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Effect of Self-Compacting Concrete and Aggregate Size on Anchorage Performance at Highly Congested Reinforcement Regions

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***Abstract*—**At highly congested reinforcement regions, which is common at beam-column joint area, clear spacing between parallel bars becomes less than maximum normal aggregate size (20mm) which has not been addressed in any design code and specifications. Limited clear spacing between parallel bars (herein after thin cover) is one of the causes which affect anchorage performance. In this study, an experimental investigation was carried out to understand anchorage performance of reinforcement in Self-Compacting Concrete (SCC) and Normal Concrete (NC) at highly congested regions under uniaxial tensile loading. Column bar was pullout whereas; beam bars were offset from column reinforcement creating thin cover as per site condition. Two different sizes of coarse aggregate were used for NC (20mm and 10mm). Strain gauges were also installed along the bar in some specimens to understand the internal stress mechanism. Test results reveal that anchorage performance is affected at highly congested reinforcement region in NC with maximum aggregate size 20mm whereas; SCC and Small Aggregate (10mm) gives better structural performance.

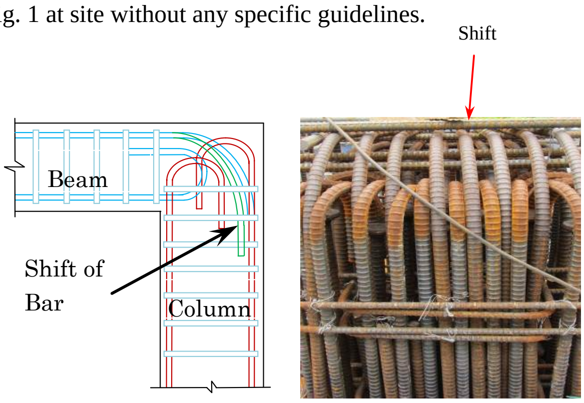
***Keywords*—**Anchorage capacity, bond, Normal Concrete, self-compacting concrete.

I. Introduction

SELF-Compacting Concrete (herein after SCC) is highly flowable concrete which can spread at all narrow spaces of highly congested area of reinforcement under its own weight without need of external vibration [1]. It is characterized by its fresh properties like filling ability, passing ability and resistance to segregation. At highly congested reinforcement regions, it is difficult to ensure proper compaction, uniform material quality and durability in Normal Concrete (herein after NC) which results in segregation and honey-comb at site. Compaction is performed by bamboos at site as it is difficult by external vibrator. High steel congestion strongly affects the structural performance and make is difficult to construct. In order to overcome these problems, SCC can provide better bond performance due to its fresh properties.

Growing seismic demand has direct influence on amount of reinforcement which occupies steel congestion problems at site. Steel congestion problems are common at beam column joint area; where bars are meeting from multiple directions shown in Fig. 1. Clear spacing between the parallel bars becomes less than maximum normal aggregate size (20mm). As a result, vulnerable area (herein after thin cover less than 20mm) is generated between parallel bars. There is no specific design guideline in any design code and specification to address this issue.

Due to limited size of structural member, it is not possible to meet anchorage requirements by straight bar. Therefore, hooks are provided to meet those requirements. Problem arises when beam reinforcement is anchored into column reinforcement shown in Fig. 1. Due to limited clear spacing between column reinforcement, bending part of beam anchorage is provided an offset from column reinforcement at some distance shown in Fig. 1 at site without any specific guidelines.



(a) Beam Column Joint (b) Shift of bar at Joint

Fig. 1 Steel Congestion Problems at Beam Column Joint Area

In 2010, Shimizu Corporation investigated the effect of shift of beam reinforcement (0 to 1.5D, where D is diameter of column reinforcement) from column reinforcement shown in Fig. 2 on anchorage performance for NC.

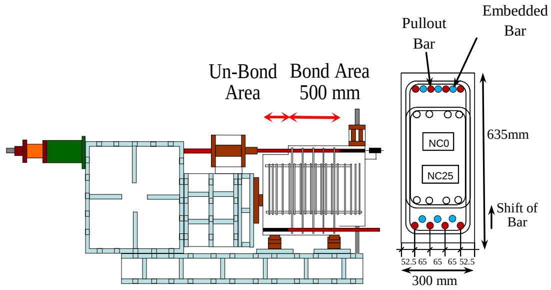


Fig. 2 Experimental Setup and Detail [2]

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Pullout tests were performed where; four column bars were pulled out and beam bars were introduced as per site condition. Based on their experimental investigation, they found that anchorage capacity is reduced if beam reinforcement is shifted from column reinforcement at distance 0 to 1D (0 to 25mm) but on the other hand, there is no affect if bars are shifted at a distance 1.5D (37.5mm) or more from column reinforcement shown in Fig. 3 [2]. Research on this aspect is limited and only few experiments have been done so far. So, it is important to know the effect of shift of bar on anchorage performance by further investigations.

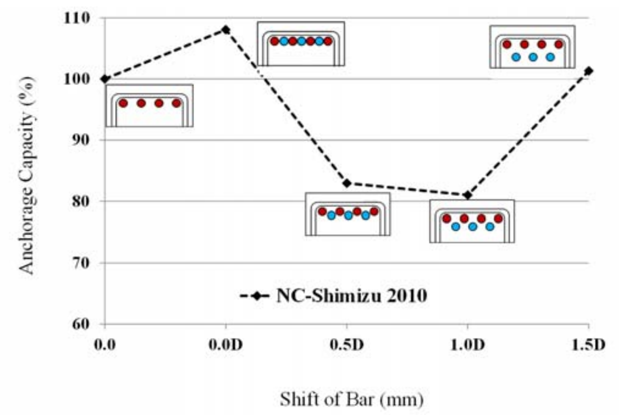


Fig. 3 Relationship between Anchorage Capacity-Shift of Bar

So, main objective was to understand the behavior due to shift of beam bar at different distances on anchorage performance by using NC and SCC. Two different sizes of aggregate were used in NC (20mm and 10mm). At highly congested regions, it is difficult for large aggregates with maximum size of 20mm to pass through narrow spaces in NC resulting segregation and bleeding which affects structural performance. Therefore, Small Aggregate (herein after SA) with maximum size of 10mm has also been used to investigate the behavior. Uniform distribution of small aggregate was expected at highly congested area. SCC has been developed to reduce the compaction problems at site in highly congested regions. But anchorage performance at highly congested area of reinforcement has not been studied yet for SCC. Better structural performance was expected in SCC due to its homogeneous behavior. Pullout tests were performed to understand the behavior, where column bar was pullout and beam bars were shifted at some distances from the column bar.

II. Background

Bond is a key element for ultimate load carrying capacity of reinforced concrete structures since it affects the anchorage performance of structural member. Bond is responsible to transfer the forces between reinforcement and surrounding concrete. Stresses at interface between steel and concrete are increased with increase in tensile load and the capacity of the interface to transmit stress begins to deteriorate at certain levels. This damage gradually spreads to the surrounding concrete. With the evolution of this process, the capacity of the interface to transmit stresses is seriously affected and relative movement at the interface between reinforcement and surrounding concrete can take place. At this stage, when concrete is cracked, load is mainly carried by reinforcement [3]-[5]. Bond is mainly assured by chemical adhesion, friction and bearing action. When the bond stresses are small, the bond efficiency is assured by chemical adhesion. On the other hand, bond efficiency is assured by bearing action between bar concrete interlock in case of larger bond stresses [6], [7]. Due to the inclination of lugs, wedging action divides this bearing force into two components, horizontal component (responsible for bond stress) and vertical (radial) component (responsible splitting of surrounding concrete). With further increase in load, bearing forces causes crushing of concrete in the vicinity of lugs. This action allows the adjacent lug to come in contact with concrete to resist the applied load. And if the concrete cover is thin, cracks can easily propagate to the outer surface [8], [9].

Generally, bond failure can be divided into two different modes: split failure and shear pullout failure. For thin covers, the failure is of splitting type. Splitting failure is characterized by small amount of slip and propagates, followed by further slip, and finally a complete loss of bond.

For lap splices, bond strength is affected by clear spacing between them. When the clear spacing between bar splices increases from 0 to 30%, the ultimate bond strength was greater than contact lap splice [10]. Load transfer within tension lap-spliced bar embedded in SCC in reinforced concrete beams was better than that of tension lap spliced bar embedded in NC [11]. There is a little difference in strength between adjacent and spaced splice of 12.5 and 25mm clear distance [12].Tied Splices developed higher bond than did the spaced bar [13].

At highly congested reinforcement region, consolidation of surrounding concrete is highly important in concrete placement and durability of structure. Achieving consolidation can require internal and external vibration. Inadequate compaction may lead to surface and structural defects and inadequate bond development with the reinforcing bars. Use of SCC can remarkably reduce the demand for significant amount of consolidation practice with its homogeneity and reliable quality in concrete placement [11], [14]-[16].

The filling capacity may improve the steel-to-concrete bond by allowing the mixture to cover the reinforcement more effectively. The mean bond strength is greater in SCC than in NC. For moderate load levels, SCC performs a stiffer behavior than NC because of its greater filling capacity and less bleeding [17]-[19]. Based on different researches, no significant difference was observed in the load-slip behavior between the SCC and NC. Bond Strength of SCC is higher than NC [20] and Mode of failure is not affected by NC and SCC [17].

Anchorage capacity and fracture pattern is significantly affected by concrete cover and anchorage type. Anchorage capacity is higher with increased cover depth [21].

III. Significance of Research

This research has significance in construction practice in reinforced concrete projects. It will facilitate design engineers to understand the anchorage performance at highly congested reinforcement regions. The behavior will also help to understand those areas of SCC which have not been addressed before. In this study, effect of thin cover on anchorage capacity due to shift of beam reinforcement was investigated. It will help to evaluate the performance of SCC and SA in highly congested regions where clear spacing between parallel bars is limited. No standard guidelines are available to address steel congestion problems as per site condition. It will help to develop design guidelines for both NC and SCC.

IV. Experiment

A. Experimental Program

1. Materials

Ordinary Portland Cement (OPC) was used as main binder. In Self-Compacting concrete, 40% of OPC contents were replaced by Limestone powder to make it economical. For SCC, super-plasticizer used was Poly-carboxylic Acid ether based with density 1.11 g/cm^3. Micro-Air 785 was used to maintain the desired air content value. Two different coarse aggregate sizes (20mm and 10mm) were used from the same source. Maximum size of 20mm is generally used in construction projects in Japan. Aggregate with maximum size of 10mm was used to understand the behavior. Particle size distribution of fine and coarse aggregate has been shown in Fig. 4. Properties of reinforcement have been listed in Table I. Screw deformed bars were used to avoid possible reduction in area of bar at location of strain gauges.

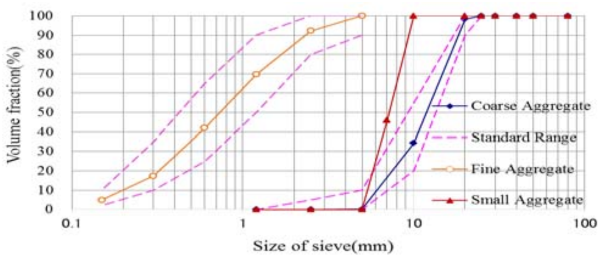


Fig. 4 Gradation of Aggregate for NC and SCC

TABLE I
MECHANICAL PROPERTIES OF REINFORCEMENT

Pullout Bar		Embedded Bar		Transverse bars		All Reinforcement
Dia. (mm)	fy (MPa)	Dia. (mm)	fy (MPa)	Dia. (mm)	fy (MPa)	Modulus of Elasticity (GPa)
25	685	25	490	13	390	190

2. Proportions of Mixes Used

Two types of concrete were used in experimental program including NC with different aggregate size and SCC with maximum aggregate size 20mm. SCC mix proportion was finalized by several trial mixes in laboratory due to its sensitivity against super-plasticizer dosage to fulfill all desired fresh properties. In all trials, water to powder ratio was kept fixed and dosage of super-plasticizer was adjusted to get desired values. The dosage of Micro-Air was also adjusted accordingly to achieve desired air content value to fulfill requirements of fresh concrete. The rational mix design method proposed by Ozawa and Okamura, 1995 [1] has been used where coarse aggregate contents are fixed so that fresh properties of SCC can be achieved adjusted by water to cement ratio and super-plasticizer dosage. Initially total volume of solid was fixed equal to 59.2%. Coarse aggregate volume was fixed equal to 50% of solid volume, whereas, the fine aggregate content was fixed equal to 40% of the mortar volume. Mix Proportion of NC has been finalized by conventional practice. In case of SA, super-plasticizer was used to improve the workability. Final mix design proportions have been shown in Table II.

TABLE II
MIX DESIGN FOR NC AND SCC MIXES (PER 1M^3)

Material	NC	SCC	SA
Cement (Kg)	366	384	358
Limestone Powder	-	256	-
Fine Aggregate (Kg)	753	718	770
Coarse Aggregate (Kg)	1056	747	1066
Max. Coarse Aggregate Size (mm)	20	20	10
Water (Kg)	161	189	155
Superplasticizer (%)	-	0.54	0.75
AE (%)	0.9	0.28	-
w/p ratio	0.45	0.31	0.45

3. Fresh Properties of SCC and NC

Before casting the specimens, fresh properties of SCC including Slump flow, Slump flow (T_{500mm}), V-funnel, V-funnel (T_{5min}) and Air content value were conducted to assure that concrete mixtures was qualified as SCC. Japanese Standard specifications for SCC have been used for conducting fresh properties [25]. Fresh properties of SCC have been listed in Table III along with NC and SA. Filling ability of SCC mixture was evaluated by slump flow test (two methods) whereas; passing ability along with segregation resistance was evaluated by the discharge time in V-funnel test (two methods).

Split cylinder tests were also performed to get tensile properties which helped to visually examine uniform distribution of coarse aggregate along the height of specimen for NC and SCC. No indication of segregation was observed in SCC shown in Fig. 5.

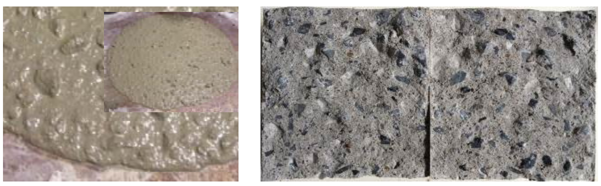


Fig. 5 SCC Behavior showing no sign of Segregation

TABLE III
FRESH PROPERTIES OF NC AND SCC

Tests	NC	SCC	SA
Slump Test			
Slump/Slump Flow (cm)	17	64.5	18
t_{50} *(s)*	-	2.53	-
Air Content (%)	5.5	6.7	6.5
V-Funnel			-
t_o (s)	-	12.56	-
t_{5min} (s)	-	13.8	-
R_m	-	0.80	-
V_m	-	0.16	-
Segregation	No	No	No
Bleeding	No	No	No

t_o = Flow-through time in V-funnel immediately after top surface leveled, t_{5min} = Flow-through time in V-funnel after 5 minutes of top surface leveled; t_{50} = time to 500mm slump flow,

R_m = Relative flow through Speed to nearest 0.01 sec, V_m = Average flow through speed to nearest 0.01 sec,

4. Casting and Curing of Specimens

All specimens were cast perpendicular to the direction of pullout force. In case of SCC, no external vibration was applied. On the other hand, NC specimens were cast as per site. In real construction site, adequate compaction is very difficult because vibrator can't be placed at highly congested area of reinforcement as it can't go to those places. Therefore, compaction is performed by bamboos at site. So, in this study, to simulate that condition, we used hand tamping by tamping rod for compaction for NC. NC specimens were cast in three layers. In each layer, 70 stokes of tamping rod were given for compaction. Specimens were hammered with wood hammer twenty times in each layer. Specimens and cylinders were cured in similar conditions. For curing, all specimens were sealed with polythene sheet with wet cloth. After 14 days, specimens were kept open to air at room temperature 20° C and relative humidity of 60 ~ 65% until day of testing.

5. Specimen Preparation for Pullout Test

The real problem of steel congestion at beam column joint has been simplified by adopting very simple specimens having bond length equal to 10D (250mm). Development length has been kept less in order to get ultimate failure load and to avoid yielding of reinforcement. Specimens have been designed in such a way that we can have splitting behavior. Five different cases were considered for both NC and SCC named as Case-01, with no embedded bar (without weak area, referenced case to calculate possible reduction), Case-02 to Case-05 having embedded reinforcement with distances to the column bar (tensioned bar) at 0D(0mm), 0.5D(12.5mm), 1.0D(25mm) and 1.5D (37.5mm) respectively, which have been shown in Fig. 6. Where, D is the diameter of pullout bar. These distances are from center of column reinforcement to center of beam reinforcement. Specimens has been planned in order to understand the real problem due to shift of bar as per actual situation of site.

The specimens which have been used in this study are shown in Fig. 6 with dimensions. Further details of specimen have been shown in Fig. 7. Pullout bar represents column reinforcement and embedded bar represents beam reinforcement. Clear spacing between the parallel bars has been kept 7.5mm as per the site condition. Main variable for the investigation was the vertical shift of beam bar at different distance with reference to the column bar. In all specimens, Column bar was pullout whereas; embedded bars were introduced at different spacing to introduce thin cover b/w parallel reinforcement bars due to congestion problem as per site condition.

To understand internal stress mechanism, strain gauges were installed at distance of 2D(50mm), 6D(150mm) shown in Fig.6 from the loaded end in case-01 and case-03 at top and bottom of pullout bar, where "D" is the diameter of bar. Concrete properties have been shown in Table IV. To remove an effect around the loading end, specimens have 200mm un-bond area in which the bar is covered with clay to remove bond.

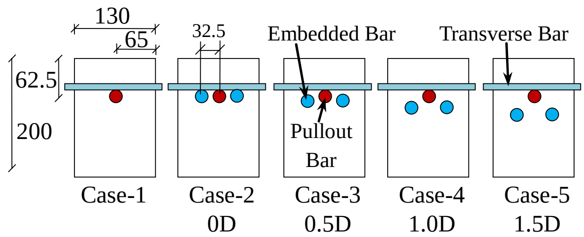


Fig. 6 Specimens Cross-Sections (mm)

B. Experimental Method

The loading arrangement has been shown in the Fig. 7 along with specimen details. The test setup was consisted of specimen placed on roller supports and loaded from one end. The axial applied load by the center hole Hydraulic Jack was measured by load cell with a capacity of 500 KN and a sensitivity of 0.025KN/mV. The pullout load was applied up to failure and relative slip of the bar was measured using Linear Variable Differential Transformers (LVDT) connected at unloaded end (free end) and resulting strain on the rebar against the load was monitored and data stored in computer. The direction of tensile load was perpendicular to the casting direction. The compression cylinder tests were performed with 10cm diameter and 20cm in height and splitting tensile strength were obtained by testing cylinders with diameter 15cm and height 15cm as per Japanese Standard [23], [24].

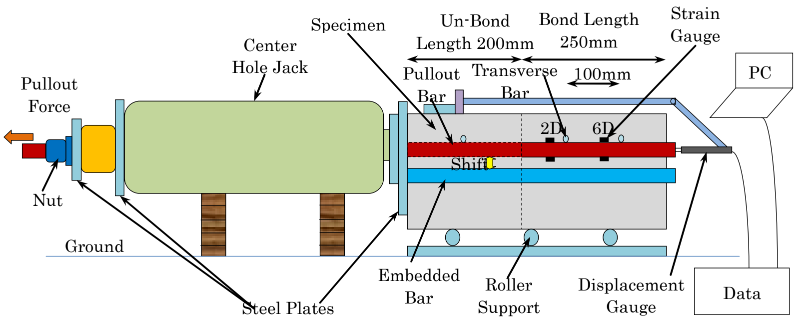


Fig. 7 Experimental setup and Specimen Detail

TABLE III
FRESH PROPERTIES OF NC AND SCC

Tests	NC	SCC	SA
Slump Test			
Slump/Slump Flow (cm)	17	64.5	18
t_{50} *(s)*	-	2.53	-
Air Content (%)	5.5	6.7	6.5
V-Funnel			-
t_o (s)	-	12.56	-
t_{5min} (s)	-	13.8	-
R_m	-	0.80	-
V_m	-	0.16	-
Segregation	No	No	No
Bleeding	No	No	No

t_o = Flow-through time in V-funnel immediately after top surface leveled, t_{5min} = Flow-through time in V-funnel after 5 minutes of top surface leveled; t_{50} = time to 500mm slump flow,

R_m = Relative flow through Speed to nearest 0.01 sec, V_m = Average flow through speed to nearest 0.01 sec,

C. Experimental Results and Discussions

All specimens showed splitting failure with sudden drop in structural capacity which means that all the bond resistance was lost after failure. Ultimate load was used to calculate bond stress. Under pullout test conditions, bond stress along the anchorage lengths can be considered to be uniformly distributed. Therefore, following expression can be used to calculate the bond stress.

$$u = \frac{T}{\pi d l} \quad (1)$$

where "*u*" is ultimate bond stress, "*T*" is ultimate failure load; "*d*" is diameter of pullout bar and "*l*" is development length. Results of all specimens are listed in Table IV. The listed data includes compressive and tensile strength of concrete at the day of testing, ultimate load, ultimate bond stress and bond ratios. Anchorage capacity was discussed in terms of bond ratio. Bond ratio is defined as the bond stress of specimen with embedded bar (with thin cover) divided by bond stress without embedded bar (without thin cover) for particular concrete type.

NC notation has been used for Normal Concrete with maximum aggregate size of 20mm. SCC notation has been used for Self-Compacting Concrete whereas; SA notation has been used for Small Aggregate i.e. NC with max coarse aggregate size of 10mm.

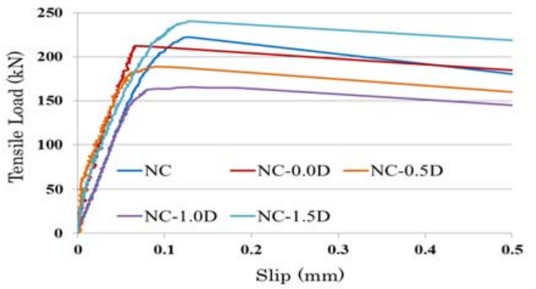


Fig. 8 Load – Slip Relationship for NC

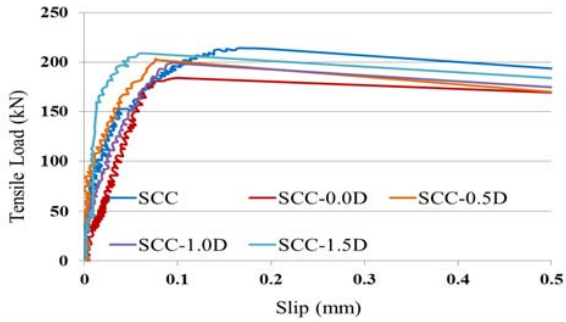


Fig. 9 Load – Slip Relationship for SCC

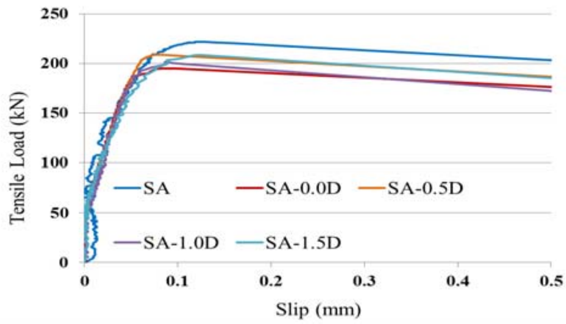


Fig. 10 Load – Slip Relationship for SA

1. Load Slip Relationship and Fracture Pattern

The load slip relationship has been shown in Fig. 8-10 for NC, SCC and SA respectively. In all specimens, side longitudinal splitting was observed. After the formation of splitting cracks, all specimens experienced sudden drop in their load carrying capacity followed by rapid diminishing load resistance. It can be observed that Load-slip behavior consisted of two different stages. The first stage consisted of stiff ascending portion. During this stage, internal circumferential tensile cracks develop in the concrete at the interface between reinforcement and surrounding concrete. Split failure occurs when radial component of the bond force exceeds the splitting tensile strength of the concrete surrounding the reinforcement. Splitting strength of the concrete surrounding the bar increases with increasing concrete cover [22]. At second stage, Splitting failure occurred with sudden drop in bond resistance.

Splitting behavior shows that the concrete cover was less than the effect of zone of significant circumferential stresses and crack was reached to member surface. For moderate loads, SCC specimens showed stiff behavior compared to NC specimens because of homogeneity and filling-ability. All the specimens show stiff behavior at the start but once the stresses exceeded the tensile capacity of concrete, sudden drop in load was observed due to splitting behavior. The experimental results are shown in Table IV. In case-1 and case-5, more brittle failure with sharp sound was observed as compared to case-2, case-03 and case-4 irrespective to concrete type and aggregate size. In case-5, recovery in anchorage capacity was observed where bars are shifted at distance 1.5D (37.5mm) which means that there was no effect of thin cover. Sudden increase in slip and drop of load shows that the pressure due to radial component of the bearing forces was accumulated around reinforcement. Due to presence of thin cover, it was not resisted by the surrounding concrete which results in sudden splitting failure.

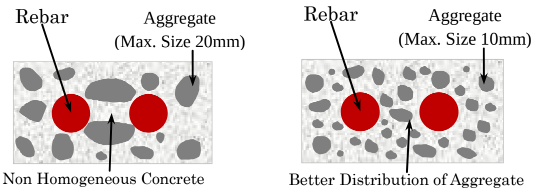
TABLE IV
TEST RESULTS

Specimen	Case No.	Shift of Beam Reinforcement from Column Reinforcement (mm)	$f'c$ (MPa)	f_t (MPa)	Ultimate Load (kN)	Ultimate Bond Stress (MPa)	Bond Ratio
NC	Case-01	-	45.79	2.78	222.46	11.33	1.00
	Case-02	0			212.61	10.83	0.96
	Case-03	12.5			188.78	9.61	0.85
	Case-04	25			165.52	8.43	0.74
	Case-05	37.5			240.59	12.25	1.08
SCC	Case-01	-	39.07	2.44	213.99	10.90	1.00
	Case-02	0			183.84	9.36	0.86
	Case-03	12.5			203.35	10.36	0.95
	Case-04	25			199.41	10.26	0.94
	Case-05	37.5			208.87	10.64	0.98
SA	Case-01	-	39.84	2.42	221.67	11.29	1.00
	Case-02	0			194.68	9.91	0.88
	Case-03	12.5			208.67	10.63	0.94
	Case-04	25			201.38	10.26	0.91
	Case-05	37.5			208.28	10.61	0.94

Fracture pattern has been shown in Figs. 13-15 for NC, SCC and SA specimens respectively. It was found that fracture pattern was not affected by concrete type and aggregate size. Fracture pattern was affected by presence of thin cover between parallel reinforcement. It was found that due to presence of thin cover i.e. case-02 to case-04; crack was propagated over the embedded bars and affected by the position of embedded bars. It means that cover surrounding the reinforcement was exhausted and crack could easily propagate over the embedded bar. Therefore, crack was affected by the position of embedded bars. In Case-5, it was found that crack was independent of position of embedded bar which means that clear cover between parallel reinforcement was enough to resist circumferential tensile stresses. It has been observed in Load-slip behavior as well where recovery in anchorage capacity was found.

2. Bond Ratios

Bond ratios were plotted versus shift of embedded bar for NC, SCC and SA shown in Fig. 12. Shift of bar is expressed in terms of D as a multiple of Bar Diameter. For NC, bond strength of specimen with embedded bar was decreased relative to bond strength of specimen with no embedded bar in case-02, case-3 and case-04. This reduction in bond strength was found because of non-homogeneous nature of NC at narrow spaces between parallel reinforcement resulting due to blockage of large coarse aggregates which has been shown in Fig. 11 (a). Blockage of aggregates results more concentration of mortar around reinforcement bar where clear spacing between parallel reinforcement becomes limited. It was found that there is no effect on anchorage performance if bar is spaced at a distance 1.5D or more from column reinforcement. It means that circumferential stresses were resisted properly and there was enough clearance for aggregate between parallel bars to pass through. Effect of tensile hoop is more pronounced in cases where bar is shifted at a distance less than 25mm.



a. Normal Concrete (NC) b. Small Aggregate (SA)

Fig. 11 Coarse Aggregate Distribution at Congested Area

For SCC, no significant reduction was found in anchorage capacity in specimen with embedded bar relative to specimen without embedded bar except case-02. Less effect on anchorage was found probably because of homogeneity, filling-ability, less segregation and bleeding at narrow spaces of reinforcement. Although in SCC maximum aggregate size is same as NC but percentage of coarse aggregate is limited in SCC to avoid possible collision and blockage of particles at highly congested regions. As a result, homogeneous behavior is observed which ultimately gives better structural performance.

In SA, almost similar behavior was found with SCC probably because of better distribution of coarse aggregate at narrow spaces shown in Fig. 11 (b). It would be more appreciating from designer point of view to limit shift of bar distance from column reinforcement.

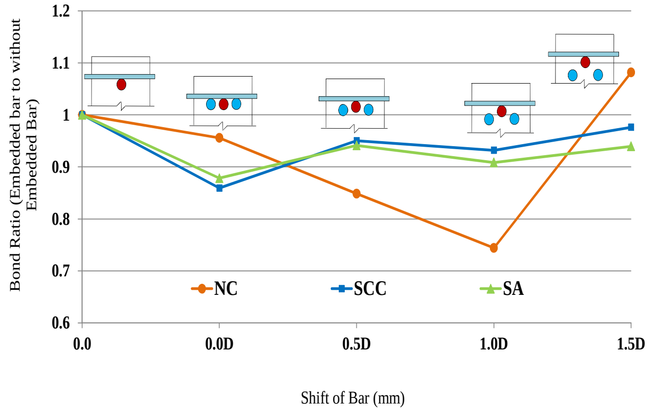


Fig. 12 Relationship between Bond Ratio-Shift of Bar

a. NC b. NC-0.0D c. NC-0.5D d. NC-1.0D e. NC-1.5D f. Typical Side Splitting

Fig. 13 Fracture Pattern of NC

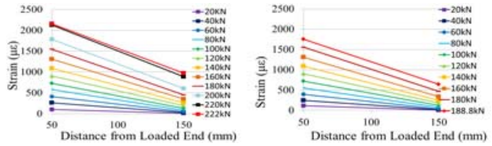
a. SCC b. SCC-0.0D c. SCC-0.5D d. SCC-1.0D e. SCC-1.5D f. Typical Side Splitting

Fig. 14 Fracture Pattern of SCC

a. SA b. SA-0.0D c. SA-0.5D d. SA-1.0D e. SA-1.5D f. Typical Side Splitting

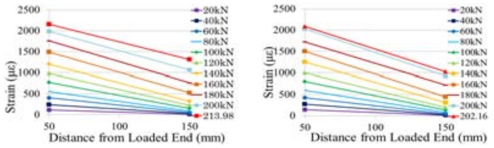
Fig. 15 Fracture Pattern of SA

From experimental results, it can be concluded that at highly congested regions, beam bars should be anchored at least at distance 1.5D (37.5) from the column reinforcement in NC.



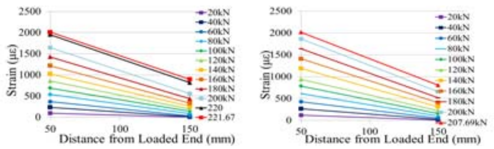
Case-01 b. Case-03

Fig. 16 Strain Profile of NC Specimens



Case-01 b. Case-03

Fig. 17 Strain Profile of SCC Specimens



Case-01 b. Case-03

Fig. 18 Strain Profile of SA Specimens

3. Strain Profile along Anchorage Length of Pullout Bar

Longitudinal strain distribution of NC, SCC and SA has been shown in Figs. 16-18. It can be observed that with increase of load, strain from the loading end towards the free end increases. Role of internal crack is very important in member subjected to uniaxial tension [7]. No significant difference was found in strain profile in case-01 and case-03 except the ultimate load capacity for particular concrete type. For moderate load, strain values in all specimen ware comparable irrespective to concrete type and aggregate size. Strain profile shows that concrete around the lugs was cracked at same rate in case-01 and case-03 irrespective of concrete type and aggregate size. Splitting behavior was more rapid as the radial component of the bond force exceeds the splitting tensile strength of the concrete surrounding the bar. Increase in reinforcement strain with increase in load clearly shows that the concrete was cracked around the reinforcement and the local behavior between steel and concrete was changed. Strain profile shows that the reinforcement bar stress was directly proportional to tensile load applied.

V. Conclusion

Based on this study, following conclusions can be drawn.

1. Splitting failure was observed in all cases causing sudden drop on structural capacity because bond capacity vanishes once the radial cracks get to outer surface of structural member. Sudden drop in slip and load confirms that cover was exhausted and large lateral pressure was accumulated around thin cover resulting splitting failure.
2. Presence of limited clear space between parallel bars due to shift of beam reinforcement cause reduction in anchorage capacity. Reduction was significant in case of Normal Concrete (NC) whereas; no significant effect was found in Self-Compacting Concrete (SCC) and Small aggregate (SA). SCC and SA have proved good commitment of bond between reinforcement and surrounding concrete even at highly congested reinforcement regions. In SA, reduction was not significant due to uniform distribution of aggregate at congested area of reinforcement. Although mortar properties of SA can be similar to NC but better distribution of SA at congested area gives better structural performance. Whereas; in SCC, there is no segregation and bleeding which results better structural performance along with filling-ability characteristics. For moderate load levels, SCC and SA performed stiffer behavior than NC. Experimental results confirmed that SCC not only reduce compaction problem at site but also, give better structural performance at highly congested reinforcement regions. Surface quality of SCC was also found better than NC.
3. It was also found that anchorage capacity was recovered in case-05 where beam bars were shifted at distance 1.5D (37.5mm) irrespective to concrete type and aggregate size. This indicates that beam bars should be anchored at least at distance 1.5D (37.5mm) from column reinforcement for Normal Concrete (NC) otherwise, anchorage requirements for should be revised based on current situation at site. No such requirement is required for SCC and SA.
4. Fracture pattern was not affected by concrete type and aggregate size. In all case, all the specimens made with SCC showed same failure as the NC ones so we may conclude that type of concrete has no effect on mode of failure.

Appendix

NC = Normal Concrete with aggregate size 20mm
SCC = Self-Compacting Concrete
SA = Small Aggregate i.e. NC with aggregate size 10mm
$f'c$ = Compressive cylinder strength of concrete at day of experiment.
f_t = Tensile strength of concrete at day of experiment

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