU	28.34	35.40
BNCB	28.44	35.59
BNCO	28.24	35.51
BSCCU	33.73	42.07
BSCCB	32.95	41.48
BSCCO	32.75	41.87

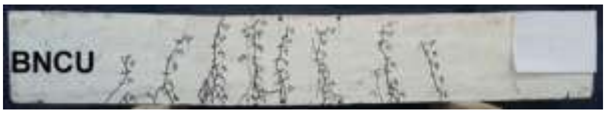

Fig -1: The tested beam BNCU

Fig -2: The tested beam BNCB

Fig -3: The tested beam BNCO

Fig -4: The tested beam BSCCU

Fig -5: The tested beam BSCCB

Fig -6: The tested beam BSCCO

3. THEORETICAL STUDY

The tested beams were analyzed using both Egyptian of Design and Practice of Concrete Structures ECP 203-2017 and American Concrete Institute ACI 318-14. Deflections of the tested beams were calculated applying the equations of ECP 203-2017 and ACI 318-14 [13, 14]. Deflections of the tested beam were calculated using equation 1 [15] for both codes.

$$\Delta = \frac{23}{648}\frac{PL^3}{E_c I_e} \quad (1)$$

3.1 ECP 203-2017

$$E_c = 4400\sqrt{f_{cu}} \quad (N/mm^2) \quad (2)$$

$$I_e = \left(\frac{M_{cr}}{M_a}\right)^3 I_g + \left[1-\left(\frac{M_{cr}}{M_a}\right)^3\right] I_{cr} \quad (mm^4) \quad (3)$$

$$n = 10 \quad (4)$$

3.2 ACI 318-14

$$E_c = 57000\sqrt{f'_c} \quad (psi) \quad (5)$$

$$I_e = \left(\frac{M_{cr}}{M_a}\right)^3 I_g + \left[1-\left(\frac{M_{cr}}{M_a}\right)^3\right] I_{cr} \quad (inch^4) \quad (3)$$

$$n = \frac{E_s}{E_c} \quad (6)$$

Where:

- E_c: Modulus of elasticity of concrete,

- f_{cu}: Cube compression strength of concrete,

- I_e: Effective moment of inertia,

- M_{cr}: Cracking moment,

- M_a: Applied load moment,

- I_g: Gross moment of inertia,

- I_{cr}: Cracking moment of inertia,

- n: Modular ratio,

- f_c': Specified compression strength of concrete, and

- E_s: Modulus of elasticity of longitudinal steel reinforcement.

For calculation of cracked section moment of inertia I_{cr}, the modular ratio n is considered. According to the ECP 203-2017, n equals 10 but for ACI 318-14, n is calculated as mention in equation 6.

4. RESULTS

Table 4 show slumps and compression strengths of the normal concrete mixes. Charts 1 and 2 show SCC mixes slump test results. Charts 3, 4 and 5 show SCC mixes J-ring test results. Charts 6 and 7 show SCC mixes V-funnel test results. Charts 8 and 9 show both early and late compression strengths of SCC mixes, respectively. Load deflection curves of the tested beams are illustrated in chart 10. Experimental, ECP 203-17 and ACI 318-14 load deflection curves of the tested beams are illustrated from chart 11 to 16. Charts 17 and 18 show cracking and failure loads of experimental, ECP 203-17 and ACI 318-14 of the tested beams, respectively.

Table -4: Slumps and Compression Strengths of the Normal Strength Mixes

Mix	Slump (cm)	Compression Strength f_{cu} (MPa)	
		$f_{cu\ 7\text{-}day}$	$f_{cu\ 28\text{-}day}$
MNC1	3.3	31.18	38.83
MNC2	4.6	30.51	37.85
MNC3	6.5	28.83	36.68
MNC4	8.1	28.05	35.61
MNC5	8.8	27.65	34.91
MNC6	10.1	26.87	33.05
MNC7	11.7	25.32	31.48
MNC8	13.4	23.44	29.81
MNC9	15.5	20.96	28.06

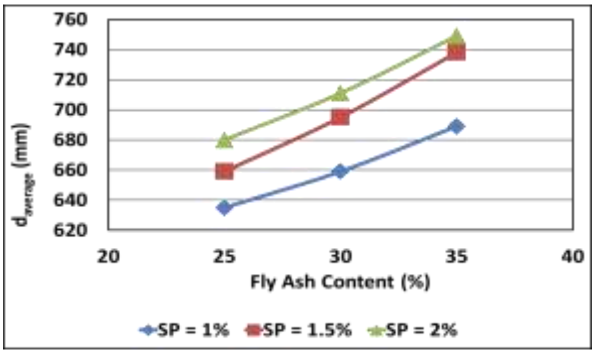

Chart -1: Slump test $d_{average}$ for different variables of FA and SP of SCC mixes

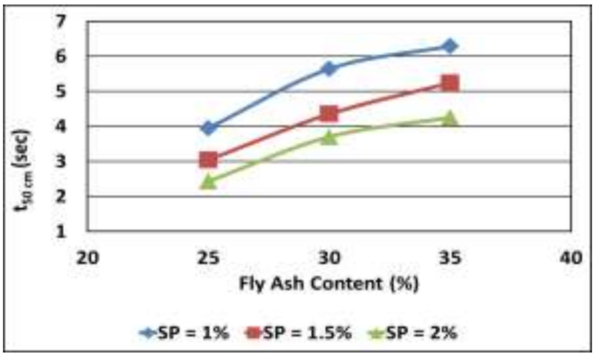

Chart -2: Slump test $t_{50\ cm}$ for different variables of FA and SP of SCC mixes

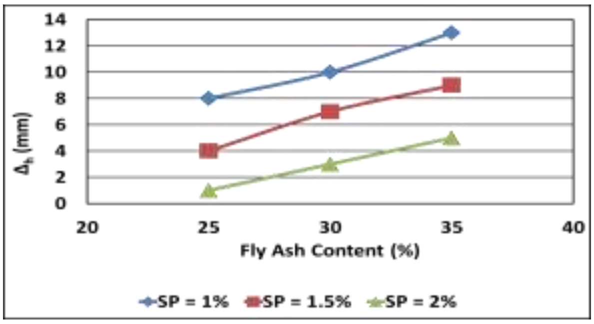

Chart -3: J-Ring test Δ_h for different variables of FA and SP of SCC mixes

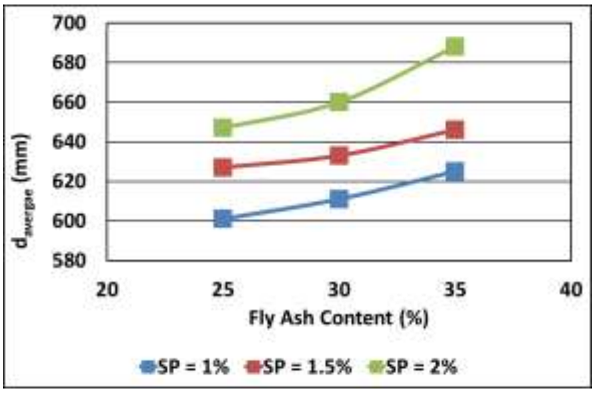

Chart -4: J-Ring test $d_{average}$ for different variables of FA and SP of SCC mixes

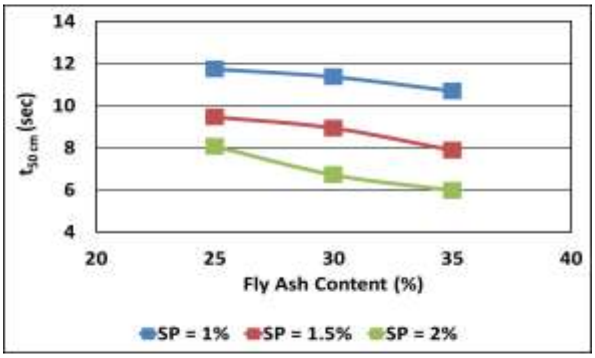

Chart -5: J-Ring test $t_{50\ cm}$ for different variables of FA and SP of SCC mixes

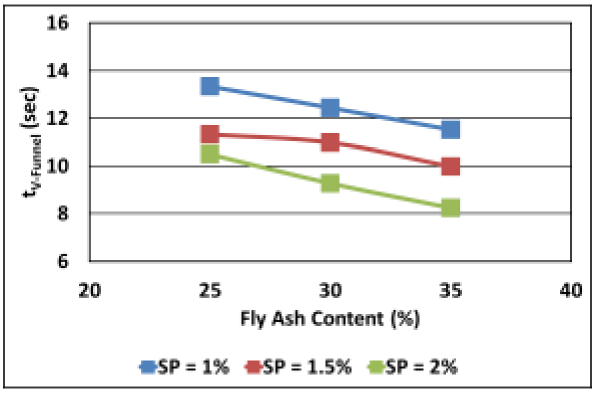

Chart -6: V-Funnel $t_{V\text{-}Funnel}$ test $t_{50\ cm}$ for different variables of FA and SP of SCC mixes

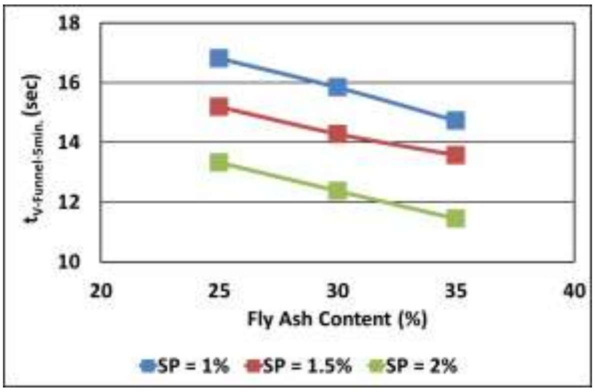

Chart -7: V-Funnel $t_{V\text{-}Funnel\text{-}5min.}$ test $t_{50\ cm}$ for different variables of FA and SP of SCC mixes

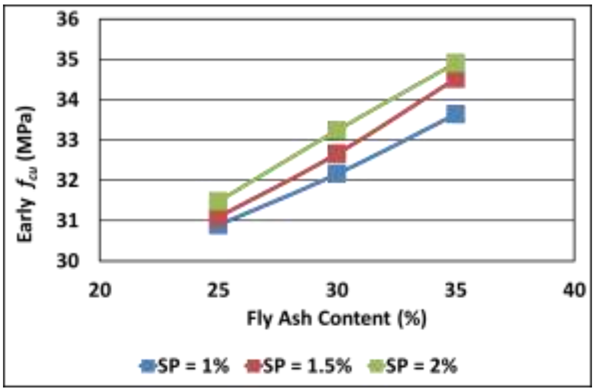

Chart -8: Early compression strengths for different variables of FA and SP of SCC mixes

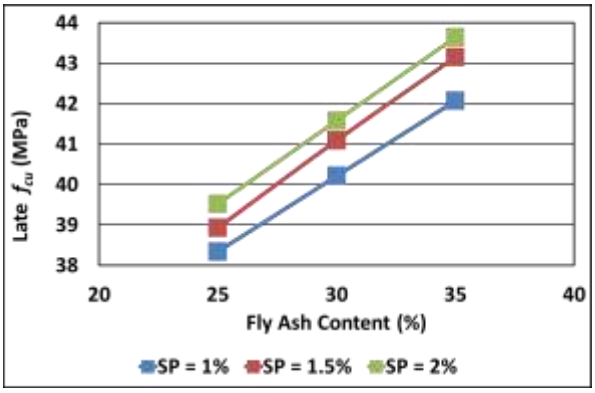

Chart -9: Late compression strengths for different variables of FA and SP of SCC mixes

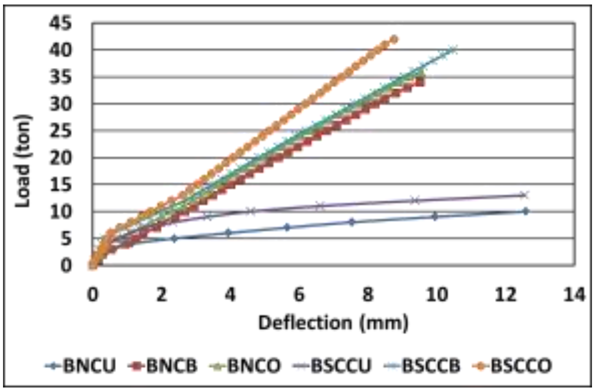

Chart -10: Load deflection curves of the tested beams

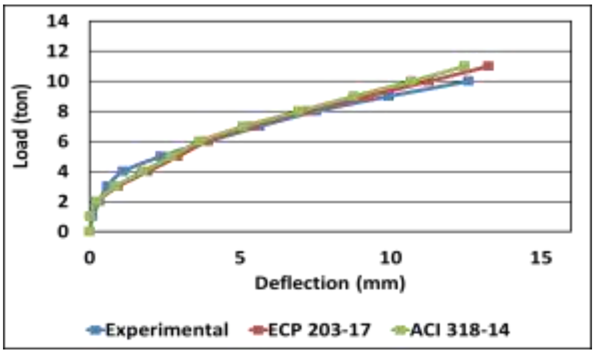

Chart -11: Load deflection curves of beam BNCU

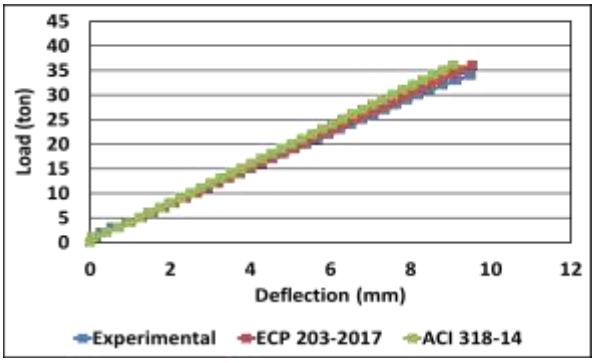

Chart -12: Load deflection curves of beam BNCB

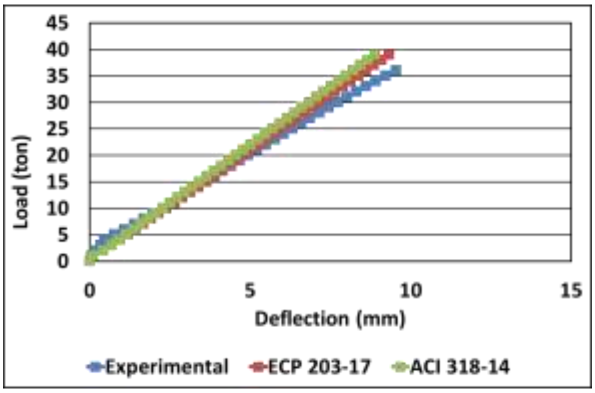

Chart -13: Load deflection curves of beam BNCO

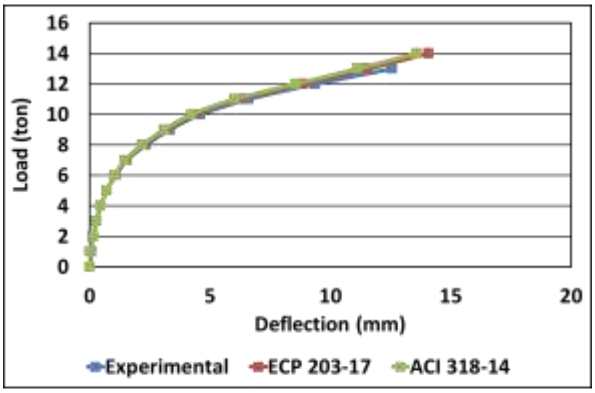

Chart -14: Load deflection curves of beam BSCCU

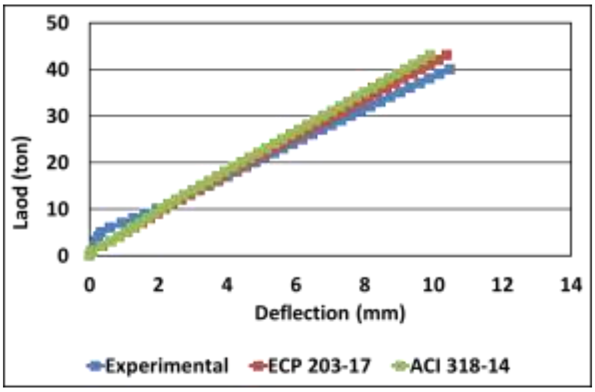

Chart -15: Load deflection curves of beam BSCCB

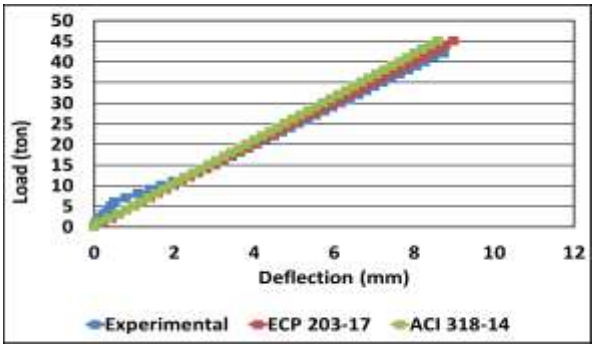

Chart -16: Load deflection curves of beam BSCCO

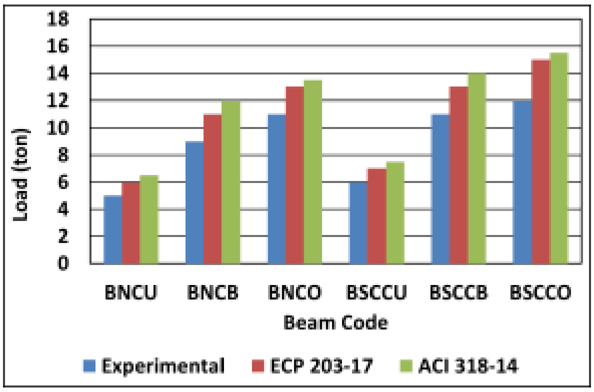

Chart -17: Experimental, ECP 203-17 and ACI 318-14 cracking loads of the tested beams

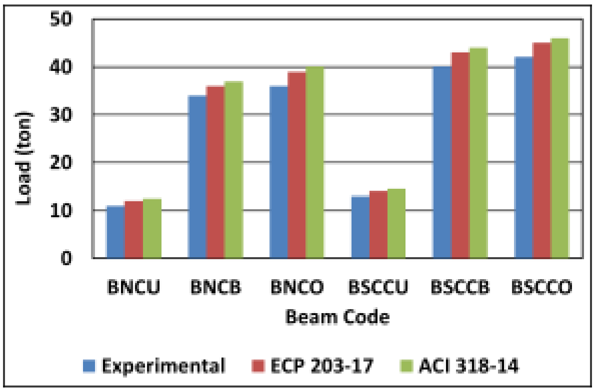

Chart -18: Experimental, ECP 203-17 and ACI 318-14 failure loads of the tested beams

5. DISCUSSIONS OF THE RESULTS

Using 35% fly ash of cement content decreased fillingability of SCC mixes more than using 30% fly ash and using 30% fly ash of cement content decreased fillingability of SCC mixes more than 25% fly ash. Using 35% fly ash of cement content increased passingability of SCC mixes more than 30% fly ash and using 30% fly ash of cement content increased passingability of SCC mixes more than 25% fly ash. Using 35% fly ash of cement content increased segregation resistance of SCC mixes more than 30% fly ash and using 30% fly ash of cement content increased segregation resistance of SCC mixes more than 25% fly ash. Using 35% fly ash of cement content increased early and late compression strengths of SCC mixes more than using 30% fly ash, and using 30% fly ash of cement content increased early and late compression strengths of SCC mixes more than 25% fly ash.

Using 1% superplasticizer of cement content decreased fillingability of SCC mixes more than using 1.5% superplasticizer and using 1.5% superplasticizer of cement content decreased fillingability of SCC mixes more than 2% of superplasticizer. Using 1% superplasticizer of cement content decreased passingability of SCC mixes more than using 1.5% superplasticizer and using 1.5% superplasticizer of cement content decreased passingability of SCC mixes more than 2% of superplasticizer. Using 1% superplasticizer of cement content decreased segregation resistance of SCC mixes more than using 1.5% superplasticizer and using 1.5% superplasticizer of cement content decreased segregation resistance of SCC mixes more than 2% of superplasticizer. Using 1% superplasticizer of cement content decreased early and late compression strengths of SCC mixes more than using 1.5% superplasticizer, and using 1.5% superplasticizer of cement content decreased early and late compression strengths of SCC mixes more than 2% of superplasticizer.

At the cracking loads of normal concrete beams with under, balanced and over reinforcement ratios, the deflections of beams BSCCU, BSCCB and BSCCO were reduced by about 45, 32 and 25%, respectively compared with beams BNCU, BNCB and BNCO. At the failure loads of normal concrete beams with under, balanced and over reinforcement ratios, the deflections of beams BSCCU, BSCCB and BSCCO were reduced by about 34, 22 and 18%, respectively compared with beams BNCU, BNCB and BNCO. Using SCC instead of normal strength concrete for beams with under, balanced and over reinforcement ratios increased cracking loads by about 20, 22 and 9%, respectively and also increased failure loads by about 30, 18 and 17%, respectively.

At the cracking load of beam BNCU, deflections of the ECP 203-2017 and ACI 318-14 were decreased by about 6.2 and 8.42% compared with the experimental deflection. At the cracking load of beam BNCB, deflections of the ECP 203-2017 and ACI 318-14 were decreased by about 1.12 and 5.62% compared with the experimental deflection. At the cracking load of beam BNCO, deflections of the ECP 203-2017 and ACI 318-14 were decreased by about 0.75 and 5.28% compared with the experimental deflection. At the cracking load of beam BSCCU, deflections of the ECP 203-2017 and ACI 318-14 were decreased by about 2.78 and 4.63% compared with the experimental deflection. At the cracking load of beam BSCCB, deflections of the ECP 203-2017 and ACI 318-14 were decreased by about 1.7 and 6.12% compared with the experimental deflection. At the cracking load of beam BSCCO, deflections of the ECP 203-2017 and ACI 318-14 were decreased by about 0.77 and 4.98% compared with experimental deflection.

At the failure load of beam BNCU, deflections of the ECP 203-2017 and ACI 318-14 were decreased by about 10.48 and 15.09% compared with the experimental deflection. At the failure load of beam BNCB, deflections of the ECP 203-2017 and ACI 318-14 were decreased by about 5.15 and 9.88% compared with the experimental deflection. At the failure load of beam BNCO, deflections of the ECP 203-2017 and ACI 318-14 were decreased by about 9.74 and 14.03% compared with the experimental deflection. At the failure load of beam BSCCU, deflections of the ECP 203-2017 and ACI 318-14 were decreased by about 8.2 and 11.46% compared with the experimental deflection. At the failure load of beam BSCCB, deflections of the ECP 203-2017 and ACI 318-14 were decreased by about 8.01 and 12.31% compared with the experimental deflection. At the failure load of beam BSCCO, deflections of the ECP 203-2017 and ACI 318-14 were decreased by about 4.23 and 8.34% compared with experimental deflection.

The cracking loads of the ECP 203-2017 and ACI 318-14 of the beam BNCU were increased by about 20 and 30%, and also, the failure loads were increased by about 9 and 14%, respectively compared with experimental results. The cracking loads of the ECP 203-2017 and ACI 318-14 of the beam BNCB were increased by about 22 and 33%, and also, the failure loads were increased by about 6 and 9%, respectively compared with experimental results. The cracking loads of the ECP 203-2017 and ACI 318-14 of the beam BNCO were increased by about 18 and 23%, and also, the failure loads were increased by about 8 and 11%, respectively compared with experimental results. The cracking loads of the ECP 203-2017 and ACI 318-14 of the beam BSCCU were increased by about 17 and 25%, and also, the failure loads were increased by about 8 and 12%, respectively compared with experimental results. The cracking loads of the ECP 203-2017 and ACI 318-14 of the beam BSCCB were increased by about 18 and 27%, and also, the failure loads were increased by about 7 and 10%, respectively compared with experimental results. The cracking loads of the ECP 203-2017 and ACI 318-14 of the beam BSCCO were increased by about 25 and 29%, and also, the failure loads were increased by about 7 and 9%, respectively compared with experimental results.

6. CONCLUSION

Reducing fly ash content and increasing superplasticizer content increase fillingability of SCC mixes. Increasing fly ash content and increasing superplasticizer content increase passingability of SCC mixes. Increasing fly ash content and increasing superplasticizer content increase segregation resistance of SCC mixes. Increasing fly ash content and increasing superplasticizer content increase both early and late compression strengths of SCC mixes. Using SCC mixes instead of normal concrete reduces deflection, and increases both cracking and failure loads of RC beams with under, balanced and over reinforcement ratios. Using SCC in casting RC beams enhanced the structural performance of RC beams with different reinforcement ratios more than normal concrete. Deflections of ECP 203-14 are closely to the experimental results of both normal and self-compacting concrete beams with under, balanced and over reinforcement more than ACI 318-14. The ECP 203-2017 considers the value of modular ratio n equals 10 but the ACI 318-14 calculates the modular ratio n value considering both reinforcement modulus of elasticity and concrete modulus of elasticity. Therefore, load deflection curves for tested RC beams with different reinforcement ratios of ECP 203-2017 are different from load deflection curves of ACI 318-14.

REFERENCES

[1] B.Geeta, S. Bhadauria and A. Saleem, 2013, "A Review: Recent Innovations in Self Compacting Concrete," International Journal of Scientific and Engineering Research, Vol. 4, Issue 11, Nov. 2013, pp. 1993–2002.

[2] O. Khaleel, S. Al-Mishhadani and H. Abdul Razak, "The Effect of Coarse Aggregate on Fresh and Hardened Properties of Self-Compacting Concrete (SCC)," Procedia Engineering 14, 2011, pp. 805–813, doi:10.1016/j.proeng.2011.07.102.

[3] A. Deepika, S. Kirshnamoorthi and G. S. Rampradheep, "Study on Properties of Self-Consolidating Concrete with Fly Ash and Silica Fume," International Journal of Innovative Research in Science, engineering and Technology, Vol. 3, Issue 4, April 2014, pp. 11245–11249.

[4] H. Moghadam, O. Arasteh Hkoshbin, "Effect of Water–Cement (w/c) on Mechanical Properties of Self-Compacting Concrete (case Study)," International Journal of Civil, Environmental, Structural, Construction and Architecture Engineering, Vol. 6, No. 5, 2012, pp. 317–320.

[5] J. Srishaila, K. Alok, P. Prakash and V. Jawali, "Influence of Fly Ash and Silica Fumes on Rheology and Mechanical Properties of Self Compacting Concrete," International Journal of Engineering Research and General Science", Vol. 3, Issue 3, July–August 2015, pp. 414–421.

[6] V. Kumar, "Study of Mix Design of Self Compacting Concrete", International research Journal of Engineering and Technology (IRJET), Vol. 02, Issue 05, August 2015, pp 1076–1078.

[7] N. Pamnani, P. Patel, A. Verma and J. Pitroda, "Comparison and Optimization of Dosage of Different Super-Plasticizer for Self Compacted Concrete Using Marsh Cone," International Journal of Engineering and Innovative Technology (IJEIT)", Vol. 2, Issue 8, February 2013, pp. 79 - 82.

[8] S. Dumne, "Effect of Superplasticizer on Fresh and Hardened Properties of Self-Compacting Concrete Containing Fly Ash," American Journal of Engineering Research (AJER), Vol. 3, Issue 3, 2014, pp. 205–211.

[9] P. Nanak, A. Pamnani and A. Kachwala, "Shear Strength of M30 Grade Self Compacting Concrete with Different Water Based Curing Techniques," International Journal of Advancement in Engineering Technology, Management and Applied Science, Vol. 2, Issue 11, November 2015, pp. 6–14.

[10] Sika Fly Ash®, Sika Egypt for Construction Chemicals, Product Data Sheet, Edition 03/2008, Version no. 03.08, www.sika.com.eg, 2008.

[11] Sika ViscoCrete®-3425, Sika Egypt for Construction Chemicals, Product Data Sheet, Edition 03/2008, Version no. 03.08, www.sika.com.eg, 2010.

[12] Egyptian Technical Specifications for Self-Compacting Concrete, ETS 2007, Housing and Building National Research Center HBRC, Edition, 2012.

[13] Egyptian Code of Design and Practice for Concrete Structures, No. 203, Year 2017, ECP 203-2017.

[14] Building Code Requirements for Structural Concrete (American Concrete Institute 318-2014) and Commentary, 2014 - An ACI Standard - Reported by ACI Committee 318, 2014.

[15] S. EL-Behairy, Reinforced Concrete Design Handbook, Sixth Edition, 2009.