ANCHORAGE PERFORMANCE OF REINFORCEMENT WITH VULNERABLE AREA AT HIGHLY CONGESTED REINFROCEMENT REGION

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1. INTRODUCTION

Due to high seismic activity, steel congestion and increase in assemblage time and concrete filling have become serious concern at site. Steel congestion problem is common at beam column joint area. Highly congested area affects the structure performance and makes it difficult to construct. Due to limited size of structural member, hooks are provided to meet the development length requirement. In general, beam reinforcement is bent into column reinforcement by 90° hook. If the clear spacing between column reinforcement is not enough to accommodate beam reinforcement, then beam reinforcement is given an offset at site without any specific guidelines as shown in Fig.1. So, it is important to understand the effect of shift of beam reinforcement on anchorage capacity.

Anchorage capacity and fracture pattern is significantly affected by concrete cover and anchorage type. Anchorage capacity is higher with increased cover depth, Inoue et al. (2011). Vulnerable area is the region where large aggregate cannot be placed. For this situation, aggregate will not be able to pass through that narrow space shown in Fig. 2, resulting in concentration of mortar is surrounding the reinforcement effecting anchorage performance. Anchorage capacity is reduced due to shift of beam reinforcement from 0D to 1.0D in vulnerable area, where, D is the diameter of pullout reinforcement bar, Hayashi et al. (2012). Research on vulnerable area is very limited therefore; pullout test was performed to understand the effect of shift of reinforcement bar on anchorage performance at highly congested reinforcement area by using beam column joint concept.

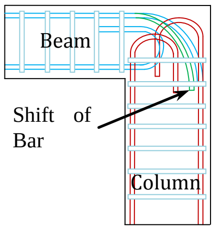

Fig.1 Typical Beam Column Joint

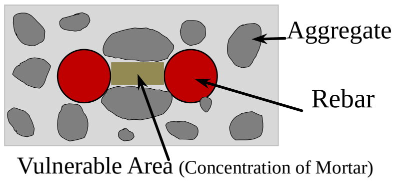

Fig.2 Vulnerable area

2. EXPERIMENTAL PROGRAM

The specimens with bonded length equal to 350mm (14D) have been studied as per site condition which conform the steel congestion problem. The development length was kept less in order to understand the effect of vulnerable area on anchorage capacity. Specimens shown in Fig. 3 and Fig. 4 have been divided into five different cases, named as case-1, with no embedded reinforcement, case-2 to case-5 having embedded reinforcement with distances to the column reinforcement at 0.0D, 0.5D, 1.0D and 1.5D respectively. Case-1 has been considered as reference to compare anchorage capacity. The clear spacing between parallel bars is kept 7.5mm as per site condition. Main variable for investigation was the vertical shift of beam reinforcement at different distances from column reinforcement shown in Fig. 3. In all specimens, pullout bar representing column reinforcement and embedded bar representing the beam reinforcement. Screw type deformed bar was used in this study. Material properties are shown in Table 1. 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. Due to thin size of specimen, it was difficult to perform compaction by vibrator. Therefore, compaction was done manually by using tamping rod. Due to high steel congestion, the compaction effort was also increased. As a result, a little bit honey combing was found in case-5 shown in Fig.9. It also confirms the actual site condition and hence

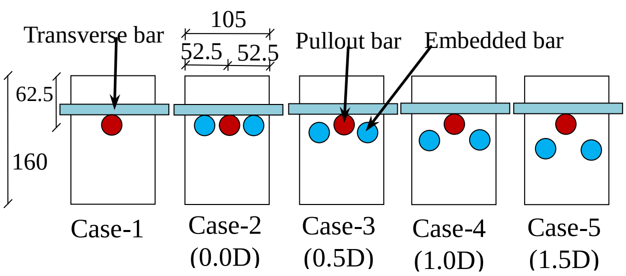

Fig. 3 Specimen Detail

Table 1 Material Properties

Pullout and Embedded Reinforcement		Transverse bars		All Reinforcement	Concrete	
Dia. (mm)	*fy* (MPa)	Dia. (mm)	*fy* (MPa)	Modulus of Elasticity (GPa)	$f'c$ (MPa)	f_t (MPa)
25	490	13	390	190	51	3.45

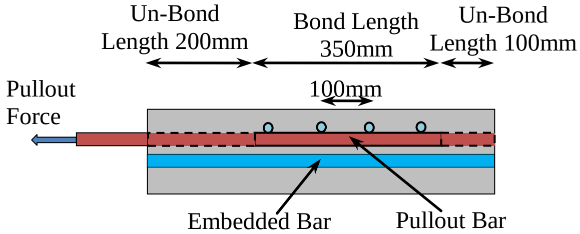

Fig.4 Side View of Specimen

Keywords: Anchorage, Development length, Pullout, Vulnerable area
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affects the surface quality and structural performance. All the specimens were casted vertically. Surface quality was not smooth as shown in Fig. 8 and Fig. 9.

3. EXPERIMENTAL METHOD

Loading arrangement has been shown in Fig.5. The test setup composed of specimens placed on roller supports and loaded from one end at a rate of 9kN/min. The load was applied by the center hole hydraulic jack was measured by load cell with a capacity of 500kN. The pullout load was applied up to failure and relative slip was measured using Linear Variable Differential Transducer (LVDT) connected at unloaded end.

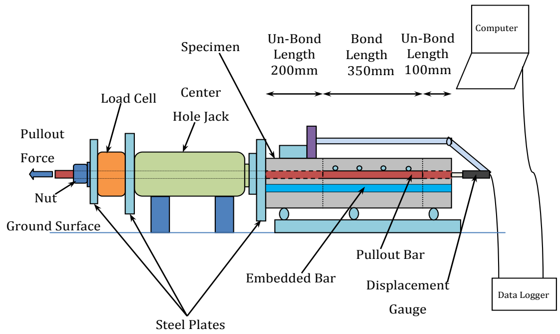

Fig.5 Loading Arrangement

3. EXPERIMENTAL RESULTS AND DISCUSSION

In all specimens, longitudinal side splitting was observed shown in Fig. 7. After the formation of splitting cracks, all specimens experienced sudden drop in their load carrying capacity followed by rapid diminishing load resistance. Maximum load of 157kN was found in case-1. Load vs. Slip relation in Fig.6 reveals that all specimens showed stiff behavior at start except case-2. In case-2 to case-5, the load reduction of 56%, 22%, 9% and 8% was found respectively w.r.t. case-1 shown in Fig. 7. Surface crack was also observed at low load in case-2 to case-4 and propagated in longitudinal direction. But the failure was not as much brittle as in case-1 and case-5. Based on previous studies, Hayashi et al. (2012), case-5 was recovered properly in terms of anchorage capacity. In this study, 8% reduction was observed in case-5 due to honey combing resulting due to improper compaction.

Significant reduction of 56% in case-2 was found because of improper compaction and thin cover (7.5mm) around the embedded reinforcement. As a result, the crack was easily propagated over the embedded bar and lateral forces against tensile stresses were not resisted properly. Reduction in anchorage capacity was found because concrete cover was less than the zone of significant circumferential stresses and crack was reached to member surface. Radial component of bearing forces causes ring tensile stresses. In case of vulnerable area, ring tensile stresses were not properly resisted by surrounding concrete because radial splitting stresses exceed the tensile capacity of the surrounding concrete at less load and splitting cracks begin to propagate from the bar surface.

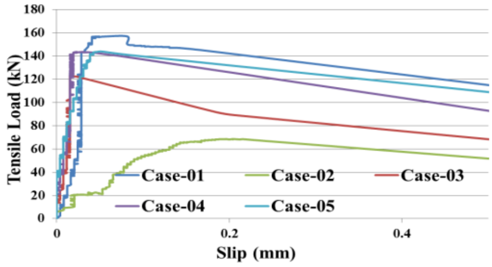

Fig. 6 Load - Slip Relationship

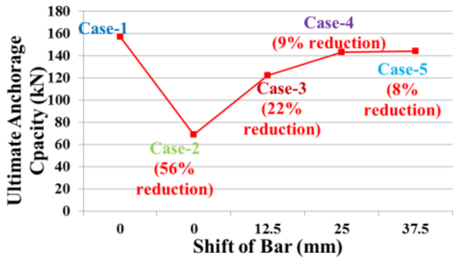

Fig.7 Ultimate anchorage capacity - shift of bar

a. Surface of Specimen b. Longitudinal Side Splitting c. Splitting

Fig.8 Surface before and after testing with fracture pattern (Case-2)

a.Honey Combing b. Splitting

Fig.9 Fracture Pattern (Case-5)

5. CONCLUSIONS

Presence of vulnerable area due to steel congestion affects the anchorage capacity. Splitting failure is observed which can cause sudden drop in structural capacity because bond capacity vanishes once the radial cracks get to the outer surface of structural element. Anchorage capacity is reduced due to shift of bar because crack propagates along the rebar at higher rate which confirm the existence of vulnerable area.

REFERENCES

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