Anchorage of 90-Degree Hooked Beam Bars in Exterior RC Joints

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Summary

This study experimentally investigated anchorage performances for raking-out failure mode o f 90-degree hooked beam bars in exterior beam-column joints to be used in a middle story, using forty column-shaped specimens with various arrangements of L-shaped beam bar anc horage. Based on the test results, a formula for accurate estimation of anchorage strength w as proposed.

Keywords: anchorage; 90-degree hook; beam-column joint; ultimate strength; developm ent length; concrete cover thickness; axial stress; lateral reinforcement.

1. Introduction

In the previous paper, we divided the anchorage failure of 90-degree hooked bars in exterio r beam-column joints in a middle story into three modes: side split failure, local compressi on failure and raking-out failure. Most of the current structural design codes require that ho oked bars be designed according to certain specifications, such as minimum requirements of concrete cover thickness, bar bend radius and location of the bend in a joint (in order to avoid the three anchorage failure modes, respectively) rather than according to thoretical cal culations of strength. In the same paper[ACI, SP-157, pp.97-116, 1995], we also proposed a formula for estimating anchorage strength of 90-degree hooked bars with raking-out failure mode. In the present paper, we have purposed a modified formula that can estimate ancho rage strength more accurately and can be applied to various designs of hooked bars anchore d in a joint.

2. Experiment

Specimens, about half normal size, had 90-degree hooked beam bars anchored into an exteri or beam-column joint situated at the midpoint of the column height. Two series of specime ns were tested: an inward and an outward hook series, in which the tails of the beam bars were directed to the joint side and the column side, respectively. We tested eleven variabl es, including horizontal development length (Ldh), moment arm of beam (jb), thickness of c over concrete, lateral reinforcement ratio, axial stress (σ o), as shown in the table. A schem a of the dimensions and bar arrangement of the specimens is shown in Fig.1. One tensile l oad, P1, was applied horizontally to the beam bars, where reactions R1 and R2 were suppo rted, and another tensile load, P2, was applied at the top of the column to generate the sa me shear force in both columns.

3. Estimation of Anchorage Strength

Fig. 2 is a schema showing a typical crack pattern in the inward hook series at the final l oading stage. The main cracks related to anchorage strength were in a chain of ⑦-③-④-⑥. The failure plane slid heavily along cracks ④-⑥ so that concrete slippage on this plane worked as a part of horizontal resistance, and the main cracks opened widely at the ultimat e stage so that the hoops crossing the failure plane worked as the remainder of the horizon tal resistance. The following modified formula was proposed for estimating anchorage streng th with raking-out failure:

$$ {}_{cal}T_u = k_N ({}_{cal}T_c + {}_{cal}T_w), \quad (1) $$

where ${}_{cal}T_c$ *(horizontal concrete resistance)=* $H / j_b \cdot {}_{cal}T_{ao}$ *for inward hooks,* ${}_{cal}T_c = H / (H - j_b) \cdot {}_{cal}T_{ao}$ *for outward hooks, and H is story height. The value of* ${}_{cal}T_{ao}$ *is analytical horizontal resistance of the failure plane and is defined by the equation* ${}_{cal}T_{ao} = k_c \cdot b_{ce} \cdot L_c \cdot \sigma_e$, *where* k_c *is a coefficient that takes into account tail direction,* b_{ce} *(effective colum n width)* $= S + 0.53\ b_c$, b_c *is the total concrete side cover thickness for beam bars,* L_c *is t he length of horizontal straight bar length minus concrete cover thickness, and* σ_e *(concret e sliding strength)* $= \sqrt{\sigma_B}$. *In Equ.(1),* ${}_{cal}T_w$ *is the horizontal resistance of hoops and is d efined by the equation* ${}_{cal}T_w = k_w \cdot k_b \cdot a_w \cdot \sigma_{wy}$, *where* k_w *(effective hoop stress factor) is 0.8 for inward hooks and 0.9 for outward hooks;* k_b *(effective concrete cover thickness fact or) is 1 at* $C_o \leqq 0.8 L_{dh}$, $3 - 2.5 C_o/L_{dh}$ *at* $0.8 < C_o/L_{dh} < 1.2$, and 0 at $1.2 \leqq C_o$; a_w *is the total sectional area of hoops within the effective zone; and* σ_{wy} *is the yield stress of the hoops. The axial stress modification factor (*k_N*) has to be used to estimate the fact that the colu mn axial stress increased the anchorage strength, but there is a upper limit to the strength -enhancing effect of axial stress. Therefore,* k_N *is defined as follows: in the case of inward hooks,* $k_N = 1 + 0.205\ \sigma_{os}$, *where* σ_{os} *is the minimum between* σ_o *and* $0.08\ \sigma_B$; *and in t he case of outward hooks,* $k_N = 1 + 0.153\ \sigma_{os}$, *where* σ_{os} *is the minimum between* σ_o *a nd* $0.16\ \sigma_B$. *The average of the ratio of observed strength* ${}_{exp}T_u$ *to* ${}_{cal}T_u$ *for 40 specimens was 1.01, and the standard deviation was 0.091. As can be seen from the relation between* ${}_{exp}T_u$ *and* ${}_{cal}T_u$ *plotted in Fig. 3, the new estimations appear to be highly accurate.*

4. Conclusions

The following conclusions were drawn on the basis of the results.

1) The anchorage strength of outward hooks is less than that of inward hooks.
2) Our previous method for estimating horizontal concrete resistance and hoop resistance in anchorage strength was extended to outward hooks as well as inward hooks.
3) A new equation for estimating the anchorage strength of 90-degree hooked bars in exteri or beam-column joints was derived from our previous equation. Our experimental results co nfirmed that estimations using this new equation have a high level of accuracy.